FINAL TECHNICAL REPORT – PHASE I

CONSERVATION AND SUSTAINABLE MANAGEMENT OF BELOWGROUND DIVERSITY IN THE NANDA DEVI BIOSPHERE RESERVE

Principal Investigator: Dr. R.K. Maikhuri

G.B. Pant Institute of Hiamalayan Environment and Development
Garhwal Unit, Srinagar (Garhwal)
July 2006

Site characterization: Nanda Devi Biosphere Reserve

Background

The Himalaya has been a perennial source of attraction, curiosity and challenge to human intellect throughout the ages. The diversity, copiousness as well as uniqueness of the plant components in various habitats retained sound and aesthetic environment of the Himalayas. However, in the recent past due to excessive exploitation, unplanned land use, natural disasters, and several developmental processes, accelerated deterioration of vegetation or loss of individual species, since we do not possess the records for several of the localities or regions. In view with the multiple stresses and depletion of vegetation and habitat, today's foremost concern of the globe in general and Himalaya in particular is the conservation of biodiversity both below ground and above ground (Gaur, 1999).

Soil microorganisms play a prominent role in the sustainability of any terrestrial ecosystem where they occur and flourish. There is a large number of soil macro, meso and micro fauna those are indispensable and directly responsible for successful completion of pedological and nutrient cycling in any area. Among the important soil fauna, earthworms, termites, ants, litter feeding arthropods and a number of invisible bacteria and fungal groups are the major determinant of soil and nutrient cycling in the terrestrial ecosystem. Soil macro fauna not only maintain the nutrient dynamics but also decompose the waste and other biomass and regulates nutrient flow in the ecosystem. The habitat structure, vegetation composition and surface litter layer is utilized by wide range of litter-feeding meso and micro fauna and their predators within natural ecosystem, resulting a complex food webs and habitat structures. The combination of soil and litter feeding species results in a diverse faunal community, which may be affected /altered or reduced due to anthropogenic activities. Soil loss or soil degradation is seldom attributed to the decline of soil fauna and the reduction of their activities. In addition to this the excessive use of fertilizers, pesticides etc are also responsible for the decline of soil macro, meso as well as micro fauna. Soil faunal community shows a variety of reactions to changes induced by land management practices. Their abundance and diversity are indicators of the quality of soils and influence soil organic matter dynamics, nutrient contents and physical parameters. Despite performing significant role in soil fertility maintenance, the role of soil faunal diversity has still achieved very less attention and very little consideration have been paid by the researchers and scientists in this direction. However, recent research in this field demonstrates that practices that eliminate soil faunal communities are not going to be sustainable in long-run especially traditional agriculture that is solely based on organic inputs. Therefore, the present study has been carried out in the buffer zone area of NDBR and adjoining areas with following objectives:

- Inventory and identification of below ground biodiversity in relation to physico-chemical properties of soil and above ground biodiversity in cultural and protected landscape comprising a range of land use/land cover types.
- Applicability of available methods of sampling of BGBD in the Himalayan landscapes.
- Effect of land use, soil fertility level and estimation and assessment of nodulation, *Rhizobia* diversity/legume growth and their impact on soil fertility.

- Indigenous land use (traditional agriculture) related to BGBD and its linkages to above ground biodiversity and ecosystem functions.
- To enhance awareness, knowledge and understanding of BGBD importance to the sustainable agriculture production in tropical landscapes by the demonstration of the methods for conservation and sustainable management.

Benchmark area description

Buffer Zone of Nanda Devi Biosphere Reserve (NDBR) at high altitude (2200-3100 m asl) and about 7 villages located at the middle altitude (600-900 m asl) in Garhwal region of Central Himalayas were considered as two windows for BGBD sampling. At High altitude in NDBR a total of 126 grid points whereas at middle altitude 121 grid points were considered for sampling. However, border areas were excluded from both of the windows.

At high altitude after excluding border areas there were only 76 grid points, of which 9 grid points were falling under built up area, small streams, rivers etc. and therefore, only 67 grid points were considered for the sampling.

Table 1. Grid Sampling (excluding the boundary points) of windows

Land use land cover type	Number of points sampled
Higher Elevation- 67 (76)	
Kitchen garden (Vegetables)	3
Kitchen garden (Medicinal plants)	6
Agriculture (Potato)	7
Agriculture (other crops)	7
Conifer Forest	29
Alpine Meadow	15

At the low altitude after excluding border areas there were only 81 points; of which 4 points were covering build up area mainly river and streams etc. and thus, only 77 points were considered for the sampling.

Table 2. Grid Sampling (excluding the boundary points) of windows

Land use land cover type	Number of points sampled
Lower elevation-77 (81)	
Kitchen garden	3
Agriculture (rain fed)	20
Agriculture (irrigated)	7
Pine forest	25
Oak Forest	22

1. Grid sampling was used for sampling post monsoon sampling.
2. For evaluating, assessing the impact of seasons on the BGBD sampling was carried out at three points of time (April, June and October) in land use representing dominant land uses of the area.

Land use land cover mapping

Visual interpretation of IRS standard geocoded false color composite on 1: 50 000 scale. Mapping of land use land cover changes during 1960s and 2002 period on 1:50,000 scale based on the thematic details given in Survey of India topographical sheet and satellite imagery.

Biosphere reserve genesis and concept

The biosphere reserve concept have been refined over the years and more and more countries have discovered the usefulness of putting this multifunctional approach to nature conservation into practices in the field biosphere reserve are protected areas of terrestrial and coastal/marine ecosystems displaying one or more characteristics *viz.*,

a) Representative examples of natural biomass;
b) Unique communities or areas with unusual features of exceptional interest;
c) Examples of harmonious landscape resulting from traditional patterns of land use;
d) Examples of degraded or modified ecosystems that are capable of being restored to more or less natural conditions and internationally recognized within the framework of UNESCO's programme on Man and Biosphere (MAB).

Reserves are nominated by national set of conditions before being included to the network. Each biosphere reserve is intended to fulfill three basic objectives:

- *In-situ* conservation of biodiversity (genetic resources, species, ecosystems) of natural and semi natural ecosystems and landscapes;
- Contribution to foster sustainable economic development of the human population living within and around the biosphere reserve;
- Provide facilities for long-term ecological studies, environmental education and training, and research and monitoring related to local, national and global issues of conservation and sustainable development.

These functions/objectives are associated together through a zonation system consisting of a core area, buffer area and transition area (see Box 1).

Box 1. Elements of Biosphere Reserves (UNESCO, 1995).

- One or more core zones: securely protected sites for conserving biological diversity, monitoring, minimally disturbed ecosystems, and undertaking non-destructive research and other low impact uses (such as eco tourism and education).
- A well-defined buffer zone(s): which usually surrounds or adjoins the core zones, and used for cooperative activities compatible with sound ecological practices, including environmental education, recreation and applied basic research.
- A flexible transition area or area of cooperation: which may contain a variety of agriculture activities, settlements and other uses and in which local communities, management agencies, scientists, non-governmental organizations, cultural groups, economic interests and other stakeholders worked together to mange and

FOREST CONSERVATION HISTORY

History of NDBR

Traditional land and resource right system was fluid and informal. The sequence of change relevant to history of conservation of the Nanda Devi Biosphere Reserve are summarized below:

a) Private land right were granted on cultivated lands along with promulgation of colonialists rights on remaining land what was notified as 'forest land (defined as all uncultivated lands including forests, pastures and snow clad areas) in 1865 but local people were allowed traditional forest resource uses:

b) Restrictions on people emerged in 1920 onwards when forest land was stratified into two classes: Reserve forest (areas where resources uses without prior permission of the Forest Department were offence; local people were granted rights of non-timber forest products uses and concessions for subsistence timber) and Civil Forest (timber poor areas surrounding the settlements free for use by villagers but land rights vested in the Revenue Department).

c) Present core zone was notified as Nanda Devi Wildlife Sanctuary in 1939. This followed recognition to killing of wild animals as a legal offence. Restrictions on grazing, through legally possible, were not imposed. The English mountaineers Eric Shipton and Tilman explored the difficult sage route to the Nanda Devi peak in 1934. This followed an opening for tourism. Tourism became a new source of income to local people.

d) Local resentment against restrictive measures turned into a mass movement by 1930 all over the Himalaya. A response to subdue mass opposition by the colonial rulers was creation of the Community Forests (locally referred to as Panchyat Forest) carved out of Reserve Forests outside the Sanctuary. Land rights of Community Forests were transferred from the Forest Department to the Revenue Department and managerial responsibilities to the local people. The area figures of the Community Forests are inconsistent, 1931 ha in Forest Department records and 4738 ha in Revenue Department records (Mohan, 1983) indicating a vague demarcation.

e) Timber was extracted on a small scale by the Forest Department in some parts of the buffer zone during 1960-1970. Large scale felling in *Cedrus deodara*, *Abies pindrow* and *Pinus wallichiana* forests was assigned to contractors from outside the region in 1970. Villagers sabotaged the felling by hugging trees and challenging the contractors to slash them before trees. This movement led by the buffer zone village Reni, popularly known as Chipko Movement ('Chipko', a Hindi word, means 'to hug') forced the government to ban commercial felling of green trees above 1000 m altitude in 1976 but removal of dead and diseased trees was permitted. This policy us continued.

f) Nanda Devi Wildlife Sanctuary was given a legal status of National Park in 1982 and absolute exclusion of local communities and tourists was enforced.

g) Nanda Devi Biosphere Reserve came in existence in 1988. The pre-existing National Park formed the core zone and forestland and settlements around core zone as buffer zone. In 1992, this Biosphere Reserve was recognized as a World Heritage Site.

It is apparent that policy interventions derived from the perceptions that (a) traditional subsistence agriculture and forest and pasture resource use practices were determined to the biodiversity and ecosystem services as well as long term detrimental to the biodiversity and ecosystem services as well as long term benefits to the local people (b) resources within the reserve were important for meeting the regional market demands and revenue to the government. Change in policy over time suggests increasing importance to the sustainable livelihood of local people, conservation of wild biodiversity and ecosystem services.

The NDBR has a long history of expedition trekking. The famous mountaineers Eric Shipton and Tilman first approached this area in 1934, which explored the sage route to Nanda Devi Peak and first saw the herds of blue sheep, locally known as Bharal (*Pseudois nayaur*). Realizing the wildlife value of this pristine area, it was declared a wildlife sanctuary in 1939. The post independence era saw a rush of mountaineers into the catchment to climb the high peaks like Nanda Devi, Trishul and Dronagiri. This led to serious damage and destruction of both flora and fauna that forced the government to declare the whole catchment a National Park in 1982. Entry into the Park was banned except for the purpose of ecological research and patrol staff. In 1988 Nanda Devi Biosphere Reserve was created, and in 1992 it became a World Heritage site. Trekking /expeditions in NDBR follow an age-old pattern of movement within the mountains. Before 1962 (Indo-China Conflict) there were traditional migratory routes generally used for trade with Tibet and also for seasonal animal grazing in the highland pastures. After establishment of the reserve, trekking/expedition/mountaineering and tourism were totally banned in the peaks in the core zone, which had an adverse effect on the income of local inhabitants.

On 18th January 1988, taking a cue from UNESCO's Man and Biosphere programme, Nanda Devi National Park (NDNP) was given the status of Nanda Devi Biosphere Reserve (NDBR). In 1992, NDBR got the recognition of a world Heritage Site and has been included in UNESCO's world network of Biosphere Reserve. The reserve is located in the northern part of the western Himalaya and covers a total area of 5860.69 sq. km with two core zones viz. Nanda Devi National Park (624.62 sq. km) and the world famous Valley of Flowers National Park (87.50 sq. km). The buffer zone (5148.50 sq. km) have the famous religious places such as Shri Badrinath Shrine and Shri Hemkund Sahib. The buffer zone of NDBR is located in the districts Chamoli, Pithoragarh and Bageshwar of Uttaranchal and includes area of reserve forests, civil forests and Panchayat forests. From geomorphologiacal point of view, the buffer zone occupies the whole Rishi Ganga catchment, (a tributary of Dhauli Ganga) which is encircled by High Himalayan peaks. India's second highest peak Nanda Devi flanks in Northern part of the reserve. A total of 47 villages are situated in buffer zone of NDBR of which 34 villages fall in Garhwal division (Chamoli District) and 13 villages in the districts of Pithoragarh and Bageshwar of Kumaon Division of Uttaranchal. However, the rural settlements are spread over an altitudinal range of 2200-3600 m asl. The Bhotiya culture lies in extreme northern part of Uttaranchal. Administratively it includes patties of Malla and Talla. Painkhanda of district Chamoli under the Tehsil Joshimath. Culturally and ethinically the inhabitants of this administrative divison form a single cultural unit, division from a single cultural unit, with well marked cultural as well as natural boundaries. Its snow-claded peaks, glaciers, precipitous streams and high, rugged mountain ranges with sporadic distribution of vegetation, characterize the surface landscape of the region. The topography of the region is, in general most rugged and tough and greater portion of the region lies above the tree line and remains covered with snow for more than half of the year. It is highly mountainous region with lofty peaks, consisting of a succession of mountain ranges and deep narrow valleys.

Table3. Altitudinal Ranges of Bhotiya inhabitants

S.N.	Bhotiya sub tribe	Valley	Mode of Settlement	Altitudinal ranges
1	Marcha	Mana, Niti	Migratory	900-3400 m asl
2	Tolcha	Niti	Settled, Migratory	2100-2500masl, 900-1s500 m asl

Window 1

High altitude study area

Climate

The climatic year consists of three distinct seasons- summer season (April - June), rainy season (June - September) and winter season (October-February). Average annual rainfall is 930 mm. about 47 % of annual rainfall occurs over a short period of two months (July-August) featuring a strong monsoonic influence. Monthly maximum and minimum temperatures range between 24.0^0C to 14.0^0C and 3.0^0C, respectively. Parent material is crystalline rock comprising garnetiferous mica schists, garnet mica quartz schists and mica quartzite. The soils, in general, are loan to sandy loam and well to extensively drained.

Temperature is one of the most variable abiotic factors, which play a significant role in the growth of the species and plant community, which regulates the function of any ecosystem. The daily temperature was recorded by maximum-minimum thermometer at the field station for the period of two year from March 2001 to March 2003. A monthly maximum and minimum temperature ranges between 27.2^0C to 15.3^0C and 16.0^0C to 2.2^0C. June-August are the hottest months of the year with an average temperature of (27^0C) and (16.04^0C).

The annual rainfall is about 936.6 mm/year. About 43% of annual rainfall occurs over a short period of two months *i.e.*, July and August, featuring strong monsoonic influence. Frequent snowfall during winter occurs from November to March. Although precipitation decline above 3300 m asl the monsoon remains important here and lower temperature imply that sub alpine area is effectively as wet as temperate zone, which receive more rain. Snow accumulates during winter and may not melt completely until the end of April or mid May. Connective storms accompanied by hail are frequent during the pre-monsoon season (February-March). Climatic data of Tolma excluding snowfall is presented in Figure showed below:

Land use land cover

Land use-land cover mapping based on the visual interpretation of Indian Remote Sensing Satellite data (False colour composite data from IRS-1A, LISS-II at 1:250,000) of 1989-91 shows that forests, alpine grasslands/ 3.2%, 5.8%, and 80.6%, respectively of the core zone and 26.8%, 5.1%, 6.9% and 60.3%, respectively, area of buffer zone before expansion of NDBR (Sahai and Kimothi, 1996). Vegetation structure and composition varies with altitude and terrain features. *Pinus wallichiana, Cedrus deodara, Cupressus torulosa, Abies pindrow, Pincea smithiana, Betula spp* and *Quercus* spp. are the dominant trees. Settled terrace farming is confined to less than 1% area of buffer zone, with a mixture of leaf litter and livestock excreta used to manure crop fields.

Biodiversity and ecological Services

The reserve is covered under the Himalayan biogeographic province 2A of India (Rodgers and Pawar, 1988), and is richly endowed with floral and faunal biodiversity. About 600 vascular plant species, including a number of rare, endangered and threatened taxa (e.g. *Dactylorhiza hataziera, Aconitum heterophyllum, Swertia chirayata , Taxus baccata)*; 18 mammals including seven endangered species including Snow Leopard *(Panthera uncia)*, Black bear *(Celenarctos thibentamus)*, Brown Deer *(Urcus arctos)*, Musk Deer *(Moschus chrysogaster)*, Bharal *(Pseudois nayaur)*, Himalayan Tahr *(Hemetragus jemlahicus)*, Serow *(Capricornis sumatraensis)*, Kokla Pheasant *(Purasic macrolopha)*, Western Tragopan *(Tragopan melanocephalus)*, Golden Eagle *(Aquila mipalansis)*, Black eagle *(Letinaetus malayensis)*, Bearded vulture *(Gypatus barbatus)* are reported from the reserve (Mohan, 1993).

The reserve covers sub-catchments including a large number of glaciers feeding the tributaries of the river Ganga. The Biosphere reserve area is, therefore significant for the people of the region in a Socio-economic and maintaining the hydrological balance of the Gangetic plains, one of the most thickly populated regions of South Asia.

Segregation of forested areas into *Panchayat forests,* for meeting community needs, as different from Reserved or Civil forests for economic and ecological benefits to a wider national community as distinct from the locals, has lead to the following adverse consequences:

a) Alienation of local communities from government-owned forest land;
b) Unsustainable exploitation of government forests by outsiders whose prime objective has always been to maximize profit rather than sustainable management of the forest itself.

Local communities have taken an active role in managing the *Van Panchayat forest;* they are indifferent towards the government forests because they do not have any legal responsibility for conservation of public resources, perhaps a response to the indifference towards them on the part of the government officials concerned themselves.

General description of the agro ecosystem of the buffer zone of NDBR

Though, the Bhotiya community is primarily trade dependent community. They have not given up agriculture but it is a subsidiary occupation for them (Nautiyal *et al.* 2003).

In the entire buffer zone, the rain-fed agriculture on steep terraces is the predominant form of land use, while only about 22.4 ha (8 percent of the total cultivated land) are irrigated. Irrigation is practiced only in one village, Malari that lies at 3200 m asl in the buffer zone. The rain fed agriculture in the villages of the lower and middle regions is practiced on two nearly halves of the agricultural land locally called as “Sari” with different crop compositions. A summer (April-Oct) and a winter crop (Oct-June) is harvested, the tradition being to let a sari lie fallow during one winter season every period of two years. In villages of the higher zone, the crops are only cultivated during the summer or “Kharif season” and lies fallow in the winter or “rabi season” for 5-6 months due to severe cold climate and harsh physical climatic conditions (Nautiyal *et al.* 2003).

Table 4. Characteristic features of the buffer zone villages situated along an elevational gradient in NDBR (Niti Valley), Uttaranchal

Parameters	**Lower Altitude**	**Middle Altitude**	**Higher Altitude**
Altitude	1900-2400 m asl	2400-2800 m asl	2800-3600 m asl
Transhumance	Not practiced	Practiced (short migration)	Practiced
Cropping patterns	3 crops per 2 year	3 crops per 2 year	1 crop per year
Distance from NDBR Core zone	5-8 km	3-4 km	>12 km
Main occupation	Agriculture	Agriculture	Agriculture
Subsidiary occupation	Animal Husbandry	Animal Husbandry	Animal Husbandry
Horticultural trees	Present	Present	Present
Number of cultivated agricultural crops	14	12	10
Number of cultivated Medicinal plant species	3	4	4
Land under traditional crops (ha)	105	61	107
Land under medicinal Crops (ha)	2.12	3.49	5.79
Total arable land	107.12	64.49	112.79
Name of Villages	Lata, Reni, Peng	Tolma, Phagti and Laung	Malari, Dronagiri and Garpak

The major crops cultivated in the middle and high altitudes of buffer zone are *Amaranthus* spp (amaranth), *Phaseolus vulgaris* (kidney bean), *P.lunetus* (a kidney bean locally known as chhimi), *Fagopyrum spp* (Buckwheat), *Eleusine coracana* (finger millet), *Panicum miliaceum* (hog millet), *Solanum tuberosum* (potato), and *Hordeum himalayens* (naked barley). Medicinal plants like *Dactylorhiza hataziera*, *Sellinum wallichianum*, *Angelica glauca*, *Aconitum heterophyllum*, *Berginia ciliata*, *Allium strachei*, *Allium humile* are also cultivated by the farmers of the high altitude. As noted, a variety of horticultural trees (apple, apricot and walnut) that provide fruits and fuel are grown on the raised margins of the rain fed terraces in the lower and middle elevational zones. Seasonal and off seasonal vegetables such as cucurbits, ginger, cabbage and green vegetables are grown in the kitchen gardens (Nautiyal *et al.*, 2003).

Crops such as *Echinochloa frumentacea*, *Glycine max*, *Fagopyrum*, *Setaria italica* and *Pennicetum typhoides*, that are grown in n1970-75, have completely vanished from the area. The area of their cultivation has reduced by 25-50 percent during the last 3 decades. However, the area under cultivation of several traditional crops such as *Amaranthus, Fagopyrum tatarium, Hordeum vulgare,* and *Solanum tuberosum* has increased during the same period because of the increasing market demand (Nautiyal *et al.* 2003).

Land use type

The vegetation is predominantly of forest communities with frequent interruption of scrub jungles, grass localities and crop fields. The covered area of forests as per the visual understanding is about 85% (Anonymous, 1981). Several environmental factors control the distribution of vegetation, however, usually in the hilly tracts vegetation is demarcated on the basis of altitudinal gradients because edaphic, topographical, climatic and associated factors are tend to be altered with the altitude. The second important factor in consideration is the aerial distance of the localities from the great Himalaya. In the paragraph below vegetation of the two windows one at high and another at middle altitude areas are discussed:

Alpine pasture

This sampling site is located near the core zone of Nanda Devi Biosphere Reserve and easily approachable from Tolma, a buffer zone village of NDBR. The area is characterized by scanty and stunting growth of few timber line tree species like *Cedrus deodara, Abies pindrow, Cupressus torulosa, Pinus roxburghii, P. wallichiana, Taxus baccata, Butela* species etc. while the stand is dominated by alpine grasses like *Agrostis nervosa, Andropogon munroi, Cympobopogon distans, Themeda caudate* etc. along with numerous medicinal herbs of higher Himalaya viz. *Dactylorhiza hataziera, Sellinum wallichianum, Angelica glauca, Aconitum heterophyllum, Berginia ciliata, Allium strachei, Swertia chirayata* etc. The duration of vegetative phase of these species in the alpine is very short, the region is covered by snow during winter season for almost 3-4 months and therefore, the occurrence and abundance of soil meso and macro fauna in the region is not common as compared to other low altitude sampling stands/landuses.

Cedrus forest

This forest exists just above the Tolma village i.e. a benchmark study area at the high altitude. The stand is dominated by the woody species of *Cedrus deodara*, shrubs are dominated by *Nepeta discolor, Berberis chitria, Hippophae rhamnoides, Principia utilis, Symplocos cochinchinensis, Wikstroema consence* whereas the dominant herbaceous vegetation includes *Potentilla argyrophylla, Synotis alata, Myriactis nepelensis, Agrimonia pilosa, Rosa mischata, Rubus acuminatus, Chenopodium botrys, Halenia elliptica, Heracleum candicans* etc.

Agriculture

Allium field

Allium is a medicinal plant, which has been brought under cultivation by the Bhotiya tribes about 30 years back. It is used as medicine, spices and condiments etc. and is grown as a monoculture in agricultural field adjoining to villages. Because of large-scale cultivation of this plant in the buffer zone villages of NDBR, which fall under the window were sampling of the meso fauna from the *Allium* field were carried out. This is a monocrop practice.

Potato field

Potato is cultivated as a monocrop in the region. It is one of the important crops of the area that gives lot of economic benefits to the inhabitants of the area.

Pea field

It is cultivated as mono crop in small plots of agriculture terraces while at low altitudes it is also cultivated as one of the crop in the mixed cropping system that is traditional also and withholds lots of promising impacts to maintain the fertility of the soil as well conserves the BGBD of the soil. This is one of the economically important and pulse crop of the area that not only withholds the soil meso fauna but also have the ability to fix nitrogen as *Rhizobium* is present in the root nodules of the crop plant.

Kitchens gardens

Kitchen gardens are small in size and owned by almost all the inhabitants of Tolma village where they grow vegetables for their own use besides some other species i.e. *Mentha arvensis*, *Cucumis sativus, Cucurbita pepo, Ipomea batatus, luffa acutangula, Lycopersicon esculentum*, *Raphnus sativus, Capsicum annum, Coriandrum sativum, Zea mays* etc. are usually cultivated along with few medicinal and aromatic plants commonly used as spices and condiments. These small kitchen gardens are rich in BGBD as lot of groups of meso fauna are recovered and reported from these gardens. The important aspect of these kitchen gardens is that not only vegetable plants but also horticultural fruit crops are also grown in these lands. Some of the important horticultural trees include *Malus plumila*, *Prunus amygdalus, Prunus persica, Juglans regia,* Plum, Cheeku, Cherry, Wild and Cultivated strawberry etc.

Forest and Pasture use management

Through radical changes were made in traditional land tenure, the age-old traditional practices that are still continuing include.

a) Forest litter, tree fodder and fuel wood easily available in sufficient quantities in areas near settlements are collected by woman. Men carry out collection of timber and bamboos and grazing in alpine meadows involving long distance travel and/transport of heavy loads. Collection of medicinal plants and wild edible and grazing near settlement is a subsidiary activity of both men and women.
b) All families make bamboo handicraft for self use but are marketed only by the socially underprivileged ones.

Changes in traditions and altogether new underprivileged ones.

(a) In the past, village wise territories of alpine pastures and forests were notionally demarcated. While one was free to collect deadwood, leaf litter and wild edibles any anytime during the year, utilization of fodder and medicinal plants was undertaken in groups during fixed periods. Decisions were taken by consensus when the community assembled for religious ceremonies. Violation of community decisions was believed to displease the goddess Nanda Devi and accompany catastrophic establishment of colonialists rights were established on all uncultivated lands. Village wise territories re-emerged with creation of the Community Forests but were not as extensive as the traditional ones and were managed through mechanisms different from the traditional ones. Decisions making power was vested in a few elected individuals of the Forest Councils and this led to marginalization of the traditional value of consensus within community. The community can recommend suspension of the Council or its member (s) to the government but such cases did not exist. Contrary to the tradition of forest resources utilization in groups, extraction of medicinal plants and dead and diseased trees in Reserve Forests is supervised by individual government officials who are not bound to seek local participation.

With establishment of National Park some village like Lata and Peng lost pastoral rights over large areas, which became a part of the Park. Other villages like Phagati, Garpak, Dronagiri and Malari which happened to be a away from the Park were not affected much. The Councils of unaffected village allowed livestock of the affected villages to graze in their territories but on payment of US$ 0.625/horse and cattle and US$ 0.125/sheep and goat. Permission of resources uses to resources poor villages by resource rich village were granted before establishment of the Park but without any fee. Livestock of village Lata and Peng are led by Anwals (a social group in central Himalaya who earn their livelihood by taking care of livestock in places far away from the native villages) for grazing in village Malari. The Anwals are paid US$ 0.125/ animal by the owner and are not responsible for losses due to natural death or killing by wildlife.

Following reservation of forests, forest and was divided into compartments and a compartment was supposed to be open to resources uses for one year followed by a regeneration period of 4-6 years. This requirement is not observed at all. In traditional system, compartments did not exist and uses were decided based on its recovery potential assessed on year-to-year basis.

(b) Until 1960, Bhotiya people used to go Tibet in the north during summers and too foothill region in the south during winters for trade. Livestock were used as the means of transport. Foothill community allowed penning of the livestock for manure. Closure of Indo-Tibetan trade in 1962, forest management practices favoring timber rather than fodder species, necessity of obtaining grazing permit from the Forest Department, reduction in potential grazing area because of conversion to agricultural land use and replacement of organic manure by inorganic fertilizers in the foot hills during 1950-70 led to abandonment of the migratory tradition and thereby more intensive uses near native areas.

(c) Local community realized the commercial value of timber following conventional forestry. Reserve Authority can take decisions on removal of dead and diseased trees from the Reserve Forests, but Forest Councils need permission from the government for the same practices in Community Forests. Procedure involves following sequences of steps: (a) submission of a proposal for sale of dead and diseased trees by the Forest Council to the Revenue Department (b) forwarding of proposal to the Reserve Authority for assessment of likely environmental impacts of the removals and market value (c) if the assessed value is US$ 125 or less and adverse impacts are not perceived by the Reserve Authority, the Council is permitted to auction the wood, but if it is exceeds the limit, Forest Department does all operations involving the Council members as observes (d) if timber extraction is done by the Forest Department 10%of the sale goes to the department as overhead charges and, of the remaining income, 20% to the District

Board for district level development projects, 40% to Revenue Department for projects of local importance decided by the Revenue Department in consultation with the Forest Council, and 40% to Forest Department for management of the Community Forests according to a plan prepared in consultation with the Forest Council. The proposal from low altitude village for commercial deadwood removal submitted two years ago is still pending.

Human impacts

Impacts of disturbance due to cutting of large size top canopy trees and fire are likely to accompany more drastic changes as compared to the change likely due to traditional uses of non-timber forest products. *Quercus* Spp. are locally the most valued multipurpose species but now valued much in the timber market. Hence the oak forest at mid altitudes suffers the least from the disturbance of removal of large trees. Intense disturbance due to tree removal is more common at high and low altitude because *Pinus roxburghii*, *Abies pindrow* and *Juglans regia* the dominant constituent of top canopy, do not have significant local uses but are valued much in the timber market. The local communities to enhance productivity of palatable grasses only in low altitude legally, use fire, through not permitted. *P. willichinana* forests which are poor in term of availability of tree fodder. People realize that *Quercus* spp. could regenerate in the absence of fire and grazing. Yet, the area is subject to surface fire before the onset of rainy season to promote growth of palatable grasses to meet the immediate fodder needs. Another threat to wild biodiversity and its ecosystem functions related to the present method of extraction of *Taxus baccata* bark used for traditional tea preparations. The present methods increase the risks of mortality because of lack of adequate protection from bark. Further, if people start extracting this resource for pharmaceutical market for maximizing monetary benefits, the regenerations of this species and its associates would pose a more serious threat.

In the Nanda Devi Biosphere Reserve forest constitute the matrix in which patches of settled agriculture are interspersed. Sustainable utilization of forest resources had been major concern of local communities as their very survival in remote isolated settlement depended on forests for manure, fodder, fuel wood, timber and medicinal plants. Traditional uses were centered around non-timber forest products. Further, forest biomass needs were low because of spare population and subsistence economy. Forest uses pressure was diffused as all forests were accessible to the local communities and intense human disturbances due to large-scale tree cuttings did not exist until colonial forest policy was in place in 1894 in India (Rao and Saxena, 1996). Deadwood from natural trees falls is more than what is needed by local people (Saxena *et al*., 1994). Increasing emphasis on a crop like potato, which does not have any fodder or manure value, implies more intensive litter removal and grazing in forests. This may lead to depletion of soil fertility and regeneration in forest if the current trends of change in crop diversity are not checked.

Major threats to biodiversity

Forest and alpine meadows within NDBR provide subsistence to the local inhabitants. Traditional resource use and management systems aimed for sustainable supply of natural resources in a geographically isolated and ecologically fragile setting. In the recent times, improvement in accessibility through road construction by the government has brought cultural changes and penetration of market forces and monetary considerations leading to commercial exploitation of the natural resources base in many locations.

Restriction of free access to reserve forests/delimiting local people to the Panchayat (community) and civil forests: (a) alienation of local communities from the government-owned reserve forest; (b) unsustainable exploitation of government forests by outsiders whose prime objectives was to maximize profit rather than to maintain sustainable yields; (c) intensification of forest resource use around settlements inability of government agencies to ensure desirable balance between exploitation and regeneration, because of a highly dissected terrain, inaccessibility, and limited manpower and financial recourses.

The region gradually became a supplier of timber and non-timber forest products (NTFP) to pharmaceutical, cosmetic and timber industries. Grazing pressure in government forests and pastures has exceeded the carrying capacity because of an influx of livestock from villages outside the buffer zone. This has rendered some parts of the catchment prone to top soil loss and landslides. Ineffective administrative controls and management practices paved the way for unsustainable extraction activities by outsiders on one hand and, promoted a sense of resentment among the local inhabitants on the other. There are instances when the local people themselves use government forests unsustainably.

Although commercial exploitation of NTFP from the area has been banned since 1982 (when it was declared a National Park), yet extraction continues because of practical difficulties in enforcing the ban. A similar situation exists in the case of poaching of wildlife. A huge number of Nepalese laborers secure livelihood from earning. These people, because of their familiarity with mountain resources, are more often hired by contractors for illicit commercial exploitation of resources in government forests for two major reasons: (a) the reserve officials hesitate to institute legal proceedings for punitive action against these foreign nationals; (b) Nepalese laborers are willing to work at much lower wage rates than that desired of the local people; and (c) there are many practical problems in establishing charges against the contractors because the laborers do not disclose their names.

One of the threats to the region's biodiversity lies in the limited capacity of government officials charged with the responsibility of protecting the environment and resources. While the local communities have taken an active role in managing the community forests, which they own, they are indifferent towards the government forests, as they do not have any legal responsibility for conservation of public resources.

Window – 2

Low altitude study area

Climate

Present study site is located in the middle altitude place called as Langasu that falls under Karanpryag Block of Chamoli district of Garhwal. Covering an area of about 7,520 sq km, about 90% of the population of the area depends on agriculture. Most occupational activities of the inhabitants of the region are forest based. 56% of the land is under irrigation (State report, 2004). Out of 17 villages those are falling in the low altitude window with in the area sampling, the present study is centered only in the 7 villages that form a small cluster (500-1000 m asl).

The climate of the area includes 70% of the total rainfall that occurs during rainy season (mid June to September) snow fall is rare in the area where this study was carried out but winter season is quite cold and windy (October-March). High velocity winds are prominent during the spring season (March-April) season. The region lies at the catchment of river Alaknanda.

Rain fed and irrigated land use systems are important agriculture ecosystems in this area with the former as a predominant form. Land holding of the farmers are scattered at the terrace fields on the hills. Paddy, Millet, Maize and pulses are the crash crops of Kharif (April -October) season while Rabi season (October-May) includes crops like wheat, barley, mustard, lentils and peas. The farmers of this region generally cultivate a variety of crop species and their numerous varieties in rain fed agro ecosystems to meet their food requirements throughout the year commonly known as "*Barahnaja*" or mixed cropping in the more scientific terminology is practiced pulses are grown in particular and in a single field about 12-20 types of different crops are sown. Dependency on the traditional crops is more prominent in inaccessible high altitude areas compared to the low altitude ones. Food consumption (per capita per year) level of the people of higher altitude villages is higher as compared to the people at middle and lower altitude villages. Around 40% of the dietary energy in the high altitude areas where high yield varieties of wheat and paddy have hardly reached, still comes from the traditional finger millet, barnyard millet and amaranth cultivars (Maikhuri *et al.* 1997).

Table 5. Traditional agroecosystem structure in Garhwal Himalaya

Lower elevation (900-1800 m asl)		**Higher Elevation (1900-2800 m asl)**	
Rainfed (Olla Sari)	**Rainfed (Palla Sari)**	**Rainfed (Mulla Sari)**	**Rainfed(Mallasari)**
Nov-April *Triticum aestivum*	**Nov-March** *Brassica campestris*	**Oct-April (Fallow)** *Solanum tuberosum* *Phaseolus vulgaris* *Amaranthus frumentace* **(April-Oct.)**	*Triticum aestivum* *Hordeum vulgare* *Hordeum himayalensis* **(Oct.-June)**
May/June-Oct *Fagopyrum esculentum* *F. tataricum* + various species of pulses commonly known as *Barahnaja*.(Mixed cropping)	**March-Oct** *Oryza sativa,* *Amaranthus frumentaceus*	*Triticum aestivum* *Hordeum vulgare* *Hordeum himalayens* **(April-June)**	*Fagopyrum tataricum* *Fagopyrum esculentum* *Phaseolus lunetus* **(July-Oct).**
Nov-March *Brassica campestris*	**Nov-April** ***Triticum aestivum,*** ***Hordeum himalayens***	*Fagopyrum tataricum* *Fagopyrum esculentum* *Phaseolus lunetus* **(July-Oct.)**	**Oct.-April (Fallow)**

March-Oct Paddy, *Amaranthusfrumentaceus*	**May/June-Oct** *Fagopyrum esculentum* *F. tataricum* + various pulse crops commonly known as *Barahnaja* practice (mixed cropping)	**CROP**	**ROTATION**

*** Crops take about 4 months (July-Oct.) for maturation changes in cropping season at high altitude village**

Land use

Oak forest

The vegetation structure of oak forest is dominated by the top canopy species, which include *Quercus leucotricophora, Quercus semicarpifolia, Quercus floribunda, Rhododendron arboreum, Sapindus mukorossi, Lyonia ovalifolia* in association of the shrub species such as *Barberis aristata, Pyricantha crenulata, Viburnum cotinifolium, Desmodium tiliaefolium* etc.Whereas the *Hedychium spicatum, Carea cruciata, Roscoea procera, Artimisia vulgaris* are dominating herbaceous species. The important change that has been observed for last five years is the extensive and fast invasion of *Eupatorium adenophorum* (syn. *Chromolena* spp) inside the dense forests of Oak.

Pine forest

The pine forest includes the tree species such as *Pinus roxburghii, Mallotus philipensis, Albizzia spp* etc. among the shrubs *Daphne cannabina, Euonymus echinatus, Barberis asiatica* etc. are predominating species while the herbaceous vegetation is represented by *Potentilla argyrophylla, Myricactis nepalensis, Heteropogon contortus etc. Chromolena* is also present in the Pine forest but its extent of invasion is comparatively lesser than the Oak forests and agricultural fields.

Agricultural land use

The cluster of 7 villages of Chamoli district, that are sampling sites for BGBD and related studies are located in the lower zone of Garhwal Himalayas (500-1000 m asl). Rain fed and irrigated land use systems are important agriculture ecosystems in this area with the former as a predominant form. Land holding of the farmers are scattered at the terrace fields on the hills.

Rainfed agricultural land

The farmers grow paddy during Kharif and wheat and mustard during Rabi season under rainfed landuse at low altitude. This land use mostly affected by various inspects/pests resulted low crop yield. The important feature of this land use is the mixed cropping which includes 12-15 varieties of pulse crops grown with other crop associates. This indigenous practice is common in middle altitude villages and helps in maintaining the fertility of the soil.

Irrigated agricultural land

Two crops, pure paddy during Kharif season and wheat and mustard during Rabi season are cultivated in the irrigated land. Besides, it is also noticed that on the margins of the water canal and bunds of the agricultural field few leguminous weeds are found growing that help in atmospheric nitrogen fixation because of *Rhizobia* present in the root nodules of the weed plant.

Kitchen garden

The kitchen gardens owned by the villagers are small in size. The vegetables commonly grown in kitchen garden include *Cucurbita maxima*, *Coriandum sativum*, *Capsicum annum Oleracea juncia*, *Rhaphanus sativas*, *Solanum melongana*, *Allium ceapa A. sativum Trigonella viridis* etc.

Soil pH

Effect of soil depth or land use type on soil pH was not as marked as in case of soil organic carbon. Oak forest soil looked more acidic than other land use/land cover types (Figure 32)

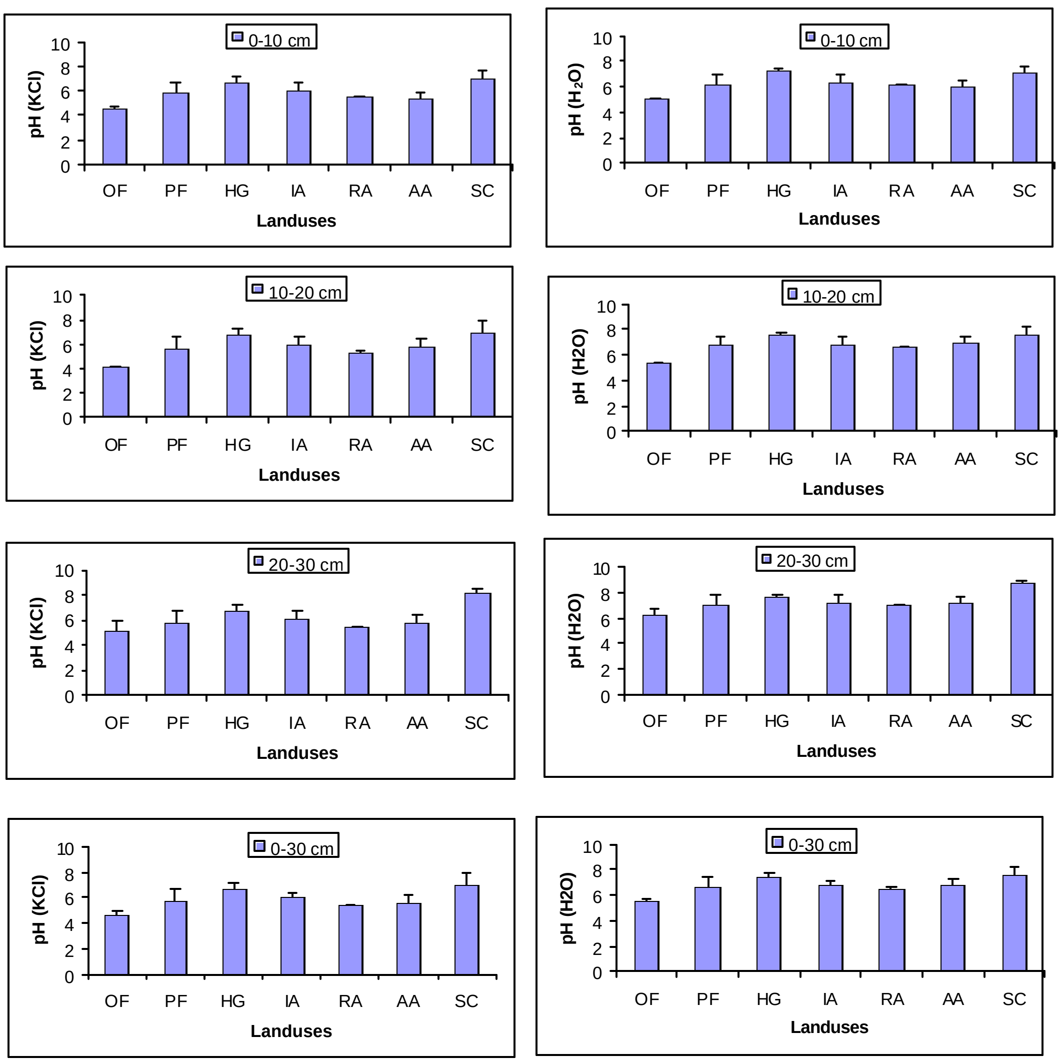


Figure Soil pH in variou land uses

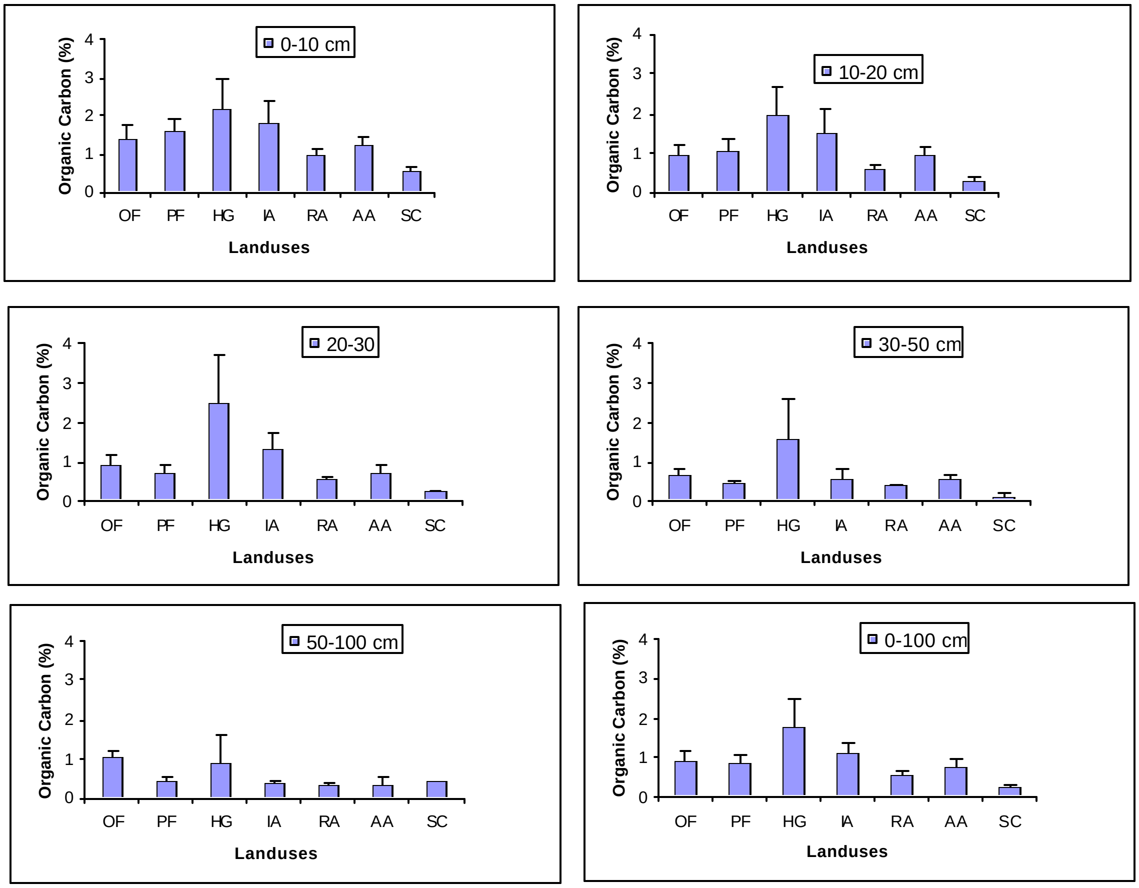


Figure Soil organic carbon content at various depths in various land uses

OF, oak forest; PF, pine forest; HG, homegarden; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; Sc, scrubland

Site characteristics of lower elevation zone have been summarized here. The data related to the higher elevation zone is still in raw form and hence not presented here.

Soil organic carbon

Soil organic carbon decreased with depth in all land use types but the pattern of this change differed between land uses. In homegardens, upper 30 cm of soil had almost similar concentration of organic carbon whereas in other land uses 0-10 cm layer had higher concentration followed by 10-20 cm and 20-30 cm. Irrigated agriculture is richer in organic carbon compared to forest soil if upper soil layer 0-30 cm is compared. However, if carbon concentration in the whole soil profile (0-100 cm) is taken into consideration, there seems no significant difference between agriculture and forest lands, homegardens showing the highest concentration (Figure 31).

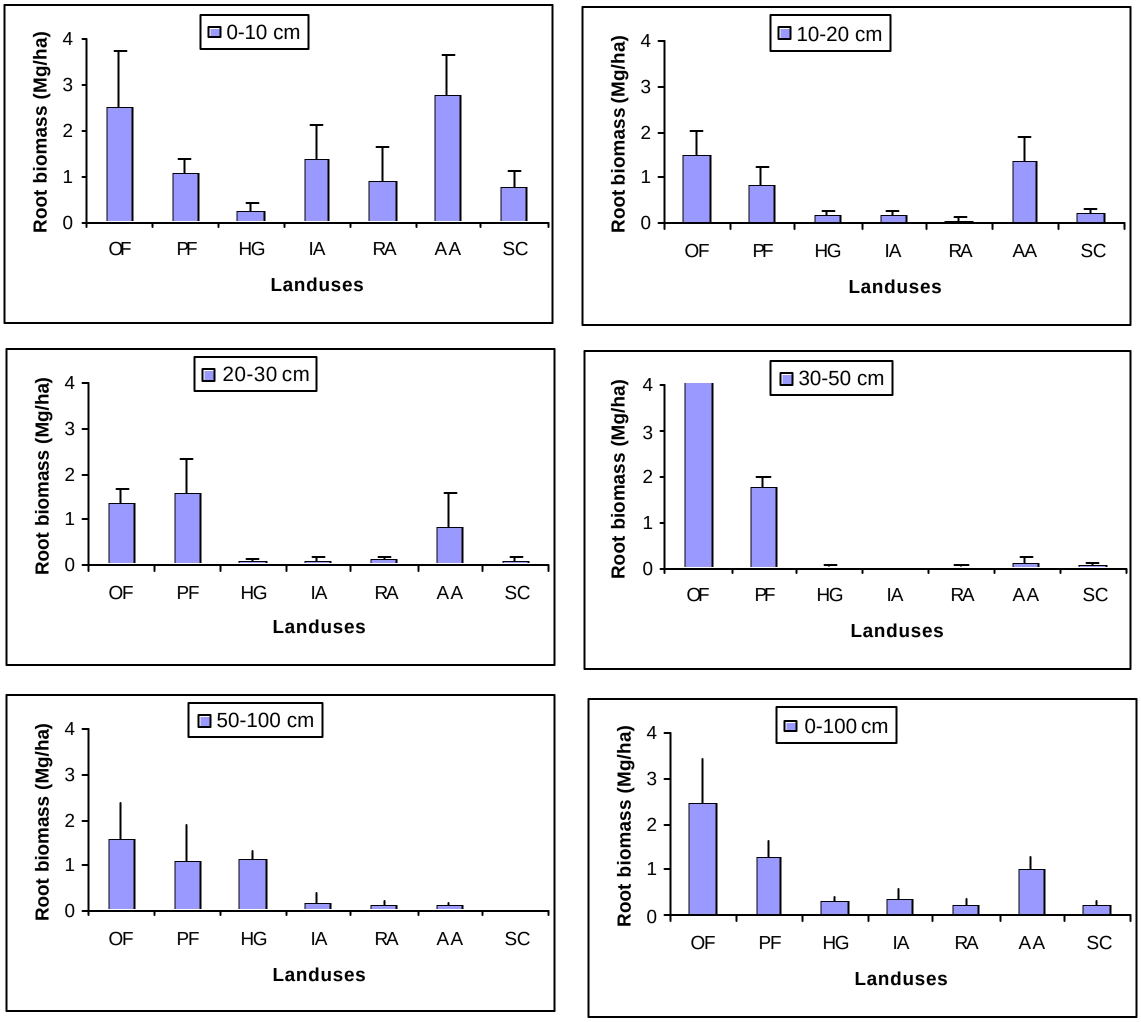


Figure Root biomass at various depths in various land uses

OF, oak forest; PF, pine forest; HG, homegarden; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; Sc, scrubland

Site characteristics of lower elevation zone have been summarized here. The data related to the higher elevation zone is still in raw form and hence not presented here.

Root biomass

Root biomass decreased with depth in all land use/cover types but the pattern of this decrease with depth varied. Irrigated agriculture, rainfed agriculture and scrub showed negligibale root biomass in soil depth > 10 cm. In contrast, significant amount of root biomass was observed in deeper soils (30-100 cm) in forests and homegardens. Total root biomass across the soil profile showed a trend of oak forest > pine forest > abandoned agricultural land >homegardens = irrigated agriculture = rainfed agriculture = scrubland (Figure 30).

Table 1. **Tree density** (individuals ha^{-1}) and basal area (m^2 ha^{-1}) (mean and SE) in different land use-land cover types in Langasu village landscape (values rounded off to one place after decimal; mature trees were not present in scrubland and hence not shown here)

Species	Rainfed farmland	Irrigated farmland	Abandoned farmland	Pine forest	Oak forest	Home Garden
Alangium salviifolium	-	-	2.8 (0.1)	-	-	-
Albizzia julibrissin	-	-	5.6 (0.1)	-	-	-
Albizzia sps.	-	-	2.8 (0.4)	-	-	-
Bauhinia purpurea	25.0 (3.9)	-	2.8 (0.3)	-	8.3 (0.4)	33.2 (0.8)
Bombax ceiba	2.8 (0.1)	-	8.3 (0.1)	-	-	-
Carica papaya	-	-	-	-	-	33.3 (0.4)
Celtis australis	36.1 (4.1)	13.9 (2.0)	16.7 (0.7)	-	-	50.0 (2.0)
Citrus aurentifolia	-	2.8 (0.1)	-	-	-	41.7 (0.1)
Citrus sinensis	-	-	-	-	-	283.2 (2.8)
Emblica officinalis	-	-	5.6 (0.1)	-	-	-
Ficus auriculata	2.8 (0.2)	-	25.0 (0.9)	-	11.1 (0.2)	8.3 (0.1)
Ficus palmata	-	-	2.8 (0.3)	-	-	8.3 (0.4)
Ficus subincisa	8.3 (0.1)	8.3 (0.8)	16.7 (0.7)	-	-	141.6 (1.8)
Ficus relegiosa	-	2.8 (0.1)	-	-	-	-
Grewia optiva	30.6 (2.7)	11.1 (0.5)	8.3 (0.2)	-	-	41.7 (1.2)
Juglans regia	-	2.8 (0.2)	-	-	-	33.3 (1.7)
Litchi chinensis	-	-	-	-	-	8.3 (0.02)
Species	**Rainfed farmland**	**Irrigated farmland**	**Abandoned farmland**	**Pine forest**	**Oak forest**	**Home Garden**
Mallotus phillipensis	-	-	25.0 (0.7)	-	-	-
Mangifera indica	-	-	-	-	-	149.9 (0.8)
Morus australis	-	5.6 (0.1)	-	-	-	8.3 (0.2)
Pinus roxburghii	-	-	19.5 (1.3)	463.9 (19.5)	2.8 (0.1)	-
Prunus persica	-	-	-	-	-	16.7 (0.5)
Psidium guajava	-	-	-	-	-	191.6 (1.0)
Punica granatum	-	-	-	-	-	16.7 (1.2)
Pyrus pashia	-	2.8 (0.1)	11.1 (0.1)	-	-	-
Rhus parviflora	-	-	19.5 (0.3)	-	-	-
Quercus leucotrichophora	-	-	44.5 (1.7)	8.3 (0.3)	516.7 (27.2)	-
Sapium insigne	-	-	5.6 (0.2)	2.8 (0.1)	5.6 (0.1)	-
Syzigium cumini	-	-	2.8 (0.1)	-	-	8.3 (.02)
Others	-	2.8 (0.1)	36.3 (0.2)	-	13.9 (0.2)	25.0 (0.8)
Total	**105.6±18.1 (11.04±3.1)**	**52.8± 22.6 (3.6±2.0)**	**261.3 ± 74.8 (7.4 ± 1.9)**	**475 ± 97.2 (19.8 ± 3.1)**	**558.3± 128.1 (28.2 ± 3.7)**	**1099.4 ± 187.6 (15.7 ± 2.9)**

Phytosociology

Species composition of tree community significantly varied in the landscape. Some species such as *Grewia optiva*, *Bauhinia purpurea* and *Celtis australis* were not found in forest lands. Species like *Ficus auriculata* were found in agricultural as well as forest land. Mean tree density varied from 52.8 in irrigated farm land to 1099.4 trees per ha in homegardens. Basal area varied from 3.6 m square/ha in irrigated farmland to 28.2 square meter/ha in oak forests (Table 16)

Litter mass

Amount of litter lying on the soil surface in forests is several times higher than that in the cropped or abandoned agricultural lands, even though huge quantities of forest leaf litter is removed for preparation of traditional farmyard manure. Homegardens have litter mass higher than cropped lands but lower than the forest litter mass (Figure 29).

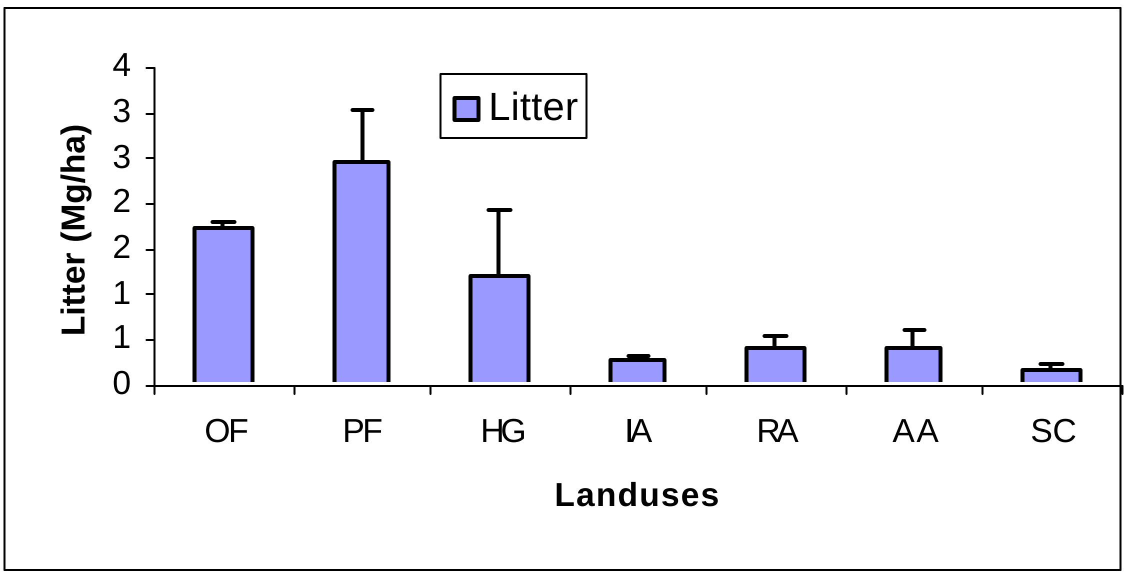


Figure: Litter mass in varius land uses

OF, oak forest; PF, pine forest; HG, homegarden; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; Sc, scrubland

Site characteristics of lower elevation zone have been summarized here. The data related to the higher elevation zone is still in raw form and hence not presented here.

Socio-economic Studies with Special Reference to Indigenous Farmers Practice and Knowledge on Soil Fertility Maintenance and Below Ground Biodiversity

Introduction

The two components of nature, viz. organisms and their environment are complex and dynamic, but also interdependent, mutually reactive and interrelated. Ecology deals with the various principles that govern such relationship between organisms and their environment.

India is a country of rich cultural and traditional heritage as well as variety and variability in living forms of organisms and thus, is considered as one among 25 mega diversity hot spots. Garhwal region of Central Himalaya is also a biodiversity rich area but due to inaccessible terrains and geographical complexity still not much has been done in the area of sustainable management and appropriate harnessing of biodiversity. Below ground biodiversity (BGBD) is one of such area of study and also the thrust area and key factor that helps to enhance the growth of above ground biodiversity. Directly or indirectly BGBD is linked and associated with the livelihood of the farming communities of Garhwal region. Local people practice many indigenous methods to increase the soil fertility of agricultural fields by emphasizing on BGBD.

Recent years have seen a dramatic increase in the per capita food production in many tropical countries. This improvement is largely based on the introduction of new crop varieties into farming programmes on fertile soils with good supplies of water, fertilizer and pesticides and certainly it has increased the yield many fold but gradually after the withdrawal of these chemicals, it results as declines in the productivity of the crops. The heavy input of the chemicals, fertilizers, insecticide, pesticide and weedicide have not only destroyed the BGBD but also deteriorated the soil fertility status. Introduction of such practices has also led to decrease in the per capita production in hilly tracts of Garhwal region. These farming systems are also commonly of low efficiency in terms of resource use and may be accompanied by rapid environmental degradation.

Traditional agricultural system plays a vital role in the subsistence, economy and living standards of Garhwal Himalayas in which about 80% of population of the area is actively engaged (Maikhuri, 2001). The agricultural land holdings in the hills are very small and per capita land holdings is estimated about 0.02 hectare. In this region, terraced slopes covering 85% of the total agricultural land are generally rainfed while the valleys covering only15% of the area are irrigated. There are more than 40 different crops cultivated along an altitudinal gradient of 300 to 3000 m *asl* (Maikhuri *et al.*, 2000). The soil particularly under rainfed agriculture is vulnerable to soil losses through combination of natural factors such as slopping topography, heavy seasonal rainfall and predominance of erosion prone soil and human factors such as intensive cultivation of land and erosion prone agricultural practices. The soil loss has been regarded both by scientists and farmers as a major reason for declining soil fertility and crop productivity in the region. Traditional agriculture of Garhwal Himalayas is now weakening due to variety of socio-cultural changes among rural communities and shrinkage in the natural resources is one of the major concerns. Therefore, sustainable and appropriate management of these resources is to be given top priority.

Present study deals with socio-economic profile, people's perception, awareness and knowledge regarding the role of BGBD in soil fertility maintenance with following objectives:

Objective of the study

- To study the impact and extent of knowledge of local farming communities about BGBD at both benchmark site (middle and high altitudes).
- To asses the extent of knowledge regarding beneficial and harmful insect pests of different land uses i.e. crops, Kitchen garden (vegetables) as well in their nearby forests.
- To document the indigenous practices of traditional farming communities in relation to soil fertility maintenance.
- To identify prominent weeds, presence of different invasive plant species in their agricultural fields, fallow lands as well as in forests and the "Non Weed" concept.
- To study the socio-economic profile of rural farming communities.

Study area

Present study was carried out at two different locations (low altitude, 700-1200 m *asl* and high altitude, 2200-2800 m *asl*) of Garhwal Himalaya. At lower altitude the study was carried out in 6 selected villages of the Karanprayag developmental block of district Chamoli located between 700-1200 m *asl*.

Depending upon the altitude and climate, the area can be broadly subdivided into sub-montane, and montane zones that support a variety of vegetation types. About 70% of the total rainfall occurs during rainy season (mid June to September), snowfall is rare in the area but winter season is quite cold and windy (October-March), high velocity winds are prominent during the spring season (March-April). The region lies at the basin of river Alaknanda.

Rainfed and irrigated land use systems are important agriculture ecosystems in the middle altitude with the former as a predominant form. Land holding of the farmers are scattered at the terrace fields on the hills. Paddy, Millet, Maize and pulses are the cash crops of *Kharif* (April -October) season while *Rabi* season (October-May) includes crops like wheat, barley, mustard, lentils and pea. The farmers of this region generally cultivate a variety of crop species and their numerous varieties in rainfed agro ecosystems to meet their food requirements throughout the year locally known as "*Barahnaja*" system, an unique type of mix cropping under which, about 10-12 different crops grown with proximity of legumes in a single field at contemporary time.

At higher altitude also 6 villages were selected for detailed study to know their socio-economic status and indigenous knowledge and practices related with management and maintenance of fertility of agricultural soil with special reference to BGBD. The selected villages are located between 2200-2800 m *asl* in high Himalayan region. These villages are part of buffer zone of Nanda Devi Biosphere Reserve, a world heritage site, falls in Niti valley of Joshimath Developmental block.

Methodology

A total of 12 villages (6 villages at low altitude and 6 at high altitude) were selected for detailed study considering the representatives of both the altitudinal locations. In these villages, survey of households was carried out by random sampling, ranging from 45% to 95% depending on the size of the villages. Data were collected with the help of questionnaire designed for the study. The PRA methodology was also used for generating, collection and documentation of desired information. For this study the respondents were categorized into 5 age groups from 20-29, 30-40, 41-50, 51-60 and >60 years. The reason behind was that, individuals below 20 years are comparatively holds a little knowledge of traditional farming and are not actively engaged in the agricultural practices, while the respondents between 31-60 age group are more experienced and actively engaged with agricultural practices and moreover they were more familiar with the reasons behind practicing the indigenous methods to enhance soil fertility of the agricultural system. Groups representing the variability within the community were given consideration for this semi-structured questionnaire on BGBD, as in age groups in various occasions contrasting views as well as valuable information were noted.

Selections of study villages

Selection of villages for present study was made randomly at both the locations while keeping in view the true representation of entire location considering several parameters viz. economic strata of households, land holdings, caste structure and geographical premises etc. The detailed socio-economic dimensions of selected villages is presented here:

Social dimensions of study area

Low altitude

The majority of households of the region are engaged in traditional farming. Broadly, the population of the region can be categorized in three caste viz. Brahmins, Rajput, and Schedule caste. Categorization of the people in these categories is as old as the Hindu mythology, according to which this categorization is mainly based on the labor distribution and nature of the work. Among these, the Brahmins are the richest peoples in terms of monetary in the region, as they are highly educated and engaged in government jobs and occupy a considerable share of total population. The Rajputs are the largest group of the inhabitants along with Brahmins possess the maximum agricultural land and the third category of the people (Schedule caste) represents the weaker section of the society (Fig. 1). They are less educated, economically poor and hold minimum agricultural land. Average family size of sampled households was recorded 5.0 individuals/family, whereas the average livestock possession was counted 4.5 cattle/family, which includes cow, bullocks, buffalo etc. and per capita landholdings was estimated 0.59 hectare with ascendancy of irrigated land (Table 1).

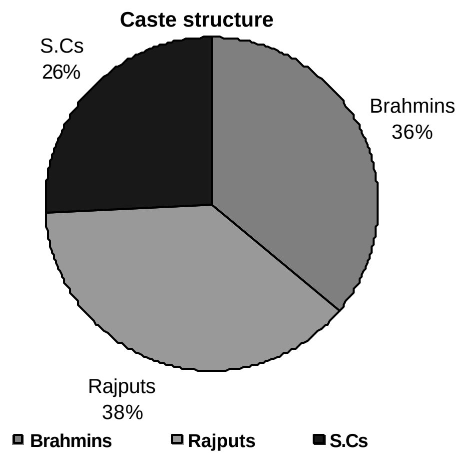


Figure 1. Population of different castes at low altitude

High altitude

The people inhibiting in buffer zone villages of NDBR belongs to two ethnic groups viz. Indo-Mangoloid (Bhotiya tribes) and Indo-Aryan. However the people inhabiting particularly in Niti valley belong to the Tolchha community, which is one of the three sub communities of Bhotiyas. Except the residents of Reni, Peng, Lata, and Tolma villages, all Tolchha Bhotiya households have two permanent dwellings, one at the higher altitudes (2400-3500m) *asl* and another at the lower elevations outside the buffer zone (800-1500 m *asl*). This community has its own culture, tradition and religious beliefs. The major occupation of this community has been sheep rearing and agriculture, with agriculture taking primacy over pastoralism in contemporary time. Average family size of the selected villages comprises of about 6.0m persons per family, while the livestock possession per family was estimated 6.0 cattle (excluding sheep and goat as now only few families having these particular animals), whereas per capita land holdings of the selected villages was recorded 1.09 hectare (Table 2).

There are two village level statuary institutions: (a) Forest council (locally called as Vanpanchayat) empowered to frame rules for subsistence uses of Community forest, (b) Village Development Council (locally called as Gram Sabha) empowered to implement government funded development projects. Both institutions established between 1940-1960 comprise 5-7 elected members. Further each village has a Youth Welfare team (locally referred as Yuvak Mangal Dal) established during 1970-75, and a Women Welfare Team (locally called as Mahila Mangal Dal) established during 1980-85. These two institutions do not have statuary status. At high altitude benchmark site in NDBR, the government is represented by the Nanda Devi Biosphere Reserve Directorate, and sectors departments dealing with land revenue, livestock, agriculture, health and education These institutions and departments are administrated by a variety of different governmental units at block or state level, creating difficulties in governmental units at block or state level, creating difficulties in coordination and integration of reserve management and planning. Whereas, at low altitude Benchmark site the government represented by line various departments involved in the rural development. These institutions and departments are administrated by a variety of different governmental units at block or state level.

Table 1: General profile of low altitude villages (window 2)

Village	**Total no. of House-holds**	**Total population**	**Average family size**	**Average livestock possession /hh**	**Total agricultural area (ha)**		**Average land holding/ family (ha)**
					Rainfed	**Irrigated**	
Langasu	45	234	5.2	4.2	17.28	6.36	0.52
Bansoli	60	332	5.5	5.1	0.90	29.55	0.50
Chamali	33	175	5.3	4.7	1.76	21.86	0.71
Bedanu	70+	382	5.4	4.8	10.05	46.48	0.80
Utron	55	270	4.9	4.0	1.82	38.20	0.72
Jilasu	56	235	4.1	4.6	4.05	15.54	0.34
Total	319	1385	5.0	4.5	35.86	157.99	0.59

Table 2: General profile of high altitude villages (window 1)

Village	**Total no. of House-holds**	**Total population**	**Average family size**	**Average livestock possession/ hh**	**Total Agricultural area (Ha)**	**Average land holding/family (Ha)**
Tolma	26	135	5.2	5.7	46.18	1.77
Bhallagaon	40	302	7.5	5.3	31.23	0.78
Suki	42	322	7.7	5.8	41.20	0.98
Phagti	28	141	5.0	6.1	42.78	1.52
Lata	75	412	5.1	4.4	51.23	0.68
Long	19	107	5.6	6.2	16.31	0.85
Total	230	1419	6.0	5.5	39.15	1.09

Household survey for indigenous knowledge on BGBD

While selecting the villages for data collection emphasis was paid to make the sample families truly representative of the whole population with respect to the income groups and land holdings. The range of percentage of sample households was between 31.43% in Bedanu to 76.92 in Tolma as per the details given in the Fig. 2-3. A total of 217 households were surveyed at both the locations (94 households at low altitude and 123 households at high altitude. The households were interviewed through the structured questionnaire.

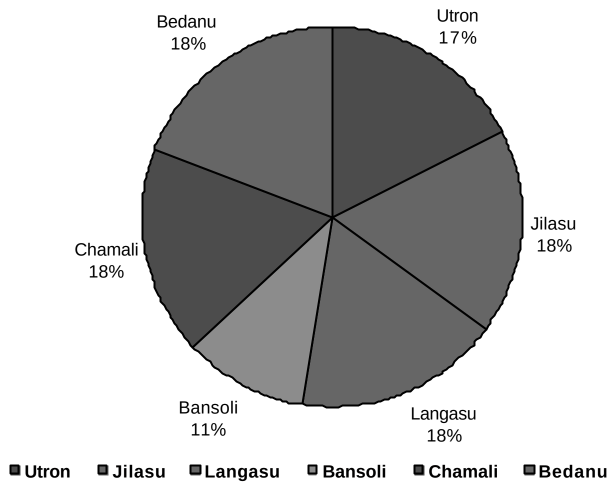


Figure 2: % of sampled households of different villages selected for survey at low altitude

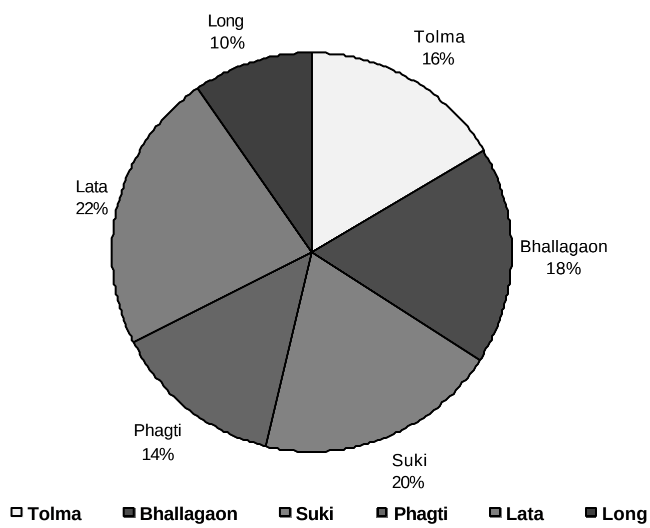


Figure 3: % sampled households of different villages selected for survey at high altitude

Table 3: Number of households and migration of families in surveyed villages of low altitude

Serial No.	Village Name	Total no. of Households	Sampled Households	% of sampled Households	Families migrated
1	Utron	55	20	36.36	17
2	Jilasu	58	20	34.48	40
3	Langasu	45	20	44.44	19
4	Bansoli	60	12	20.00	29
5	Chamali	33	20	60.60	11
6	Bedanu	70+	22	31.43	22
Total		319	94	29.47	138

Table 4: Number of households and migration of families in surveyed villages of high altitude

Serial No.	Village Name	Total no. of Households	Sampled Households	% of sampled Households	Families migrated
1	Tolma	26	20	76.92	2
2	Bhallagaon	40	22	55.00	4
3	Suki	42	24	57.14	-
4	Phagti	28	17	60.71	3
5	Lata	75	28	37.33	5
6	Long	19	12	63.15	-
Total		230	135	58.69	16

Economic profile of selected villages

The economy of the higher altitude villages based on diverse activities i.e. agriculture, livestock, sale of NTFPs and earning from jobs while working in Govt. and private sector. The average annual per family income from these villages estimated between Rs. 7372 – 8000 per year. However, at lower altitude villages, the major income sources are the employment in Govt. services, private jobs, and daily wage works and returned from agriculture. The annual average per family income in these villages was ranged between Rs. 9500 – 10250 per year.

Questionnaire preparation

Formal questionnaire for interviewing the villagers were designed to know indigenous knowledge on BGBD and soil fertility maintenance. This was tested in the field and standardized. The questionnaire thus finalized and used in surveys is enclosed. The formal questions were used to interview the people/farmers in the sampled villages at the household level. A household was defined as all those who stayed and worked in the same house.

Survey methodology

The survey was undertaken in between December 2004 and February 2005 in study area at following parameters:

***Reconnaissance survey*:** It was carried out at both the benchmark sites to study the social structure of the villages and to standardize the questionnaire. In this survey semi structured interviews and group interviews were carried out.

***Secondary data collection*:** The secondary information regarding, census, and other general information was collected from different sources i.e. Village micro plans, Revenue department, Gram panchayat, Block office etc.

***Primary data collection*:** These data were collected from 217 households belonging to 12 case study villages located in middle and high altitude window with the help of designed questionnaire.

Surveys related to social aspects etc. were carried out to make an assessment about various indigenous techniques used by the farmers to enhance the fertility and nutrient status of the soil of the agricultural fields.

The study was quantitative one i.e. empirical; it has helped to found ways or indicators to measure, following attributes:

- Major insect pests of rainfed and irrigated fields and in the nearby forest areas.
- Indigenous practice involved in preparation of FYM and its impact on their agricultural fields.
- Spraying of ash on different crops grown under kitchen garden (i.e. vegetables) and people's perception behind the practice.
- Extent of knowledge regarding the weeds, invasive plant species and to study the *Non Weed Concept* i.e. the useful aspects of certain weed species.
- Concept regarding the beneficial pests and insects.

Observations

The present study aims at to quantify and collect information regarding some indigenous practice and further to undertake in depth studies on these traditional techniques so that some suitable and improved techniques could be built over these to solve the problem of declining soil fertility of this area. The farmer's knowledge, perception and responses towards indigenous practices of BGBD and soil fertility maintenance is presented in Table 4. About 22% males and 49% females were found aware about the damage caused by particular insect in the rainfed and irrigated agriculture lower elevation, whereas it was found that about 30% males and 67% females are aware of infection caused to crop due to diseases in root and seed born. About 25% villagers of the area were found engaged in spraying ash for their kitchen garden crops i.e. Onion and Garlic kitchen gardens but they were unaware of the fact behind this indigenous practice and the reason behind was the lack of scientific awareness as well as extension activities in the village. Only about 7% males and 10% of females among the total respondents were aware about the beneficial role of spiders and earthworms in their crop lands as well as other land uses and rest of them even in opinion of that earthworms are also harmful to their crop. The 99% of the respondents were also aware with the application and beneficial aspect of using tree leaves for preparation of FYM and its role in agriculture.

At high altitude about 33% male and 66% female respondents were aware of insect presence in agriculture, about 43% male and 56% female were found aware about harmful insects. Besides, in most of the cases more than 40% of respondents among male and female were also found well aware about crop seed infections, and use of FYM etc.

However, less than 10% of the respondents were not found much aware extension activities, benefits of earthworm etc.

Age characteristics of sampled population:

Table: 5 Number and % of male and female individuals of different age groups sampled for the study at low and high altitudes.

Age group (Years)	Male		Female		Total	
	No. of individuals interviewed	% of total male population of sampled households	No. of individuals interviewed	% of total female population of samp led households	No. of male and female individuals interviewed	% of total individuals sampled
At low altitude						
20-29	3	12.5	5	16.3	8	10.9
30-40	4	16.6	13	26.5	17	23.2
41-50	4	16.6	5	10.2	9	12.3
51-60	3	12.5	20	40.8	23	31.5
>60	10	41.6	3	6.1	13	17.8
Total	**24**		**49**		**73**	
At high altitude						
20-29	9	10.2	15	8.7	24	19.5
30-40	11	19.7	21	13.4	32	26.0
41-50	14	21.4	26	37.6	40	32.5
51-60	10	14.3	18	29.5	28	22.7
>60	4	18.7	5	11.2	9	7.3
Total	**48**		**75**		**123**	

Table 5: People/Farmers response about indigenous knowledge on BGBD and related aspects.

Parameter	**% of respondents**			
	Low Altitude		**High altitude**	
	Male	**Female**	**Male**	**Female**
A. Indigenous Knowledge about BGBD				
Ques: Do you know about BGBD (insects in your agricultural fields)				
Yes	**22**	**49**	**33**	**66**
No	-	-	-	-
B. Major harmful insects.				
(RF+IR) Grub	**30**	**67**	**43**	**56**
(IG) B/G Caterpillar	**03**	**15**	**30**	**25**
C. Which part of the crops infected (crops e.g. Wheat, Paddy, Potato, Apple, Kidney bean, *Fagopyrum* etc)				

Root	**30**	**67**	**59**	**40**
Seed	**03**	**15**	**22**	**29**
D. Use of Ash in spraying	**23**	**27**	**14**	**18**
E. Use of Cattle bedding and Farm Yard Manure (FYM)	**100**	**100**	**100**	**100**
F. Extension activities in the Village	**03**	**05**	**09**	**03**
G. Beneficial role of Earthworm & Spider in the Agricultural field	**07**	**10**	**17**	**07**
H. Invasion of a particular weed in different land Uses of the Village	**21**	**94**	**35**	**60**
I. Use of Gamaxene and 4 eight against Grubs	**26**	**42**	**44**	**25**
J. Formation of Root galls in some fruit trees (Orange)	**10**	**03**	**45**	**08**
K. Is there any indigenous method to eradicate the harmful insects and pests (like fire before sowing Paddy nursery)	**33**	**79**	**-**	**-**
L. Best time leaf litter collection for FYM preparation				
Autumn	**12**	**28**	**12**	**61**
Winters	**10**	**31**	**07**	**19**
Whole Year	**10**	**07**	**-**	**-**

Indigenous methods used for the maintenance of soil fertility

The farming communities in the Garhwal hills of Uttaranchal are extremely rich in their indigenous knowledge and techniques. They have developed and refined these knowledge and techniques over centuries to carry out farming under diverse, uncertain, risky and fragile ecological conditions. There is evidence that researchers can learn from indigenous knowledge system, both about farmer practice and the ecological processes operating in farmer's field. When researchers do so, they may change their views that what kind of strategy is useful to farmers both because the information they given about the operative processes and the confidence they have that research of a particular type is relevant and can be useful and should be communicated to farmers.

Various examples demonstrates that modern knowledge and advancements either has its origin in the farming communities or has been built upon the knowledge base already existing among these communities

For the hill farmers of this region, managing soil fertility has been essential to their survival. However, there is a common notion that the soil fertility is declining over time. Researchers/Scientists have been slow to understand the complexity of indigenous soil fertility management and consequently have been unable to substantially improve soil fertility, although many sophisticated and labour intensive methods have been developed. Some of the common soil fertility management methods described below:

Application of Farm Yard Manure (FYM)

Applying Farm Yard Manure (FYM) in the agricultural fields is one of the most useful and significant indigenous methods practiced almost more or less in all the villages of the region. Hill agriculture is mainly having two major types of land uses viz. irrigated and rainfed.

To maintain the fertility of the soil, FYM is applied twice a year on the fields. FYM is a wise practice of using the fully decomposed organic matter of cow dung and other livestock excreta reared by the inhabitants of the area, animal bedding, grasses, feed left over together. The leaves used for animal bedding not only keep the livestock clean and warm but also used to maintain or enhance the fertility level of the soil. The preference towards leaves used for cattle bedding depends upon the availability of resources in nearby forests, as they are one of the major constituent of the FYM. However, people/farmer from middle altitude of area give preference for the Oak leaves as they have a common perception that Pine needles are the main cause behind the insect pest attack and root and soil borne diseases in the crop fields of the area. The quantity of FYM used for agricultural field depends upon the number of livestock reared, nearness from the forest, area of agricultural field as well as the manpower available.

Based on the application of FYM earthworms also get introduced in the cropland and increase the fertility of the soil, as a large number of earthworms are present in the place where organic decomposition of cow dung takes place. This is a time taking process and good FYM is prepared within a period of about 3-4 months of continuous open-air decomposition of cow dung with other leaf litter as discussed above.

One more practice regarding the FYM preparation is prevalent and observed particularly at higher altitude areas where farmers maintain two cattle sheds one near to their village whereas another near to their agricultural fields so as to reduce the labour in carrying the FYM. In this practice they only shift their livestock from one cattle shed to other according to the growing season of different crops.

Mixed Cropping and Crop Rotation

Mixed cropping is termed as beneficial cropping pattern for soil throughout the world. The similar practice also exists in the traditional farming system of Garhwal Himalaya. The farming communities of the area are using this indigenous practice for over centuries. Mix cropping system of the region is locally known as *Barahnaja* system. *Barahnaja* is mixed cropping system of growing 10-12 different crops together while incorporating legume crops in the field at the same time. Some of the common crop plants sown in this practice are Rajma (*Phaseolus vulgaris*), Gahet (*Macrotyloma uniflorum*), Kong (*Pisum arvense*), Sonta (*Vigna unguiculata)*, Rains (*Vigna angularis*), Kalabhatt (*Glycine spp*.) Urd (*Vigna mongo*), Moong (*Vigna radiata*), Soyabean (*Glycine max*), Ragi (*Elusine coracana*), Ramdana (*Amaranthus spp.*) etc. This practice is considered beneficial mainly because diverse canopies of a variety of crops help to check the soil erosion during the rainy season minimize the growth of weeds and simultaneously different crops do not compete for similar nutrient from the soil. While, more emphasis is given on the leguminous crops in mixed cropping as they have capacity to fix the atmospheric nitrogen in to soil through biological nitrogen fixation.

Ash Spraying

Spraying of ash is a common and indigenous practice used almost in each and every household for the sake of increasing fertility of the various crops. But ash is mainly sprayed weekly or fortnightly in their kitchen garden crops near to their households. Amount of ash applied has not been quantified but mainly they make use of it for crops like Onion, Garlic, Coriander, and Spinach etc. Although the farmers of this area are not familiar with the scientific reason of it but it is very clear to them that it is highly useful for crops and also enhance the yield.

Fallowing

Keeping agricultural land fallow for a brief period of 4-6 months is a general practice in the rainfed agro-ecosystems of the study area. In this technique, no crop is cultivated during *Rabi* season on the land from where the mixed crop of finger millet and pulses are taken during Kharif season. Based on in-depth knowledge and long experiences farmers well recognized that fallowing of land provide time to soil for convalescence, which otherwise gets exhausted due to intensive cropping.

Terracing

Terracing is a critical aspect of rainfed agriculture in the hills, primarily because of their ability to substantially reduce erosion and secondary to make tillage and other agricultural practices easier to carry out. Very early in the development of agriculture in hill, farmers recognized the value of terraces as the major precondition for the maintenance of soil fertility. The existing bench terrace systems are a trademark of hill farmer's determination to maintain their rainfed agricultural systems.

Respondents were asked to list the number of practices followed in the region for maintaining soil fertility so as to improve crop productivity. More than 82% of respondents at both the locations (low and high altitude areas) highlighted that farmyard manure (FYM), leaf litter from the forest and mix cropping are the most common and prevalent practices in the region for maintaining soil fertility. In addition to this, particularly at high altitude, more than 96% of respondents expressed that in-situ manuring, fallowing and mulching are also good practices adopted in the region. Though, farmers of low altitude also expressed the same but the % of respondents were less as compared to higher altitude.

The other practices listed and practiced at various magnitude found at both the study sites were terracing of agricultural land, burning previous crop remains, and Ash from house and kitchen waste (Table 6). The fact however, is that all such indigenous knowledge and techniques are gradually fading away because of lack of proper documentation/recording and due to many other reasons.

Table 6: % People/Farmers responses regarding indigenous practices of soil fertility maintenance

Indigenous practice of soil fertility maintenance	**% of total response**	
	Low altitude	**High altitude**
Farm Yard Manure (FYM)	100	100
Leaf Litter from forest	80	90
Mixed cropping and legume in crop rotation	95	82
Green manuring	30	40
Mulching	20	60
Slashing of plant species from terrace walls	35	28
Burning of previous crop remains	48	63
Terracing of agricultural land	70	55
In-situ manuring	80	96
Fallowing	75	68

Ash from house and kitchen waste	37	20

- **L A - Total number of respondents = 94**
- **H A -Total number of respondents = 118**

Farmer's knowledge on other aspects directly/indirectly linked to AGBD-BGBD and sustainable livelihood:

Weeds and Non-weeds

Chromolaena odorata commonly known as Eupatorium is an alien, obnoxious and aggressive weed. It has occupied pastures, marginal lands, open areas, old forests and interior shrub jungles, of low altitude as well as high altitude localities of Garhwal Himalayas where it is highly competitive and does not let often grow local flora. It is a menace in plantations, agricultural crops and smothers vegetation, as it possesses allelopathic potentialities and growth inhibitors.

The weed poses a grave threat to the floral biodiversity of Central Himalayas, where it is competitively repeating the existing indigenous rich flora, thereby creating ecological imbalance. The rapid spread of weed is due to excessive seed production and also wind dispersal of seeds. All these point highlight that Eupatorium is a threat to agriculture and environment particularly at low altitude. Hence, there is an urgent need to manage weed growth and its spread so as to maintain ecological integrity in resolving the problems imposed by Eupatorium, current control methods are not applicable of providing long lasting solutions since manual control is uneconomical due to re sprouting and perennial nature of the weed. Herbicide control is not only a costly affair but also causes environmental pollution. Whereas the positive aspect as told by the inhabitants of this area is that *Cromolaena odorata* in spite of so many deleterious effects on the soil and agro ecosystem is helpful in binding the soil of the forests that reduces soil erosion due to rainfall and felling of trees.

Discussion

For the study a semi-structured questionnaire was designed and survey was conducted to know the socio-economic conditions and indigenous practices related with BGBD and soil fertility maintenance. The study villages were randomly selected keeping the view of true reorientation of entire society. The respondents were categorized into five major age categories ranging from 20-29, 30-40, 41-50, 51-60, and greater than 60, where more emphasis was given on the women folk of the village and the persons belongs to category of 51-60 years. The simple reason behind this was, that in this region men folk mostly working on various jobs and migrated outside to earn their livelihood. While, women not only do their daily homework but are also engaged with so many other activities like agriculture, fuel and fodder collection from forests etc. So, they are the only source having information and experiences pertaining to BGBD and other related indigenous practices for its conservation and management. While, most of the men enquired regarding these practices were belongs to the age group greater than 60 years and most of them were retired persons. Since majority of them were out of their village for a longer period and thus information regarding BGBD and other indigenous practices available with them was observed less in comparison to the women folk of the area since they are solely involved in agriculture. The knowledge base in relation to BGBD was also found less among the respondents of between the age group of 10-19 and 20-29 years and the reason is obvious that most of the youngsters migrate from the villages either to obtain better education or jobs out side.

The other category which was under taken to evaluate the indigenous practices used for maintaining soil fertility and BGBD was occupation which include three different categories viz. farmers, housewife and others. In the category of others correspondents having different occupational skills were considered and includes teachers, students, businessmen, government employees etc. while, housewife was considered as a broad category which includes women folk of that area either working or non working as both are involved with less or more in the area of agriculture or forest related activities but they were not included in the category of farmers. However, about 63.02% females under the category of housewife were sampled whereas in the category of farmers those involved in agriculture only about 23.9% of correspondents were sampled and least (10%) correspondents were interviewed under the category of others. The similar proportion of the respondents was covered in relation to BGBD and related indigenous aspects from the category of occupational characteristic. Although, women folk of the area were more aware about the BGBD and indigenous practices but they were least aware about BGBD found in the forest areas besides, scientific and other reasons behind indigenous practice as well as the eradication measures against harmful insect, pest damaging agricultural and other crops.

Although agriculture is practiced at very small portion of the total geographical area due to topography and complex terrains but still, it is the primary economic activity of the people inhabited in the region. It was the general perception of the farmers of this region that during recent past the agricultural crops are severely attacked by various insect/pest and also damage by many diseases, which are unknown to them. This is responsible for decline of crop productivity, which directly leads economic, and food insecurity of the farming communities. Thus reduction in the crop biodiversity as well as the yield per crop, in the present case is a cumulative effect of a variety of factors including:

- Reduced availability of the biomass from the pasture, the very base of sustaining traditional diversified agriculture
- Rapid socio economic and cultural changes favoring a shift from subsistence to market economy
- Large-scale migration for off farm employment as well for education.
- Lack of scientific approach for agriculture and
- Lack of in-depth scientific information on BGBD as well as its economic use for increasing the crop yield.

Conclusion

The indigenous methods of maintaining soil fertility described in this paper are the time tested ones by the traditional farming communities of the Central Himalayas. If the scientific studies of these are thoroughly undertaken then only we would be able to build over the existing techniques. It becomes highly imperative in the present context of fast socio-economic changes, environmental degradation, out migration of the people leaving agricultural land abandoned in the region that is directly or indirectly responsible for declining soil fertility. Majorities of above discussed methods of soil fertility maintenance are based on forest resources that are dwindling at an ever-increasing rate due to a variety of pressures. Strengthening traditional agro forestry and rehabilitation of the degraded land through agro forestry inputs or ecological restoration approach ensuring people participation is possible remedial measure to cope with the situation (Maikhuri *et al.*, 1997 a, b; 2000).

Uniqueness of crop diversity as perceived by local people in Central Himalaya – the areas distinguished for best crop quality

	Crop	The locality giving best produce as discerned from survey
1	Cucurbits (specially pumpkins and cucumber), Gahat (Macrotyloma uniflorum)	Bacchelikhal
2	Onion (Allium cepa)	Mullegaon
3	Sesame (Sesamum indicum)	Gauchar
4	Gahat (Macrotyloma uniflorum)	Sonla, Saknidar
5	Potato (Solanum tuberosum)	Joshimath, Harsil, Chirbatia
6	Lentil (Lens esculenta)	Tihri, Takoli
7	Ginger (Zingiber officinalis)	Daggarpatti, Agrakhal
8	Tor (Cajanus cajan)	Guptakashi, Jalai
9	China (Panicum miliaceum)	Maletha
10	Jhangora (Echinocloa frumentacea)	Srikot, Chauras
11	Jakhya (Cleome viscose)	Srinagar
12	Rains (Vigna angularis)	Guptakashi, Dwarahat
13	Gol muli (Raphanus sativa)	Dwarahat
	Gadheri/Pinalu/Kuchain (Colocasia sps)	Dugadda, Dagar, Bageswar, Dwarahat
14	Tor, Kala Bhatt (Glycine sps)	Ukhimath
15	Cabbage (Brassica oleracea var. capitata)	Narayankuti
16	Bhangjira (Perrilla frutescence)	Adibadri
17	Cheura (Diploknema butyrissea)	Gangolihat
18	Chua (Amaranthus paniculatus)	Gairsen
19	Dry chillies	Chaura, Kichgad
20	Rajma (Phaseolus vulgaris)	Harsil, Joshimath
21	Apple	Harsil, Rawain
22	Malta (Citrus sps.)	Ukhimath, Jakholi

	Low altitude	High altitude
Three insects viz., white grub, a caterpillar and a stem borer reduce yields.		
There is no need to kill all insects in the crop		
Insecticide spray will increase yields		
Insecticides will kill natural enemies		
Some insects are beneficial to rice yields		
Insecticides are harmful to human and livestock health		
Insecticide can cause more pest problem		

Table . Local concerns for pests and indigenous responses to reduce damage

Kind of pest	Degree of concern	Responses to reduce damage
Monkeys for all crops, specially winter crops(upto 2000 m), bear in higher altitudes (2000-2400 m), and porcupine and wild boar (damage more due to trampling) all crops and all altitudes	Very high	Physical impediments to the pest, keeping watchman and dogs, lighting fire and putting effigies to repel pests
Birds for legumes (early stages of legume growth – they eat cotyledons) at lower elevation and temperate fruits at higher elevations	Very high	Keeping watchman to repel pests by making loud voices/sounds, and putting effigies to repel pests
White grubs for all summer crops at lower altitudes	Very high	Proper composting of manure
Stem borer in amaranth at higher altitude	Very high	Crop diversification

Fungal disease in potato at lower elevations and irrigated conditions	Very high	Crop diversification, removal and burning of infested plants
Caterpillar infestation in legumes at the flowering and fruiting stage at lower elevations	Very high	Crop diversification
Post harvest fungal and insect damaging pulses except Glycine max, a crop which not at all dmaged	Very high	Frequent sun-drying and smoking
Insect attack (stem borer and leaf folder) in rice in irrigated agriculture	Very high	Crop diversification
Smut of cereals	Very high	Crop diversification
Fungal disease in potato at lower elevations in rainfed conditions	Moderate	Crop diversification, removal and burning of infested plants
Ants at the time of sowing in rainfed agriculture	Moderate	None
Other fungal and bacterial diseases	Negligible	None
Weeds in summer cereals and millets	Very high	Manual intensive weeding
Weeds in legume crops	Negligible	Manual casual weeding

Macrofauna: Nanda Devi Biosphere Reserve

1. Introduction

Nanda Devi Biosphere Reserve is globally distinguished as a World Heritage site. Significant published information is available on aboveground diversity and people-policy-natural resource-development linkages (Maikhuri et al., 2000, 2001, 2003; Rao et al., 2003). The work done on belowground diversity in terms of its abundance and functions in qunatiative terms is quite deficient in that (a) the available quantitative data, by and large, is confined to earthworms and soil physico-chemical-biological properties (Julka and Paliwal, 2005; Rao et al., 2005) (b) earthworm abundance has been analysed over small geographical areas (e.g., selected land uses within one village) (c) importance of other groups of soil macrofauna has not been adequately realised. Enormous ecological and management diversity in mountain landscapes warrant generalizations based on sampling in limited area. Soil macrofauna inventory in quantitative terms provides a very useful information about soil quality in relation economic and ecological values of ecosystems (Doube and Schmidt, 1997; Carter et al., 1997)

2. Methods

Macrofauna were segregated from litter layer, and 0-10 cm, 10-20 cm and 20-30 cm layers of soil standard size monoliths following a systematic grid based sampling design. Further, sampling was done covering all the three seasons, April month in pre-monsoon warm season, July in monsoon season and October in post-monsoon season. A point was not sampled if it had rained there during the last 24 hours. The land use - land cover types sampled for soil fauna inventory were also analysed in terms of vegetation structure and composition, litter mass, root biomass and soil physico-chemical properties.

3. Results

3.1. Earthworms

3. 1.1. Numerical abundance/species richness

In low elevation zone, earthworms showed the highest density during monsoon season in agricultural land use, during post-monsoon season in oak forests and similar abundance during pre- and post-monsoon in pine forests. In higher elevation zone, earthworms were found to be absent in alpine pasture and *Cedrus* forests, but present in all types of agricultural land uses. Home garden and medicinal plant cultivation area showed the highest density during post monsoon season, potato field during pre-monsoon and a similar density during pre and post monsoon period in pea cultivation area. Homegarden was the only land use where earthworms occurred in all seasons (Figure 1).

In both elevation zones, earthworms were more numerous in agricultural land use compared to forests and pastures. Within agricultural land use, earthworm density was significantly higher in home gardens as compared to other agroecosystem types. At lower elevations, where both rainfed and irrigated agriculture are practiced, earthworm population rainfed system was higher than that in the irrigated one. There was no significant difference between pine and oak forests that occurred only at lower elevations (Figure 1).

Coefficient of variation in earthworm population varied from 57% in homegarden (higher elevation) to 219% in oak forests during post-monsoon, 56% in homegarden (higher elevation) to 306% in homegarden (lower elevations) during pre-monsoon and from 73% in pine forest/medicinal plant cultivation to 488% in homegarden (higher elevation) during monsoon season (Table 1).

3.1.2. Biomass

Earthworm biomass in the post-monsoon season is shown in Figure 2. Land use effect on earthworm biomass in lower elevations was not as marked as in higher elevations. Oak forest, pine forest, homegarden and rainfed agriculture showed almost similar earthworm biomass at lower elevations. On the other hand, at higher elevations, homegarden showed more than three-fold higher biomass as compared to medicinal plant or pea cultivation. The effect of land use on biomass of earthworms showed the same trend as that on density (Figure 2).

3.1.3. Species richness

In all, eight species of earthworms were captured (Table 2-4a). Two species were sampled from higher altitudes compared to six species from lower altitudes. *Dendrodrilus rubidus* occurred only in high altitude agroecosystems, *Aporrectodea caliginosa* in all high elevation agroecosystem types and home garden system in lower altitudes and, the remaining six species viz., *Lannogaster pusillus*, *Metaphire houlleti*, *Ocnerodrilus occidentalis*, *Metaphire anomala*, *Amynthas corticis* and *Drawida nepalensis* only in agroeceosystms and forest ecosystems at lower elevations. Comparing species richness by season, it is observed that only one species occurred during pre-monsoon season compared to six species during monsoon and post monsoon season. Species occurrence seemed to be related to season. *Drawida nepalensis* was observed only during post-monsoon season, *Aporrectodea caliginosa* during both pre and post monsoon season but not during monsoon season, while other species occurred during monsoon season only.

Data and conclusions drawn from other studies carried out on earthworms in the Himalaya are summarized in Table 4b for comparison.

3.2. Hymenoptera

3.2.1. Numerical abundance

In almost all land use types, hymenoptera population was lowest during post-monsoon season, while the differences between pre-monsoon and monsoon seasons were not significant. This group was sampled from all land use types in all seasons, except during post-monsoon in C*edrus* forest, medicinal plant cultivation and potato cultivation at higher elevations (Figure 3).

At lower elevations, oak forests showed the lowest hymenoptera population during pre-monsoon and monsoon months, while there were no significant differences in population size in different forests and agroecosystems during post monsoon. Rainfed agriculture showed higher density during monsoon and post monsoon period compared to irrigated agricultural land use, these two land uses showed similar numerical abundance during pre-monsoon season. In higher elevations, alpine pastures showed the lowest density in all months. *Cedrus* forest showed higher density during pre-monsoon month but lower values during monsoon and post-monsoon months compared to all agricultural land uses except potato cultivation.

Coefficient of variation varied from 79% in rainfed agriculture (lower elevations) to 207% in pine forest during post-monsoon, from 33% in homegarden (higher elevation) to 185% in oak forest during pre-monsoon and from 60% homegarden (higher elevation) to 165% in potato cultivation (Table 5).

3.2.2. Biomass

Biomass of hymenopterans during postmonsoon season is shown in Figure 4. Homegarden and rainfed agriculture showed significantly higher biomass compared to oak and pine forest at lower elevations, though these sites did not differ significantly in terms of numerical abundance of hymenoptera. Agroecosystems at lower elevations showed more than six-fold higher biomass of hymenoptera as compared to the higher elevation agroecosystems.

3.3. Numerical abundance of Isoptera

3.3.1. Numerical abundance

Isoptera individuals were altogether absent in higher elevation zone. In lower elevation zone, significantly higher density was noted during monsoon season in all land uses except homegardens where numerical abundance observed during monsoon and summer did not vary significantly (Figure 5). Coefficient of variation varied from 79% in rainfed agriculture to 206% in pine forest during post-monsoon, from 143% in irrigated agriculture to 182% in oak forest during summer and from 93% in oak forest to 220% in irrigated agriculture during rainy season (Table 6).

Isoptera population density was significantly higher in rainfed agriculture compared to irrigated agriculture and in pine forests compared to oak forests in all the three months. Homegardens had a significantly higher density during summer compared to all other land use/cover types. During post-monsoon season, irrigated agricultural land use and homegardens did not show any termite, while the differences in density of termites between pine forests, oak forests and rainfed agriculture were not significant during rainy season. During post-monsoon, irrigated agriculture did not have any termite population while the differences in population density in other land uses were not significant.

Biomass of termites estimated during post-monsoon season did not differ significantly between oak forest, pine forests and rainfed agriculture, while this group was altogether absent in homegardens and irrigated agriculture at this point of time (Figure 6).

3.4. Coleoptera

3.4.1. Numerical abundance

The highest coleopteran population was observed during monsoon season in all land uses at lower elevations except irrigated agriculture where this group showed highest abundance during summer season followed by monsoon, with no significant difference between the two seasons. In higher elevations, the population density during rainy season was significantly higher than that in post-monsoon and/or summer season in cedrus forests and medicinal plant cultivation area. In contrary, population density in summer season was significantly higher than that in monsoon season and/or post monsoon season in homegardens, potato cultivation and pea cultivation. In alpine pastures, population size in monsoon and post-mosnoon season did not differ significantly, while this group was altogether absent during summer season. Coefficient of variation varied from 79% in rainfed agriculture to 199% in pine forest during post-monsoon, from 6% in pea cultivation to about 175% in pine forest and potato cultivation during summer and from 59% in homegardens to 335% in irrigated agriculture during monsoon (Table 7).

Al lower elevations, Coleoptera population density was markedly higher in irrigated agriculture than that in forest or other agricultural land uses during summer season, whereas the differences between land uses were not so marked during monsoon or post-monsoon season. In higher elevations, numerical abundance of coleopteran individuals in agricultural land uses during summer was significantly higher than that in forest or alpine pastures. The lowest population during post-monsoon season was observed in *Cedrus* forests and potato cultivation.

3.4.2. Biomass

The magnitude of the effect of land use on coleopteran abundance in terms of biomass differed from that in terms of numerical abundance. Biomass in post-monsoon season in homegardens was > 6 times higher than that in other land uses at lower elevations, while different land uses did not differ in terms of numerical abundance. At higher elevations, the land use effect was more marked in terms of numerical abundance than biomass (Figure 8).

3.5. Myriapoda

3.5.1. Numerical abundance

Myriapods occurred in all land use/cover types in higher elevations and only in pine forest and rainfed agriculture at lower elevations. The organisms were observed during monsoon month only in homegardens and medicinal plant cultivation area in higher elevations. Wherver these organisms occurred in two seasons, the effect of month/season was not significant except in cedrus forests where organisms were more numerous during summer month compared to post monsoon (Figure 9). Coefficient of variation varied from about 175% pea cultivation to 206% in pine forest during post-monsoon, from 65% in pea/medicinal plant cultivation to 175% in pine forests during pre-monsoon and from 59% in homegardens to 119% in medicinal plant cultivation at higher elevations (Table 8).

In lower elevations, density in rainfed agriculture was significantly higher in pre-monsoon month and lower in post-monsoon month in rainfed agriculture compared to pine forest, the two land uses where this group of organisms were sampled. At lower elevations, medicinal plant cultivation, pea cultivation and potato cultivation land showed similar density but lower than that in *Cedrus* forests and homegardens, with no significant difference between the latter two land use types.

3.5.2. Biomass

Magnitude of effect of land use in terms of biomass was more pronounced as compared to that in terms of density. Alpine pasture, *Cedrus* forest and pea cultivation had almost similar density during post-monsoon but biomass in pea cultivation area was more 4-times and 2-times greater in pea cultivation as compared to *Cedrus* forest and alpine pastures, respectively (Figure 10).

3.6. Dictyoptera

3.6.1. Numerical abundance

Dictyoptera population was altogether absent in higher elevation zone and in one land use/cover type at lower elevations, viz., irrigated agriculture. Pine forest at lower elevation was the only land use where this group was sampled in all the three seasons. Numerical abundance in pine forest was higher than that in oak forest during monsoon when this group was present in both forests (Figure 11). Pine forest, homegarden and rainfed agriculture did not differ significantly. Coefficient of variation varied from 94% in oak forest to 207% in pine forests in lower elevation zone (Table 9).

3.6.2. Biomass

Biomass of this group during post-monsoon season is given in Figure 12.

3.7. Diptera

3.7.1. Numerical abundance

Diptera occurred in all land uses but not in all seasons in all land uses. Thus, they were sampled from oak forest and homegardens at lower elevations only in one season, during pre-monsoon in the former and monsoon in the latter. Though population size varied, significant differences were not observed (Figure 13). Coefficient of variation varied from 59% in homegarden at higher elevations in pre-monsoon to 220% in irrigated agriculture at lower elevations (Table 10).

3.7.2. Biomass

Diptera biomass in *Cedrus* forest was markedly higher than other land uses where this group was found during post-monsoon season (Figure 14).

3.8. Hemiptera

3.8.1. Numerical abundance

Hemiptera individuals were sampled from all land uses, except alpine pastures. Homegarden and irrigated agriculture at lower elevations had significantly higher abundance at lower elevations compared to other land use types. Coefficient of variation in Hemiptera population varied from 59% in high elevation homegarden in monsoon to 220% in irrigated agriculture at lower elevation and potato cultivation at higher elevation in pre-monsoon season (Figure 15, Table 11).

3.8.2. Biomass

Cedrus forest and homegardens at higher elevations had markedly higher biomass compared to medicnal plant cultivation area, pea cultivation at higher elevations and rainfed agriculture at lower elevations where these organisms were found in post-monsoon season (Figure 16).

3.9. Orthoptera

3.9.1. Numerical abundance

Orthoptera population was absent in pine forests at lower elevations and alpine pastures and food crop cultivation area in higher elevations. Differences between landuses were not significant. Coefficient of variation of Orthoptera population varied from 93% in oak forest in monsoon to 220% in irrigated agriculture in pre-monsoon and monsoon months (Figure 17, Table 12).

3.9.1. Biomass

Biomass of Orthoptera was markedly higher in higher elevation homegarden compared to that in medicinal plant cultivation at higher elevation and rainfed agriculture at lower elevations (Figure 18).

3.10. Others

Numerical abundance and biomass of data of acarina, aranae and other unclassified organisms are given in Figures 19-24 and their coefficient of variation of density in Table 13-15.

4. Macrofauna community

Density of soil fauna considering all groups together did not differ significantly by landuse, except that pine forests had significantly higher abundance as compared to oak forests, in lower elevation landscape. Farmers didn't allow sampling in irrigated fields during October as it interfered with their agricultural operations. However, in high elevation landscape, uncultivated lands had significantly lower density as compared to the cultivated ones. Within cultivated lands, numerical abundance was significantly higher in home gardens as compared to medicinal plant cultivation or pea cultivation area. Effect of land use was more marked in terms of relative abundance of different groups compared to density of all soil fauna pooled together. Thus home gardens and rainfed agriculture at lower elevations had comparable total fauna density but the former had a higher abundance of earthworms and lower of isoptera compared to the latter. At higher elevations, alpine pastures and *Cedrus* forests had similar fauna density but the former had a higher abundance of coleoptera and lower of the 'other fauna' group compared to the latter. Medicinal plant cultivation and pea cultivation areas resembled in terms of total fauna abundance but the former showed markedly higher abundance of eathworms and lower of 'other fauna group' compared to the latter (Figures 25, 26 & 27, Table 16).

The highest macrofauna biomass was observed in homegardens in lower as well as higher elevation landscapes. In lower elevation landscpae, forest (oak forest and pine forest) and rainfed agriculture did not differ in terms of total biomass. However, relative dominance of different groups varied. Oak forest showed significantly higher proportion of coleopterans, pine forest of earthworms and rainfed agriculture of hymenopterans. In higher elevation landscape, of the two uncultivated land use/cover types, *Cedrus* forest had less than the total biomass in alpine pastures. The relative proportion of different groups also markedly varied between these two land use/cover types, *Cedrus* forest showing a significantly higher proportion of biomass contributed by the 'other fauna' but absence of coleoptera biomass. Medicinal plant cultivation area had also similar total biomass as pea cultivation area but coleoptera was the group next to earthworms in the former and myriapoda in the latter (Figure 28 and Table 16).

5. Ecological characteristics of land use-land cover types

Site characteristics of lower elevation zone have been summarized here. The data related to the higher elevation zone is still in raw form and hence not presented here.

5.1. Litter mass

Amount of litter lying on the soil surface in forests is several times higher than that in the cropped or abandoned agricultural lands, even though huge quantities of forest leaf litter is removed for preparation of traditional farmyard manure. Homegardens have litter mass higher than cropped lands but lower than the forest litter mass (Figure 29).

5.2. Root biomass

Root biomass decreased with depth in all land use/cover types but the pattern of this decrease with depth varied. Irrigated agriculture, rainfed agriculture and scrub showed negligibale root biomass in soil depth > 10 cm. In contrast, significant amount of root biomass was observed in deeper soils (30-100 cm) in forests and homegardens. Total root biomass across the soil profile showed a trend of oak forest > pine forest > abandoned agricultural land >homegardens = irrigated agriculture = rainfed agriculture = scrubland (Figure 30).

5.3. Soil organic carbon

Soil organic carbon decreased with depth in all land use types but the pattern of this change differed between land uses. In homegardens, upper 30 cm of soil had almost similar concentration of organic carbon whereas in other land uses 0-10 cm layer had higher concentration followed by 10-20 cm and 20-30 cm. Irrigated agriculture is richer in organic carbon compared to forest soil if upper soil layer 0-30 cm is compared. However, if carbon concentration in the whole soil profile (0-100 cm) is taken into consideration, there seems no significant difference between agriculture and forest lands, homegardens showing the highest concentration (Figure 31).

5.4. Soil pH

Effect of soil depth or land use type on soil pH was not as marked as in case of soil organic carbon. Oak forest soil looked more acidic than other land use/land cover types (Figure 32)

5.5. Phytosociology

Species composition of tree community significantly varied in the landscape. Some species such as *Grewia optiva*, *Bauhinia purpurea* and *Celtis australis* were not found in forest lands. Species like *Ficus auriculata* were found in agricultural as well as forest land. Mean tree density varied from 52.8 in irrigated farm land to 1099.4 trees per ha in homegardens. Basal area varied from 3.6 m square/ha in irrigated farmland to 28.2 square meter/ha in oak forests (Table 16)

6. Discussion

A detailed analysis of structure and composition of soil fauna is relevant for gaining a better understanding of soil fauna- ecosystem function-human intervention relationships. Poor knowledge on these relationships could lead to extremely undesirable outcomes of management interventions, e.g., depletion of native macrofauna coupled with invasion of the compacting earthworm Pheritima corethrurus leading to soil/ecosystem degradation in Brazil (Barros, 1999; Chauvel et al., 1999) and reduction in water and nutrient absorption due abundance of rhizophagous scrab beetles (Moron, 1997; Villalobos, 1994), the latter also observed in the rainfed agriculture at lower elevations in the present study area. Soil macrofauna biomass and abundance observed in this study are within the reported range of values (300 kg/ha by Brown et al., 2004 to 732 kg/ha by Lavelle et al., 1997).

The impacts of management practices on soil fauna depend upon the land use histories, e.g., conversion of nutrient-poor savanna to native pastures follows an increase but of native forests to pastures a decrease in soil macrofauna population and earthworm diversity (Lee, 1985; Fraser, 1994; Edwards et al., 1995; Lavelle et al., 1997; Decans et al., 1994; Brown et al., 2004). Brown et al. (2004) found that a change from native to introduced pasture species in Brazil was accompanied by a more prominent change in earthworm fauna rather than pooled biomass of all soil macrofauna. Unlike many other sites where exotic earthworms outcompeted the native ones in following severe perturbations, Fragoso (2001) and Brown et al. (2004) did not observe such a change during conversion of native to exotic pastures in Brazil. Land use change – soil macrofauna relationship depends upon the nature and magnitude of changes in the environment coupled with the land use change. Thus, agriculture may have a positive effect on earthworms if it improves food supply as a result of recycling of nutritious crop residues, organic manure is added to the soil and loosening of soil occurs to an extent that facilitates burrowing by earthworms (Edwards and Lofty, 1969; Zeisi, 1969; Lagerlof et al., 2002). In contrast, arable cultivation based on intensive use of agrochemicals, export of biomass and occurrence of bare soil conditions is likely to lead to depletion of earthworm abundance and diversity in comparison to uncultivated lands (Curry, 1986, 1998). In the latter situations, small patches of uncultivated lands, e.g., field boundaries, hedgerows, may be significant from the point of view of conservation of earthworms (Andersen, 1985).

In most of the available studies, the land use systems compared are virtually independent systems and the changes in land uses or in management practices within a given land use are relatively recent ones, unlike the present landscape where conversion of natural ecosystems to the managed ones is quite old, there are significant flows of resources between different land use –land cover types and land uses in respect of nature and intensity of disturbances. The inputs, outputs and disturbances may be such that land use differences may not be necessarily reflected in terms of differences in soil macrofauna abundance and diversity. Thus, conversion of oak to pine forests is a change that occurred about 70-80 years before, while conversion of natural ecosystems to agroecosystems is likely to have occurred at least before two centuries. Some changes are recent ones also, like, abandonment of some agricultural lands. Irrigated agricultural lands are more intensively tilled and receive higher amount of manure as compared to the rainfed agriculture. There is not much difference in soil organic carbon in agricultural and forest lands because huge amount of organic matter (in the form of leaf litter and livestock feed) are removed from forests and applied to agricultural fields in the form of manure (mixture of forest leaf litter and livestock excreta). Homegardens are the richest land use systems in terms of soil organic carbon, represent the most intensive land use system (land use intensity viewed as the rate of manure and labour input or the amount of biomass output/exported) and the highest abundance of macrofauna. The data presented here do not support the hypothesis that land use intensification may result in depletion of beneficial soil fauna, increase in abundance of harmful fauna or loss of belowground biodiversity. In general most coniferous litter is marginally palatable to the majority of earthworms (Bernier and Ponge, 1994) and therefore a change from broadleaved forests to coniferous forests may result in a decline in earthworm diversity and abundance (Curry, 1998; Paoletti, 1999). Our results do not support this conclusion.

Correlation of macrofauna with soil physico-chemical properties is likely but conclusions related to this relationship will depend upon the gradient of variation in macrofauna/properties of soil sampled. The litter feeding organisms are likely to be more by litter quality and quantity and geophagous by soil properties. Haynes et al. (2002) found a strong relationship between soil organic carbon and exchangeable Ca with earthworm abundance and biomass across a wide land use gradient including different levels of land use intensification in annual agricultural crops as well as forest tree plantation systems. While organic carbon content is an indicator of food availability, earthworms are characterized by a high Ca requirement because of its excretion from calciferous glands (Briones et al., 1992; Lee, 1985). This study does show the highest earthworm abundance in homegardens characterized by the highest levels of soil organic carbon and exchangeable calcium, but a simple statistical model does not explain the soil fauna-soil physico-chemical properties relationships.

Only two genera could be identified from the collections during the course of the present study thirty genera are likely to occur in Nanda Devi Biosphere Region based on the information and knowledge accumulated over a long period of time (Table 17, 18). Even though 'likely genera' are to some extent a matter of conjecture, the difference between the 'likely diversity' and 'captured diversity' in the present case is quite large. This lower efficiency in capturing diversity partly derives from exclusion of microhabitats preferred by termites in any systematic sampling design and absence of the caste/life cycle stage required for taxonomic identification at the time of sampling in efforts that are concerned more about quantitative dimension of diversity rather than species richness alone. In case of earthworms, species viz., Bimostus parvus, Octolasion tyrtaeum, Eutyphoeus spp., Eisenia fetida, Amynthas alexandri, Amynthus diffringens, Perionyx sps., reported from the land use-land cover types covered in the present study but far away from the study area/biosphere reserve were not sampled during this investigation. More efforts are needed to find out effort vs degree of diversity sampled.

References

Andersen, C., 1985. Earthworms in hedgerows. In: Hald, A.B. (Ed.), The Impact of Pesticides on the Wild Flora and Fauna in Agroecosystem. Miljostyrelsens Center for Jordokologi, Miljo and Energiministeriet, Copenhagen, pp. 46-48.

Barros, M.E., 1999, Effet de la macrofauna sur la structure et les processus physiques du sol de paturages degrades d Amazonie. Ph.D. Thesis. Universite Paris VI, Paris.

Bhaduria, T. and Ramakrishnan, P.S. 1989. Earthworm population dynamics and contribution to nutrient cycling during cropping and fallow phases of shifting agriculture (Jhum) in north-east India. Journal of Applied Ecology, 26, 505-520.

Bhaduria, T., Ramakrishnan, P.S. and Srivastava, K.N. 2000. Diversity and distribution of endemic and exotic earthworms in natural and regenerating ecosystems in the Central Himalayas, India. Soil Biology and Biochemistry, 32, 2045-2054.

Briones, M.J.I., Mascato, R., Mato, S., 1992. Relationships of earthworms with environmental factors studies by means of detrended canonical correspondence analysis. Acta Oecol. 13, 617-626.

Brown, G.G., Moreno, A.G., Barois, I, Fragoso, C., Rojas, P., Hernandez, B. and Patron, J.C. 2004. Soil macrofauna in SE Mexican pastures and the effect of conversion from native to introduced pastures. Agriculture, Ecosystems and Environment, 103, 313-327.

Carter, M.R., Gregorich, E.G., Anderson, D.W., Doran, J.W., Janzen, H.H., Pierce, F.J., 1997. Concepts of soil quality and their significance. In: Gregorich, E.G., Carter, M.R. (Eds.), Soil Quality for Crop Production and Ecosystem Health. Elsevier, Amsterdam, pp. 1-19.

Chauvel, A., Grimaldi, M., Barros, E., Blanchart, E., Sarrazin, M., Lavelle, P., 1999. Pasture degradation by an Amazonian earthworm. Nature 389, 32-33.

Curry, J.P., 1986. Effects on management on soil decomposers and decomposition processes in grassland. In: Mitchel, M.J., Nakas, J.P. (Eds.), Microfloral and Faunal Interactions in Natural and Agro-ecosystems. Martinus Nijhoff/Dr W. Junk, Dordrecht. Pp. 349-398.

Curry, J.P., 1998. Factors affecting earthworm abundance in soil. In: Edwards, C.A. (Ed.). Earthworm Ecology – from Darwin to Vermiculture. Chapman and Hall, London, pp. 215-228.

Curry, J.P., 1998. Factors affecting earthworm abundance in soil. In: Edwards, CA. (Ed.). Earthworm Ecology CRC Press, Boca Raton, pp. 37-64.

Dash, M.C. and Patra, U.C. 1977. Density, biomass, and energy budget of a tropical earthworm population from a grassland site in Orissa, India. Indian Review of Ecology and Biology of Soil, 14, 461-471.

Decans, T., Lavelle, P., Jimenez Jaen, J.J., Escobar, G., Rippstein, G., 1994. Impact of land management on soil macrofauna in the Oriental Llanos of Colombia. Eur. J. Soil Biol. 30, 157-168.

Edwards, C.A., Lofty, J.R., 1969. Effects of cultivation on earthworm populations. Rep. Rothamsted Exp. Stn. For 1968, pp. 247-248.

Haynes, R.J., Dominy, C.S. and Graham, M.H. 2003. Effect of agricultural land use on soil organic matter status and the compostion of earthworm communities in KwaZulu-Natal, South Africa. Agriculture, Ecosystems and Environment, 95, 453-464.

Kaushal, B.R. and Bisht, S.P.S. 1994. Population dynamics of the earthworm *Amynthas alexandri* (Annelida: Megascolecidae) in Kumaon Himalayan pasture soil. Biology and Fertility of Soils, 17, 9-13.

Kaushal, B.R., Bisht, S.P.S. and Kalia, S. 1994. Effect of diet on cast production by the megascolecid earthworm *Amynthas alexandri* in laboratory culture. Biology and Fertility of Soils, 17, 14-17.

Kaushal, B.R., Bisht, S.P.S. and Kalia, S. 1995. Population dynamics of the earthworm *Amynthas alexandri* (Megascolecidae: Annelida) in cultivated soils of the Kumaon Himalayas. Applied Soil Ecology, 2, 125-130

Lagerlof, J., Goffre, B. and Vincent, C. 2002. The importance of field boundaries for earthworms (Lumbricidae) in the Swedish agricultural landscape. Agriculture, Ecosystems and Environment, 89, 91-103.

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., Heal, O.W., Ghillion, S., 1997. Soil function in a changing world: the role of invertebrate ecosystem engineers. Eur. J. Soil Biol. 33, 159-193.

Mishra, K.C. and Ramakrishnan, P.S. 1988. Earthworm population dynamics in different jhum fallows developed after slash and burn agriculture in north-eastern India. Proceedings Indian Academy of Sciences (Animal Sciences), 97, 309-318.

Mishra, P.C. and Dash, M.C. 1984. Population dynamics and respiratory metabolism of earthworm population in a subtropical dry woodland of western Orissa, India. Tropical Ecology, 25, 103-116.

Moron, M.A., 1997. El control de los coleopteros melolonthidae rizofagos en los cultivos de gramineas en Mexico. In: Vaz-de-Mello, F.Z., Oliveira, L.J., Louzada, J.N.C., Salvadori, J.R., Escobar, F. (Eds.), Memorias da IV Reuniao Latino-Americana de Scarabaeoidologia. Embrapa-Soja, Londrina, pp. 102-112.

Paoletti, M.G., 1999. The role of earthworms for assessment of sustainability and as bioindicators. Agric. Ecosystem. Environ. 74, 137-155.

Reddy, M.V. 1987. Seasonal structure of earthworm (Pheritima spp.) populations in humid tropical deciduous woodland. In: On Earthworms, Edited by A.M. Bonvicini Pagliai and P. Omodeo, Selected Symposia and Monographs U.Z.I.., 2, Mucchi, Modena, 191-197.

Reddy, M.V. and Pash, M. 1993. Influence of rainfall, temperature and some soil physico-chemical variables on seasonal population structure and vertical distribution of earthworms in two semi-arid tropical grassland soils. International Journal of Biometeorology, 37, 19-26.

Senapati, B.K. 1992. Biotic interactions between soil nematodes and earthworms. Soil Biology and Biochemistry, 24, 1441-1444

Sinha, B., Bhaduria, T., Ramakrishnan, P.S., Saxena, K.G. and Maikhuri, R.K. 2003. Impact of landscape modification on earthworm diversity and abundance in the Haryali sacred landscape, Garwhal Himalaya. Pedobiologia, 47, 357-370.

Villalobos, F.J., 1994. The contribution of melolonthid larvae to soil fertility. In: Proceedings of the 15th World Congress of Soil Science, vol. 4a. ISSS, Acapulco, pp. 129-143.

Zicsi, A., 1969. Uber die Auswirkung der Nachfrucht und Bodenbearbeitung auf die Aktivitat der Regenwurmer. Pedobiologia 9, 141-146.

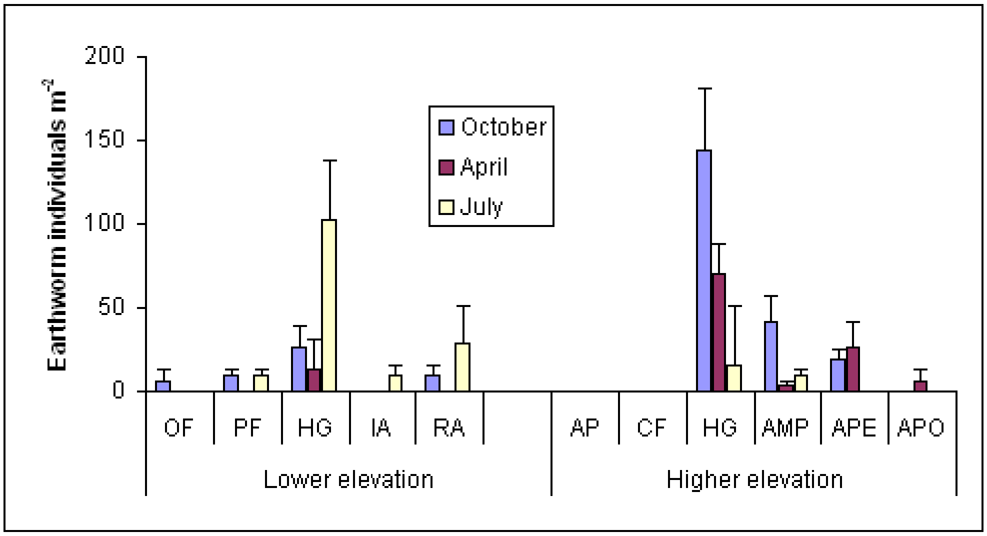


Figure 1. Numerical abundance of earthworms (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover. OF, oak forests; PF, pine forests; HG, home garden; IA, irrigated agriculture; RA, rainfed agriculture; AP, alpine pasture; CF, cedrus forests; AMP, agriculture – medicinal plants; APE, agriculture- pea; APO, agriculture - potato

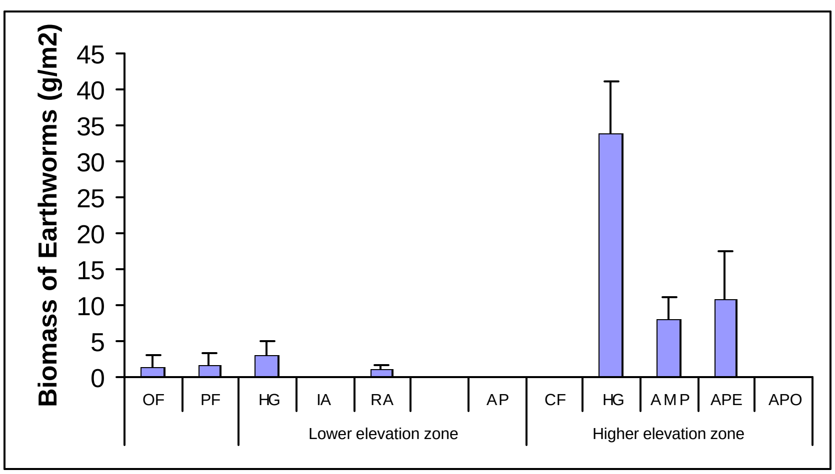


Figure 2. Mean biomass and SEM of Earthworms in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

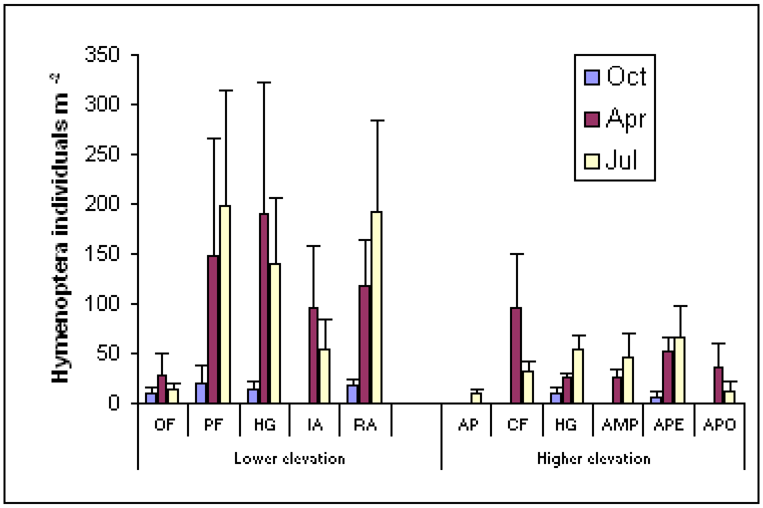


Figure 3. Numerical abundance of Hymenoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

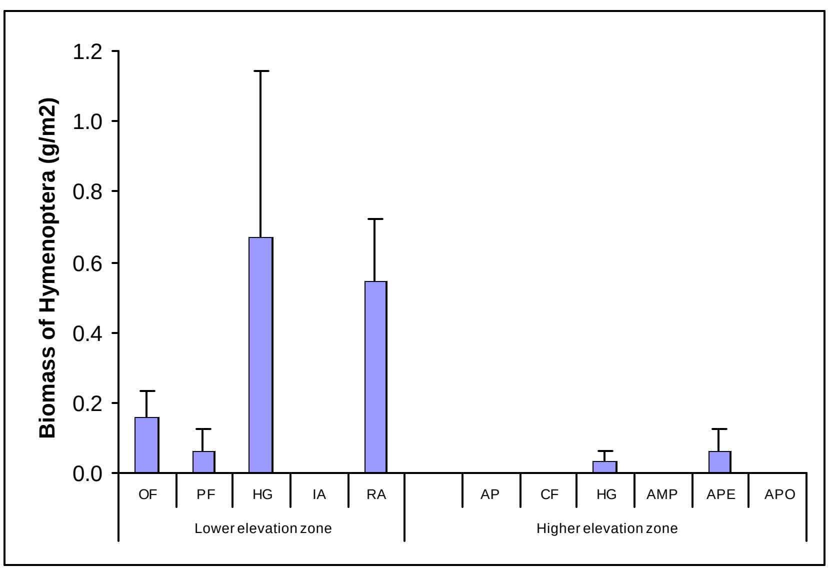


Figure 4. Mean biomass and SEM of Hymenoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

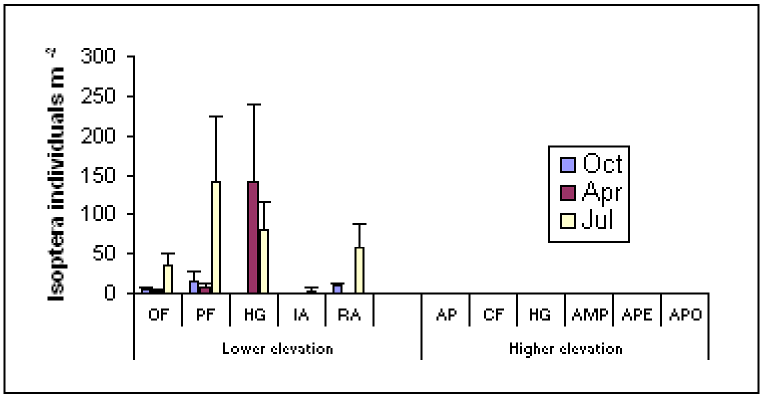


Figure 5. Numerical abundance of Isoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

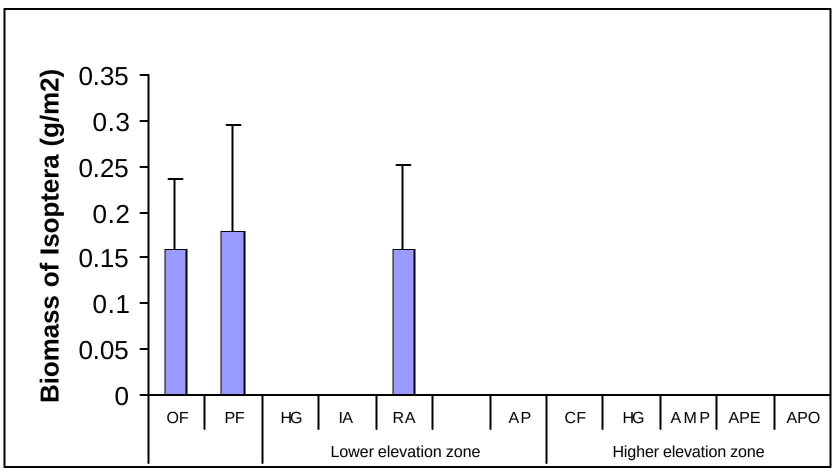


Figure 6. Mean biomass and SEM of Isoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

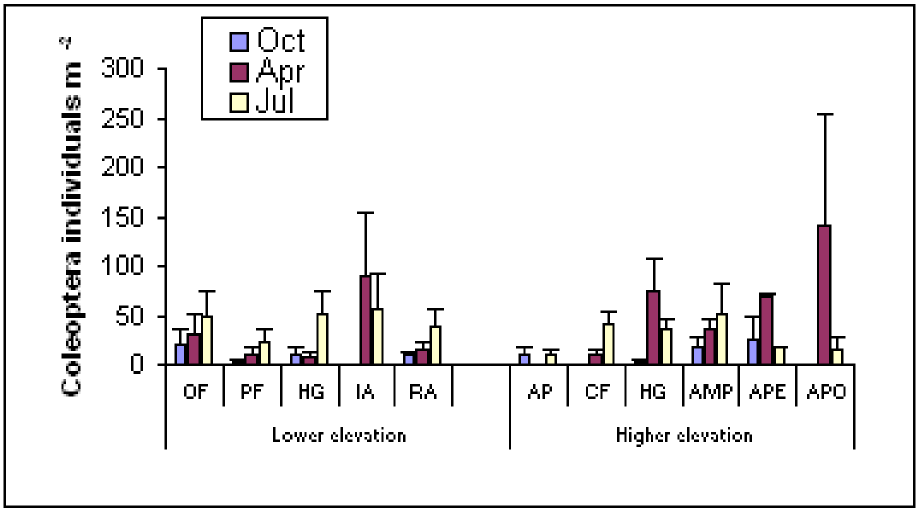


Figure 7. Numerical abundance of Coleoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

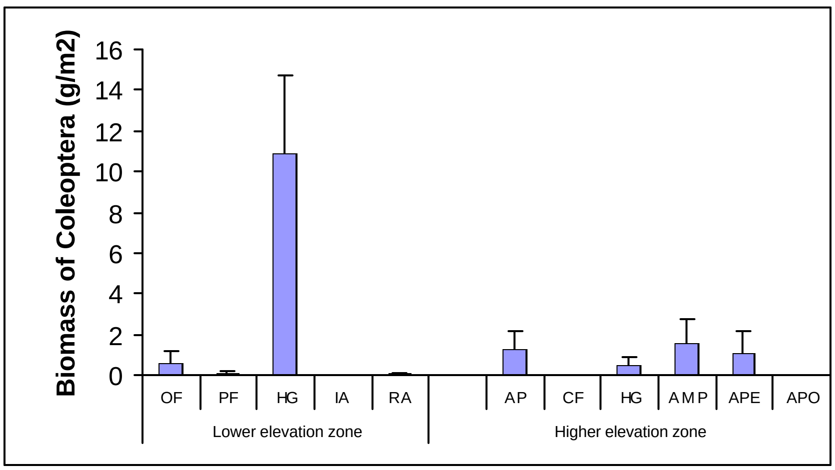


Figure 8. Mean biomass and SEM of Coleoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

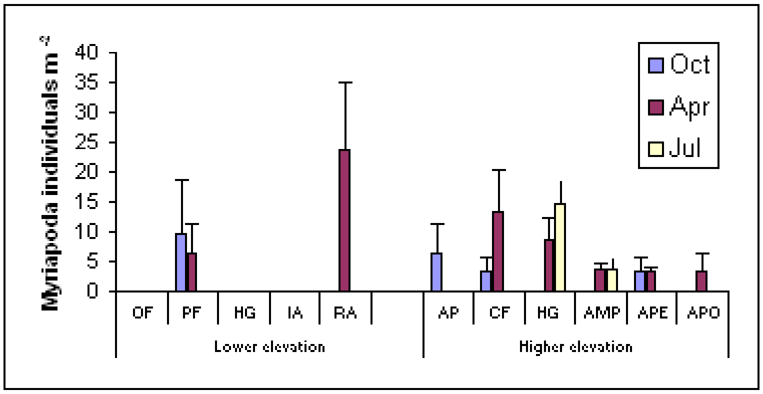


Figure 9. Numerical abundance of Myriopoda (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

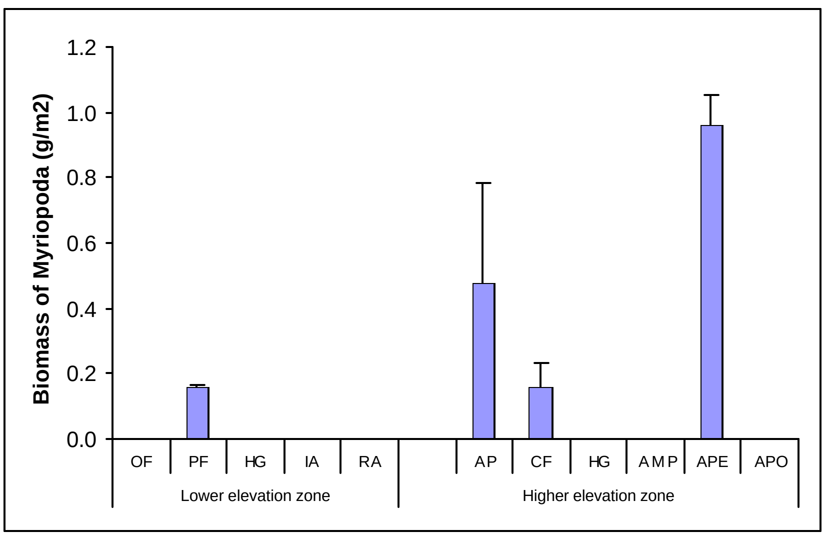


Figure 10. Mean biomass and SEM of Myriopoda in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

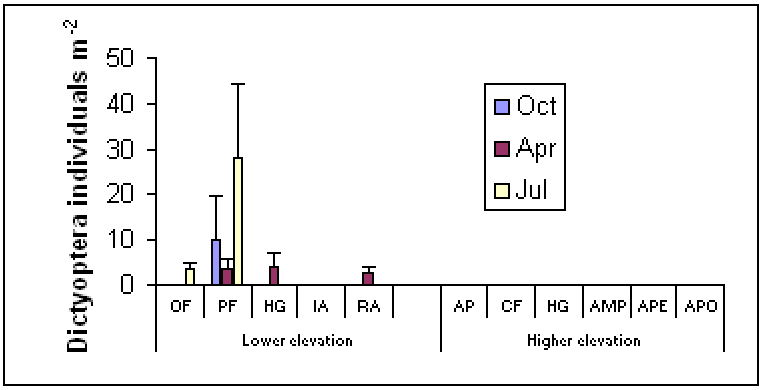


Figure 11. Numerical abundance of Dictyoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM). Sampling in April was not done in alpine pasture because of snow cover.

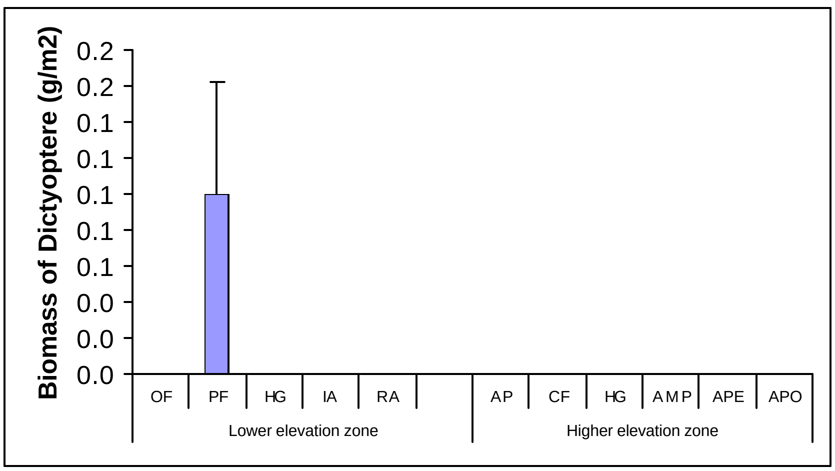


Figure 12. Mean biomass and SEM of Dictyoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

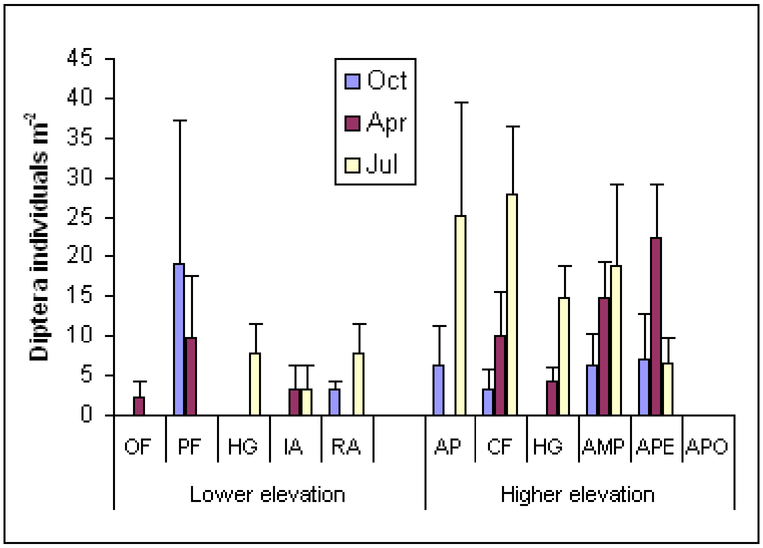


Figure 13. Numerical abundance of Diptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

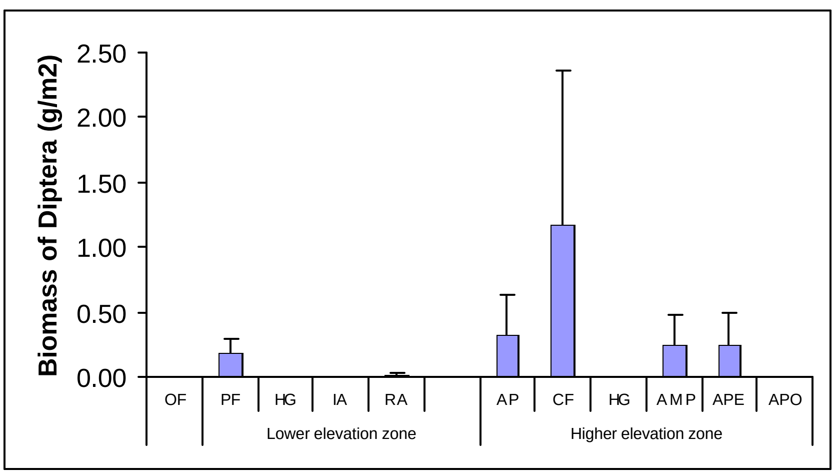


Figure 14. Mean biomass and SEM of Diptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

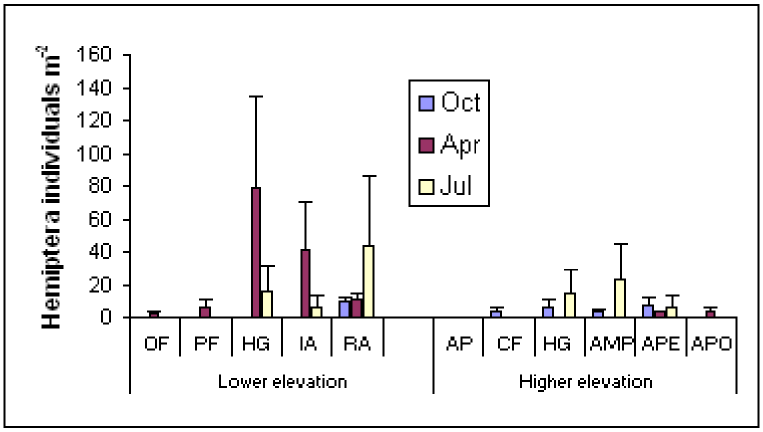


Figure 15. Numerical abundance of Hemiptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

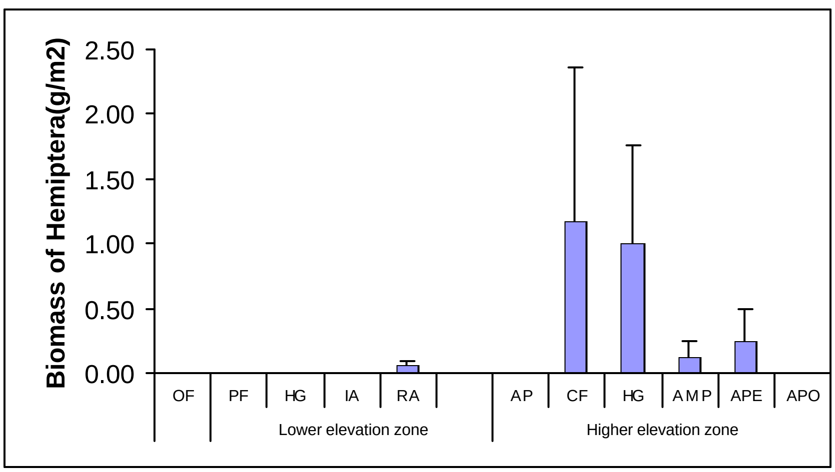


Figure 16. Mean biomass and SEM of Hemiptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

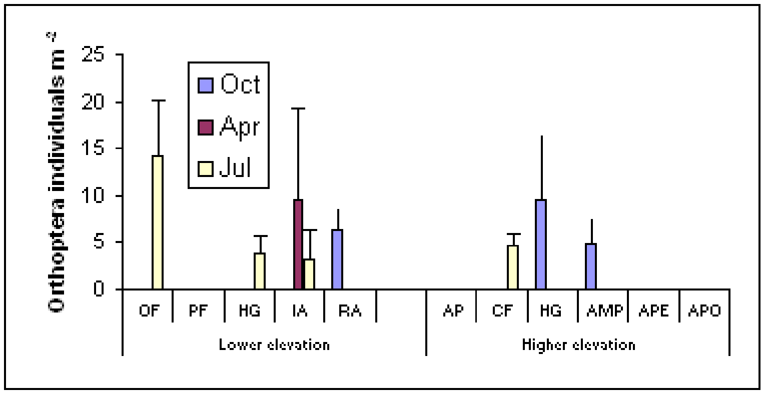


Figure 17. Numerical abundance of Orthoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

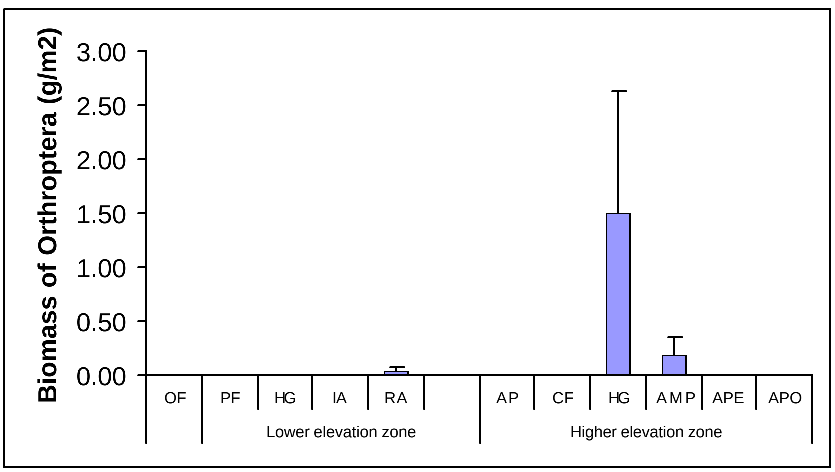


Figure 18. Mean biomass and SEM of Orthoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

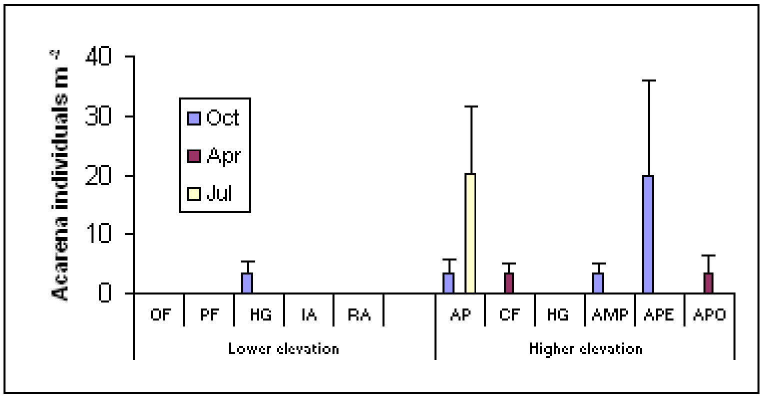


Figure 19. Numerical abundance of Acarena (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

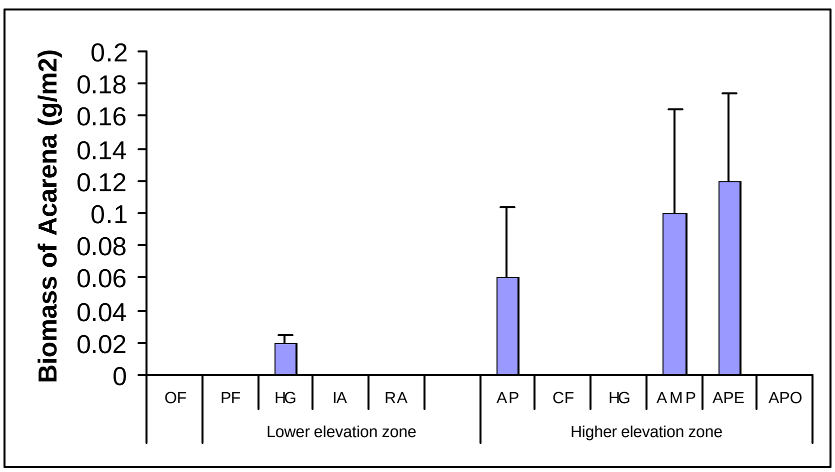


Figure 20. Mean biomass and SEM of acarena in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

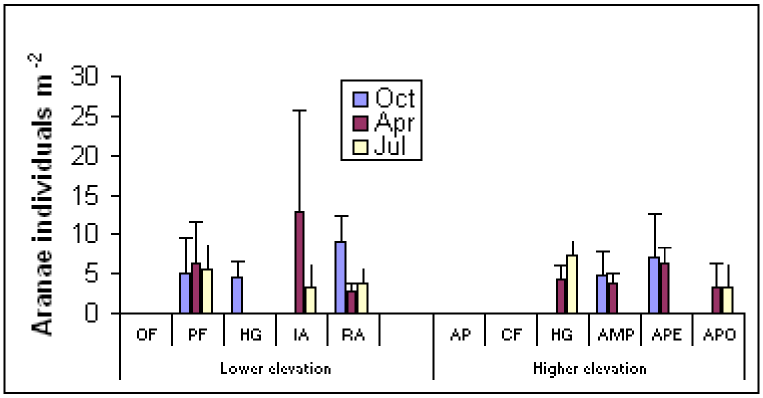


Figure 21. Numerical abundance of Aranae (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

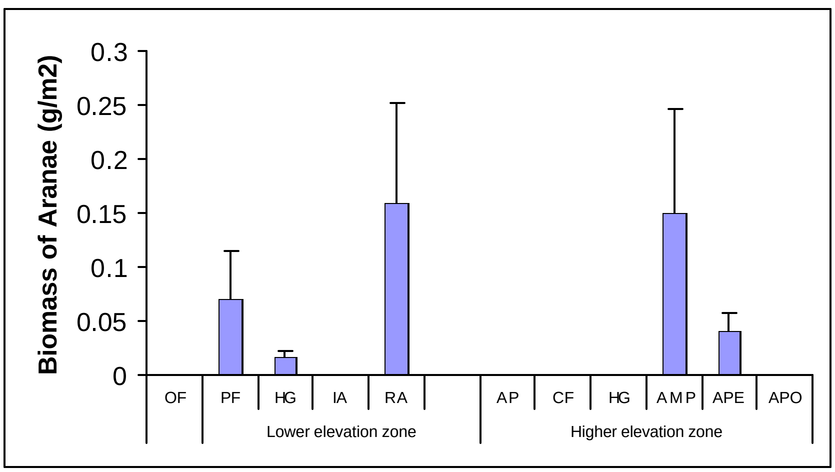


Figure 22. Mean biomass and SEM of Aranae in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn’t allow sampling in irrigated agricultural fields.

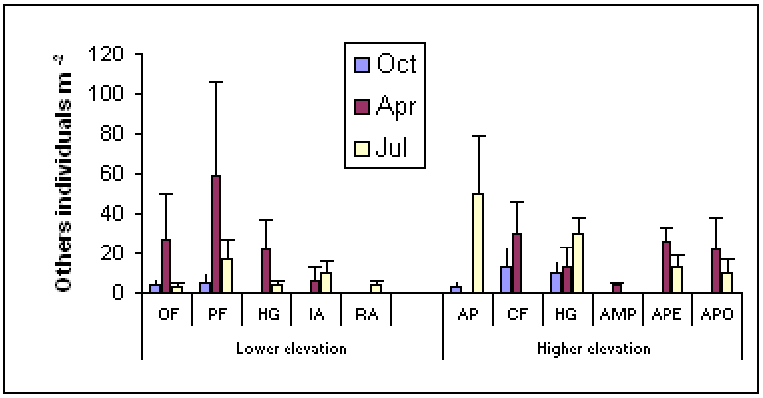


Figure 23. Numerical abundance of Others (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

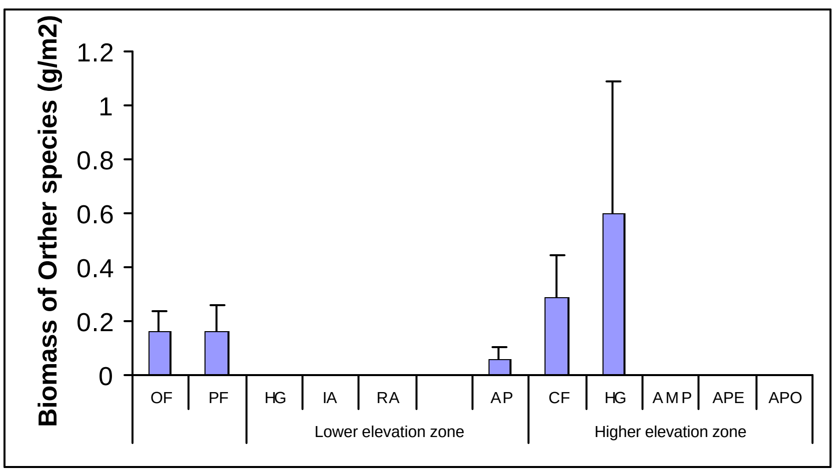
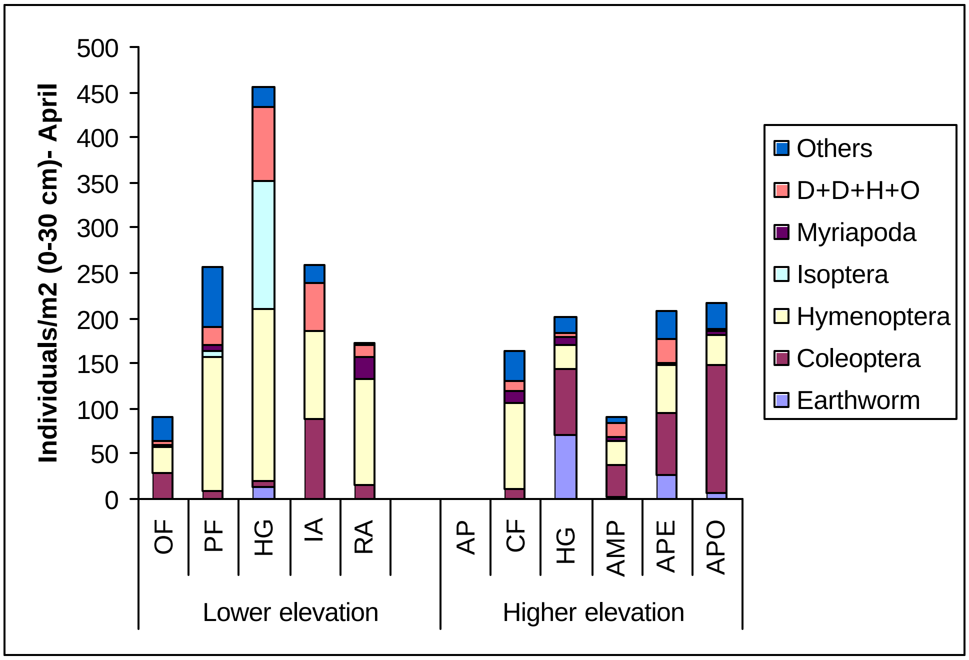


Figure 24. Mean biomass and SEM of other organisms in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields



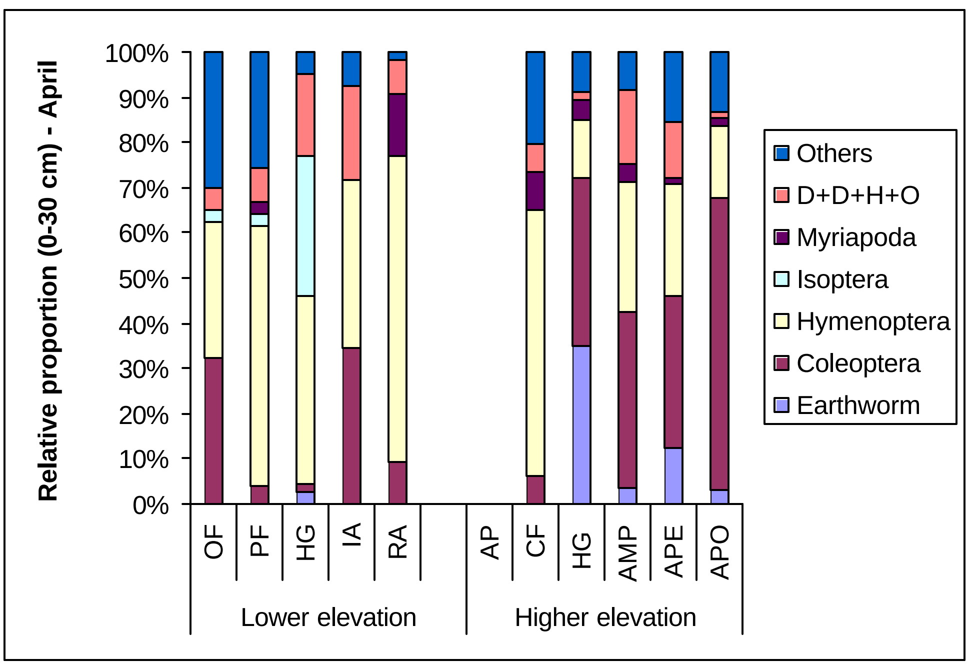


Figure 25. Absolute and relative abundance of soil fauna (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during April in different land use types. Sampling in was not done in alpine pasture because of snow cover.

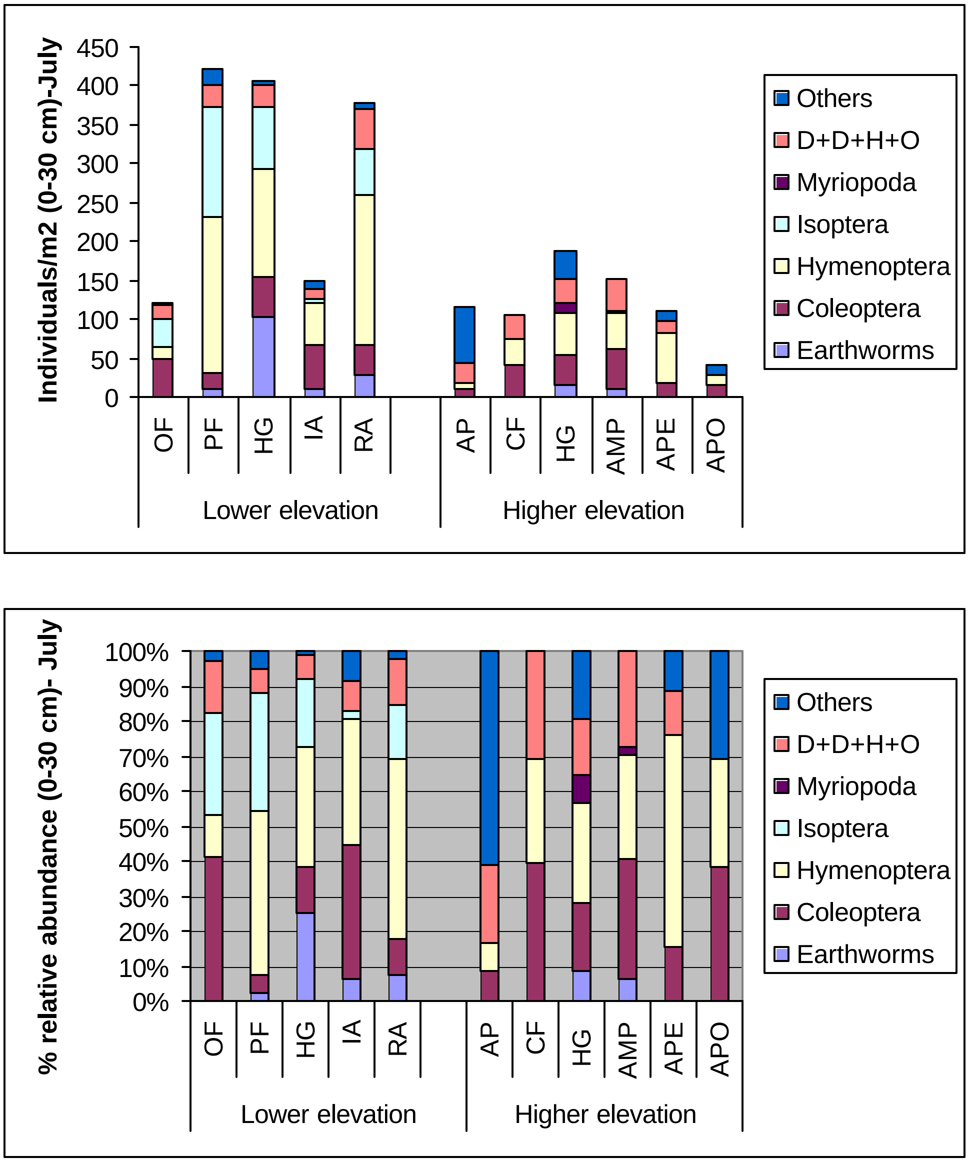


Figure 26. Absolute and relative abundance of soil fauna (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during July in different land use types. Sampling in was not done in alpine pasture because of snow cover.

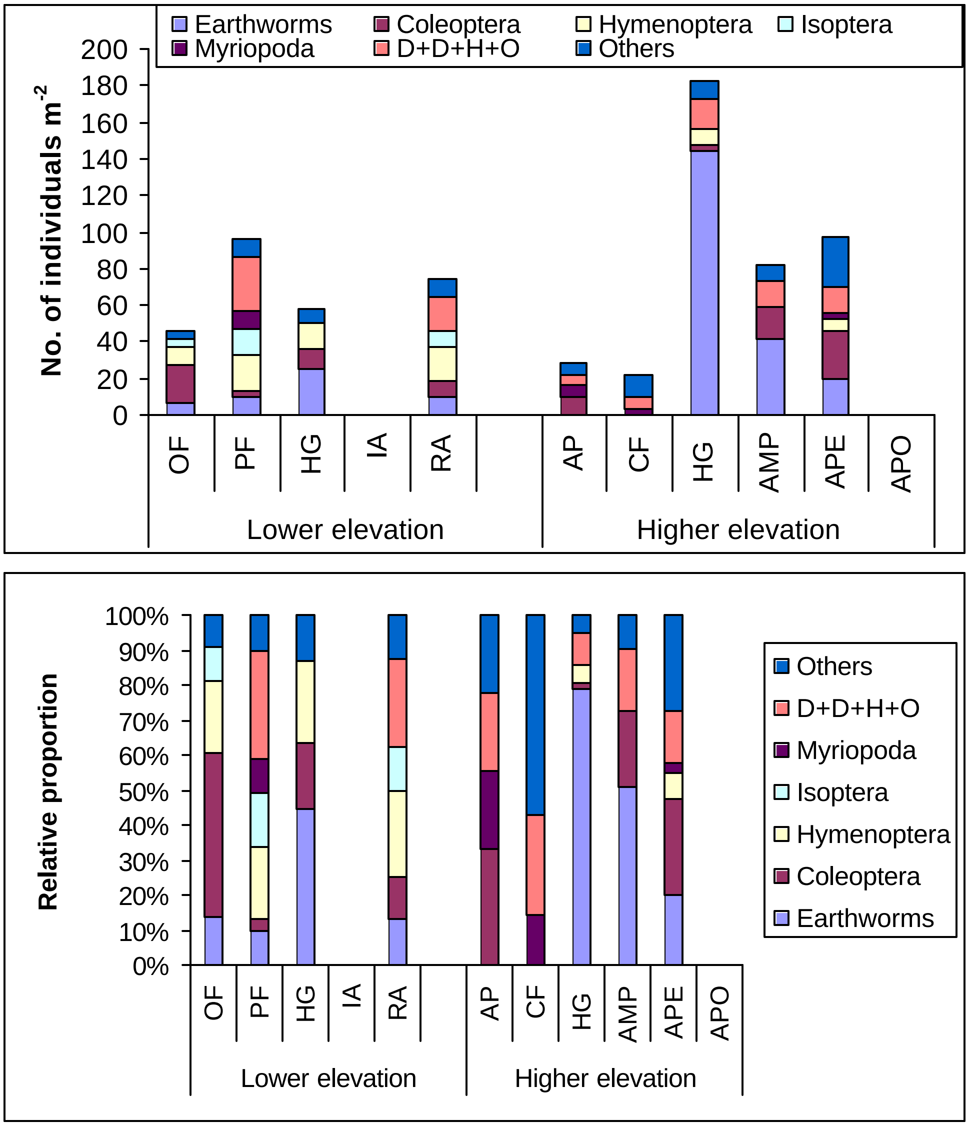


Figure 27. Absolute and relative abundance of soil fauna (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during October in different land use types. Sampling in was not done in alpine pasture because of snow cover.

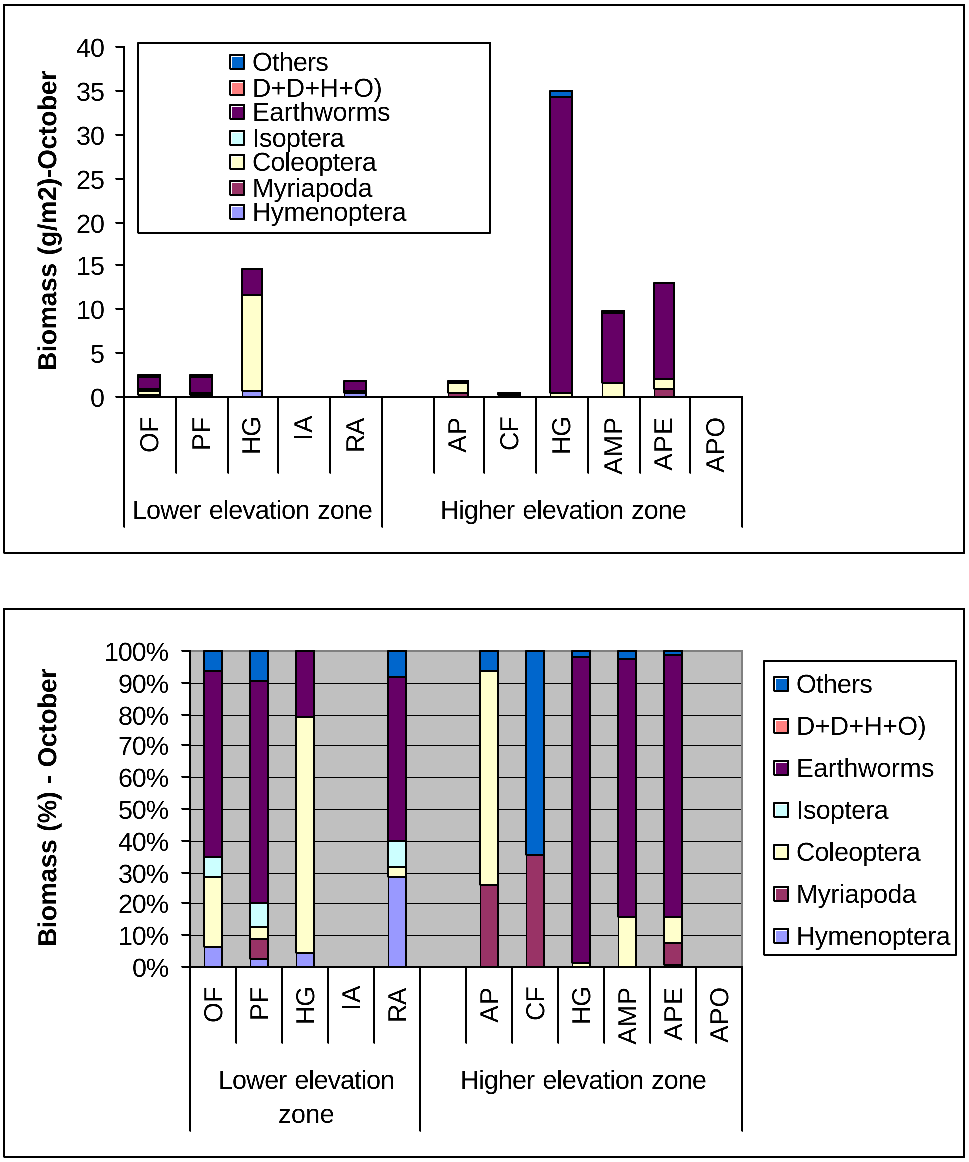


Figure 28. Absolute and relative biomass of soil fauna (0-30 cm) in different land uses during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

Table 1 Coefficient of variation of earthworm population density (0-30 cm) in different land use types in different months of sampling

	October	April	July
Lower elevation zone			
Oak forest	219	0	0
Pine forest	73	0	73
Homegarden	121	306	76
Irrigated agriculture	NA	0	147
Rainfed agriculture	146	0	167
Higher elevation zone			
Alpine meadows/pastures	0	NA	0
Cedrus forest	0	0	0
Homegarden	57	56	488
Agriculture-medicinal plants	83	220	73
Agriculture-pea	73	134	0
Agriculture-potato	NA	220	0

Table 2. Numerical abundance of earthworm species (individuals per m2) in dfferent land usees during winter (October)

	Lower elevation						Higher elevation				
	HG	OF	IA	RA	PF	AMP	CF	KG/HA	AP	PEA	POTATO
Lannogaster pusillus	0	0	0	0	6.4	0	0	0	0	0	0
Metaphire houlleti	25.6	0	0	6.4	0	0	0	0	0	0	0
Ocnerodrilus occidentalis	0	0	0	0	0	0	0	0	0	0	0
Dendrodrilus rubidus	0	0	0	0	0	0	0	6.4	0	0	0
Aporrectodea caliginosa	0	0	0	0	0	41.6	0	137.6	0	19.2	0
Metaphire anomala	0	0	0	0	3.2	0	0	0	0	0	0
Amynthas corticis	0	0	0	0	0	0	0	0	0	0	0
Drawida nepalensis	0	6.4	0	3.2	0	0	0	0	0	0	0

Table 3. Numerical abundance of earthworm species (individuals per m2) in dfferent land usees during summer (April)

	Lower elevation						Higher elevation				
	KG/LA	OF	IRR/LA	RF/LA	PF	AG/MP/HA	CF	KG/HA	AP	PEA	POTATO
Lannogaster pusillus	0	0	0	0	0	0	0	0	0	0	0
Metaphire houlleti	0	0	0	0	0	0	0	0	0	0	0
Ocnerodrilus occidentalis	0	0	0	0	0	0	0	0	0	0	0
Dendrodrilus rubidus	0	0	0	0	0	0	0	0	0	0	0
Aporrectodea caliginosa	12.8	0	0	0	0	3.2	0	70.4	0	25.6	6.4
Metaphire anomala	0	0	0	0	0	0	0	0	0	0	0
Amynthas corticis	0	0	0	0	0	0	0	0	0	0	0
Drawida nepalensis	0	0	0	0	0	0	0	0	0	0	0

Table 4a.Numerical abundance of earthworm species (individuals per m2) in dfferent land usees during rainy season (July)

	Lower elevation						Higher elevation				
	KG/LA	OF	IRR/LA	RF/LA	PF	AG/MP/HA	CF	KG/HA	AP	PEA	POTATO
Lannogaster pusillus	96	0	0	6.4	6.4	0	0	0	0	0	0
Metaphire houlleti	6.4	0	0	0	0	0	0	0	0	0	0
Ocnerodrilus occidentalis	0	0	0	6.4	0	0	0	0	0	0	0
Dendrodrilus rubidus	0	0	0	0	0	9.6	0	16	0	0	0
Aporrectodea caliginosa	0	0	0	0	0	0	0	0	0	0	0

Table 4b. A summary of studies carried out on earthworm diversity and abundance in the Himalayan region and comparable areas

Author and study area	Earthworm diversity	Major trends and abundance
Bhaduria et al. (2000): 0-30 cm, monthly sampling in mid elevation village landscape of central Himalaya	Eight species (I)Lumbricidae *Bimostus parvus, Octolasion tyrtaeum* (II) Octochaetidae *Octochaetona beatrix* (III) Megascolecidae *Amythas corticis, Eutyohoeus festivus, Eutyphoeus nanianus, Eutyphoeus waltonii* (IV) Moniligastridae *Drawida* sp.	Highest density of all species observed during rainy season, except *Amynthas corticis* which showed winter peaking in Pine forests. Total earthworm abundance peaked in rainy season in all land use types studied. During rainy season: Climax forest-526, mixed forest -309, Grassland-353; 5 year old pine, 287; 40 year old pine, 940 The highest species diversity in pine forests
Senapati (1992): upland irrigated rice field in Orissa	Five species: *Drawida willsi,* *Drawida calebi,* *Ocnerodrilus occidentalis,* *Lampito mauritii,* *Octochaetona surensis*	1399 worms per m^2 during August – the peak size of population
Kaushal and Bisht (1994) – monthly sampling in pasture soil	Three species *Amynthas alexandri,* *Amynthus diffringens,* *Eisenia fetida*	Maximum density 138.8 individuals and 25.2 g per m^2 biomass recorded towards the end of rainy season (October/December)
Kaushal et al. (1995): cultivated soils near an urban centre	Only one species *Amynthas alexandri*	Maximum density of 58.4 individuals per m^2 observed during rainy season
Sinha et al. (2003)- mid altitude village landscape in Garhwal Himalaya	Seven species *Drawida nepalensis,* *Allbophora parva,* *Eutyphoeus pharpingianus,* *Octochaetona beatrix,* *Perionyx* sp., *Lennogaster pusillus,* *Amynthas corticis*	Maximum density of 108-247 in forests and 89-235 in agroecosystems; abundance in pine forest higher but diversity lower as compared to oak forest; abundance higher in pine forests
Bhaduria and Ramakrishnan (1989): shifting	Five species *Amynthas diffringens,* *Drawida assamensis,* *Eutyphoeus festivus,*	Population of *Amynthas diffringens* peaked during winter months and of other species during rainy season

agriculture in Shillong	*Nelloscolex strigosus, Tonoscolex horaii*	4-47 mature individuals per m^2 in cropping phase and upto 50 individuals per m^2 in fallow phase
Mishra and Ramakrishna (1988): shifting agriculture in north-eastern India (Nangpoh)	Three species *Megascolides antrophytes, Drawida assamensis, Nelloscolex strigosus*	Maximum population size : 68 worms per m^2 (i.e., 675000 worms per ha)
Dash and Patra (1977): grasslands in Orissa		Maximum density of 80 individuals per m^2 (i.e., 800,000 individuals/ha)
Reddy (1987): humid tropical deciduous wooodlant	Five species *Amynthas* (= *Pheritima*) *alexandri*, *Metaphire* (= *Pheritima*) *postuma*, *Metaphire* (= *Pheritima*) *houlleti*, *Amynthas* (= *Pheritima*) *diffringens*, *Dichogaster* sps.	Maximum population of 315 individuals per m^2 Within a forest, population may vary from 28 to 281 individuals per m^2 in different microsites Observed two peaks during and towards the end of rainy season
Mishra and Dash (1984): subtropical dry woodland of western Orissa		131 individuals per m^2
Present study	Eight species: *Lennogaster pusillus, Metaphire houlleti, Metaphire anomala, Ocnerodrilus occidentalis, Dendrodrilus rubidus, Aporrectodea caliginosa(endogeic), Amynthas cortices, Drawida nepalensis*	

Table 5 Coefficient of variation of Hymenoptera population (0-30 cm) in different land use types

	October	April	July
Lower elevation zone			
Oak forest	154	185	93
Pine forest	207	176	129
Homegarden	143	154	103
Irrigated agriculture	NA	154	118
Rainfed agriculture	79	88	105
Higher elevation zone			
Alpine meadows/pastures	0	NA	126
Cedrus forest	0	121	69
Homegarden	157	33	60
Agriculture-medicinal plants	0	66	121
Agriculture-pea	179	66	105
Agriculture-potato	NA	152	165

Table 6 Coefficient of variation of Isoptera population (0-30 cm) in different land use types

	October	April	July
Lower elevation zone			
Oak forest	153	182	93
Pine forest	206	175	129
Homegarden	0	154	103
Irrigated agriculture	NA	143	220
Rainfed agriculture	79	0	105
Higher elevation zone			
Alpine meadows/pastures	0	NA	0
Cedrus forest	0	0	0
Homegarden	0	0	0
Agriculture-medicinal plants	0	0	0
Agriculture-pea	0	0	0
Agriculture-potato	NA	0	0

Table 7 Coefficient of variation of Coleoptera population (0-30 cm) in different land use types

Lower elevation zone	**October**	**April**	**July**
Oak forest	154	156	110
Pine forest	199	175	129
Homegarden	143	152	97
Irrigated agriculture	NA	157	335
Rainfed agriculture	79	88	105
Higher elevation zone			
Alpine meadows/pastures	170	NA	127
Cedrus forest	0	122	67
Homegarden	157	96	59
Agriculture-medicinal plants	133	66	121
Agriculture-pea	179	6	0
Agriculture-potato	NA	178	176

Table 8 Coefficient of variation of Myriopoda population (0-30 cm) in different land use types

Lower elevation zone	**October**	**April**	**July**
Oak forest	0	0	0
Pine forest	206	175	0
Homegarden	0	0	0
Irrigated agriculture	NA	0	0
Rainfed agriculture	0	105	0
Higher elevation zone			
Alpine meadows/pastures	168	NA	0
Cedrus forest	179	119	0
Homegarden	0	100	59
Agriculture-medicinal plants	0	65	119
Agriculture-pea	175	65	0
Agriculture-potato	NA	220	0

Table 9 Coefficient of variation of Dictyoptera population (0-30 cm) in different land use types

Lower elevation zone	**October**	**April**	**July**
Oak forest	0	0	94
Pine forest	207	173	128
Homegarden	0	156	0
Irrigated agriculture	NA	0	0
Rainfed agriculture	0	90	0
Higher elevation zone			
Alpine meadows/pastures	0	NA	0
Cedrus forest	0	0	0
Homegarden	0	0	0
Agriculture-medicinal plants	0	0	0
Agriculture-pea	0	0	0
Agriculture-potato	NA	0	0

Table 10 Coefficient of variation of Diptera population (0-30 cm) in different land use types

Lower elevation zone	**October**	**April**	**July**
Oak forest	0	182	0
Pine forest	205	177	0
Homegarden	0	0	104
Irrigated agriculture	NA	220	220
Rainfed agriculture	78	0	105
Higher elevation zone			
Alpine meadows/pastures	168	NA	126
Cedrus forest	179	122	67
Homegarden	0	94	59
Agriculture-medicinal plants	134	66	121
Agriculture-pea	179	66	107
Agriculture-potato	NA	0	0

Table 11 Coefficient of variation of Hemiptera population (0-30 cm) in different land use types

Lower elevation zone	October	April	July
Oak forest	0	182	0
Pine forest	0	175	0
Homegarden	0	154	104
Irrigated agriculture	NA	220	134
Rainfed agriculture	79	89	105
Higher elevation zone			
Alpine meadows/pastures	0	NA	0
Cedrus forest	179	0	0
Homegarden	158	0	59
Agriculture-medicinal plants	138	0	121
Agriculture-pea	179	65	105
Agriculture-potato	NA	220	0

Table 12 Coefficient of variation of Orthoptera population (0-30 cm) in different land use types

Lower elevation zone	October	April	July
Oak forest	0	0	93
Pine forest	0	0	0
Homegarden	0	0	102
Irrigated agriculture	NA	220	220
Rainfed agriculture	78	0	0
Higher elevation zone			
Alpine meadows/pastures	0	NA	0
Cedrus forest	0	0	67
Homegarden	158	0	0
Agriculture-medicinal plants	133	0	0
Agriculture-pea	0	0	0
Agriculture-potato	NA	0	0

Table 13 Coefficient of variation of Acarena population (0-30 cm) in different land use types

Lower elevation zone	**October**	**April**	**July**
Oak forest	0	0	0
Pine forest	0	0	0
Homegarden	144	0	0
Irrigated agriculture	NA	0	0
Rainfed agriculture	0	0	0
Higher elevation zone			
Alpine meadows/pastures	172	NA	0
Cedrus forest	0	117	0
Homegarden	0	0	0
Agriculture-medicinal plants	138	0	0
Agriculture-pea	179	0	0
Agriculture-potato	NA	220	0

Table 14 Coefficient of variation of Aranae population (0-30 cm) in different land use types

Lower elevation zone	**October**	**April**	**July**
Oak forest	0	0	0
Pine forest	207	175	130
Homegarden	103	0	0
Irrigated agriculture	NA	220	220
Rainfed agriculture	79	90	105
Higher elevation zone			
Alpine meadows/pastures	0	NA	0
Cedrus forest	0	0	0
Homegarden	0	93	60
Agriculture-medicinal plants	133	69	0
Agriculture-pea	179	65	0
Agriculture-potato	NA	220	220

Table 15 Coefficient of variation of Others species population (0-30 cm) in different land use types

Lower elevation zone	**October**	**April**	**July**
Oak forest	153	185	94
Pine forest	202	175	129
Homegarden	0	152	102
Irrigated agriculture	NA	220	147
Rainfed agriculture	0	0	107
Higher elevation zone			
Alpine meadows/pastures	172	NA	126
Cedrus forest	180	121	0
Homegarden	158	161	60
Agriculture-medicinal plants	0	65	0
Agriculture-pea	0	68	105
Agriculture-potato	NA	149	162

Table 16. Tree density (individuals ha^{-1}) and basal area (m^2 ha^{-1}) (mean and SE) in different land use-land cover types in Langasu village landscape (values rounded off to one place after decimal; mature trees were not present in scrubland and hence not shown here)

Species	**Sites**					
	Rainfed farmland	**Irrigated farmland**	**Abandoned farmland**	**Pine forest**	**Oak forest**	**Home Garden**
Alangium salviifolium	-	-	2.8 (0.1)	-	-	-
Albizzia julibrissin	-	-	5.6 (0.1)	-	-	-
Albizzia sps.	-	-	2.8 (0.4)	-	-	-
Bauhinia purpurea	25.0 (3.9)	-	2.8 (0.3)	-	8.3 (0.4)	33.2 (0.8)
Bombax ceiba	2.8 (0.1)	-	8.3 (0.1)	-	-	-
Carica papaya	-	-	-	-	-	33.3 (0.4)
Celtis australis	36.1 (4.1)	13.9 (2.0)	16.7 (0.7)	-	-	50.0 (2.0)
Citrus aurentifolia	-	2.8 (0.1)	-	-	-	41.7 (0.1)
Citrus sinensis	-	-	-	-	-	283.2 (2.8)
Emblica officinalis	-	-	5.6 (0.1)	-	-	-
Ficus auriculata	2.8 (0.2)	-	25.0 (0.9)	-	11.1 (0.2)	8.3 (0.1)
Ficus palmata	-	-	2.8 (0.3)	-	-	8.3 (0.4)
Ficus subincisa	8.3 (0.1)	8.3 (0.8)	16.7 (0.7)	-	-	141.6 (1.8)
Ficus relegiosa	-	2.8 (0.1)	-	-	-	-

Grewia optiva	30.6 (2.7)	11.1 (0.5)	8.3 (0.2)	-	-	41.7 (1.2)
Juglans regia	-	2.8 (0.2)	-	-	-	33.3 (1.7)
Litchi chinensis	-	-	-	-	-	8.3 (0.02)
Mallotus phillipensis	-	-	25.0 (0.7)	-	-	-
Mangifera indica	-	-	-	-	-	149.9 (0.8)
Morus australis	-	5.6 (0.1)	-	-	-	8.3 (0.2)
Pinus roxburghii	-	-	19.5 (1.3)	463.9 (19.5)	2.8 (0.1)	-
Prunus persica	-	-	-	-	-	16.7 (0.5)
Psidium guajava	-	-	-	-	-	191.6 (1.0)
Punica granatum	-	-	-	-	-	16.7 (1.2)
Pyrus pashia	-	2.8 (0.1)	11.1 (0.1)	-	-	-
Rhus parviflora	-	-	19.5 (0.3)	-	-	-
Quercus leucotrichophora	-	-	44.5 (1.7)	8.3 (0.3)	516.7 (27.2)	-
Sapium insigne	-	-	5.6 (0.2)	2.8 (0.1)	5.6 (0.1)	-
Syzigium cumini	-	-	2.8 (0.1)	-	-	8.3 (.02)
Others	-	2.8 (0.1)	36.3 (0.2)	-	13.9 (0.2)	25.0 (0.8)
Total	105.6±18.1 (11.04± 3.1)	52.8± 22.6 (3.6±2.0)	261.3 ± 74.8 (7.4 ± 1.9)	475 ± 97.2 (19.8 ± 3.1)	558.3± 128.1 (28.2 ± 3.7)	1099.4 ± 187.6 (15.7 ± 2.9)

Table 17. Occurrence of termite taxa during three seasons in different land uses in the lower elevation village landscape based on the samples collected in the present study

	Pre-monsoon (April)	**Monsoon (July)**	**Post-monsoon (October)**
Oak forest	Unknown Nymphal Stage	*Euhamitermes* sp.	None
Pine forest	*Euhamitermes* sp; Immature stage of Unknown sp.	Euhamitermes sp.	*Euhamitermes sp.; Odontotermes sp; Odontotermes Assmuthi Holongaen*
Homegarden	*Odontotermes* Sp; *Odontotermes parvidens* Holmg & Holog; Unknown nymphal stage	*Euhamitermes* sp.	Unknown specimen
Rainfed agriculture	None	*Euhamitermes* sp	None
Irrigated agriculture	None	None	None

Table 18. Likely occurrence of termite genera based on the information collected by Indian survey organizations over a long period of time (Based on M.L. Thakur, unpublished)

Genera likely to occur only in Nilgiri Biosphere Reserve	Genera likely to occur only in Nanda Devi Biosphere Reserve	General likely to occur in both Nilgiri and Nandadevi Biosphere Reserve
Cryptotermes	Archotermopsis	Stylotermes
Procryptotermes		Glyptotermes
Synhamitermes		Neotermes
Speculitermes		Heterotermes
Eurytermes		Coptotermes
Dicuspiditermes		Eremotermes
Homallotermes		Euhamitermes
Pseudocapritermes		Angulitermes
Malayasiocapritermes		Microtermes
Labiocapritermes		Odontotermes
Pericapritermes		Microcerotermes
Indocapritermes		Trinervitermes
Krishnacapritermes		
Macrotermes		
Hypotermes		
Ampoulitermes		
Ceylonitermes		
Grallatoermes		
Nasutitermes		

Vesicular arbuscular mycorrhiza: Nanda Devi Biosphere Reserve

1. Introduction

Mycorrhiza constitute a significant element of beneficial belowground organisms. The knowledge on belowground biodiversity in quantitative terms in the Central Himalayan region has, by and large, been confined to macrofauna, more so the earthworms. A few efforts have been made to characterize mycorrhizal diversity in the north-eastern Himalaya (see Tiwari, 2005; Bagyaraj and Balakrishna, 2005). Knowledge on mycorrhizal diversity and its relationships with aboveground diversity, soil characteristics, and management practices around the Nanda Devi Biosphere Reserve is altogether lacking. This study was an attempt to fill up this knowledge gap.

2. Method

Spores from 0-10 cm and 10-20 cm soil sampled following a systematic sampling design in a lower elevation landscape around the Nanda Devi Biosphere Reserve were collected covering all the three seasons (data of only one season presented here) were extracted following wet sieving and sucrose centrifugation method. Pre-testing of available methodologies indicated a marked difference in spore recovery depending upon the soil was blended or not. Blending improved recovery particularly in samples having larger amount of fine roots.

	Blending	**Non-blending**
Pine forests	310	300
Oak forests	288	108
Irrigated agriculture	243	208
Abandoned agricultural land	331	220
Homegardens	135	132
Scrubland	180	150
Rainfed agriculture	140	110
Rainfed agriculture	225	192
Mean	**232**	**177**
SD	**75**	**66**
SE	**27**	**23**

This observation led to blending of all samples for a period of 30 seconds before wet sieving. In some samples total spore abundance was estimated across the total soil profile. Further, a few Agroforestry trees were selected to ascertain their effect on mycorrhiza spore populations in Agroforestry systems.

3. Results

3.1. Frequency of occurrence in the landscape

In all 34 species, 13 belonging to the genus *Acaulospora*, 3 to *Gigaspora*, 8 to *Glomus* and 10 to the genus *Scutellospora* were sampled in soils collected from different land uses in the lower elevation village landscape. It may be noted that about 3% of spores in abandoned agricultural land to 13% in oak forests could not be identified at species level.

Four species of *Acaulospora* (*A. lacunose, A. rugosa, A. sporocarpia, A. tuberculata*), one of *Glomus* (*G. manihotis*), and six of *Scutellospora* (*S. carolloidea, S. cerradensis, S. dipurpurascea, S. gregaria, S. rubra* and *S. scutata*) were present in 0-10 cm surface but absent in sub-surface soil (10-20 cm). Only one species viz. *S. erythropa* was present in sub-surface but absent in surface soil. These species confined to only one depth belonged to rare or occasional frequency class (1-20% and 21-40% frequency of occurrence). In the landscape, only one species of *Scutellospora* was dominant compared to 3 of *Glomus*, 5 of *Acaulospora* and none of *Gigaspora*. Twenty three species were sampled from the subsurface soil compared to 34 species in surface soil, indicating a decline in species richness with increasing depth of soil (Table 1).

3.2. Spore Abundance by species in different land use types

3.2.1. Spore abundance in 0-10 cm soil layer

Acaulospora lacunosa was sampled only from pine forests, *Gigaspora geosporum* only from abandoned agricultural land and, *Scutellospora dipurpurascea* and *S. scutata* only from irrigated agriculture. Twelve species occurred in all land uses but the degree abundance varied between sites. Thus, *Acaulospora delicate* and *G. tenebrosum* occurred in all land used but more abundant in scrub land. *Glomus pansihalos* and *G. tenebrousum* were more dominant in pine forests compared to oak forests, while *Acaulospora morrowiae* was more abundant in oak forests. Irrigated agriculture differed from rainfed agriculture in terms of higher density of *Acaulospora morrowiae*, *Glomus tenebrosum* and *Glomus pansihalos* spores but lower of *Glomus intrradices* and *Glomus aggregatum* compared to that in rainfed agriculture (Table 2,3).

3.2.2. Spore abundance in 10-20 cm soil layer

Acaulospora elegans occurred only in oak forests, *Gigaspora geosporum* and *Scutellaspora calospora* only in rainfed agriculture, *Scutellospora erythropa* only in irrigated agriculture, *Glomus pansihalos* only in homegardens and *Glomus viscosum* only in oak forests. Nine species were common to all the landuses but the land uses differed in terms of relative abundance of several species. *Glomus intraradices* was the most dominant species in scrubland, *G. aggregatum* in rainfed agriculture and *Glomus tenebrosum* in pine forest, oak forest, homegardens, irrigated agriculture and abandoned agricultural land. (Table 4,5)

Three species of *Glomus* viz., *Glomus aggregatum, G. intraradices* and *G. tenebrosum* accounted for > 50% of spores in almost all landuses, considering 0-10 cm and 10-20 cm horizons together or separately. (Table 6, 7). Coefficient of variation differed by species and depth but, in none of the cases, it exceeded a value of 190% (Tables 8,9,10).

3.2.3. Total spore abundance in 0-20 cm soil layer

Total spore abundance decreased with depth in all land use types except rainfed agriculture and scrub where no change or a marginal increase was observed. There was a significant interaction of land use and depth. Oak and pine forest did not differ in terms of spore abundance in 10-20 cm depth but the latter showed markedly higher abundance compared to the former in 0-10 cm horizon. Abandoned agricultural land had comparable spore density in 0-10 cm depth but about 50% lower in 10-20 cm depth compared to rainfed agriculture or scrubland. Pooled spore abundance in 0-20 cm horizon showed a trend of pine forests > oak forests = rainfed agriculture = scrubland > irrigated agriculture > homegardens = abandoned agricultural land (Figure 1).

Coefficient variation in most of the cases was lower for pooled abundance in 0-20 cm horizon compared to that in 0-10 cm and 10-20 cm layers separately. Coefficient of variation in total spore abundance was lower than that of species wise abundance. In none of the land uses, coefficient of variation exceeded a value of 75% (Table 11).

3.3. Spore abundance in rhizosphere of selected agroforestry trees

Spore abundance in rhizosphere of four important agroforestry species across the entire soil profile is presented in Figure 2 and coefficient of variation in Table 12. A significant effect of species and depth is evident. Spore abundance significantly declined below 20 cm depth in *Bauhinia variegata* (a legume) and below 30 cm depth in *Celtis australis*. Spore abundance in *Grewia oppositifolia* and Chhanchri (local name) was very low compared to *Bauhinia* and *Celtis*. The change in spore abundance with depth in these two species was not as marked as in *Bauhinia* and *Celtis*. It is evident that significant number of spores is present in deeper soil layers.

4. Discussion

A cross section of studies summarized in table 13 shows that the spore abundance, species dominance and diversity data in the present case falls within the range of reported values.

Acknowledgements

The authors wish to acknowledge technical and scientific support from National coordinator of TSBF-CIAT/GEF/UNEP project on Conservation and Sustainable Management of Belowground Diversity.

Table 1: Frequency of occurrence of different Mycorrhizal species in the landscape
Ab, absent; 1-20%, rare; 21-40%, occasional; 41-60%, frequent; 61-80%, common; 81-100%, dominant.

Mycorrhizal species	0-10 cm	10-20 cm	0-20 cm
Acaulospora delicata	C	C	D
Acaulospora dilatata	C	D	D
Acaulospora elegans	O	R	O
Acaulospora lacunosa	R	Ab	R
Acaulospora mellea	F	O	F
Acaulospora morrowiae	D	D	D
Acaulospora myriocarpa	F	F	D
Acaulospora rehmii	F	R	F
Acaulospora rugosa	R	Ab	R
Acaulospora sporocarpia	R	Ab	R
Acaulospora trappei	D	C	D
Acaulospora tuberculata	O	Ab	O
Acaulspora scrobiculata	O	R	O
Gigaspora albida	O	O	F
Gigaspora geosporum	R	R	R
Gigaspora gigantea	F	O	C
Glomus aggregatum	D	D	D
Glomus etunicatum	O	R	O
Glomus intraradices	D	D	D
Glomus manihotis	O	Ab	O
Glomus pansihalos	F	R	F
Glomus tenebrosum	C	D	D
Glomus verruculosum	F	R	F
Glomus viscosum	R	R	O
Scutellospora calospora	F	R	F
Scutellospora carolloidea	R	Ab	R
Scutellospora cerradensis	R	Ab	R
Scutellospora dipurpurascens	R	Ab	R
Scutellospora gregaria	O	Ab	O
Scutellospora erythropa	Ab	R	R
Scutellospora heterogama	C	D	D
Scutellospora pellucida	F	O	C
Scutellospora rubra	R	Ab	R
Scutellospora scutata	R	Ab	R
Others	?	?	?

Table 2: Abundance (number of spores g^{-1} soil) of Mycorrhizal species in different landuses in 0-10 cm soil layer

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SC
Acaulospora delicata	0.10	0.75	0.60	0.44	1.09	0.24	2.21
Acaulospora dilatata	0.18	1.01	0.35	0.52	0.73	0.05	0.39
Acaulospora elegans	0.11	0.08	0.04	0.10	0.00	0.00	0.08
Acaulospora lacunosa	0.00	0.18	0.00	0.00	0.00	0.00	0.00
Acaulospora mellea	0.09	0.42	0.23	0.14	0.00	0.31	0.17
Acaulospora morrowiae	1.97	0.85	2.06	1.30	1.38	0.37	0.64
Acaulospora myriocarpa	0.34	0.75	0.00	0.11	0.30	0.23	0.20
Acaulospora rehmii	0.18	0.11	0.20	0.11	0.00	0.06	0.02
Acaulospora rugosa	0.00	0.04	0.04	0.00	0.00	0.11	0.00
Acaulospora sporocarpia	0.72	0.00	0.00	0.00	0.09	0.00	0.00
Acaulospora trappei	0.84	1.70	0.23	0.63	1.49	0.59	0.39
Acaulospora tuberculata	0.00	0.00	0.14	0.37	0.04	0.10	0.03
Acaulspora scrobiculata	0.06	0.00	0.00	0.18	0.00	0.08	0.07
Gigaspora albida	0.00	0.15	0.04	0.03	0.00	0.15	0.09
Gigaspora geosporum	0.00	0.00	0.00	0.00	0.00	0.04	0.00
Gigaspora gigantea	0.00	0.15	0.04	0.11	0.32	0.30	0.03
Glomus aggregatum	4.91	10.22	1.80	4.39	4.99	2.80	4.53
Glomus etunicatum	0.00	0.31	0.11	0.04	0.04	0.00	0.00
Glomus intraradices	4.76	10.31	2.49	5.48	6.73	4.19	6.57
Glomus manihotis	0.06	0.13	0.03	0.08	0.00	0.05	0.00
Glomus pansihalos	2.04	7.79	1.89	2.41	1.32	0.57	4.22
Glomus tenebrosum	4.72	13.30	4.11	4.01	5.05	3.08	1.94
Glomus verruculosum	0.09	0.07	0.04	0.07	0.38	0.03	0.03
Glomus viscosum	0.00	0.11	0.07	0.12	0.43	0.00	0.00
Scutellospora calospora	0.30	0.62	0.37	0.27	0.26	0.87	0.02
Scutellospora carolloidea	0.00	0.12	0.00	0.00	0.00	0.07	0.00
Scutellospora cerradencis	0.00	0.00	0.00	0.05	0.00	0.08	0.00
Scutellospora dipurpurescens	0.00	0.00	0.00	0.11	0.00	0.00	0.00
Scutellospora gregaria	0.33	0.27	0.57	0.52	0.43	0.16	0.91
Scutellospora erythropa	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scutellospora heterogama	0.82	1.47	0.55	0.53	1.76	0.32	0.17
Scutellospora pellucida	0.63	0.48	0.08	0.00	0.18	0.00	0.03
Scutellopora rubra	0.08	0.04	0.00	0.00	0.00	0.00	0.28
Scutellospora scutata	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Others	3.45	6.34	1.36	1.23	1.21	0.48	1.36
Total spores	26.77	57.76	**17.43**	**23.41**	**28.24**	**15.34**	**24.37**

Table 3: Relative abundance of different Mycorrhizal species (spores g^{-1} soil) in different landuses at 0-10 cm depth soil

Species	**OF**	**PF**	**HG**	**IA**	**RA**	**AA**	**SC**
Acaulospora delicata	0.4	1.3	3.4	1.9	3.9	1.6	9.1
Acaulospora dilatata	0.7	1.7	2.0	2.2	2.6	0.3	1.6
Acaulospora elegans	0.4	0.1	0.2	0.4	0.0	0.0	0.3
Acaulospora lacunosa	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Acaulospora mellea	0.3	0.7	1.3	0.6	0.0	2.0	0.7
Acaulospora morrowiae	7.3	1.5	11.8	5.6	4.9	2.4	2.6
Acaulospora myriocarpa	1.3	1.3	0.0	0.5	1.1	1.5	0.8
Acaulospora rehmii	0.7	0.2	1.1	0.5	0.0	0.4	0.1
Acaulospora rugosa	0.0	0.1	0.2	0.0	0.0	0.7	0.0
Acaulospora sporocarpia	2.7	0.0	0.0	0.0	0.3	0.0	0.0
Acaulospora trappei	3.1	2.9	1.3	2.7	5.3	3.8	1.6
Acaulospora tuberculata	0.0	0.0	0.8	1.6	0.2	0.7	0.1
Acaulspora scrobiculata	0.2	0.0	0.0	0.8	0.0	0.5	0.3
Gigaspora albida	0.0	0.3	0.2	0.1	0.0	1.0	0.4
Gigaspora geosporum	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Gigaspora gigantea	0.0	0.3	0.2	0.5	1.1	2.0	0.1
Glomus aggregatum	18.3	17.7	10.3	18.7	17.7	18.2	18.6
Glomus etunicatum	0.0	0.5	0.7	0.2	0.2	0.0	0.0
Glomus intraradices	17.8	17.9	14.3	23.4	23.8	27.3	27.0
Glomus manihotis	0.2	0.2	0.2	0.3	0.0	0.3	0.0
Glomus pansihalos	7.6	13.5	10.9	10.3	4.7	3.7	17.3
Glomus tenebrosum	17.6	23.0	23.6	17.1	17.9	20.1	8.0
Glomus verruculosum	0.3	0.1	0.2	0.3	1.4	0.2	0.1
Glomus viscosum	0.0	0.2	0.4	0.5	1.5	0.0	0.0
Scutellospora calospora	1.1	1.1	2.1	1.2	0.9	5.7	0.1
Scutellospora carolloidea	0.0	0.2	0.0	0.0	0.0	0.5	0.0
Scutellospora cerradensis	0.0	0.0	0.0	0.2	0.0	0.5	0.0
Scutellospora dipurpurascens	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Scutellospora gregaria	1.2	0.5	3.3	2.2	1.5	1.0	3.7
Scutellospora heterogama	3.1	2.6	3.1	2.2	6.2	2.1	0.7
Scutellospora pellucida	2.4	0.8	0.5	0.0	0.6	0.0	0.1
Scutellospora rubra	0.3	0.1	0.0	0.0	0.0	0.0	1.1
Scutellospora scutata	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Others	12.9	11.0	7.8	5.3	4.3	3.1	5.6

Table 4: Abundance (number of spores g^{-1} soil) of Mycorrhizal species in different landuses in 10-20 cm soil layer

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SC
Acaulospora delicata	0.35	0.35	0.19	0.97	0.29	0.65	1.20
Acaulospora dilatata	0.16	0.21	0.08	0.60	0.27	0.37	1.79
Acaulospora elegans	0.13	0.00	0.04	0.00	0.00	0.00	0.00
Acaulospora lacunosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acaulospora mellea	0.07	0.55	0.11	0.19	0.12	0.03	0.00
Acaulospora morrowiae	1.97	1.23	0.24	1.68	1.88	0.59	2.05
Acaulospora myriocarpa	0.37	0.21	0.19	0.08	0.55	0.16	0.25
Acaulospora rehmii	0.04	0.21	0.00	0.00	0.04	0.00	0.33
Acaulospora rugosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acaulospora sporocarpia	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acaulospora trappei	0.24	0.23	0.21	0.33	0.51	0.12	0.76
Acaulospora tuberculata	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acaulspora scrobiculata	0.00	0.00	0.00	0.05	0.17	0.00	0.00
Gigaspora albida	0.00	0.19	0.11	0.07	0.09	0.00	0.14
Gigaspora geosporum	0.00	0.00	0.00	0.00	0.07	0.00	0.00
Gigaspora gigantea	0.04	0.00	0.05	0.40	0.00	0.00	0.00
Glomus aggregatum	1.60	2.87	1.48	2.61	6.12	0.96	4.26
Glomus etunicatum	0.07	0.00	0.17	0.00	0.00	0.00	0.00
Glomus intraradices	2.65	1.45	2.17	2.48	2.52	1.07	6.22
Glomus manihotis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glomus pansihalos	0.00	0.00	0.15	0.00	0.00	0.00	0.00
Glomus tenebrosum	9.76	9.22	2.49	3.31	5.30	3.43	4.55
Glomus verruculosum	0.07	0.09	0.04	0.00	0.08	0.00	0.00
Glomus viscosum	0.73	0.00	0.00	0.00	0.00	0.00	0.00
Scutellospora calospora	0.00	0.00	0.00	0.00	0.44	0.00	0.00
Scutellospora carolloidea	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scutellospora cerradencis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scutellospora dipurpurescens	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scutellospora gregaria	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scutellospora erythropa	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Scutellospora heterogama	1.17	0.67	0.60	1.77	1.91	0.51	2.25
Scutellospora pellucida	0.11	0.00	0.04	0.00	0.15	0.12	0.35
Scutellopora rubra	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scutellospora scutata	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Others	0.19	0.44	0.55	0.29	0.26	0.00	0.00
Total spores	19.72	17.93	8.91	14.93	20.76	8.00	24.15

Table 5: Relative abundance of different Mycorrhizal species (spores g^{-1} soil) in different landuses at 10-20 cm depth soil

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SC
Acaulospora delicata	0.3	0.4	0.2	1.0	0.3	0.7	1.2
Acaulospora dilatata	0.2	0.2	0.1	0.6	0.3	0.4	1.8
Acaulospora elegans	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Acaulospora mellea	0.1	0.5	0.1	0.2	0.1	0.0	0.0
Acaulospora morrowiae	2.0	1.2	0.2	1.7	1.9	0.6	2.1
Acaulospora myriocarpa	0.4	0.2	0.2	0.1	0.5	0.2	0.3
Acaulospora rehmii	0.0	0.2	0.0	0.0	0.0	0.0	0.3
Acaulospora trappei	0.2	0.2	0.2	0.3	0.5	0.1	0.8
Acaulspora scrobiculata	0.0	0.0	0.0	0.1	0.2	0.0	0.0
Gigaspora albida	0.0	0.2	0.1	0.1	0.1	0.0	0.1
Gigaspora geosporum	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Gigaspora gigantea	0.0	0.0	0.1	0.4	0.0	0.0	0.0
Glomus aggregatum	1.6	2.9	1.5	2.6	6.1	1.0	4.3
Glomus etunicatum	0.1	0.0	0.2	0.0	0.0	0.0	0.0
Glomus intraradices	2.7	1.5	2.2	2.5	2.5	1.1	6.2
Glomus pansihalos	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Glomus tenebrosum	9.8	9.2	2.5	3.3	5.3	3.4	4.5
Glomus verruculosum	0.1	0.1	0.0	0.0	0.1	0.0	0.0
Glomus viscosum	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Scutellospora calospora	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Scutellospora erythropa	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Scutellospora heterogama	1.2	0.7	0.6	1.8	1.9	0.5	2.3
Scutellospora pellucida	0.1	0.0	0.0	0.0	0.1	0.1	0.3
Others	0.2	0.4	0.5	0.3	0.3	0.0	0.0

Table 6: Abundance (number of spores g^{-1} soil) of Mycorrhizal species in different landuses in 0-20 cm soil layer

Mycorrhizal species	**OF**	**PF**	**HG**	**IA**	**RA**	**AA**	**SC**
Acaulospora delicata	0.45	1.10	0.78	1.42	1.38	0.89	3.41
Acaulospora dilatata	0.34	1.22	0.43	1.12	0.99	0.43	2.18
Acaulospora elegans	0.24	0.08	0.08	0.10	0.00	0.00	0.08
Acaulospora lacunosa	0.00	0.18	0.00	0.00	0.00	0.00	0.00
Acaulospora mellea	0.16	0.96	0.33	0.32	0.12	0.34	0.17
Acaulospora morrowiae	3.94	2.08	2.30	2.98	3.26	0.96	2.69
Acaulospora myriocarpa	0.71	0.96	0.19	0.19	0.85	0.39	0.46
Acaulospora rehmii	0.22	0.32	0.20	0.11	0.04	0.06	0.35
Acaulospora rugosa	0.00	0.04	0.04	0.00	0.00	0.11	0.00
Acaulospora sporocarpia	0.72	0.00	0.00	0.00	0.09	0.00	0.00
Acaulospora trappei	1.08	1.93	0.44	0.96	2.00	0.71	1.15
Acaulospora tuberculata	0.00	0.00	0.14	0.37	0.04	0.10	0.03
Acaulspora scrobiculata	0.06	0.00	0.00	0.23	0.17	0.08	0.07
Gigaspora albida	0.00	0.34	0.15	0.10	0.09	0.15	0.23
Gigaspora geosporum	0.00	0.00	0.00	0.00	0.07	0.04	0.00
Gigaspora gigantea	0.04	0.15	0.09	0.51	0.32	0.30	0.03
Glomus aggregatum	6.51	13.09	3.28	7.00	11.12	3.76	8.79
Glomus etunicatum	0.07	0.31	0.29	0.04	0.04	0.00	0.00
Glomus intraradices	7.41	11.76	4.66	7.96	9.25	5.26	12.79
Glomus manihotis	0.06	0.13	0.03	0.08	0.00	0.05	0.00
Glomus pansihalos	2.04	7.79	2.04	2.41	1.32	0.57	4.22
Glomus tenebrosum	14.48	22.51	6.60	7.32	10.35	6.51	6.49
Glomus verruculosum	0.16	0.17	0.08	0.07	0.46	0.03	0.03
Glomus viscosum	0.73	0.11	0.07	0.12	0.43	0.00	0.00
Scutellospora calospora	0.30	0.62	0.37	0.27	0.70	0.87	0.02
Scutellospora carolloidea	0.00	0.12	0.00	0.00	0.00	0.07	0.00
Scutellospora cerradencis	0.00	0.00	0.00	0.05	0.00	0.08	0.00
Scutellospora dipurpurescens	0.00	0.00	0.00	0.11	0.00	0.00	0.00
Scutellospora gregaria	0.33	0.27	0.57	0.52	0.43	0.16	0.91
Scutellospora erythropa	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Scutellospora heterogama	1.99	2.15	1.15	2.30	3.67	0.83	2.42
Scutellospora pellucida	0.74	0.48	0.12	0.00	0.32	0.12	0.37
Scutellopora rubra	0.08	0.04	0.00	0.00	0.00	0.00	0.28
Scutellospora scutata	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Others	3.63	6.78	1.90	1.52	1.47	0.48	1.36
Total spores	46.49	75.69	26.34	38.35	49.01	23.34	48.52

Table 7: Relative abundance of different Mycorrhizal species (spores g^{-1} soil) in different landuses at 0-20 cm depth soil

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SC
Acaulospora delicata	0.96	1.45	2.97	3.69	2.82	3.83	7.02
Acaulospora dilatata	0.73	1.61	1.62	2.92	2.03	1.83	4.49
Acaulospora elegans	0.52	0.11	0.30	0.25	0.00	0.00	0.16
Acaulospora lacunosa	0.00	0.23	0.00	0.00	0.00	0.00	0.00
Acaulospora mellea	0.34	1.27	1.27	0.84	0.24	1.44	0.36
Acaulospora morrowiae	8.47	2.74	8.72	7.78	6.65	4.10	5.55
Acaulospora myriocarpa	1.53	1.27	0.71	0.50	1.73	1.67	0.94
Acaulospora rehmii	0.48	0.43	0.76	0.29	0.08	0.27	0.73
Acaulospora rugosa	0.00	0.05	0.14	0.00	0.00	0.49	0.00
Acaulospora sporocarpia	1.56	0.00	0.00	0.00	0.19	0.00	0.00
Acaulospora trappei	2.32	2.55	1.67	2.51	4.07	3.03	2.37
Acaulospora tuberculata	0.00	0.00	0.52	0.97	0.09	0.44	0.07
Acaulspora scrobiculata	0.14	0.00	0.00	0.60	0.35	0.34	0.15
Gigaspora albida	0.00	0.45	0.57	0.26	0.19	0.64	0.47
Gigaspora geosporum	0.00	0.00	0.00	0.00	0.14	0.16	0.00
Gigaspora gigantea	0.09	0.19	0.35	1.33	0.66	1.29	0.05
Glomus aggregatum	14.00	17.29	12.47	18.25	22.68	16.09	18.11
Glomus etunicatum	0.14	0.41	1.09	0.10	0.09	0.00	0.00
Glomus intraradices	15.94	15.54	17.69	20.77	18.87	22.53	26.36
Glomus manihotis	0.14	0.18	0.13	0.21	0.00	0.23	0.00
Glomus pansihalos	4.40	10.29	7.74	6.28	2.70	2.44	8.70
Glomus tenebrosum	31.14	29.74	25.06	19.08	21.13	27.87	13.38
Glomus verruculosum	0.34	0.22	0.30	0.19	0.95	0.11	0.05
Glomus viscosum	1.58	0.14	0.28	0.31	0.88	0.00	0.00
Scutellospora calospora	0.65	0.82	1.42	0.71	1.44	3.73	0.04
Scutellospora carolloidea	0.00	0.16	0.00	0.00	0.00	0.31	0.00
Scutellospora cerradensis	0.00	0.00	0.00	0.14	0.00	0.34	0.00
Scutellospora dipurpurascens	0.00	0.00	0.00	0.29	0.00	0.00	0.00
Scutellospora gregaria	0.70	0.35	2.18	1.36	0.88	0.69	1.87
Scutellospora erythropa	0.00	0.00	0.00	0.24	0.00	0.00	0.00
Scutellospora heterogama	4.29	2.84	4.35	6.00	7.49	3.56	4.99
Scutellospora pellucida	1.58	0.63	0.47	0.00	0.66	0.51	0.77
Scutellospora rubra	0.16	0.05	0.00	0.00	0.00	0.00	0.57
Scutellospora scutata	0.00	0.00	0.00	0.14	0.00	0.00	0.00
Others	7.82	8.96	7.23	3.97	3.01	2.06	2.80

Table 8: Coefficient of variation of different Mycorrhizal species in different landusesat 0-10 cm depth soil

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SC
Acaulospora delicata	124.9	66.3	115.4	67.0	137.45	173.2	154.0
Acaulospora dilatata	106.0	52.3	173.2	112.1	173.20	173.2	75.9
Acaulospora elegans	173.2	173.2	173.2	173.2			173.2
Acaulospora lacunosa		173.2					
Acaulospora mellea	173.2	126.6	106.4	173.2		173.2	89.6
Acaulospora morrowiae	76.7	98.9	65.4	48.3	149.93	133.3	81.1
Acaulospora myriocarpa	94.7	164.1		173.2	107.29	104.6	136.7
Acaulospora rehmii	103.8	173.2	140.0	173.2		87.0	173.2
Acaulospora rugosa		173.2	173.2			173.2	
Acaulospora sporocarpia	146.5				173.21		
Acaulospora trappei	78.9	120.8	90.6	120.0	144.95	70.0	24.4
Acaulospora tuberculata			173.2	173.2	173.21	173.2	173.2
Acaulspora scrobiculata	173.2			87.8		173.2	173.2
Gigaspora albida		128.9	173.2	173.2		173.2	89.2
Gigaspora geosporum						173.2	
Gigaspora gigantea		128.9	173.2	173.2	39.80	67.7	173.2
Glomus aggregatum	25.1	75.6	61.7	44.1	58.09	51.5	39.9
Glomus etunicatum		131.5	173.2	173.2	173.21		
Glomus intraradices	63.8	77.9	31.0	41.4	58.92	48.8	24.4
Glomus manihotis	173.2	173.2	173.2	90.1		173.2	
Glomus pansihalos	173.2	167.0	173.2	173.2	173.21	173.2	172.0
Glomus tenebrosum	108.3	120.7	117.8	69.0	146.32	90.2	88.4
Glomus verruculosum	120.2	173.2	173.2	87.7	173.21	173.2	173.2
Glomus viscosum		173.2	173.2	173.2	173.21		
Scutellospora calospora	96.8	79.9	173.2	173.2	173.21	173.2	173.2
Scutellospora carolloidea		97.4				173.2	
Scutellospora cerradensis				173.2		173.2	
Scutellospora dipurpurascens				173.2			
Scutellospora gregaria	173.2	173.2	173.2	142.9	173.21	173.2	173.2
Scutellospora heterogama	89.0	86.6	93.3	116.4	173.21	42.7	121.6
Scutellospora pellucida	90.0	88.6	88.5		99.07		173.2
Scutellospora rubra	173.2	173.2					118.8
Scutellospora scutata				173.2			
Others	75.1	137.4	99.0	67.6	48.10	128.4	61.9

Table 9: Coefficient of variation of different Mycorrhizal species in different landusesat 10-20 cm depth soil

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SC
Acaulospora delicata	173.2	88.8	173.2	29.7	53.3	54.9	101.7
Acaulospora dilatata	114.6	28.6	86.6	33.3	105.4	80.4	52.6
Acaulospora elegans	173.2		173.2				
Acaulospora mellea	173.2	173.2	173.2	173.2	100.0	173.2	
Acaulospora morrowiae	142.8	114.6	50.0	66.7	9.3	17.2	21.4
Acaulospora myriocarpa	173.2	173.2	121.8	173.2	86.7	86.6	89.8
Acaulospora rehmii	173.2	173.2			173.2		173.2
Acaulospora trappei	173.2	97.2	47.2	30.2	127.2	100.0	13.1
Acaulspora scrobiculata				173.2	173.2		
Gigaspora albida		103.6	173.2	173.2	173.2		173.2
Gigaspora geosporum					173.2		
Gigaspora gigantea	173.2		173.2	34.6			
Glomus aggregatum	78.9	67.8	35.8	85.1	67.8	43.9	48.7
Glomus etunicatum	173.2		118.4				
Glomus intraradices	86.3	29.2	94.0	79.7	102.4	27.6	55.9
Glomus pansihalos			110.2				
Glomus tenebrosum	103.3	56.4	38.0	38.6	29.4	7.9	15.0
Glomus verruculosum	173.2	173.2	173.2		173.2		
Glomus viscosum	173.2						
Scutellospora calospora					173.2		
Scutellospora erythropa				173.2			
Scutellospora heterogama	118.1	78.9	173.2	36.7	55.9	74.6	18.1
Scutellospora pellucida	173.2		173.2		128.9	100.0	87.4
Others	173.2	110.2	142.7	173.2	33.2		

Table 10: Coefficient of variation of different Mycorrhizal species in different landuses at 0-20 cm depth soil

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SC
Acaulospora delicata	129.5	20.5	63.1	25.9	99.0	6.8	102.5
Acaulospora dilatata	86.7	44.1	149.5	43.0	152.8	53.3	37.3
Acaulospora elegans	88.2	173.2	173.2	173.2			173.2
Acaulospora lacunosa		173.2					
Acaulospora mellea	89.4	152.1	124.9	173.2	100.0	153.1	89.6
Acaulospora morrowiae	105.5	54.2	53.4	49.8	65.7	51.9	31.0
Acaulospora myriocarpa	52.6	112.3	121.8	89.8	27.6	73.4	82.2
Acaulospora rehmii	113.8	99.0	140.0	173.2	173.2	87.0	173.2
Acaulospora rugosa		173.2	173.2			173.2	
Acaulospora sporocarpia	146.5				173.2		
Acaulospora trappei	58.3	104.7	68.6	79.8	101.1	41.2	8.6
Acaulospora tuberculata			173.2	173.2	173.2	173.2	173.2
Acaulspora scrobiculata	173.2			97.9	173.2	173.2	173.2
Gigaspora albida		44.4	173.2	100.0	173.2	173.2	68.3
Gigaspora geosporum					173.2	173.2	
Gigaspora gigantea	173.2	128.9	89.2	10.2	39.9	67.7	173.2
Glomus aggregatum	8.5	57.3	37.6	58.0	11.8	47.8	42.8
Glomus etunicatum	173.2	131.5	138.5	173.2	173.2		
Glomus intraradices	52.0	64.9	35.3	46.3	32.9	44.0	24.8
Glomus manihotis	173.2	173.2	173.2	90.1		173.2	
Glomus pansihalos	173.2	167.0	159.8	173.2	173.2	173.2	172.0
Glomus tenebrosum	46.1	64.5	84.1	32.3	59.7	39.2	35.4
Glomus verruculosum	141.3	173.2	86.6	87.7	130.9	173.2	173.2
Glomus viscosum	173.2	173.2	173.2	173.2	173.2		
Scutellospora calospora	96.8	79.9	173.2	173.2	94.4	173.2	173.2
Scutellospora carolloidea		97.4				173.2	
Scutellospora cerradensis				173.2		173.2	
Scutellospora dipurpurascens				173.2			
Scutellospora gregaria	173.2	173.2	173.2	142.9	173.2	173.2	173.2
Scutellospora erythropa				173.2			
Scutellospora heterogama	105.7	62.1	128.6	26.8	54.3	30.9	24.9
Scutellospora pellucida	53.3	88.6	94.0		71.5	100.0	86.6
Scutellospora rubra	173.2	173.2					118.8
Scutellospora scutata				173.2			
Others	80.1	127.7	60.2	58.1	35.8	128.4	61.9

Table 11: Coefficient of Variation of total spores in different landuses at various depths of soil

Land use	**0-10 cm**	**10-20 cm**	**0-20 cm**
OF	43.5	73.4	24.0
PF	71.1	55.1	46.7
HG	47.4	46.1	23.8
IA	21.0	55.2	31.1
RA	67.4	44.7	25.3
AA	55.4	19.5	37.9
SC	39.2	15.4	13.2

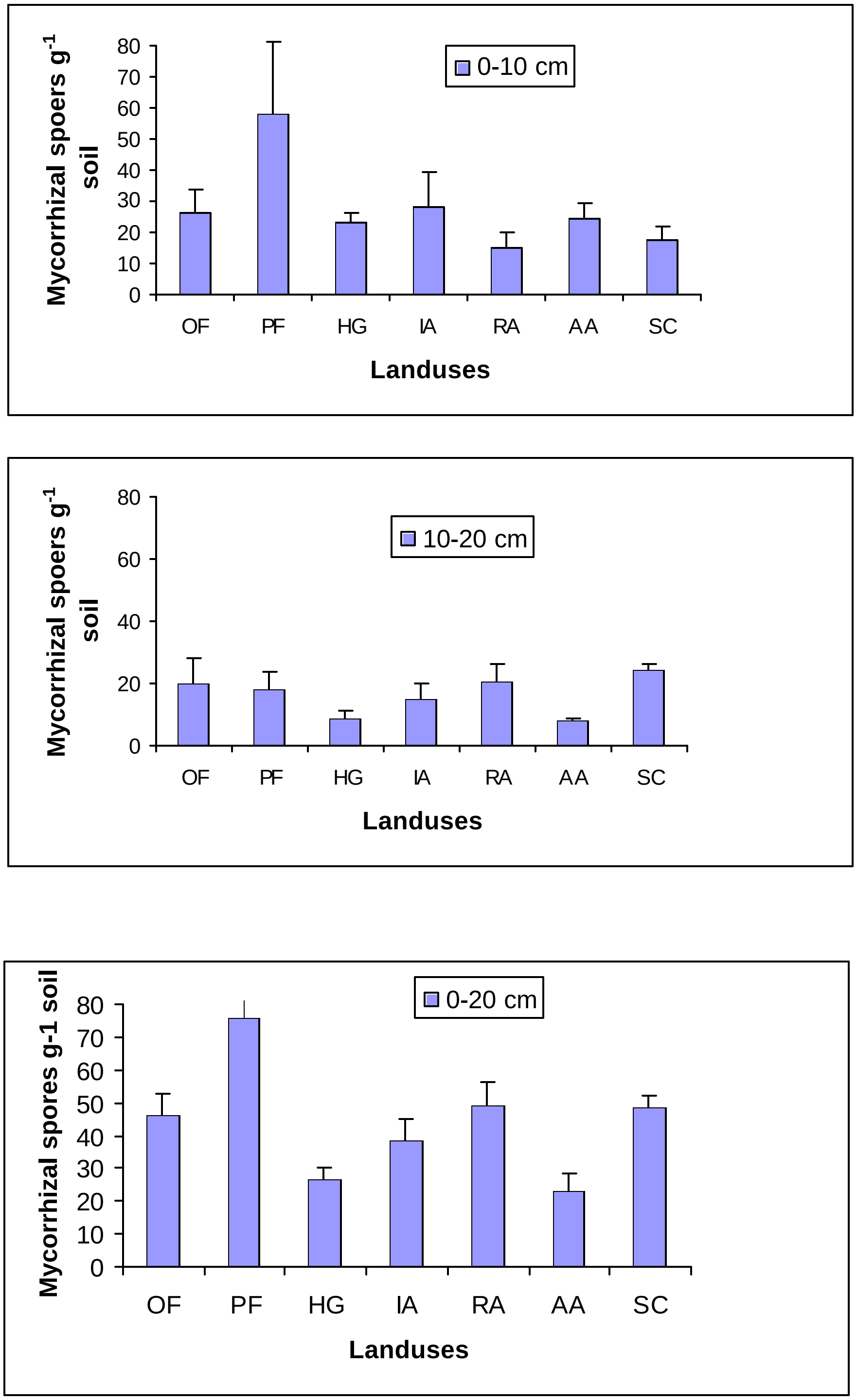


Figure 1. Numerical abundance of mycorrhizal spores in soil.

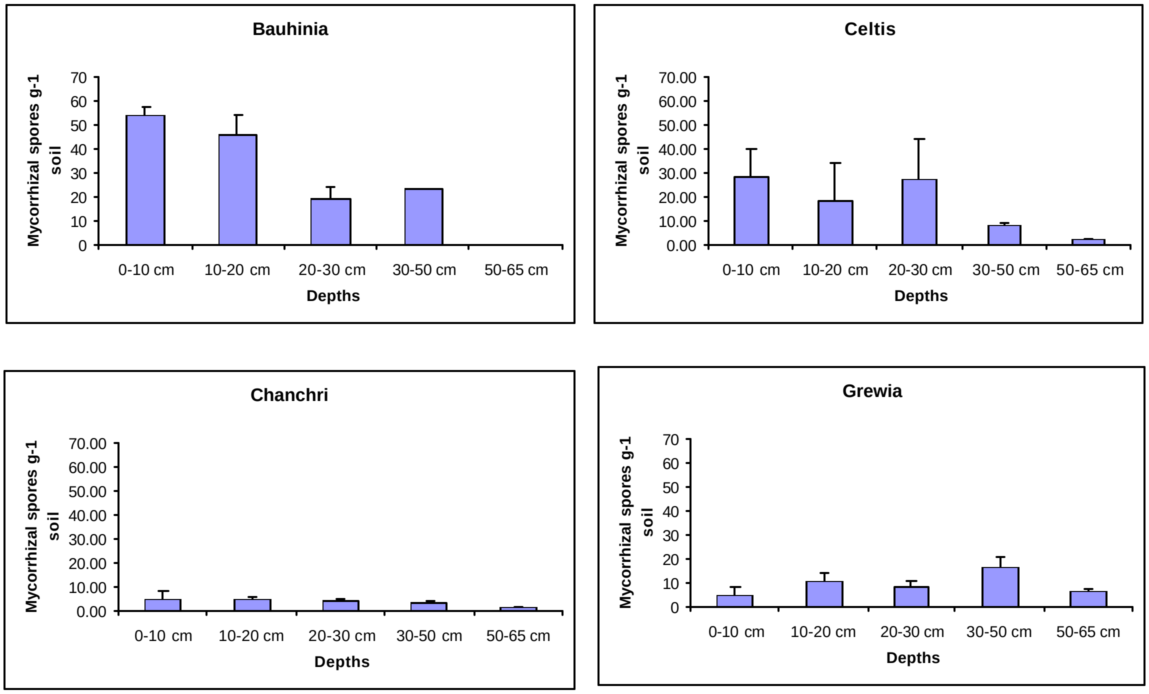


Figure 2. Numerical abundance of mycorrhizal spores in soil profiles under different Agroforestry trees

Table 12: Coeffiecient of Variation of Mycorhizal spores of different tree species with different depths

Tree species	0-10 cm	10-20 cm	20-30 cm	30-50 cm	50-65 cm	completes profile
Bauhinia	11.19	30.12	43.34	0.00		15.58
Celtis	69.45	143.81	106.09	24.96	0.00	85.35
Chanchri	119.09	50.62	31.26	22.01	88.27	30.55
Grewia	102.07	56.90	37.59	46.87	26.97	7.36

Table 13. A profile of selected studies on mycorrhiza spore abundance

Study area/authors	Reported spore abundance	Other distinguishing points
Shaded/agroforestry and unshaded coffee system in Brazil: Cardoso et al. (2003)	2-130 spores per g soil	
Neem-based Agroforestry systems in Rajasthan (arid-semi-arid region): Pande and Tarafdar (2004)	1.2 – 4.4 spores per g soil	Three genera viz. Glomus, Gigaspora and Sclerocystis with 15 species
Primary and secondary tropical seasonal rainforests in Xishuangbanna, china	0.3-0.9 spores per g soil	
Closed canopy and gaps in tropical rain forests in Mexico: Guadarrama and Alvarez-Sanchez (1999)	0.4 – 2.6 spores g soil	Four genera (Glomus, Gigaspora, Sclerocystis and Acaulospora) and 16 morpho-species
Field plots in Coimbatore: Muthukumar and Udaiyan (2000)	2.5 spores per g soil	Acaulospora Scutellospora Glomus Sclerocystis
Acacia farnesiana plantation and Acacia planifrons plantation near Coimbatore: Udaiyan et al. (1996)	5-15 spores per g soil	Four genera with eight species: Acaulospora, Gigaspora, Glomus and Sclerocystis
Scrub vegetation around Islamabad: Rashid et al. (1997)	3-3.8 spores per g soil	Three genera (Glomus, Gigaspora and Acaulospora) – also mentioned 'unknowns'
Agricultural soils (maize and strawberry): Sutton and Barron (1972)	70-86 per g soil	
Maple forests in eastern Canada (Moutoglis and Widden, (1996)	27-1600 per g soil	Two genera – Glomus and Acaulospora
Tropical rain forests in Costa Rica: Lovelock et al. (2003)	518-4794 per 100 cm3 soil	Acaulospora Scutellospora Gigaspora Glomus
Slightly/highly degraded and protected forests in eastern Himalayan state of	2.2 – 8.1 spores per g soil	Five genera (Acaulospora,

Arunachal Pradesh: Tiwari (2005)		Entrosphospora, Glomus, Gigaspora and Scutellospora) with 44 species
Red loam oxisol – agriculutural soil (Harinikumar et al., 1990)	151-197 spores per 25 ml soil	
Farmers fields in the Guinea savanna: (Sanginga et al., 1999)		Four AMF genera (Glomus, Acaulospora, Gigaspora and Sclerocystis) comprising 29 species
Rhizosphere of leguminous trees in Alger hills : Santhaguru et al. (1995)		Six genera (Acaulospora, Entrophosphora, Gigaspora, Glomus, Sclerocystis and Scutellospora) with 21 species
Semiarid tropical alfisols/agricultural soils: Lee et al. (1996)	14-26 spores per g soil	
Agricultural soils in north-eastern India/pot experiment: Panja and Chaudhuri (2004)	1.2-7.8 spores per g soil	Glomus, Acaulospora and Gigaspora
P deficient soil in pot with Leucaena: Bagyarj et al. (1989)	163-180 in 25 ml of unioculated and 212-312 per 25 ml of inoculated soil	

Nematodes and Meso-fauna: Nanda Devi Biosphere Reserve

1. Introduction

While several efforts have been made to document the biodiversity in different parts of the Himalayan region, efforts made towards characterization of nematodes and meso-fauna diversity are very limited.

2. Methods

The steps followed and steps recommended in the standard methods for nematodes are given in Table 1.

The extraction of microarthropods was performed with heat extractor configured following Tullgren or Barlese Funnel extractor design as described in Wolley (1982), Edwards (1991) and Meyer (1996). Organisms extracted over a period of 3 days were enumerated and examined. Microarthropods were examined under a light microscope in a chequred petridish that was numbered, to aid in tabulation of counts. Microarthropods were classified into mites, collembola, protura, diplura and microscopic ant groups.

3. Results

Nematode abundance in 0-10 cm soil layer was significantly higher than that in 10-20 cm layer in all land uses but the rate of decline differed between species. The steepest decline was observed in homegardens. The trend in abundance in 0-10 cm layer was irrigated agriculture = rainfed agriculture = abandoned agriculture > homegarden = scrubland = pine forest = oak forest. In case of 10-20 cm layer, the forest sties had significantly lower abundance as compared to agricultural lands and scrubland. If the data of the two depths are pooled, it is observed that nematode density was highest in irrigated agriculture, rainfed agriculture and abandoned agricultural land and lowest in forests while scrubland and homegardens showed intermediate levels (Figure 1 Table 2). Coefficient of variation in 0-10 cm layer varied from 3.7 to 67.6, from 5.9 to 120.8 in 10-20 cm layer and from 17.9 to 66.7 in scrubland (Table 3).

Collembola were more numerous in rainfed agriculture and irrigated agriculture (> 170 individuals m^{-2}) compared to oak forest and pine forest (total population <10 individuals m^{-2}). Soil population was much smaller than the litter population size (Figure 2).

Protura population abundance was several folds higher in oak forest, rainfed agriculture and irrigated agriculture as compared to pine forest. Relative proportion of population in soil and litter varied across sites. Pine forest showed protura absence in soil and oak forest in litter (Figure 3).

Diplura was found only in soil in all land uses. Rainfed agriculture and oak forest have higher population abundance as compared to irrigated agriculture and pine forest land uses (Figure 4).

Mites were the highest in number in all the sites. They were present in both litter and soil layers in all land uses. Rainfed agriculture land use had larger population than other land uses. Litter population contributed more than 80% of individuals in all landuses (Figure 5).

Microscopic ants were recorded in oak forest litter (Figure 6).

Relative proportion of different microarthropod groups in litter component of different land uses indicate that mites constituted the most dominant group of microarthropods associated with litter on all sites. Collembola was the second most dominant group in rainfed and irrigated agroecosystem land uses and diplura, the third most dominant group in these land uses. In Oak forest and pine forest diplura was the second most abundant group followed by collembola. Pine forest microarthropod group was represented exclusively by mites. Oak forest lacked collembolan and diplura. Rainfed and irrigated agriculture land lacked microscopic ants and diplura.

The total population (soil + litter) in different land uses are given in Table 4. Mites were the most dominant group in all sites but the degree of dominance varied. They contributed 97% of total individuals in pine forest followed by 79% in oak forest, 75% in rainfed agriculture, 65% in homegarden and 54% in irrigated agriculture land use. Total population of all microarthropods varied from 560 individuals m^{-2} in pine forest land use to 1231 Individuals m^{-2} in Homegarden. Differences between sites were more marked in population size of individual groups as compared to the total population considering all groups together.

4. Discussion

Badejo et al. (1999) compared mite population in agroforestry, grassland and secondary forest plots in dry and wet season in southwest Nigeria. The highest mite population was observed in Glircidia plots (3044/m^2) for the dry season and Leucaena plots (30240/m^2) for the wet season. Mite diversity was higher under Leucaena than other Agroforestry plots.

5. References

Badejo, M.A. and Tian, G. 1999. Abundance of soil mites under four Agroforestry tree species with contrasting litter quality. Biology and Fertility of Soils, 30, 107-112.

Table 1. Description of methods

Sl.No	Steps followed (I)	Steps followed (II)	Steps recommended
1	25 g of soil sample taken in a beaker and add about 250 ml of water and mix with glass rod for 30 seconds.	100 g soil taken in bowl, added 2 lit of water, unclogged soil, stirred and passed through 500 micrometer sieve (20 mesh size), residue on sieve washed 2-3 times depending upon the soil type	300 cc of soil sample taken in a bucket and add about half a bucket of water and mix well
2	Wait for 2 minutes for sedimentation of soil. Then pass the suspension passed through 125 micrometer placed over 32 micrometer sieves. The material on 125 micrometer sieve was transferred to 32 micrometer sieve. This procedure eased the process because 32 micrometer sieve was clogged if suspension was poured directly on it.	Stir the suspension, wait for 40 seconds and pass the supernatant through 250 micrometer (60 mesh size) sieve inclined at about 45 degree angle and this process ir repeated for the residue on 250 micrometer	Wait for 2 minutes for sedimentation of soil. The suspension was poured on 38 micrometer sieve. It is assumed that the sediment does not contain any nematode in the soil settled at the bottom.
3	The soil remain on the sieve are taken in centrifuge tubes around 25 ml of water and centrifuged at 3500 rpm for 5 minutes.	Suspension passed through 250 um was passed through 32 um sieve inclined at 45 degree and this process was repeated	The material remain on the sieve are taken in centrifuge tubes around 25 ml of water and centrifuged at 3500 rpm for 5 minutes.
4	Then discard the supernatant water in the tubes and add 40-60% sucrose solution and centrifuge again at 3000 rpm for 2 minutes.	Suspension passed through 32 um was discarded and the residue was. Residue was taken in a beaker and 30-40 of water added. Two layers of tissue paper placed over a	Then discard the supernatant water in the tubes and add 40-60% sucrose solution and centrifuge again at 3000 rpm for 2 minutes.

		mesh temporarily fixed over a pertriplate and the suspension is poured slowly over the tissue paper. This arrnagment of tissue paper in contact with the suspension was kept for 48 hours.	
5	The supernatant sucrose solution is poured on 32 micrometer sieve and nematodes on sieves washed with a jet of water.		The supernatant sucrose solution is poured on 32 micrometer sieve and nematodes on sieves washed with a jet of water.
6	The nematodes are washed into a beaker and makeup the volume to 10-15 ml of water.		The nematodes are washed into a beaker and makeup the volume to 10-15 ml of water.
7	From the above extraction solution, nematodes are counted for 5 ml and calculated for total extraction.		From the above extraction solution, nematodes are counted for 5 ml and calculated for total extraction.

Limitations of sucrose centrifugation

1. Some nematodes remain in the soil/sediment pellet after centrifugation.
2. It is very difficult to completely wash-off sucrose and this results in damage/decomposition of nematodes.

Table 2. **Nematode density (individuals/100 g soil) in different landuses during post monsoon period (October)**

Land use	0-10 cm		10-20 cm	
Oak Forest (OF)	181.33	+73.07	97.33	+67.87
Pine Forest (PF)	158.66	+54.55	72.00	+10.05
Home Garden (HG)	250.66	+97.76	78.67	+2.66
Irrigated Agriculture Land (IA)	349.33	+105.68	198.67	+89.33
Rainfed Agriculture Land (RA)	306.66	+156.76	146.67	+48.77
Abandoned Agriculture Land (AA)	349.33	+7.41	162.67	+49.37
Scrub Land (SL)	248.00	+116.00	101.33	+23.69

Table 3. Coeffiecient of Variation of Nematodes in different landuses at different depths

Landuses	0-10 cm	10-20 cm	0-20 cm
Oak Forest (OF)	69.8	120.8	45.6
Pine Forest (PF)	59.6	24.2	38.5
Home Garden (HG)	67.6	5.9	52.0
Irrigated Agriculture Land (IA)	52.4	77.9	31.4
Rainfed Agriculture Land (RA)	88.5	57.6	42.8
Abandoned Agriculture Land (AA)	3.7	52.6	17.9
Scrub Land (SL)	81.0	40.5	66.7

Table 4. Population size of different microarthropod groups and total population considering all the groups together (number of individuals in litter + soil layers)

Land use	Collembola	Protura	Diplura	Mites	Microscopic ants	Total
Oak forest (OF)	8	74	8	600	70	760
Pine forest (PF)	6	6	3	545	0	560
Rainfed agriculture (RA)	200	84	19	910	0	1213
Irrigated agriculture (IA)	370	84	6	542	0	1002
Homegarden (HG)	220	9	207	795	0	1231
Total	804	257	243	3392	70	

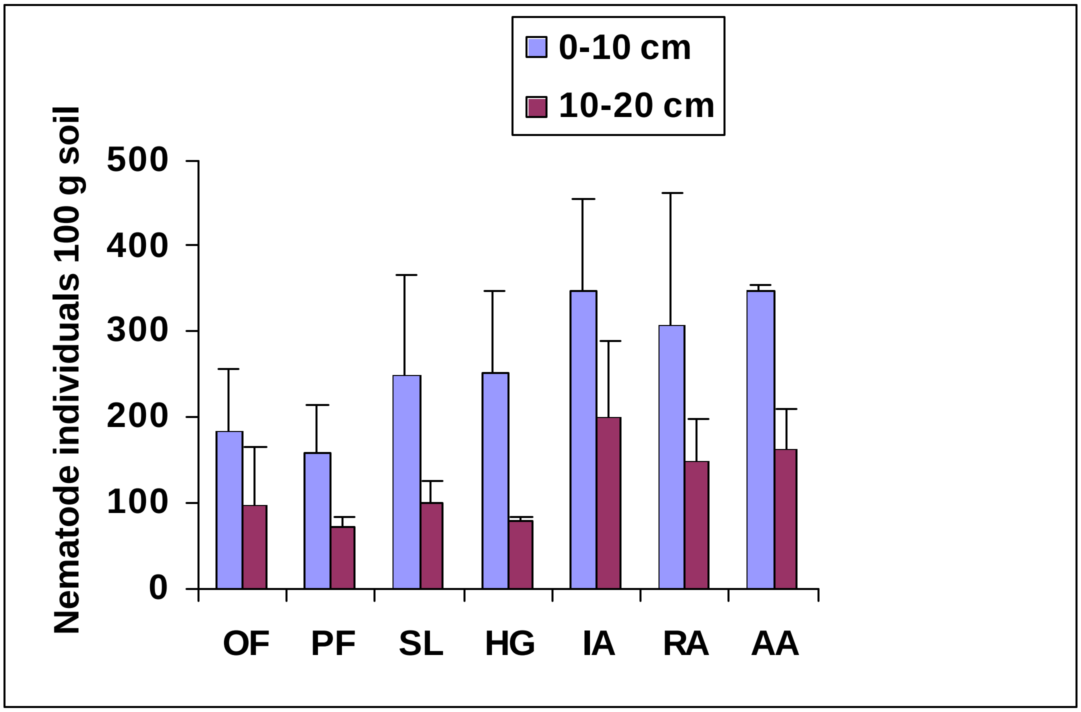


Figure 1. Numerical abundance of nematodes in soil at various depths during post monsoon period (October) at lower elevations in Himalaya.

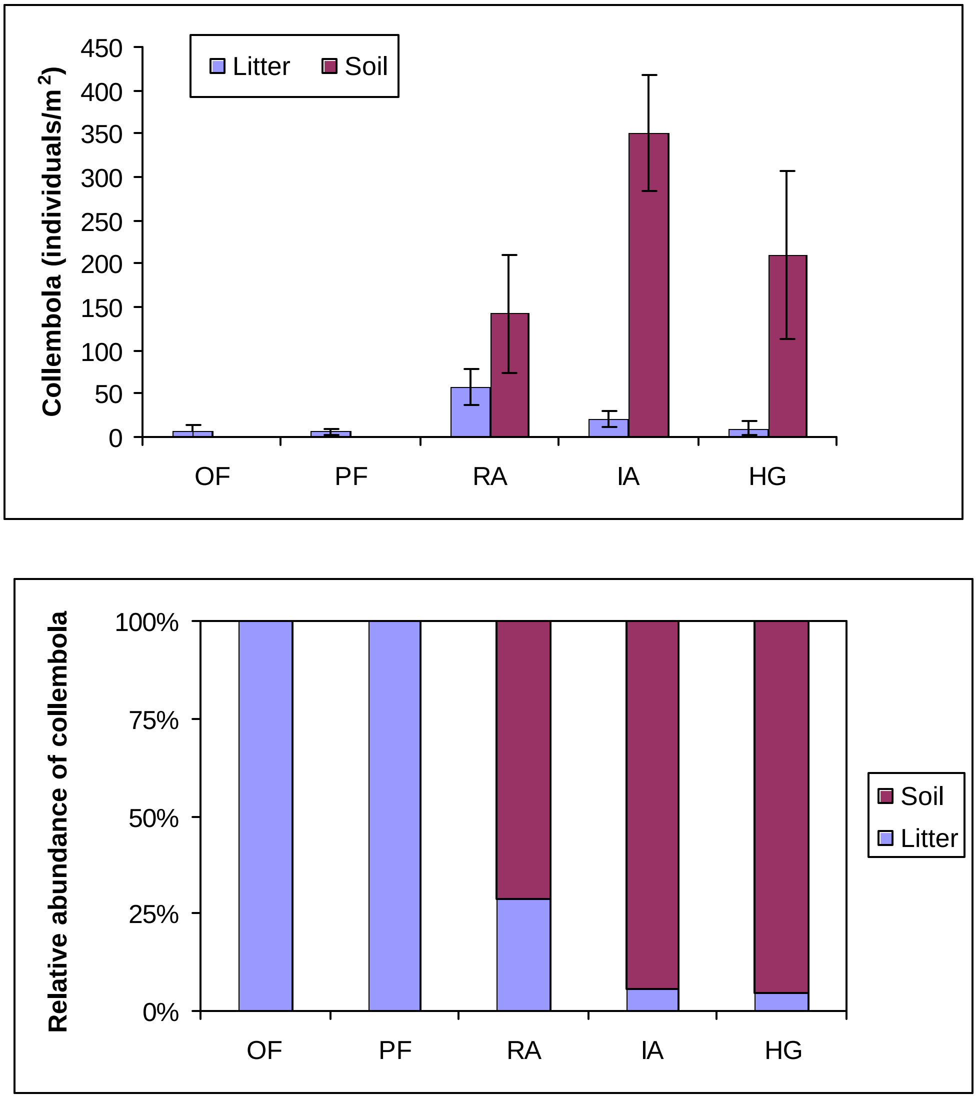
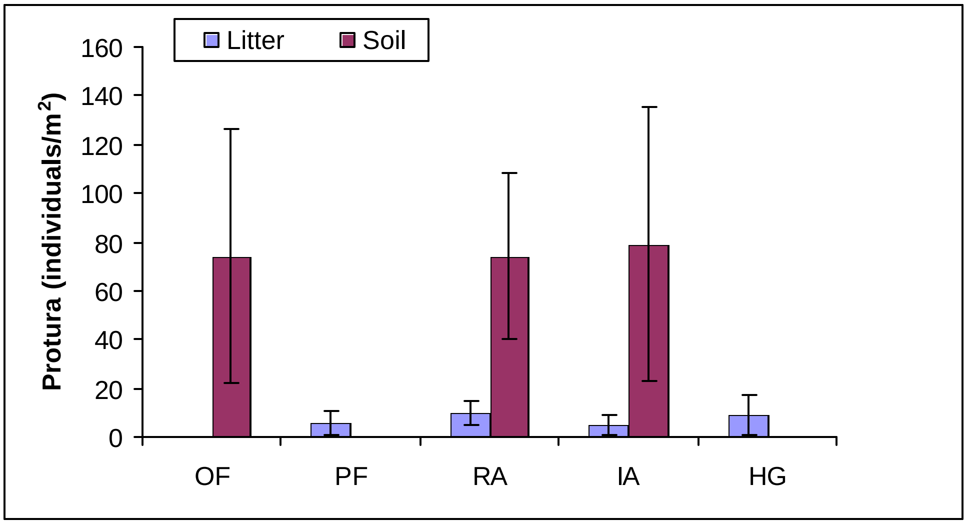


Figure 2. Absolute and relative abundance of Collembola in different land uses during post monsoon period (October) at lower elevation in Himalaya.



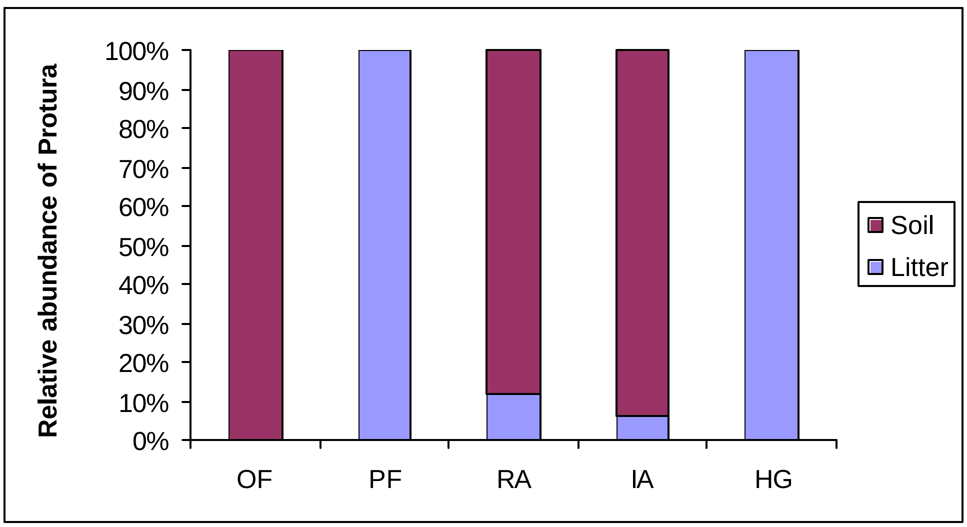


Figure 3. Absolute and relative abundance of Protura in different land uses during post monsoon period (October) at lower elevation in Himalaya.

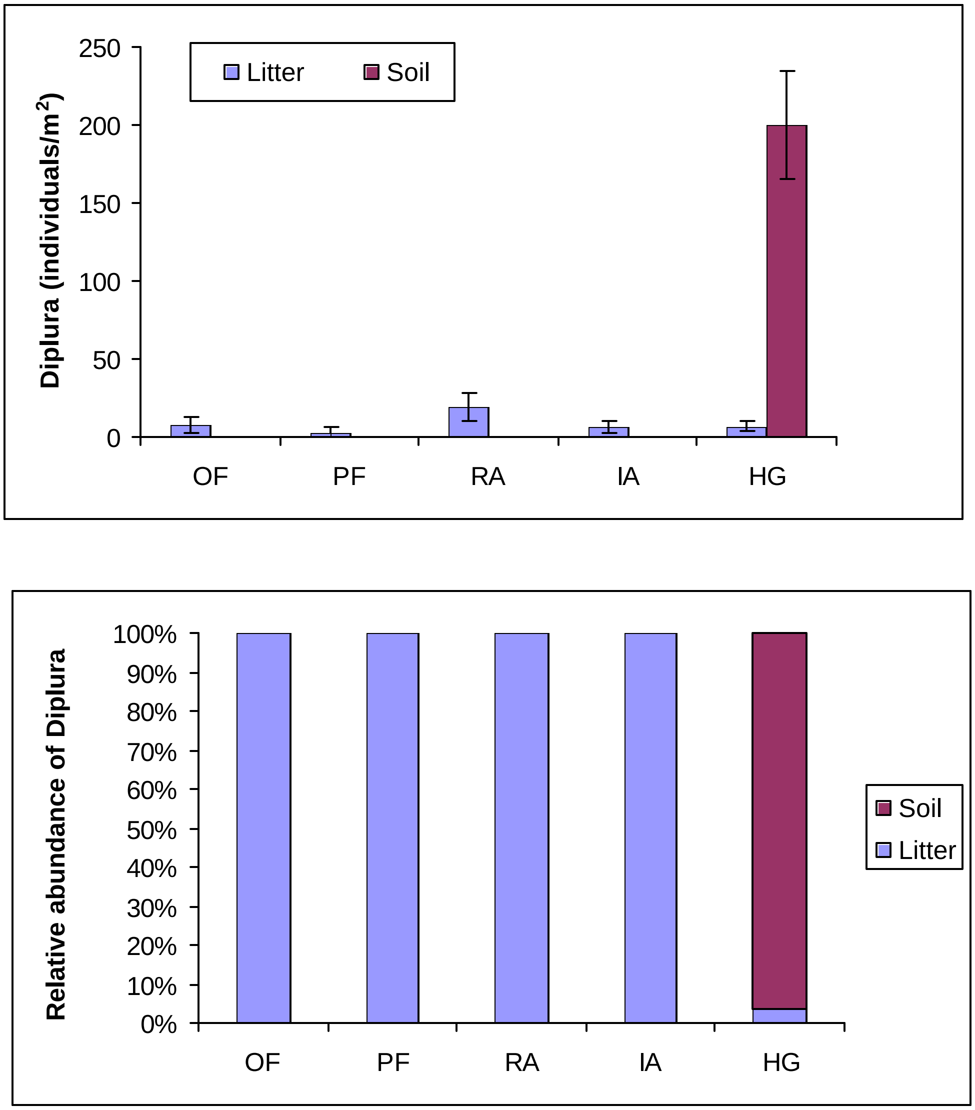


Figure 4. Absolute and relative abundance of Diplura in different land uses during post monsoon period (October) at lower elevation in Himalaya.

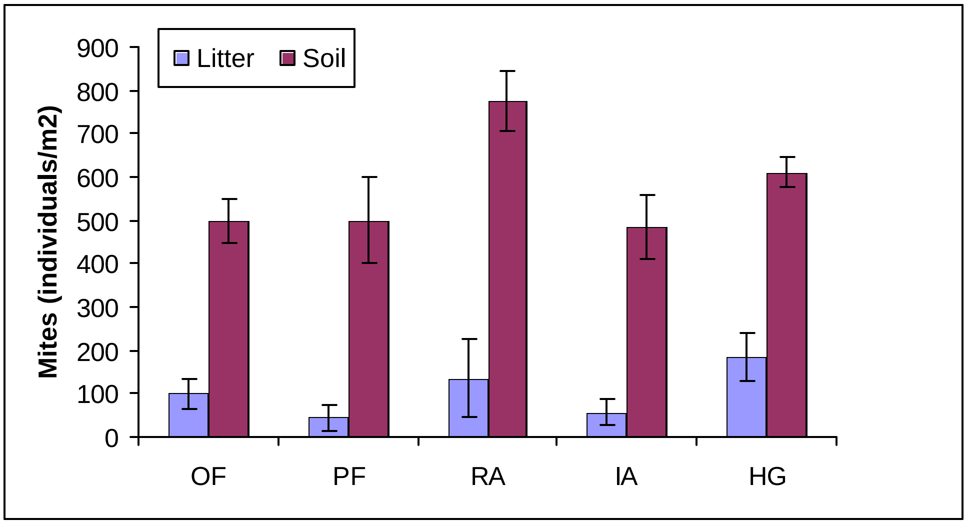


Figure 5. Absolute and relative abundance of Mites in different land uses during post monsoon period (October) at lower elevation in Himalaya.

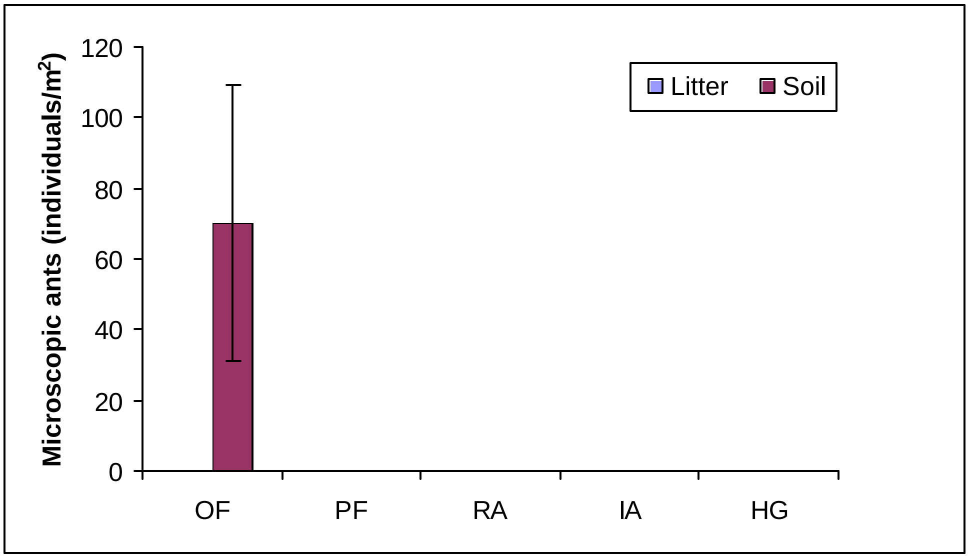


Figure 6. Abundance of Microscopic ants in different land uses during post monsoon period (October) at lower elevation in Himalaya.

Indigenous pest management strategies and agrodiversity: implications for sustainable agriculture in the Himalaya

1. Introduction

Pest, within the context of agriculture, means any organism that interferes with crop production such that quality and/or quality of agronomic/economic yields are reduced. Insects, diseases and weeds have been considered to be the major crop pests. Many other organisms such as wild mammals and birds may cause even more serious yield loss but have not received much attention for their role as pests. A crop pest may be noxious from the point of view of its negative impact on yields, but may appear useful if viewed from other concerns for sustainable human development. Thus, weeds are noxious in that they compete with crops for fundamental resources or produce some allelopathic substances that reduce crop vigour, but some weeds have medicinal and fodder values. Weeds also have a role in soil and nutrient conservation (Ramakrishnan, 1992). Conventional approaches to pest control, viz., spray of synthetic pesticides, often tend to eliminate pest without evaluating the multiple costs and benefits associated with such eliminations over a range of spatial and temporal scale. Such approaches may enhance immediate returns over a short-term period but may be detrimental to ecological balance with high risks of secondary pest problems and to human health, and thus do not meet the requirements of sustainable agricultural development. Such experiences have led to evolution of integrated pest management packages that build on multiple mechanisms to reduce the damage caused by pests and tend to strike a balance in environmental and economic costs and benefits looked at a range of temporal scale.

A deep understanding of farmers' perceptions of pest situations is extremely important as these perceptions determine pest management practices adopted by farmers. Deficiency in this knowledge has been found to be one of the causes promoting pest management practices not sound from environmental and socio-economic sustainability considerations (Conway and Barbier, 1990; Heong et al., 2002). Himalayan mountain system covers partly/fully eight countries of south Asia viz., Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. This paper deals with farmers' perceptions and indigenous knowledge related to pests and pest management within a broader perspective of agrobiodiversity and agroecosystem management in the Indian Himalayan region.

2. The traditional settled farming system

Agricultural land use, that covers < 20% of total geographical area of the Indian Himalaya, is dispersed as 'patches' in the 'matrix' of forests. Traditional agriculture is a crop-tree-livestock integrated subsistence land use (size of most land holdings falling in the range of 0.3 ha to 2 ha) sustained with organic matter and nutrient inputs derived from forests. Forests meet about 50% of livestock feed. Forest leaf litter is used as animal bedding. The mixture of leaf litter and livestock excreta is applied as manure in crop fields. Modern inputs such as chemical fertilizers and pesticides are rarely used and are confined to isolated pockets. Diversity viewed in terms of agroecosystem diversity or crop diversity or cultivar diversity is immense.

2.1. Agroecosystem diversity – the landscape perspective

Differentiation of rural landscapes into a variety of agroecosystem types is a common feature in Indian central Himalaya. A typical mid-altitude landscape is differentiated into (a) multispecies complex homegardens that are closest to the dwellings (b) rainfed agroecosystems devoid of trees (c) tree-crop mixed rainfed agroecosystems (d) irrigated agroecosystems, usually devoid of trees (e) slash-burn type shifting agriculture. This differentiation is related to inherent soil and water resource characteristics, local topography, distance from the dwellings and input-output relations (Nautiyal et al., 1998). Thus, farm tree density decreases with increasing distance from the dwellings. Shifting agriculture is confined to pockets in pockets where gravel content is quite high and soil is very shallow. Irrigated agroecosystems to gently sloping locations with well drained soil where diversion of water from perennial streams through gravitational force is feasible. Relative proportion of area under different agroecosystem types and spatial distribution varies among villages depending upon the interaction of biophysical and socio-economic factors. Thus, slash-burn type shifting agriculture is likely to be absent in villages where gravely and shallow soils are lacking and irrigated agriculture where topographic conditions and water resources are such that diversion of water to fields through gravitational force are not feasible.

2.2. Agrobiodiversity: species and cultivar diversity

Even though holdings are quite small, crop diversity is quite high (Table 2). Number of crops cultivated by a household may vary from 17 to 30 (Sharma and Sharma, 1993; Rao and Saxena, 1994; Maikhuri et al., 2000; Semwal et al., 2004). Crop diversity in rainfed agroecosystems is substantially higher than that in irrigated agroecosystems and that in a given agroecosystem type during rainy season is higher than that during winter season. Mixing of three species of buckwheat and six of pulses is the most diverse crop system reported from the region (Singh et al., 1997). High crop diversity is achieved through rotation of pure crops in space and time and through mixed crop systems. Except for paddy, local cultivars of a given crop are randomly mixed. High levels of crop yields (e.g., 6.5 t of wheat and 14 t of potato per ha) and food sufficiency in many villages insulated from external forces due to extreme inaccessibility (Chandrasekhar, 2003; Semwal et al., 2004) testify the potential of indigenous knowledge based organic farming. Most of the crops are represented by multiple farmer selected cultivars. Paddy is genetically the most diverse crop as illustrated by a farmer maintaining about 20 varieties of paddy. Farmers' descriptors of cultivars include colour, taste, adaptation to a given soil type and a given climatic regime but not resistance or susceptibility to insects and diseases (Table 3). In our surveys, we did not come across any crop or cultivar that was described in terms of its susceptibility to insect pests and diseases. *Perilla frutescence* is a crop which, because of its stringent order, is believed to repel some wild mammal pests. Mustard is also believed to repel wild animals but not as effectively as *P. frutescence*.

Farm trees constitute an important component of agricultural biodiversity. Direct benefits from trees are the major descriptors of farm trees in indigenous knowledge (Table 4), though tree species differ in terms of their suitability as perching sites for crop pests like birds and monkeys, litter quality and nutrient cycling, shading of crops and tree-crop competition for belowground resources (Semwal et al., 2002, 2003). Positive roles of trees in terms of their ability to conserve soil and to suppress pests (Keller and Goldstein, 1998; Kamara et al., 2000) are neither perceived by farmers nor are substantiated from scientific studies (Singh, 2002). Diversity, species composition and abundance of farm trees vary depending upon the ecological as well as economic functions of trees. Agricultural landscapes surrounded by degraded forests or dense forests dominated by species yielding poor quality of fuelwood, fodder and leaf litter are dominated by high quality multipurpose trees. Thus, maintenance of multipurpose trees in farm land is an adaptive response to scarcity of tree based resources needed for livelihood (Nautiyal et al., 1998). A perception that negative impacts of trees on crop yields are more intense under irrigated conditions and in locations away from dwellings accounts for exclusive cultivation of annual crops in such agroecosystems.

3. Local perceptions related to crop pests and diseases

A high level of diversification in agricultural land use is an adaptation to cope up with a variety of risks and limitations faced by upland farmers. Pests figure as the last concern of traditional farmers, risks arising from the poor land/soil quality being the most important concern followed by those associated with human labour input (Table 5). The degree of concern for different pests also varies and depends upon the degree of damage to crops together with indigenous capacity to reduce damage (Table 6). Monkeys, porcupine and wild boar among large mammals, partridge among birds, white grubs, stem borer of amaranth, stem borer and leaf folder of irrigated paddy among insects, blight of potato in irrigated conditions at lower elevations and smut of cereals among microbes and weeds in summer cereal/millet crops draw a high level of farmers' concern. Blight of potato at lower elevations and predation of seeds by ants in rainfed agriculture are of moderate concern. Farmers have negligible concern for weeds in legume crops because they believe in very weak negative interactions between legume crops and weeds and for several fungal and bacterial diseases (e.g., rust of wheat) because of their rarity in time and space. Thus, even though irrigated farming may enable higher returns (Maikhuri et al., 1997), such a practice is restricted because of the risks of high infestation of pests. They stress on legumes in slash-burn type shifting agriculture because here the weeds accumulate nutrients and conserve soil needed for long term sustainability of such systems and do not interfere much with crop production (Ramakrishnan, 1992). Even though paddy is the most preferred staple crop of rainy season, its acreage is limited to escape the risks of complete crop failure.

The number of folk names of pest organisms and diseases may be viewed as an indicator of the richness of indigenous knowledge on biology and ecology of pests (Wilkie, 2000; Jinxiu et al., 2004). In this respect, indigenous knowledge seems quite deficient as there are no folk names for many diseases and pests reported in scientific literature and many diseases (distinguished by causal organism and symptoms) reported by scientists are referred to by a common name in folk knowledge (Table 6, 7). There are more than thirty species of white grub in zoological taxonomy but such a high degree of differentiation is not recognized by farmers. Yet, farmers do have some perceptions about how the serious pests can be controlled. It is believed that flooding of crop fields can drastically reduce white grub population. This control measure is environmentally sound in flat lands around streams but not on terraced slopes where flood irrigation is economically unviable and such a practice runs the risks of collapse of terraces. There is a belief that delayed monsoon aggravates infestation by white grubs and losses under such scenarios cannot be averted. In high altitude regions where crop diversity and management practices have not changed much with time, large scale damage to amaranths caused by insects (e.g., *Hymenia recurvalis*) is a recent pheonomena. Farmers attribute this to global warming. Application of manure that has not decomposed properly is considered to promote all insect pests, diseases and weeds. Farmers have a perception that seeds from healthy plants, sun-drying and smoking reduce the possibility of crop infection.

Practices such as use of biopesticides or catch crops to control pests have not evolved in the region. Many localities are traditionally distinguished for a very high quality of a given crop produce (Table 8). Presumably, rare infection of the distinguished crop because of location specific environmental and agronomic conditions is one of the attributes that led to such differentiation.

Conventional measures to control pests by spray of pesticides (Table 9) need to be implemented by individual farmers. In contrast traditional pest management strategies are based on actions implemented at both individual farmer and village community level. Time of fallowing and establishing camp fire and watch towers to repel large mammals are examples of community level actions to reduce damage caused by bird and mammal pests. In a typical mid-altitude landscape where climate permits harvest of two crops in a year, rainfed terraced slope region is divided into two halves termed as *Sar*. Each household owns at least one plot in each *Sar*, and the tradition is to fallow a *Sar* during one winter-crop season over a period of two years

(Figure 1). It is believed that such fallowing reduces soil insect and microbial pests, promotes function of beneficial soil organisms and contributes towards keeping birds and mammal pests away from the *Sar* that is cropped. The timing, placement and responsibilities related to camp fire and watch tower to drive away birds and mammal pests are also decided by the community. Exchange of healthy seeds without any cost consideration is a cultural tradition reducing the likelihood of seed borne diseases. The magnitude of crop diversification, quality of manure, tillage, irrigation, weeding intensity, physical protection of individual plots or fruit trees from large animal pests and use of pesticides are the individual farmer/family level decisions that influence pest population and associated damage. Thus, a casual management by a family, if it leads to proliferation of pests, may become detrimental to the larger community, an aspect which is not perceived by farmers.

4. The changes in agroecosystems and their implications

For the traditional farmers, the goal of maximization of food quality, quantity and economic benefits was sub-ordinate to long-term sustainability and avoidance of risks of complete crop failure. A set of simultaneous changes induced by policies, e.g., improvement in accessibility (expansion of road network), encouragement of cash crops with comparative advantages in hills, establishment of public agencies supplying staple food grains as well as modern inputs (chemical fertilizers, pesticides and high yielding variety of seeds of some crops) at subsidized price and, increase in employment opportunities in secondary/tertiary sectors leading to out-migration and the practice of renting of agricultural land/share cropping migration are leading to changes in agroecosystem structure and crop diversity with significant implications for some pest populations and sustainability of agriculture . Though agricultural land use expansion in the Indian Himalayan region is not as extensive as in other mountain regions, there has been a significant loss of agrodiversity (agroecosystem diversity as well as diversity of crops and cultivars grown in a given ecosystem type) and changes in agroecosystem input-output balances (Jackson et al., 1998; Kammerbauer and Ardon, 1999; Rao and Pant, 2001; Semwal et al., 2004). Yet, use of pesticides as well as chemical fertilisers is not yet as common as in many other mountain regions (Poudel et al., 2000; Heong et al., 2002).

A trend of preference for securing livelihood through off-farm occupations and consequently migration of adult males/whole families for services in secondary/tertiary sectors in urban areas has set in since last few decades. Shortage of labour required to do agriculture together with a concern for retaining the land ownership rights (considering a possibility of reverting back to agricultural occupation in future), fosters share-cropping or renting the land for agriculture by other farmers. These arrangements are always informal for a variety of reasons including the fear of owners to loose their land ownerships in accordance with the existing policies. Farmers cultivating land but not having land ownership rights are drawn more towards the motive of maximization of profit over short-term than to long-term sustainability of agroecosystems. The former motive drives stress on cash crops and consequently loss of agrodiversity that tends to reduce crop failure due to a variety of risks including those arising from pests. Though all crops are affected by one or the other pest, devastating damage is observed as regular phenomena in case of cash crops that have been introduced (introduced varieties of potato and vegetables) and receive chemical fertilizers and irrigation at lower elevations. Such situations foster use of pesticides. Though pesticides are supplied at subsidized price (50% subsidy) by the government agencies, but such facility is available in selected villages for a period of 5 years with a quota fixed for a family. A reason for uncommon use of pesticide is that quota fixed is not sufficient to meet the total requirement if a family puts all land under cash crop. Thus, environmental, socio-economic and policy factors are such that pesticides are currently used in isolated pockets and for a brief period of time. Evolution of resistance to pesticides over a period of time and adverse effects of these chemicals on beneficial organisms are neither scientifically investigated in detail nor are understood by majority of farmers.

Damage caused by large animal pests viz., Wild boar (*Sus scrofa*), bear (*Selenarctos thibetanus*), musk deer (*Moschus chrusogaster*), porcupine (*Hystrix indica*), monkey (*Presbytes entellus*) and partridge (*Alectoris chukor*) is ranked as high or medium at lower elevations and medium to negligible in high altitudes. Because of a belief that population of these animals has increased in the recent past as result of conservation policies and programmes, people expect compensation for damage caused by them from the government. Loss of crop yields could be as high as 50% of total economic yield in villages bordering conservation areas. Unfortunately, while policy provides for some compensation for damage to livestock and human life by wildlife, there is no provison for compensation for damage to crops, a point of people-conservation conflict (Rao et al., 2002).

5. Conclusions

The traditional perceptions related to pests, crop losses caused by them and strategies to reduce losses differ from the scientific conceptions and recommendations. Risks arising from pests were viewed in conjunction with other risks and determinants of crop productivity and long-term sustainability of agroecosystems. While conventional pest management aimed for enhancing crop yield by eliminating the pest, traditional system seem to have taken pest occurrence to be unpredictable and unavoidable and hence focused on designing cropping systems that avoid complete crop failure and individual as well as community scale management practices that reduce the chances of build-up of pest population and damage caused by them. A high level of diversification at agroecosystem scale as well as in terms of number of crops and cultivars grown seem to be the key mechanism of avoiding the likelihood of explosion of pest population, though this argument may be questioned on the basis of lack of rigorous scientific experiments supporting it. Further, a high level of diversification enabled not only coping up with the pests but also other risks such as the ones arising from climatic uncertainty, variability in soil properties and shortage of labour. There are examples of large scale damage to crops as result of 'bad climate' but not because of pests so far in the region. Increasing instances of insects and diseases at a local scale in situations where cash crops dominate point to the possibility of large scale pest damage in future, a risk neither perceived by majority of farmers nor by the policy makers. Some policy incentives for crop and cultivar diversification can reduce this risk. The concept of addressing a problem or a prospect not in isolation but in conjunction with other problems and prospects observed in traditional agricultural systems can be viewed as an analogue concept of the present day 'integrated pest/nutrient/farming system management' concepts aiming for sustainable agriculture.

Acknowledgements

We are greatful to the Director, G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora for the facilities and to the Director, TSBF institute of CIAT, Nairobi for partial financial support through Global Environment Facility (GEF) and implementation support by the United Nations Environment Programme (UNEP).

References

Chandrasekhar, K. 2003. *Ecological Analysis of Settled Agropastoral Farming in Cold Desert (Spiti Catchment, Himachal Pradesh*). Ph.D. Thesis, Jawaharlal Nehru University, New Delhi, India.

Conway, G.R. and Barbier, E.B. 1990. After the Green Revolution: Sustainable Agriculture for Development, Earthscan Publications Limited, London, pp. 205.

Heong, K.L., Escalada, M.M., Sengsoulivong, V. and Schiller, J. 2002. Insect management beliefs and practices of rice farmers in Laos. Agriculture, Ecosystems and Environment, 92, 137-145.

Jackson, W.J., Tamarkar, R.M., Hunt, S. and Shepherd, K.R. 1998. Land use changes in two middle hill districts of Nepal. Mountain Research and Development, 18, 193-212.

Jinxiu, W., Hongmao, L., Hubin, H. and Gao, L. 2004. Participatory approach for rapid assessment of plant diversity through a folk classification system in a tropical rainforest: case study in Xishuangbanna, China. Conservation Biology, 18, 1139-1142.

Kamara, a.Y., Akobundu, I.O., Chikoye, D. and Jutzi, S.C. 2000. Selective control of weeds in an arable crop by mulches from some multipurpose trees in Southwestern Nigeria. Agroforestry Systems, 50, 17-26.

Kammerbauer, J. and Ardon, C. 1999. Land use dynamics and landscape change pattern in a typical watershed in the hillside region of central Honduras. Agriculture, Ecosystems and Environment, 75, 93-100.

Keller, A.A. and Goldstein, R.A. 1998. Impact of carbon storage through restoration of drylands on the global carbon cycle. Environmental Management, 22, 757-766.

Maikhuri, R.K., Nautiyal, S., Rao, K.S., Chandrasekhar, K., Gavali, R. and Saxena, K.G. 2000. Analysis and resolution of protected area - people conflicts in Nanda Devi Biosphere Reserve, India. Environmental Conservation, 27, 43-53.

Maikhuri, R.K., Semwal, R.L., Rao, K.S. and Saxena, K.G. 1997. Rehabilitation of degraded community lands for sustainable development in Himalaya: a case study in Garhwal Himalaya, India. International Journal of Sustainable Development and World Ecology, 4,: 192-203.

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

Nautiyal, S. Maikhuri, R.K., Semwal, R.L., Rao, K.S. and Saxena, K.G. 1998. Agroforestry systems in the rural landscape - a case study in Garhwal Himalaya, India. Agroforestry Systems, 41, 151-165.

Poundel, D.D., Midmore, D.J. and West, L.T. 2000. Farmer participatory research to minimize soil erosion on steepland vegetable systems in the Phillippines. Agricultural Eosystems and Environment, 79, 113-117.

Ramakrishnan, P.S. 1992. Shifting Agriculture and Sustainable Development of North-Eastern India. UNESCO-MAB Series, Parthenon Publication, Carnforth, U.K.

Rao, K.S. and Pant, Rekha. 2001. Land use dynamics and landscape change pattern in a typical micro watershed in the mid elevation zone of central Himalaya, India. Agriculture, Ecosystems and Environment, 86, 113-124.

Rao, K.S. and Saxena, K.G. 1994. Sustainable Development and Rehabilitation of Degraded Village Lands in Himalaya. Bishen Singh Mahendra Pal Singh, Dehradun, India.

Rao, K.S., Maikhuri, R.K, Nautiyal, S. and Saxena, K.G. 2002. Crop damage and livestock depredation by wildlife: a case study from Nanda Devi Biosphere Reserve, India. Journal of Environmental Management, 66, 317-327.

Semwal, R.L., Maikhuri, R.K., Rao, K.S., Sen, K.K. and Saxena, K.G. 2003. Leaf litter decomposition and nutrient release patterns of six multipurpose tree species of central Himalaya, India. Biomass and Bioenergy, 24, 3-11.

Semwal, R.L., Maikhuri, R.K., Rao, K.S., Singh, K. and Saxena, K.G. 2002. Crop productivity under differentially 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.

Sharma, S. and Sharma, E. 1993. Energy budget and efficiency of some cropping systems in Sikkim Himalaya. Journal of Sustainable Agriculture, 3, 85-94.

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. 2002. Ecological Diversity in Relation to Agricultural Land Use Intensity in a Mid-Altitude Village in Central Himalaya. Ph.D. Thesis, Jawaharlal Nehru University, New Delhi, India.

Wilkie, P. 2000. The limitations of vernacular names in an inventory study, Central Kalimantan, Indonesia. Biodiversity and Conservation, 8, 1457-1467.

Table 1. Relative area of different agroecosystem types in a mid altitude village landscape (number of households: 48; mean size of land holding: 1.7 ha) in Indian central Himalaya (Based on Singh, 2002).

Agroecosystem type	Relative area (% of total agricultural area)
Settled agriculture	
Rainfed agroecosystems	
Home garden	3
Annual crop based agroecosystem	44
Tree-crop mixed agroecosystem	14
Irrigated agroecosystems	1
Shifting agriculture	
Cropped fields	25
Fallow fields	13

Table 2. Area (% of total cropped area) and 95 period and monetary value of yield (mean ± SE) of different crops in villages near and away from the core zone of the Nanda Devi Biosphere Reserve, India. Values for any variable with different superscript letters are significantly different (*P*<0.05) within rows.

Crops	Lower altitude region		High altitude region	
	% of total cropped area (%)	Monetary Value (US$/ha)	% of total cropped area (%)	Monetary value (US$/ha)
Food crops				
Monocropping				
Amaranthus paniculatus	4.4	289±31	-	-
Brassica campestris	0.6^{a}	$519±37^{a}$	3.1^{b}	$494±34^{a}$
Echinochloa frumentocea	0	-	0	-
Eleusine coracana	0.6	311±28	-	-
Fagopyrum esculentum	7.7^{a}	$337±21^{a}$	16.3^{b}	$503±27^{b}$
Fagopyrum tataricum	8.2^{a}	$343±30^{a}$	2.3^{b}	$474±28^{b}$
Glycine max	0	-	0	-
Hordeum himalayens	5.6^{a}	$235±s27^{a}$	8.1^{a}	$239±15^{a}$
Hordeum vulgare	4.0	247±24	0	-
Pennisetum typhoides	0	-	0	-
Panicum miliaceum	0.6^{a}	$268±27^{a}$	2.5^{b}	$310±27^{a}$
Phaseolus lunetus	14.6^{a}	$549±62^{a}$	8.6^{b}	$626±63^{a}$
Phaseolus vulgaris	6.0^{a}	$906±27^{a}$	8.9^{a}	$969±82^{a}$
Pisum sativum (Var.1)	0.3	485±49	0	-
Pisum sativum (Var.2)	0.3^{a}	$547±55^{a}$	2.3^{b}	$647±44^{a}$
Solanum tuberosum	6.6^{a}	$805±81^{a}$	31.3^{b}	$1048±28^{b}$
Setaria italica	0	-	0	-
Triticum aestivum	21.3	265±29	0	-
Mixed cropping				
A.paniculatius +P.vulgaris	3.4	842±92	-	-
H.himalayens+Pisum sativum(var.-2)	-	-	4.8	511±27
S.tuberosum + P.vulgaris	10.1^{a}	$1133±115^{a}$	7.1^{b}	$1505±68^{b}$
S.tuberasum +	4.0	1151±75	-	-

Crops	Lower altitude region		High altitude region	
	% of total cropped area (%)	Monetary Value (US$/ha)	% of total cropped area (%)	Monetary value (US$/ha)
P.vulgaris+ A.paniculatus				
Medicinal plants				
Allium humile	0.9[a]	846±79[a]	2.3[b]	945±87[a]
Allium stracheyi	0.9[a]	502±48[a]	1.2[a]	560±87[a]
Angelica glavacai	-	-	0.3	544±57
Carum carvi	-	-	0.3	971±85
Dactylorhiza hatagirea	-	-	0.2	786±80
Megacarpaea polyandra	-	-	0.2	272±19
Pleurosperum angelicoides	-	-	0.2	627±60
Saussurea costus	-	-	0.3	690±68

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

Table 3. Farmers descriptors of cultivars of paddy in Indian central Himalaya (unpublished data from Vimla)

Landraces	**Compactness of panicle type**	**Awning**	**Maturity: <130 days after sowing – early; 131-140 days – intermediate; >141 days - late**	Seed coat colour	Threshability	**Plant height (Cm) >110 cm – long; <110 cm - short**
Rainfed landraces						
Bagseri dhan	Intermediate	Absent	Late	Light yellow with speckled black	Easy	Short
Bakul	Intermediate	Absent	Late	Light yellow	Easy	Long
Bauran dud	High	Short and partly awned	Late	Light yellow	Easy	Long
Dangoli dhan	Low	Absent	Late	Light yellow	Easy	Long
Dud	Intermediate	Absent	Late	Light yellow	Easy	Long
Jauli	Intermediate	Short and partly awned	Late	Light yellow	Easy	Long
Jhokia	Intermediate	Absent	Late	White	Easy	Long
Jhusyav	High	Short and partly awned	Late	Yellow	Difficult	Long
Kauthuni	Intermediate	Absent	Late	Yellowish orange	Easy	Short
Khimu	Intermediate	Absent	Intermediate	Light yellow with black tip	Easy	long
Lal dhan	High	Short and partly awned	Late	Reddish orange	Intermediate	long

Lal jhiruli	High	Absent	Late	Reddish orange with black speckles	Easy	Long
Uprau gajai	Intermediate	Absent	Late	Light yellow with speckled black	Easy	Long
Irrigated landraces						
Govind	Intermediate	Short and partly awned	Intermediate	Light yellow	Difficult	Short
Kali jhiruli	Intermediate	Absent	Early	Blackish yellow	Easy	Long
Pappu	Intermediate	Absent	Early	Light yellow	Easy	Short
Seemar gajai	Intermediate	Absent	Early	Blackish yellow	Easy	Long
Thapchini	High	Absent	Intermediate	Light yellow	Easy	Short
Thapuli	High	Absent	Intermediate	Light yellow	Easy	Long

Table 4. Local uses, management practices and ecological features of multipurpose farm tree species in Central Himalaya Region, India (based on Nautiyal et. al., 1998).

Species Name	Vernacular	Local uses	Management practices	Ecological features
Alibizzia lebbek Linn.	Siris	Fuelwood, fodder, timber	Lopping	Deciduous, common in farms and open forests upto 1000 – 1200 m a.s.l.
Alnus nepalensis D. Don	Utis	Fuelwood, timber	Lopping + cutting	Deciduous, rare occurrence in farms, forms nearly mono-specific patches at newly exposed moist soils at 1000 – 2500 m a.s.l.
Boehmeria rugulosa Wedd	Genthi	Fuelwood, fodder, timber	Lopping + pollarding	Evergreen, common in farms upto 1200-1400 m a.s.l. but rare in forests.
Celtis australis Linn.	Kharik	Fuelwood, fodder, timber	Lopping + cutting	Deciduous, common in farms and occasional occurrence in forests upto 2000 m a.s.l.
Dalbergia sissoo Roxb.	Sisham	Fuelwood, timber	Lopping + cutting	Deciduous, rare occurrence in farms up to 1500- 1800 m a.s.l. and forests on slopes, dominant species of riverine vegetation.
Ficus glomerata Roxb.	Gular	Fuelwood, fodder	Lopping + pollarding	Deciduous, common in farms but rare in forests upto 1500-1600 m a.s.l.
Grewia optiva Drum	Bhimal	Fuelwood, fodder, timber	Lopping + pollarding	Deciduous common in upland farms but rare in forests upto 1000-1200 m a.s.l.
Prunus cerasoides D. Don	Paiyan	Fuelwood, fodder	Lopping	Deciduous, common on farms and forests in 800- 2500 m a.s.l. zone
Pyrus pashia Buch-Ham	Molu	Fuelwood, fodder	Cutting + Lopping + stock for *Pyrus* commune	Deciduous, common in farms and degraded open forest in 800 – 2500 m a.s. l. zone.
Sapium sebiferum Roxb.	Charvi	Fuelwood, oil from seeds	Cutting + Lopping	Deciduous, native of China but naturalized in North Western/ Central Himalaya, common in farms and open forests around tea plantations.

Table 5. Concern of risks related to loss of crop yields due to pests and other factors as reported by farmers. Values of % responses for a given degree of risk (n = 70; Rao et al., unpublished).

Risks due to	Magnitude of concern	
	High	Low
Land and soil quality	100	0
Availability of labour at proper time	35	65
Availability of seeds of desired quality	85	15
Availability of manure of better quality in sufficient amount	90	10
Climatic uncertainty	100	0
Insects and diseases	80	20
Weeds	10	90
Wild large mammals and birds	60	40

Table 6. Local concerns for different pests and indigenous responses to reduce damage.

Kind of pest	Degree of concern	Responses to reduce damage
Monkeys for all crops, specially winter crops(upto 2000 m), bear in higher altitudes (2000-2400 m), and porcupine and wild boar (damage more due to trampling) all crops and all altitudes	Very high	Physical impediments to the pest, keeping watchman and dogs, lighting fire and putting effigies to repel pests
Birds for legumes (early stages of legume growth – they eat cotyledons) at lower elevation and temperate fruits at higher elevations	Very high	Keeping watchman to repel pests by making loud voices/sounds, and putting effigies to repel pests
White grubs for all summer crops at lower altitudes	Very high	Proper composting of manure
Stem borer in amaranth at higher altitude	Very high	Crop diversification
Fungal disease in potato at lower elevations and irrigated conditions	Very high	Crop diversification, removal and burning of infested plants
Caterpillar infestation in legumes at the flowering and fruiting stage at lower elevations	Very high	Crop diversification
Post harvest fungal and insect damaging pulses except *Glycine max*, a crop which not at all damaged	Very high	Frequent sun-drying and smoking
Insect attack (stem borer and leaf folder) in rice in irrigated agriculture	Very high	Crop diversification
Smut of cereals	Very high	Crop diversification
Fungal disease in potato at lower elevations in rainfed conditions	Moderate	Crop diversification, removal and burning of infested plants
Ants at the time of sowing in rainfed agriculture	Moderate	None
Other fungal and bacterial diseases	Negligible	None
Weeds in summer cereals and millets	Very high	Manual intensive weeding
Weeds in legume crops	Negligible	Manual casual weeding

Table 7. Disease and insects reported in scientific literature as relevant to Indian central Himalaya (based largely on publications of Vivekananda Parvatiya Krishi Anusandhan Shala, Almora, India).

Crop	**Name of disease/insect causing damage**
Wheat	Yellow and brown rusts, loose smut, powdery mildew, hill bunt
Barley	Stripe, covered smut
Rice	Blast, brown leaf spot, and false smut,
Finger millet	Neck and finger blast
Maize	Turcicum leaf blight
Pea	White rot, powdery mildew, leaf miner, pod borer
Tomato	Buck eye rot, fruit borer
Bean	Root rot, anthracnose, hairy caterpillar and sucking bug, blister beetle
Lentil	Root rot, wilt
Soybean	Frog eye leaf spot, anthracnose
French bean/rajmash	Fuscous blight
A number of rainy season/summer season crops	White grub (nearly 40 species)

Table 8. Uniqueness of crop diversity as perceived by local people in Central Himalaya.

Crop	**The locality giving best produce as discerned from survey**
Cucurbits (specially pumpkins and cucumber), Gahat (*Macrotyloma uniflorum*)	Bacchelikhal
Onion (*Allium cepa*)	Mullegaon
Sesame (*Sesamum indicum*)	Gauchar
Gahat (*Macrotyloma uniflorum*)	Sonla, Saknidar
Potato (*Solanum tuberosum*)	Joshimath, Harsil, Chirbatia
Lentil (*Lens esculenta*)	Tihri, Takoli
Ginger (*Zingiber officinalis*)	Daggarpatti, Agrakhal
Tor (*Cajanus cajan*)	Guptakashi, Jalai
China (*Panicum miliaceum*)	Maletha
Jhangora (*Echinocloa frumentacea*)	Srikot, Chauras
Jakhya (*Cleome viscosa*)	Srinagar
Rains (*Vigna angularis*)	Guptakashi, Dwarahat
Gol muli (*Raphanus sativa*)	Dwarahat
Gadheri/Pinalu/Kuchain (*Colocasia* sps)	Dugadda, Dagar, Bageswar, Dwarahat
Tor, Kala Bhatt (*Glycine* sps)	Ukhimath
Cabbage (*Brassica oleracea* var. *capitata*)	Narayankuti
Bhangjira (*Perrilla frutescence*)	Adibadri
Cheura (*Diploknema butyrissea*)	Gangolihat
Chua (*Amaranthus paniculatus*)	Gairsen
Dry chillies	Chaura, Kichgad
Rajma (*Phaseolus vulgaris*)	Harsil, Joshimath
Apple	Harsil, Rawain
Malta (*Citrus* sps.)	Ukhimath, Jakholi

Table 9. Recommended chemical control measures for diseases, insects and weeds in Indian Central Himalaya (drawn largely from the publications of Vivekananda Parvatiya Krishi Anusandhan Shala, Almora, India).

Chemical control measures	**Target disease/insects/weeds**
Mancozeb (0.25%)	Leaf blight in wheat and maize, brown spot in rice
Propiconazole (0.05%)	Rust and leaf diseases in barley and wheat
Ediphenphos (0.1%) or Carbendazim (0.1%) or Tricyclazole (0.06%)	Blast in rice
Copper oxychloride (0.3%)	False smut in rice Buck eye rot of tomato
Carbendazim (0.1%)	Smut in barnyard millet, leaf spots in soybean and black gram
Karate 5 EC + Nimbecidine (1:1)	Leaf folder and stem borer in rice
Quinalphos or monocrotophos (0.05%)	Pest complex of soybean
Isoproturon mixed with calcium sulfate	Weeds