FINAL TECHNICAL REPORT

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

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Chapter 1

Site Characterization: Nanda Devi Biosphere Reserve

1. Introduction

The protected area network (PAN) in the Himalayan region, occupying 9.2% area of Indian Himalaya, comprises of three biosphere reserves, 18 national parks and 71 wildlife Sanctuaries. Nanda Devi Biosphere Reserve (NDBR), a world heritage site is one of the unique areas, has high ecological, cultural, religious, spiritual values and rich in biodiversity, and covers a total area of 5860.69 km^2 with two core zones. The NDBR harbours about 400 species of trees, 570 species of herbs and shrubs, 86 species of mammals, 534 species of birds and 54 species of reptiles and amphibians. Many of these species are rare and endangered. In view with the multiple stresses and depletion of biodiversity, today's foremost concern of the globe in general and Himalaya in particular is the conservation of biodiversity both below- and above-ground.

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. 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. 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. Therefore, the present study has been carried out in the buffer zone of NDBR and adjoining areas with following objectives:

- Inventory and identification of belowground biodiversity in relation to physico-chemical properties of soil and aboveground biodiversity in cultural and protected landscape comprising a range of land use/land cover types.

- Applicability of available methods of sampling of belowground biodiversity (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 aboveground 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.

2. Materials and Methods

2.1. Benchmark Area Description

Buffer Zone of 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 (Fig.1.1a,b,c,d).

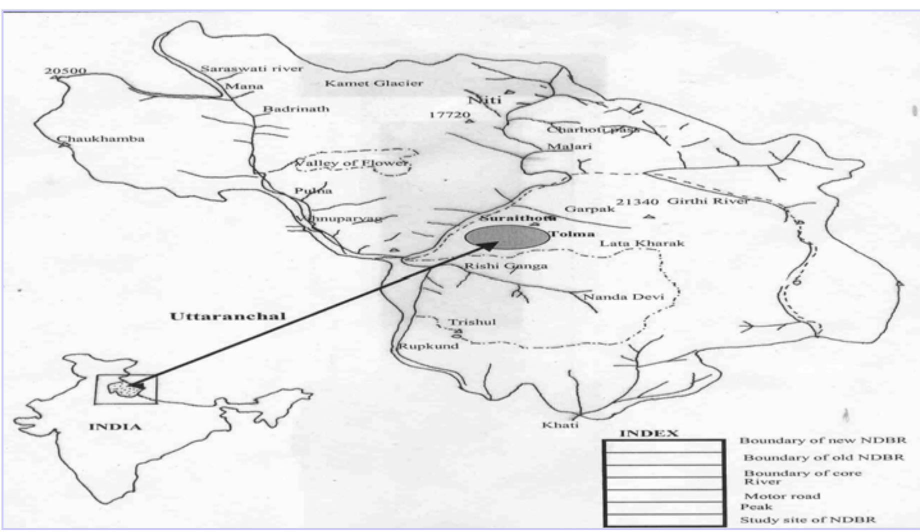

Figure 1.1a. Location map of the study site

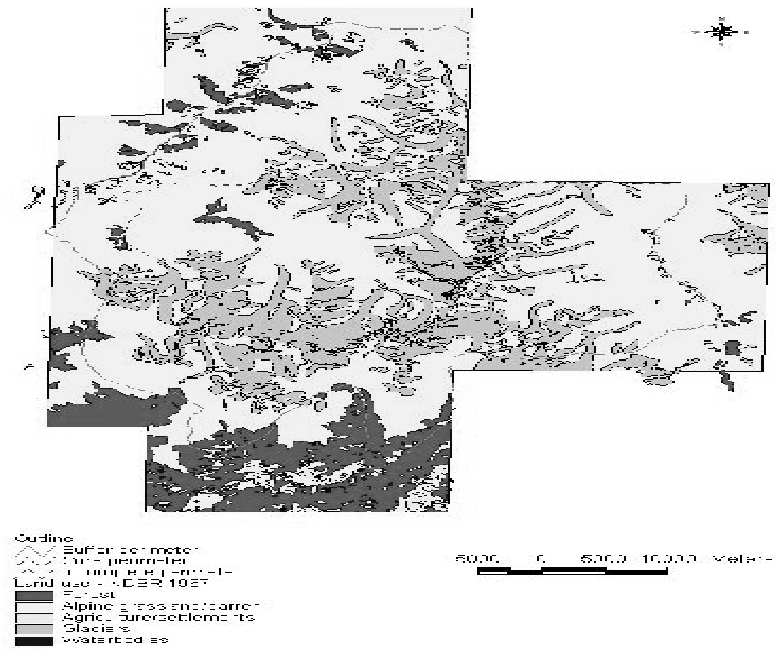

Figure 1.1b. Location map of the study site

Figure 1.1c. Location map of the study site

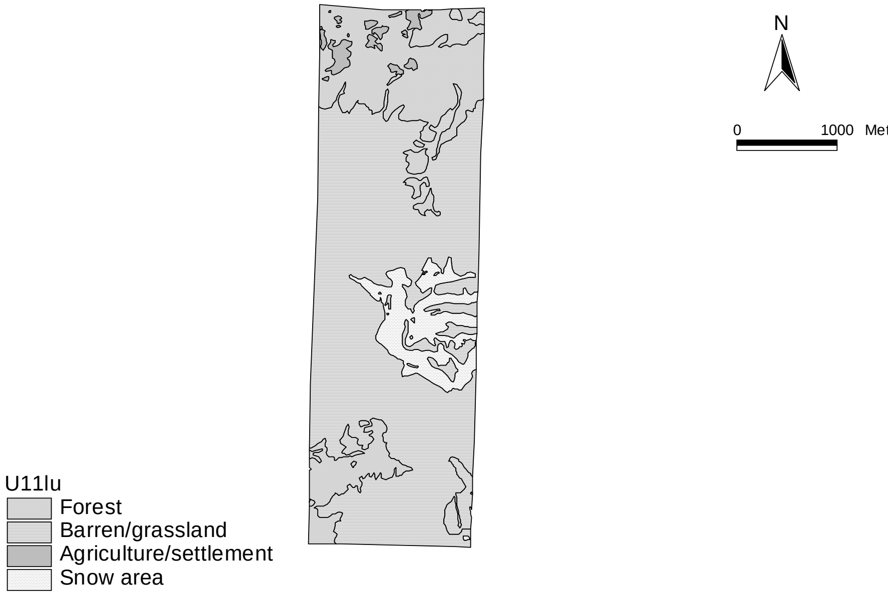

Figure 1.1d. Location map of the study site

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 1.1. Grid Sampling (excluding the boundary points) of windows at higher altitude (2200-3100m asl).

Land use type	**Number of points sampled**
Higher elevation - 67 (76)	
Kitchen garden (vegetables)	3
Kitchen garden (pedicinal plants)	6
Agriculture (potato)	7
Agriculture (other crops)	7
Conifer forest	29
Alpine meadow	15

At the low altitude (600-900m asl) 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 1.2. Grid Sampling (excluding the boundary points) of windows at low altitude (600-900m asl).

Land use 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 (agriculture, pine and oak forest) land uses of the area.

2.2. 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. Dynamics of various land cover categories with special emphasis on vegetation (forest) has been brought out using landsat – TM data of 1986 and IRSLISS-III data of 1999. The land cover/vegetation maps (spatial layers) have been integrated by overlay technique in which the mismatch in the land cover/vegetation classes of the two layers the change areas.

2.3. 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). 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 sustainable develop the area's resources.

2.4. Conservation History of NDBR

The NDBR has a long history of conservation. 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 lying in the core zone, which had an adverse effect on the income of local inhabitants. In 2000 the Valley of Flower National Park was included as second core zone of NDBR and the total area was extended from 2264.64 sq.km to 5860.69 sq.km.

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 Uttarakhand. 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 under Joshimath Tehsil of district Chamoli. Culturally and ethinically the inhabitants of this administrative divison form a single cultural unit, with well marked cultural as well as natural boundaries.

Table 1.3. 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	2100-2500m asl 900-1s500 m asl

Window 1

3. High Altitude Study Area

3.1. Climate

The climatic year consists of three distinct seasons- summer season (April - June), rainy season (June - September) and winter season (October - February). 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^{0}C to 15.3^{0}C and 16.0^{0}C to 2.2^{0}C. June - August are the hottest months of the year with an average temperature of (27^{0}C) and (16.04^{0}C).

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 1.2. 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.

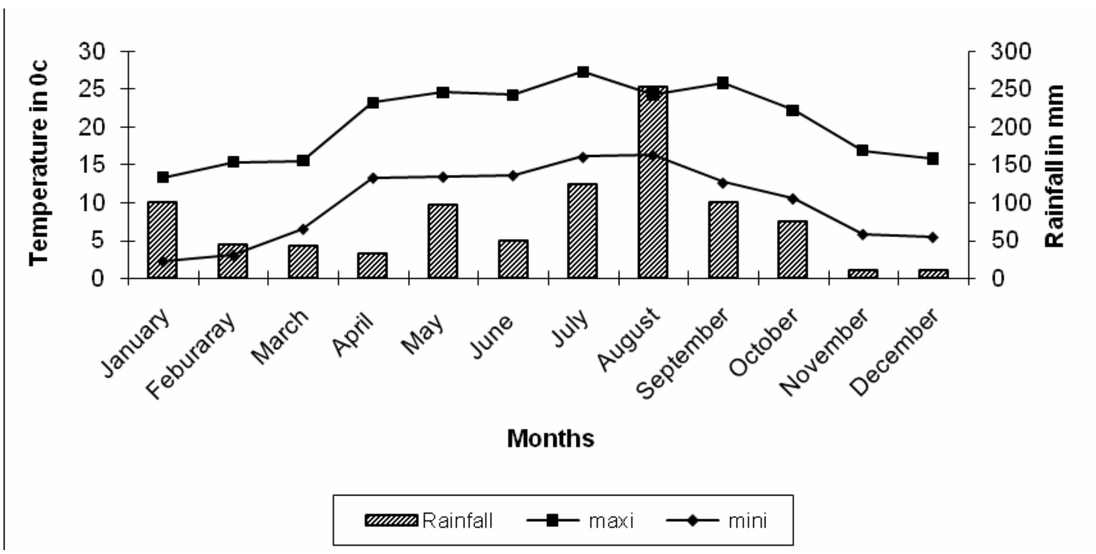

Figure 1.2. Climatic data (maximum and minimum temperature and rainfall) for the study area (NDBR).

3.2. Land Use Land Cover

Land transformations have occurred in 119.13 km^2 area, out of which 115.11 km^2 of area shows positive and 4.02 km^2 show negative (in terms of vegetation). Increase of 9.077 km^2, which is very significant areal extent of forest was 632.21 km^2 in 1986, 641.28 km^2 in 1999 registering an increase 0f 9.07km^2, which is very significant. The forest area under pine 3.19 km^2, oak 42.45 km^2, mixed 9.74 km^2, bluepine 74.77 km^2 and birch/fir 126.28 km^2 remained unchanged from1986 to 1999. However, Deodar forest was 84.21 km^2 in 1986 and 84.10 km^2 in 1999 thus showing a decrease of 0.15 km^2, conifer mixed forest, which was 178.26km^2 in 1986 reduced marginally by 0.2 km^2 in 1999. An increase in Juniper forest from113.31 km^2 1986 to 117.96 km^2 in 1999 has also been observed. These data reveals the positive changes of density are very significant and also indicate the absence or minimal external damaging factors.The closed forest has shown an increase from 221.91 km^2 in 1986 to 267.86 km^2 in 1999. In terms of percent to total forest area it was 35.10 in 1986 and 42.00 in 1999, which indicate an improvement by approximately 7%. Alpine grassland has shown a decrease of 0.22 km^2 from 271.57 in 1986 to 271.35 km^2 in 1999. This is because of occurrence of landslides.The agricultural land has not shown any change and remained 21.15 km^2 in 1986 as well as 1999.

3.2.1. Deodar Forest

Deodar closed forest was 53.41 km^2 in 1988 and has exhibited significant positive change in 1999 (62.05 km^2). The net changes in the deodar closed forest to active landslide (6.11 km^2), deodar open to deodar closed (8.00 km^2) and deodar degraded to deodar closed (0.74 km^2) clearly accounts for increase in extent of deodar closed forest during 1986-1999.

3.2.2. Conifer Mixed Forest

The areal extent of conifer mixed closed forest was 71.35 km^2 in 1986 which has increased to 90.27 km^2 in 1999 indicating a significant increase of 18.92 km^2. It indicates recovery of demaged ecosystem due to absence/minimal anthropological damaging forces. A minor negative change(0.05 km^2) in the form of an active landslide has accurred in this forest and on the other hand 18.90 km^2 of open forest has got transformed into this forest .Conifer mixed open forest had an extent of 80.23 km^2 in 1986 and 78.92 km^2 in 1999. Mountain scrubland which occupied 205.86 km^2 in 1986 has decreased to 200.42 km^2 in 1999. Out of the total area under this, 4.65 km^2 had got transferred into juniper – degraded forest along with 0.80 km^2 to active landslide.

3.2.3. Alpine Grassland

Alpine grassland has shown a decrease of 0.22 km^2 from 271.57 in 1986 to 271.35 km^2 in 1999. This is because of the occurrence of landslides.

3.2.4. Low Altitude Grasslands

The low altitude grassland with an area of 0.05 km^2 has shown a decrease from 3.54 km^2 in 1986 to 3.49 km^2 in 1999 due to landslides.

3.2.5. Agricultural Land

The agricultural land has not shown any change and remained 21.15 km^2 in 1986 as well as 1999.

3.2.6. Snow Cover

The snow cover has shown an increase of 1.93 km^2 from 4500.43 km^2 in 1986 to 4502.36 km^2. The froction of barren/rocky

3.3. 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; and
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.

3.4. General Description of the Agroecosystem 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 1.4. Characteristic features of the buffer zone villages situated along an elevational gradient in NDBR (Niti Valley), Uttarakhand.

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	Animal Husbandry	Animal Husbandry

	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* and *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 1970-75, 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).

3.5. 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:

3.5.1. 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.

3.5.2. 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.

3.6. Agriculture

3.6.1. 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.

3.6.2. 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.

3.6.3. 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.

3.6.4. 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 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.

3.6.5. Soil pH

In general it was found that the soil under majority of the land uses is acidic in nature.The soil pH under pea, potato and allium cultivation at various soil depths at high altitude ranged between 5.3 to 6.7 (Fig.1.3).

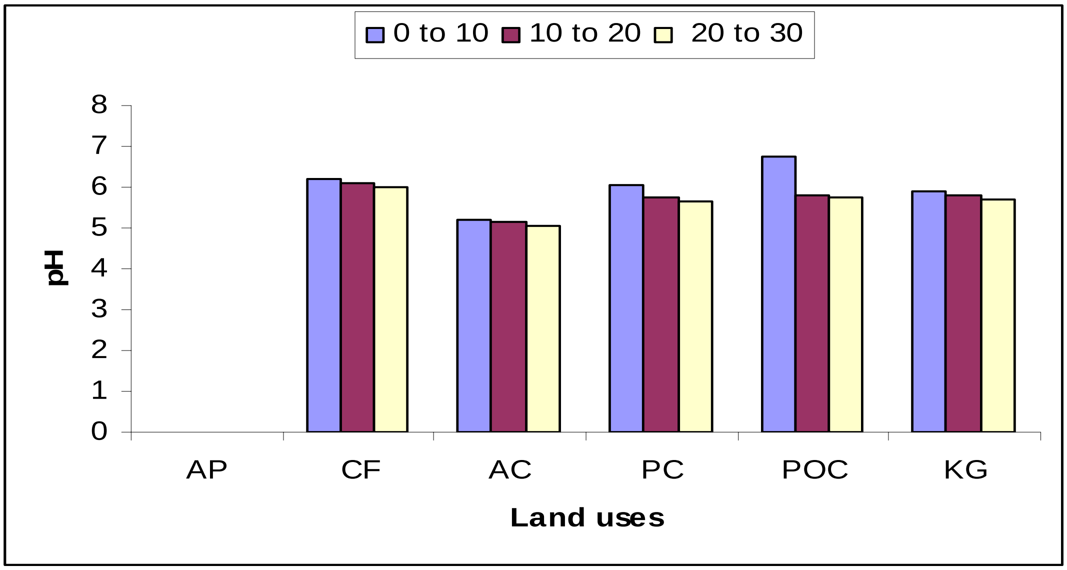

Figure 1.3. Soil pH in various land uses: alpine pasture (AP), cedrus forest (CF), allium cultivation (AC), pea cultivation (PC), potato cultivation (POC) and kitchen garden (KG).

3.6.6. Soil Organic Carbon

Under different soil depths, it was found that carbon% decreases along the soil depths. At higher altitude it was found higher in alpine pasture in all the soil depths as compared to other land uses (Fig.1.4).

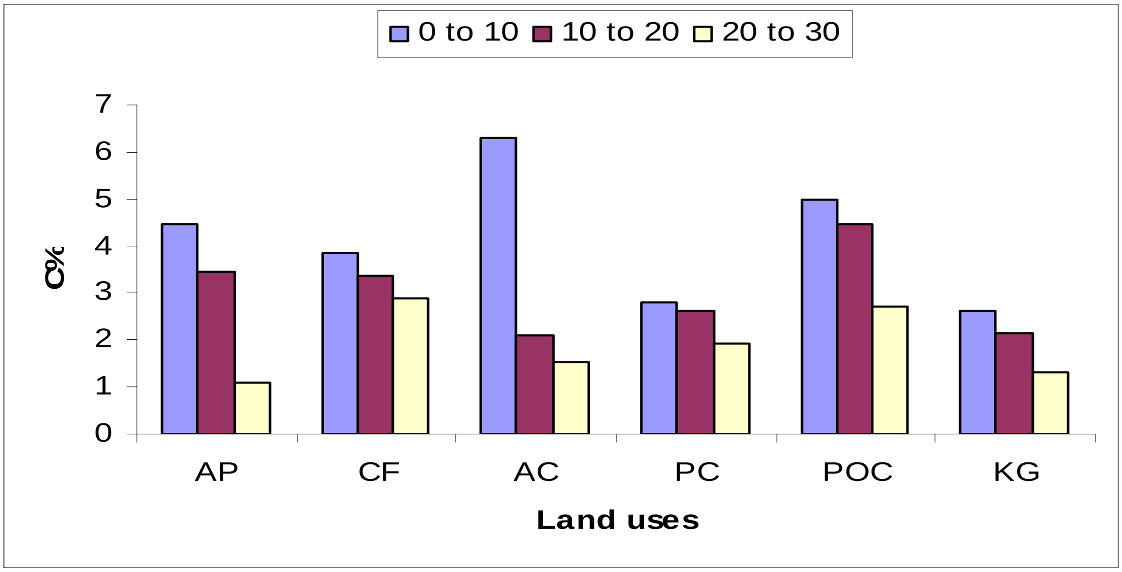

Figure 1.4. Soil organic carbon content at various depth in various land uses: alpine pasture (AP), cedrus forest (CF), *Allium* cultivation (AC), pea cultivation (PC), potato cultivation (POC) and kitchen garden (KG).

4. Forest and Pasture Use Management

Though 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 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 an 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 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, and (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.

5. Human Impacts and Major Threats to Biodiversity Conservation

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; and (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

6. Low Altitude Study Area

6.1. 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). 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 cash 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 rainfed agro-ecosystems to meet their food requirements throughout the year commonly known as "*Barahnaja*" or mixed cropping in the more scientific terminology in which 10-12 crops such as pulses and traditional crops are grown together. 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 yielding 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 1.5. 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**

6.2. Land Use

6.2.1. 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.

6.2.2. 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.

6.3. 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.

6.3.1. 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.

6.3.2. 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.

6.3.3. 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.

6.4. 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 1.5).

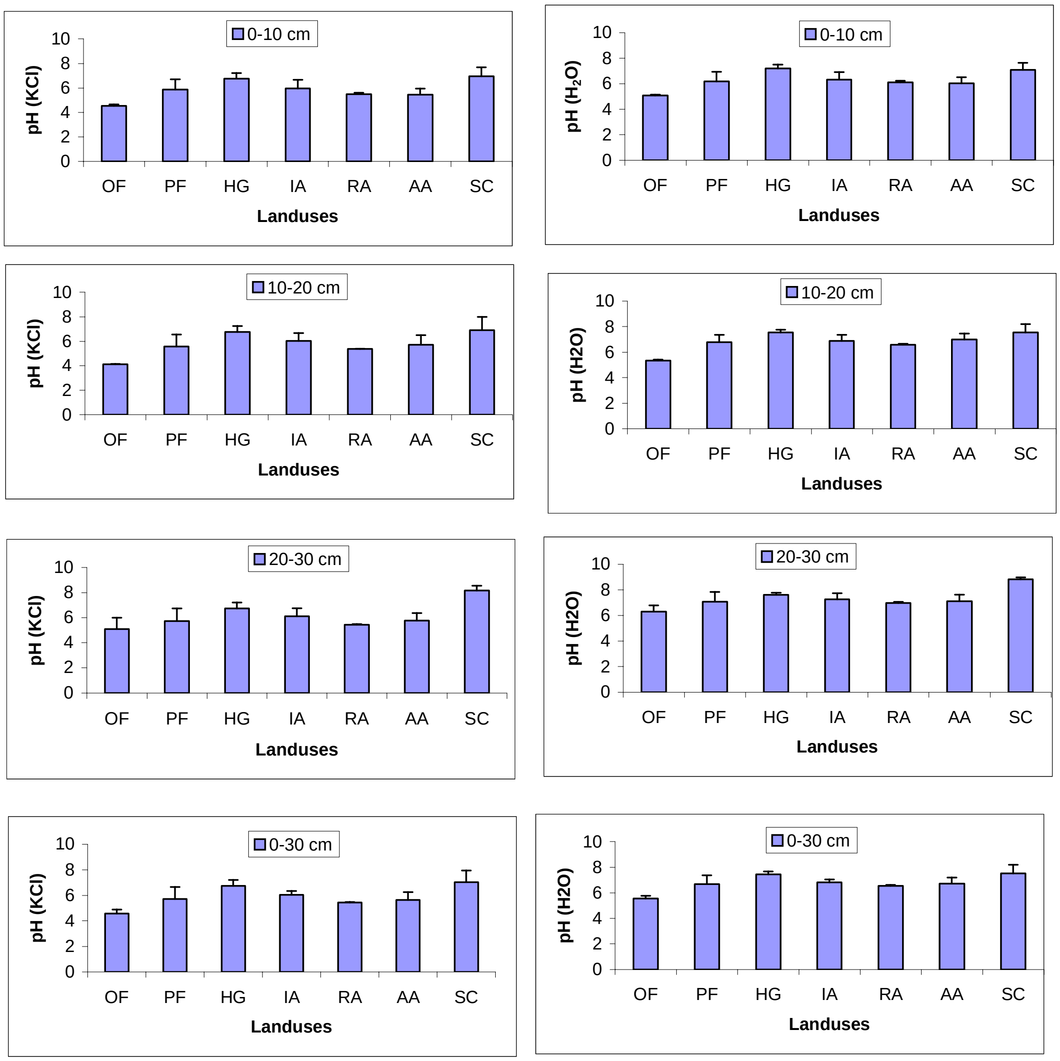

Figure 1.5. Soil pH in variou land uses: oak forest (OF), pine forest (PF), homegarden (HG), irrigated agriculture (IA), rainfed agriculture (RA), abandoned agriculture (AA) and scrubland (Sc).

6.5. 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 1.6).

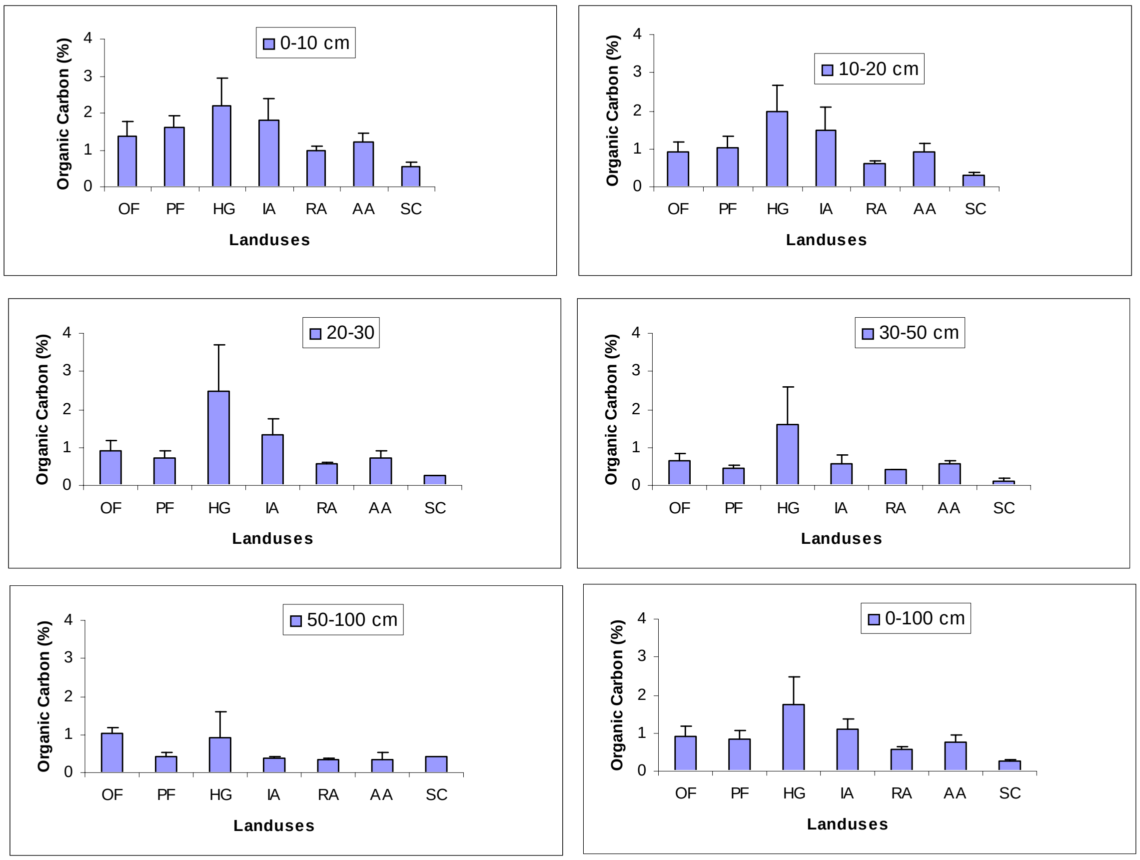

Figure 1.6. Soil organic carbon content at various depths in various land uses: oak forest (OF), pine forest (PF), homegarden (HG), irrigated agriculture (IA), rainfed agriculture (RA), abandoned agriculture (AA) and scrubland (Sc).

6.6. 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 1.7).

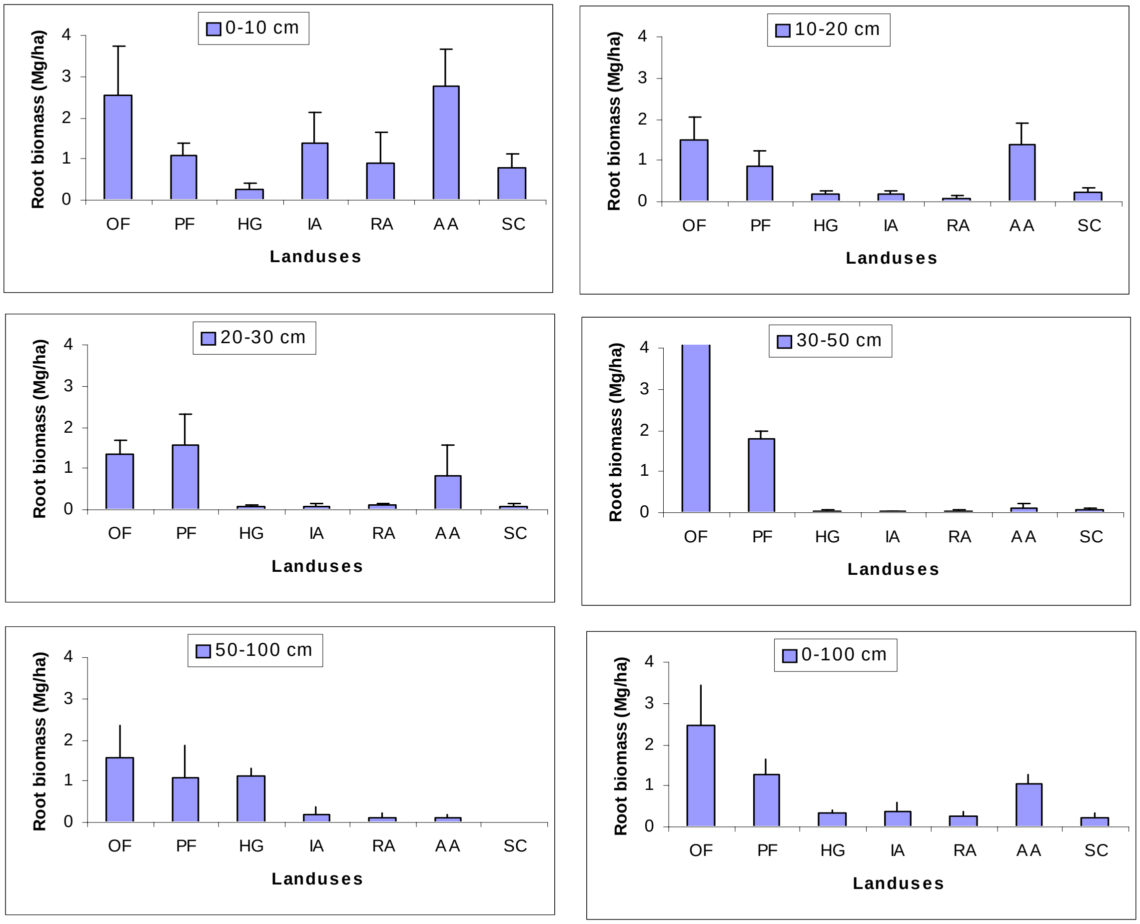

Figure 1.7. Root biomass at various depths in various land uses: oak forest (OF), pine forest (PF), homegarden (HG), irrigated agriculture (IA), rainfed agriculture (RA), abandoned agriculture (AA) and scrubland (Sc).

6.7. 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 1.6).

Table 1.6. 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)
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)**

6.8. 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 1.8).

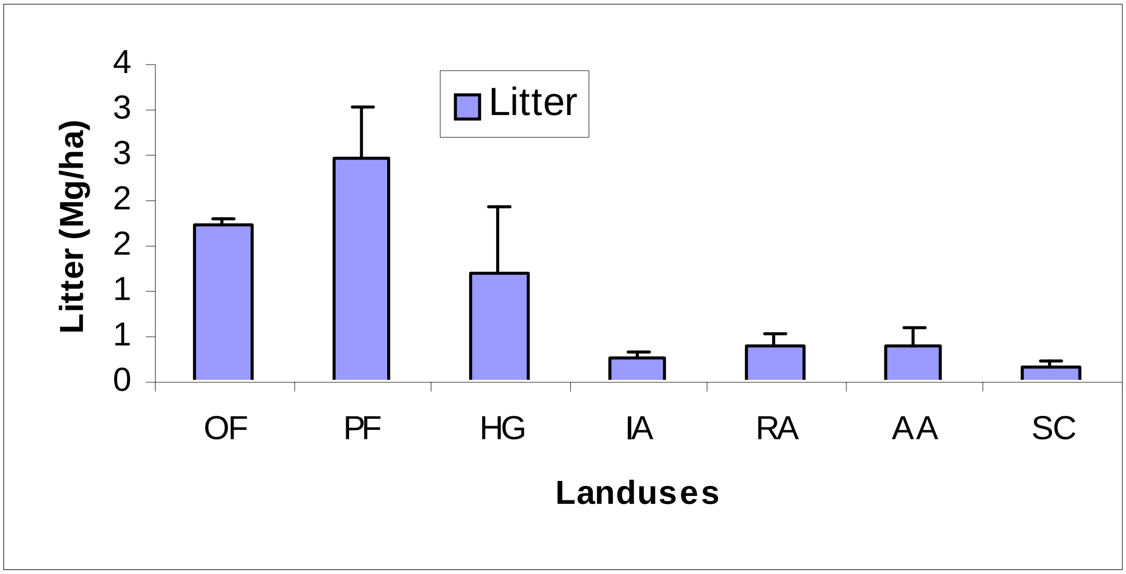

Figure 1.8. Litter mass in varius land uses: oak forest (OF), pine forest (PF), homegarden (HG), irrigated agriculture (IA), rainfed agriculture (RA), abandoned agriculture (AA) and scrubland (Sc).

6.9. Discussion

The fact that India is recognized as one among the 12 mega biodiverse regions of the world, is mainly due to the presence of the Himalaya. The biodiversity of the region to a great extent owes its existence to age old cultural values of the society, wherein, protection of various lifeforms are maintained through sacred groves and efforts of village communities. The protected areas located in Himalaya in general and NDBR which covered in Himalayan highlands biogeographic provice (2A) of India and represent a flatform to promote biodiversity conservation in diverse ecosystems having a mosaic of anthropogenic landscale. The area harbors very rear and endangered floral and faunal elements.

Soil is probably one of more species rich habitats of terrestrial ecosystem. During the past 20 years, the recognition of the importance of soil fauna in the functioning of soils and by extension of terrestrial ecosystems has been continuously growing, ending in some important application in agriculture. Despite the general agreement about the ecological importance of soil fauna and its economic consequences, the absence of concern about this group from conservationists in their studies is conspicuous. The multiple values of soil fauna discussed in body of literature provides good arguments to justify concerns about decreasing soil biodiversity. Hence, soil biodiversity ensures the multiplicity of the ecological, environmental and instrumental function of soil fauna in a wide variety of environmental conditions. Even if the functional importance of soil biodiversity still lacks sufficient studies to be clearly understood, its conservation is vital as an insurance against unpredictable or expected environmental changes that may impair ecosystem functioning in the future.

As a consequence, soil fauna are not taken into account in preliminary biodiversity surveys that are undertaken for protected areas planning. At the local scale, impact studies necessary prior to the establishment of any kind of infrastructure do not consider soil taxa. This is also the case when similar studies needed to define the place and shape of national parks or reserves. This is still obvious when biodiversity spatial patterns are addressed for the identification of proprietary conservation areas i.g. biodiversity hotspots.

In view of the above, in-depth studies on the topic conservation and sustainable management of BGBD has been initiated in NDBR since October 2004. In this study two benchmark areas with diverse land uses located in the buffer zone of NDBR between 2200 – 3100 m asl and at middle altitude between 600 – 900m asl were considered as a two windows for BGBD samplings and other related studies. At higher altitude of NDBR, a total of 126 grid points whereas at middle altitude about 121 grind points were selected and marked for sampling, border areas were excluded from both the windows. About a total of 11 land uses at both the windows were selected for detail investingation which include kitchen garden (V), kitchen garden (M), agriculture (P), agriculture (G), Cedrus forest, and alpine meadow at high altitude and kitchen garden, agriculture (IR), agriculture (RF), pine and oak forests at middle altitude.

All the land uses of both the windows were studied in detail in relation to vegetation analysis, land use cover change at two points of time 1986 and 1999, cropping and yield pattern of major agroecosystems, soil physic-chemical properties (particularly pH, nitrogen and organic carbon content) and so on. All the land uses as described in the text were investigated in detail for BGBD studies such as inventorization, identification, population dynamics, species abundance, richness and biomass studies etc. In addition to this, studies on many other aspects directly/indirectly relevant to BGBD or impacting BGBD in selected land uses were also conducted such as socio-economic studies and indigenous practices of maintaining soil fertility, agronomic practices and pest management by local communities inhabited there.

Conservation of BGBD can not be achieved without improving the economic conditions of the inhabitants living in and around the biosphere. Inhabitants being the focal points of every conservation effort, attempt should strive for a balance between conservation and development.

Wherever needed, experiences from elsewhere, both from within and outside BR areas should be available for adaptation within a given situation. An inter-institutional arrangement for sharing experiences gained from varied situations is an important requirement. Strong linkages between governmental and NGOs, and other local institutions need to be built for sharing experiences, for tackling developmental concerns, viewed from their perspective rathen than from ours. Unless local people are involved in the process of formulation and implementation of conservation policies and programmes, the objective of BGBD conservation and biosphere management cannot be achieved. These are some of the lessons that we have learnt working with the communities in the NDBR area in the Central Himalaya during the first phase of the project.

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Chapter 2

Socio-economic Studies with Special Reference to Indigenous Farmers Practice and Knowledge on Soil Fertility Maintenance and Below Ground Biodiversity in Nanda Devi Biosphere Reserve and Adjoining Areas

1. 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 relationships 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 field of sustainable management and appropriate harnessing of biodiversity. Below ground biodiversity (BGBD) is an important aspect of study and also the major 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 or maintain the soil fertility of agricultural land as well as to conserve 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, the productivity of the crops declines gradually. 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 reduce the per capita production in hilly tracts of the region.

Traditional agricultural system plays a vital role in the subsistence, economy and living standards of Garhwal Himalaya in which about 80% of population of the area is actively engaged (Maikhuri *et al.*, 2001). The agricultural land holdings in the hills are very small and per capita land holdings is estimated about 0.02 ha. In this region, terraced slopes covering 85% of the total agricultural land are generally rainfed while the valleys covering only 15% 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 sloping 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 considered as a major reason for declining soil fertility and crop productivity in the region. Traditional agriculture of this region 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.

A semi structured questionnaire survey was conducted with an objective to understand the socioeconomic profile and extent of awareness regarding BGBD among the local inhabitants in general and women folk of the area in particular in NDBR and nearby areas. The average family size is 6.1, with number of females generally exceeding than the number of males. The literacy rate in the area is about 69%. Wealth ranking exercise indicated that the poor, medium and rich families are 30%, 50% and 20% , respectively. Majority of the respondents (households) at both the elevations have small landholdings which ranges between 0.08 – 0.6 ha/family. Traditional cropping practices are declining in this area and farmers are also applying chemical fertilizer to some extent. Application of farm yard manure (FYM) is a general practice in both rainfed (RF) and irrigated (IR) type of agriculture in the region. However, quality and quantity of FYM application may vary from field to field according to the area of the cropland, human resource and number of livestock in the family. For example, in agriculture fields of 0.2 hec normally about 500 kg – 900 kg of FYM is applied. Almost all the farmers apply in organic fertilizers particularly in irrigated croplands. About 85% of the families of low altitude own both rainfed and irrigated agriculture land while 15% have only Irrigated agriculture using the stream water for irrigation whereas, at high altitude villages all the families have rainfed agriculture. With respect to BGBD, about 90% of the respondents are aware of the soil fauna like earthworms, ants and Coleoptera beetle larvae while only 12% are also familiar with centipedes and millipedes. Although, almost all the respondents are literate and have the tendency to imbibe new knowledge and techniques to improve their productivity of the croplands yet there are no proper extension activities are present in the area to support small and marginal farmers. Indigenous practices to increase productivity and to maintain the soil fertility are still prevalent in the region that include mulching, terracing, agro forestry, FYM application, ash spray etc. are also discussed in the paper in detail.

Present study is an attempts (a) to assess the extent of knowledge of local farming communities about BGBD at both the study sites (middle and high altitudes), (b) to assess the extent of knowledge regarding beneficial and harmful insect and pests of different land uses i.e. agriculture, kitchen (vegetables) garden as well in their nearby forests, (c) to study the socio-economic profile, people perception, awareness and knowledge of rural farming communities about the role of BGBD in soil fertility maintenance, and (d) to document the indigenous practices of traditional farming communities in relation to soil fertility maintenance.

2. 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 agroecosystems in the low 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 Development block.

3. 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 participatory rapid appraisal (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. The reason behind was that, individuals below 20 years 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.

3.1. 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 are presented here.

3.2. Social Dimensions of Study Area

3.2.1. 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. 2.1). 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 2.1).

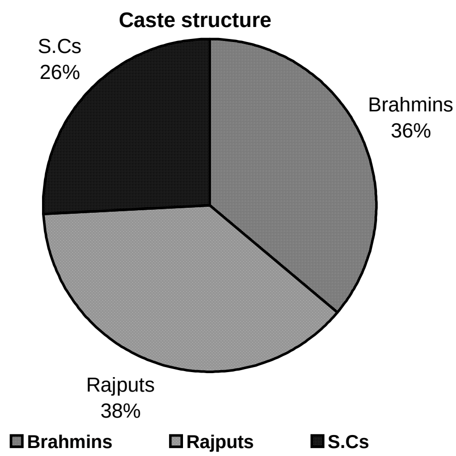

Figure 2.1. Population of different castes at low altitude

Table 2.1. 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

3.2.2. 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 (800-1500m 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 have these particular animals), whereas per capita land holdings of the selected villages was recorded 1.09 hectare (Table 2.2).

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 comprises 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 different governmental units at block or state level, creating difficulties in governmental units at block or state level and developmental processes in coordination and integration of reserve management planning. Whereas, at low altitude benchmark site the government represented by various line departments involved in the rural development. These institutions and departments are administrated by different governmental units at block or state level.

Table 2.2. 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

3.3. 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. 2.2 & 2.3 and Table 2.1 & 2.2. 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.

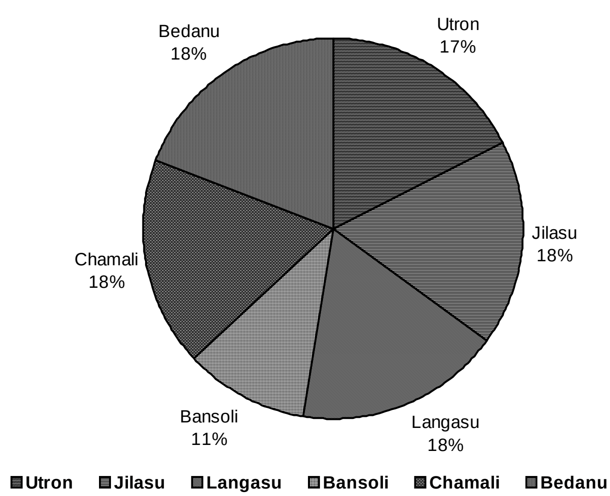

Figure 2.2. % of sampled households of different villages selected for survey at low altitude

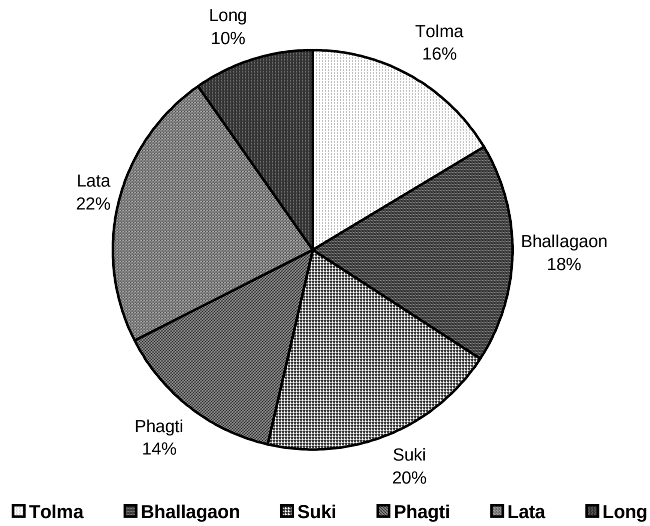

Figure 2.3. % sampled households of different villages selected for survey at high altitude

Table 2.3. 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 2.4. 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

3.4. 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 household income of 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 househould income in these villages was ranged between Rs. 9500 – 10250 per year.

3.5. 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.

3.6. Survey Methodology

The survey was undertaken in between December 2004 to February 2005 in study area on following parameters:

3.6.1. 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.

3.6.2. 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.

3.6.3. Primary Data Collection**:** These data were collected from 217 households belonging to 12 villages located in low and high altitude windows 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 find ways or indicators to measure, following attributes:

- Major insects/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.

3.7. 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 2.6. 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 this 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 were even of opinion of that earthworms are also harmful to their crop. The 99% of the respondents were aware of the 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 and pest presence in agriculture and about 43% male and 56% female were found aware about harmful insects/pests (Table 2.9). 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. Less than 10% of the respondents were not aware of extension activities, benefits of earthworms etc.

Table 2.5. 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 sampled 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 2.6. 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**	-	-

3.8. 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 the 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 practices and the ecological processes operating in the farmer's field (Table 2.7). When researchers do so, they may change their views about the what kind of strategy useful to farmers both because the information they provided about the operative processes and the confidence they have that research of a particular type is relevant and can be useful and nedd to be communicated to farmers.

Table 2.7. 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**

Various examples demonstrate that modern knowledge and advancements have their origin in the farming communities or have 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 are described below:

3.8.1. Application of FYM

Applying FYM in the agricultural fields is one of the most useful and significant indigenous method practiced almost more or less in all the villages of the region.

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, animal bedding, grasses and feed left over. The leaves used for animal bedding not only keep the livestock clean and warm but are 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, farmers 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 applied in 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 leaf litter.

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.

3.8.2. 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 (Table 2.8). Some of the common crop plants sown in this practice are Rajma

(*Phaseolus vulgaris*), Gahet (*Macrotyloma uniflorum*), Kong (*Pisum arvense*), Cowpea (*Vigna unguiculata)*, Rains (*Vigna angularis*), Kalabhatt (*Glycine spp.*) Urd (*Vigna mongo*), Moong (*Vigna radiata*), Soyabean (*Glycine max*), Ragi (*Elusine coracana*), Ramdana (*Amaranthus spp.*) etc. (Table 2.9). 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 soil through biological nitrogen fixation.

Table 2.8. 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*)	Bachhelikhal
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	Radish (*Raphanus sativa*)	Dwarahat
14	Gadheri/Pinalu/Kuchain (*Colocasia* sps)	Dugadda, Dagar, Bageswar, Dwarahat
15	Tor, Kala Bhatt (*Glycine* sps)	Ukhimath
16	Cabbage (*Brassica oleracea* var. capitata)	Narayankuti
17	Bhangjira (*Perrilla frutescence*)	Adibadri
18	Cheura (*Diploknema butyrissea*)	Gangolihat
19	Chua (*Amaranthus paniculatus*)	Gairsen
20	Dry chillies	Chaura, Kichgad
21	Rajma (*Phaseolus vulgaris*)	Harsil, Joshimath
22	Apple	Harsil, Rawain
23	Malta (*Citrus* sps.)	Ukhimath, Jakholi

Table 2.9. 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

3.8.3. 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.

3.8.4. 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.

3.8.5. 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 2.6). 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.

3.9. Soil Nomenclature and Soil Fertility Status

The valleys and gentle slops have considerable soil depth, developed from colluvium and alluvium, the texture of such soil is generally course and least acidic. Usually south facing slopes are too precipitous and well exposed to denudation, hence have shallow, dry and less fertile soil, whereas the north facing slopes support deep, moist fertile soil. The montane zones representing warm temperate or cool temperate like climates have two major soil types a) brown forest soil under humid and dense broad leaved forests and b) pedozolic soil under sub-humid coniferous forests. The soils, in general, are loam to sandy loam and well to excessively drained. Cultivated areas are mainly confined to valleys with Fluvisols or brunified. Brunizem and chernozem support forested areas in the middle altitude. On the other hand the slops of the ridges occupied by lithosol mainly constitute the barren land.

Hill farming is beginning to face major fertility transfer constraints, as the hill farmers put a higher premium on land devoted to food production rather than forests and pastures. With these changes in landuse, land and labour constaints are affecting traditional soil fertility maintenance systems in the hills. Land constraints figure in two major ways. First, the need to maintain forests to supply fodder and leaf litter is causing major difficulties. It has been estimated by some researchers that at least 3ha of forest land are needed to maintain each unit of adult livestock. Otherwise, deterioration in livestock products, including manure, increases markedly. Similarly, other researchers have suggested that as much as 50 tonnes /ha of leaf litter is necesary to maintain current fertility levels. Even under proper management,this translates to more than a couple of hectares of forest land. Obviously, more careful research is needed to establish the relationship between productivity changes, forests and pasture lands. But the conclusion is quite clear. In a situation where average holdings are less then a half ha, and where forests and pasture lands are rapidly declining , land constraints for supporting traditional methods of fertility transfers will soon become very severe. With additional pressures on forests from firewood and minor timber demand, the problem becomes even more critical.

In general, in the present case the status of soil organic carbon % decrease as soil depths increases. Among five landuses studied at low altitude, the % organic carbon was ranged between 0.48 to 3.25%. At higher altitude the soil organic carbon was found higher under Allium cultivation (3.1%). The nitrogen content (%) was found higher in the soil of oak forest (0.42%) and minimum in irrigated land at low altitude. However, among the land uses at high altitude, Allium cultivation exhibited higher content of nitrogen (0.66%) and least value was obtained under potato cultivation (0.23%).

3.10. Farmer's Knowledge on Other Aspects Directly/Indirectly Linked to AGBD-BGBD and Sustainable Livelihood

3.10.1. 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 local flora often grow. 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 between 1200 – 2000m asl 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 of do not provide 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.

3.11. 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 belonged 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 criteria which was undertaken to evaluate the indigenous practices used for maintaining soil fertility and BGBD was occupation namely farmers, housewife and others. In the category of others correspondents having different occupational skills were considered and included 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 more or less in agriculture or forest related activities. 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 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 are also damaged by many diseases, which are unknown to them. This is responsible for decline of crop productivity, which directly leads to 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.

3.12. 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’s participation is the possible remedial measure to cope with the situation (Maikhuri *et al.*, 1997a, b; 2000).

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Chapter 3

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. Most of the pest problems emerged during recent past due to introduction of HYV of crops and varietal improvement, excess use of inorganic fertilizers, insecticides, monocropping, unseasonal crop cultivation, high density planting and growing the same crop repeatedly. 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 (Table 3.1). 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.

Table 3.1. 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

2.2. Agrobiodiversity: Species and Cultivar Diversity

Even though holdings are quite small, crop diversity is quite high (Table 3.2). 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 3.3). 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*.

Table 3.2. 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 + P.vulgaris+ A.paniculatus	4.0	1151±75	-	-
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).**

Farm trees constitute an important component of agricultural biodiversity. Direct benefits from trees are the major descriptors of farm trees in indigenous knowledge (Table 3.4.), 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 negative impact 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.

Table 3.3. 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 3.4. 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.

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 3.5). 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 3.6). 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 3.6 & 3.7.). 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.

Table 3.5. 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 3.6. 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 3.7. 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

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 3.8). 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 3.9) 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. 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.

Table 3.8. 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

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. Application of farm yard manure (FYM)/ biocompost, mixed cropping, cultivation of the crops at the right season, crop rotation and use of indigenous seeds that could minimize or check pest infestation.

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.

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Chapter 4

Macrofauna: Nanda Devi Biosphere Reserve

1. Introduction

Over the last two decades, an expanding body of research has explored and documented the integral role of diverse soil communities in building soil health and broader ecosystem function. Despite consensus within the scientific community regarding importance of soil fauna, enormous literature available reveals that soils compromised through unsustainable agricultural practices, deforestation and due to several other activities. Soil macro and meso fauna provide beneficial services in situ, as well as to surrounding environment. For example, soil macrofauna can increase agricultural production by enhancing soil drainage, creating passages for plant roots, aerating the soil and recycling organic matter and nutrients. Despite the general agreement about the ecological importance of soil fauna and its economic consequences, the absence of concern about this group from conservationists in their studies is conspicuous.

NDBR 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), and 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; Dash et al., 1985).

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 (Fig.4.1).

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 (Fig. 4.1).

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 4.1.).

3.1.2. Biomass

Earthworm biomass in the post-monsoon season is shown in Fig. 4.2. 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 (Fig. 4.2).

3.1.3. Species Richness

In all, eight species of earthworms were observed in the species (Table 4.2 - 4.4a). 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 4.4b 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 (Fig. 4.3).

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 4.5).

3.2.2. Biomass

Biomass of hymenopterans during postmonsoon season is shown in Figure 4.4. 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. 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 4.5.). 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 4.6).

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 4.6).

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 4.7).

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 4.8).

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 4.9). 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 4.8).

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 (Fig. 4.10).

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 (Fig. 4.11). 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 4.9).

3.6.2. Biomass

Biomass of this group during post-monsoon season is given in Fig. 4.12.

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 4.13). Coefficient of variation varied from 59% in homegarden at higher elevations in pre-monsoon to 220% in irrigated agriculture at lower elevations (Table 4.10).

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 4.14).

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 4.15; Table 4.11).

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 4.16).

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 4.17., Table 4.12).

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 4.18).

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 4.13- 4.15.

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 (Figs. 4.25., 4.26. & 4.27; Table 4.16).

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 4.28 and Table 4.16).

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 (Fig. 4.29).

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 4.30.).

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 4.31.).

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 4.32.).

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 4.16.).

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 competing 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 (Mishra and Dash, 1984; Senapati and Dash, 1984; Senapati et al., 1979; 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; Senapati and Dsah, 1984; 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 (Dash et al., 1984; Dash et al., 1986). 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 4.17, 4.18.). 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.

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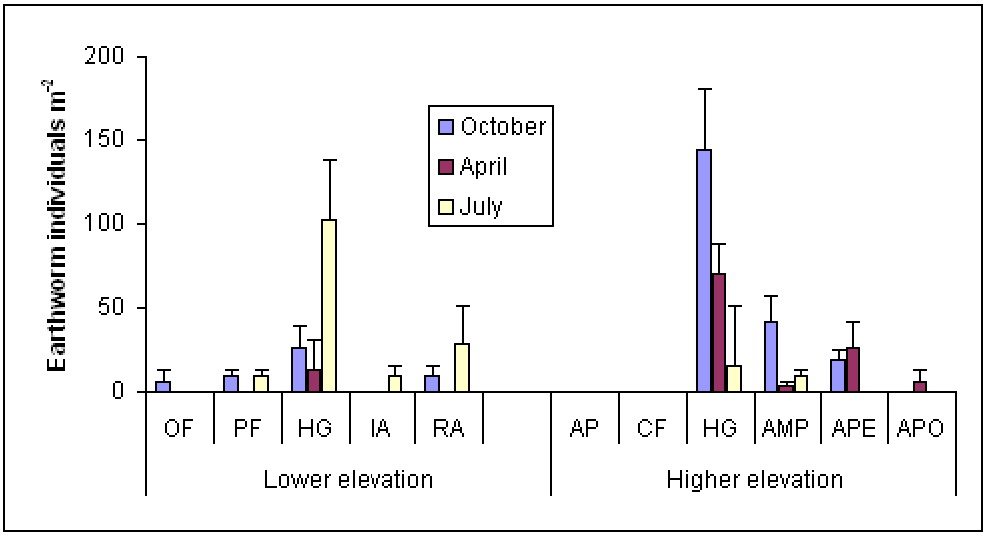


Figure 4.1. Numerical abundance of earthworms (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover. OF, oak forests; PF, pine forests; HG, home garden; IA, irrigated

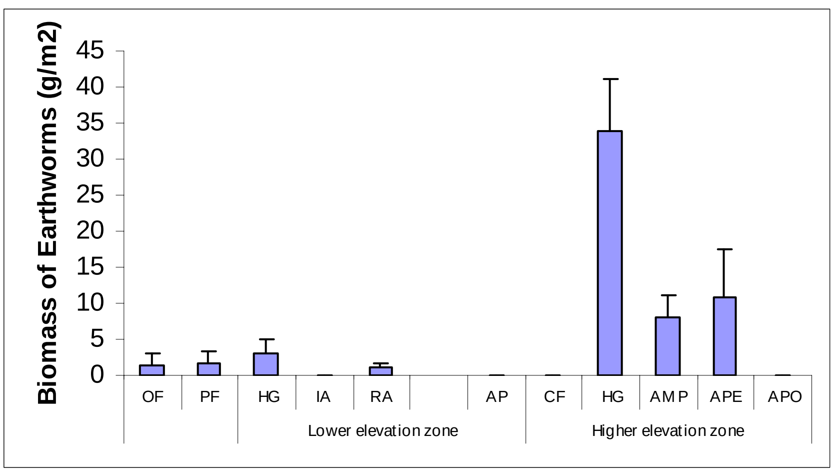


Figure 4.2. Mean biomass and SEM of Earthworms in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

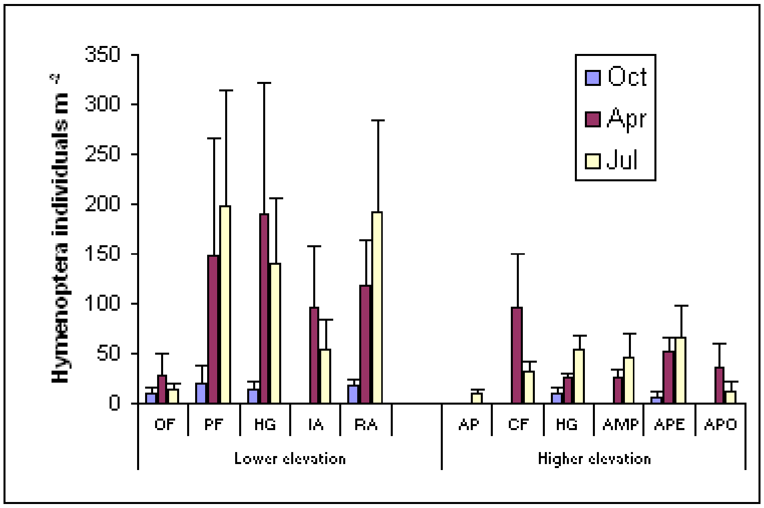


Figure 4.3. Numerical abundance of Hymenoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

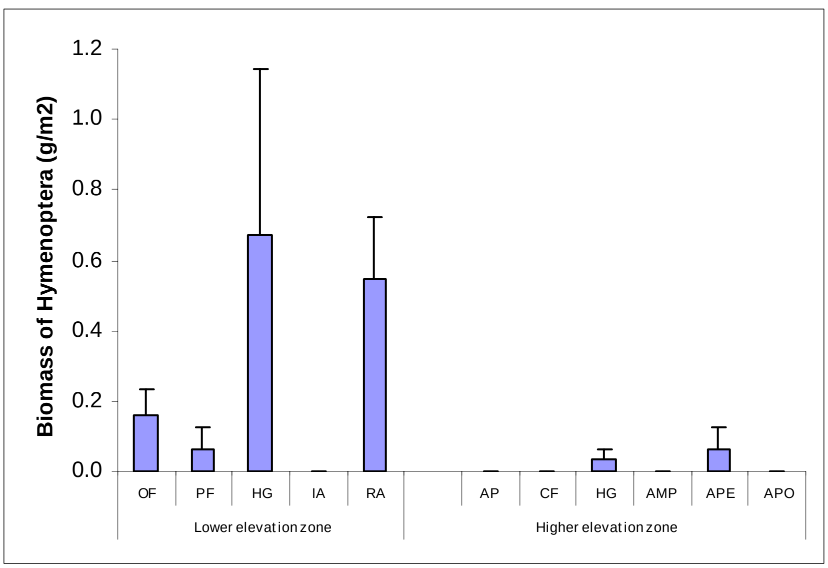


Figure 4.4. Mean biomass and SEM of Hymenoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

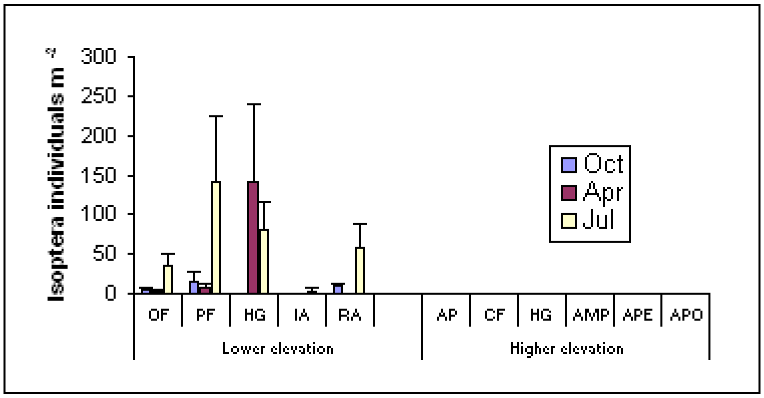


Figure 4.5. Numerical abundance of Isoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

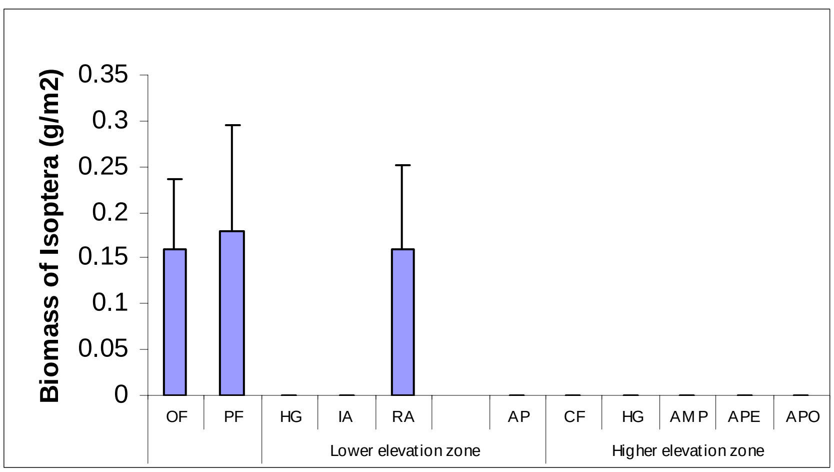


Figure 4.6. Mean biomass and SEM of Isoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

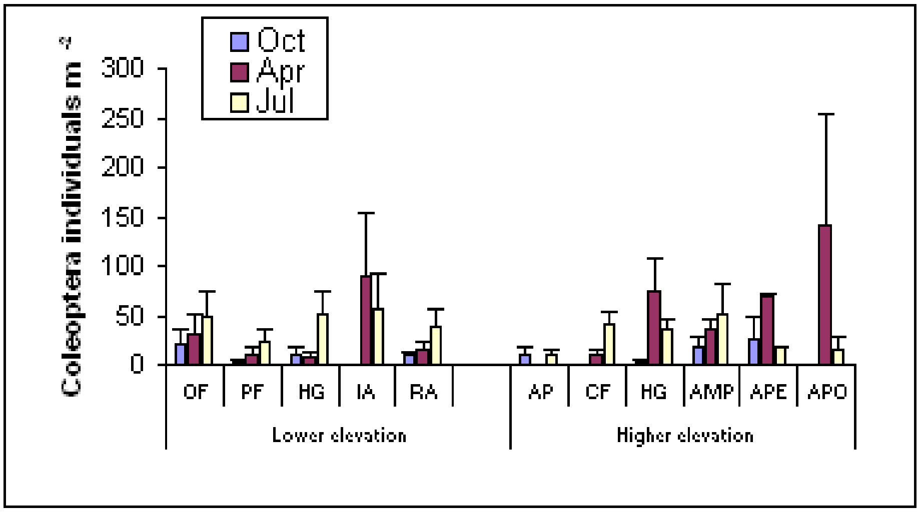


Figure 4.7. Numerical abundance of Coleoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

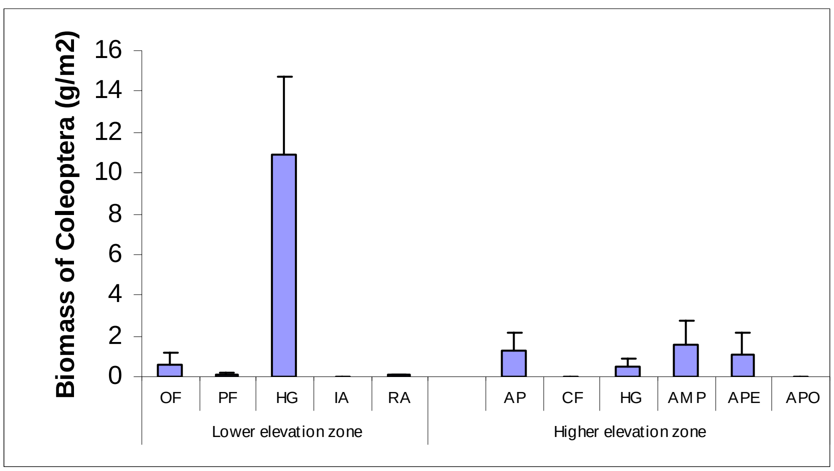


Figure 4.8. Mean biomass and SEM of Coleoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

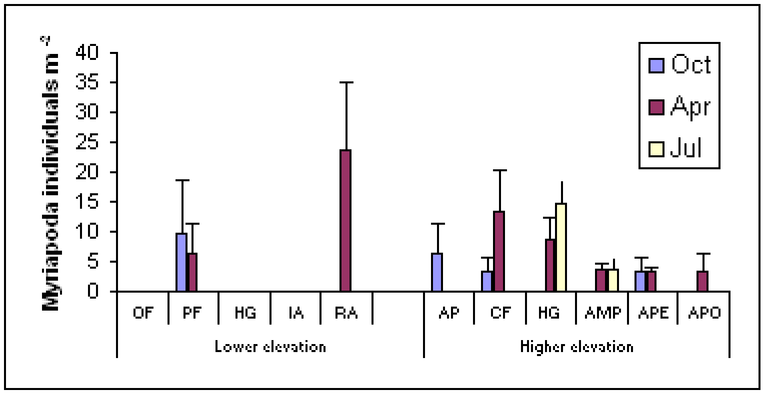


Figure 4.9. Numerical abundance of Myriopoda (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

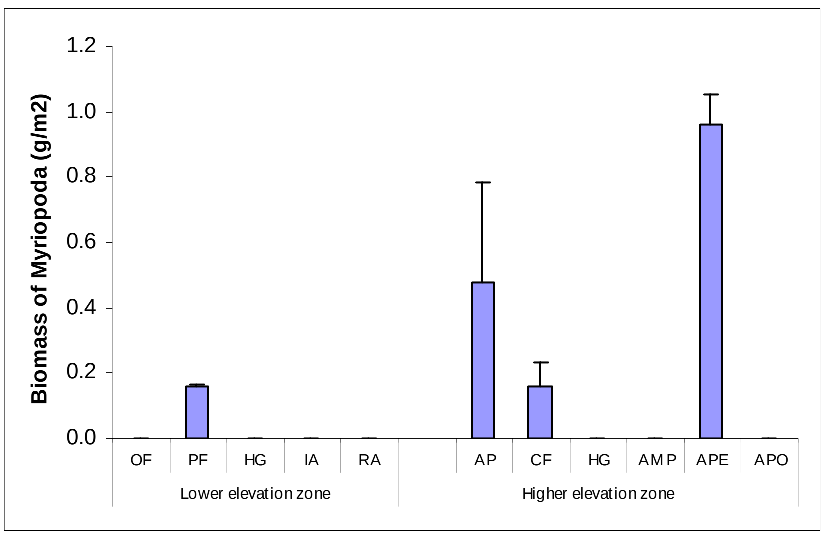


Figure 4.10. Mean biomass and SEM of Myriopoda in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

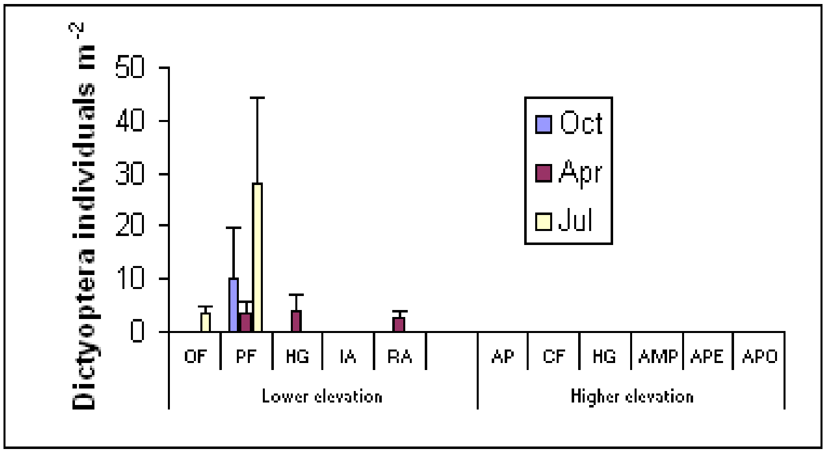


Figure 4.11. Numerical abundance of Dictyoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM). Sampling in April was not done in alpine pasture because of snow cover.

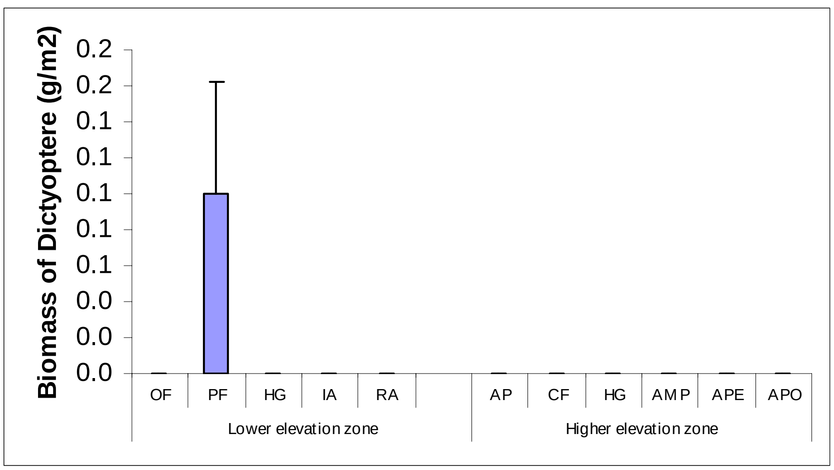


Figure 4.12. Mean biomass and SEM of Dictyoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

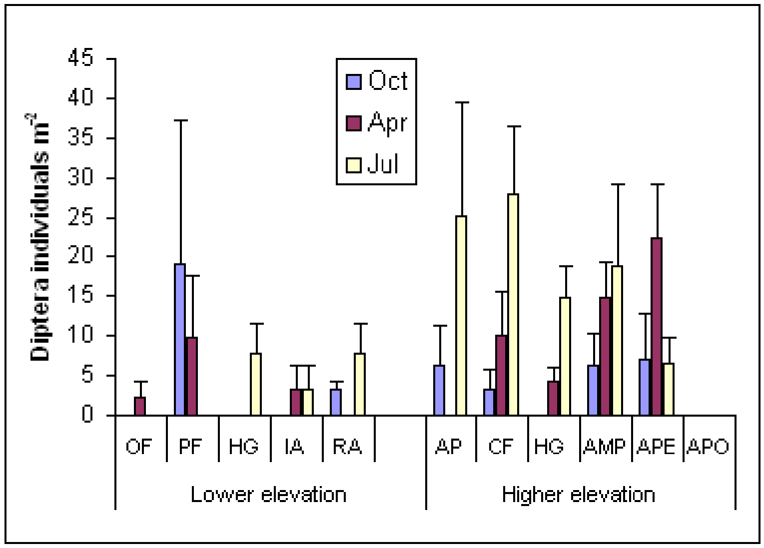


Figure 4.13. Numerical abundance of Diptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

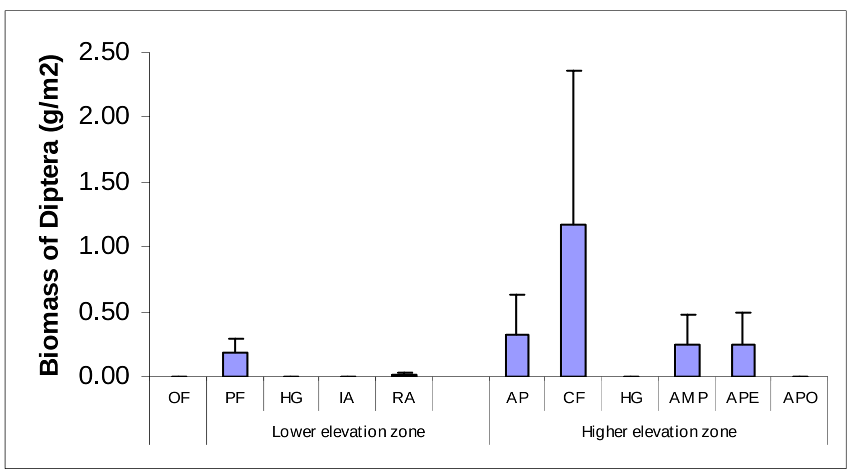


Figure 4.14. Mean biomass and SEM of Diptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

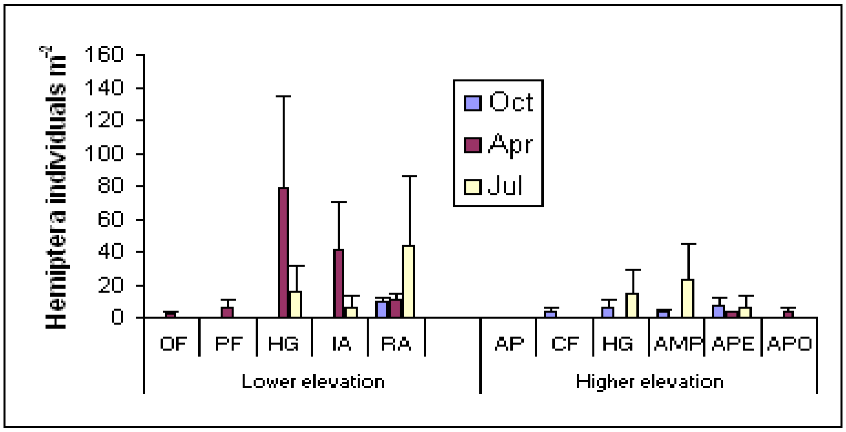


Figure 4.15. Numerical abundance of Hemiptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

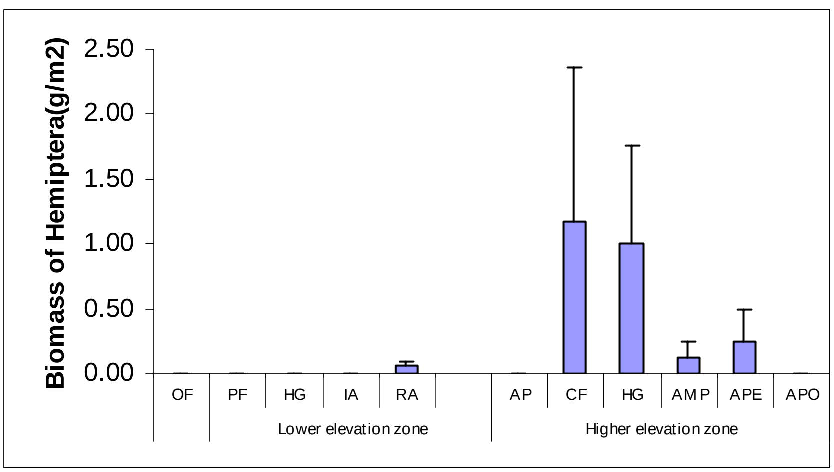


Figure 4.16. Mean biomass and SEM of Hemiptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

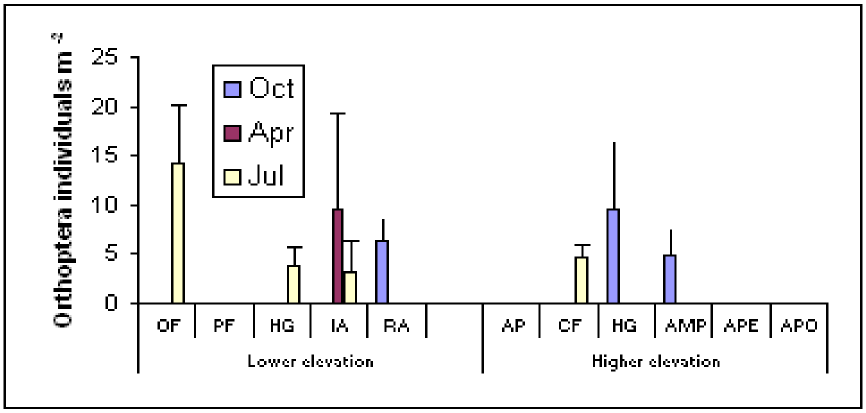


Figure 4.17. Numerical abundance of Orthoptera (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

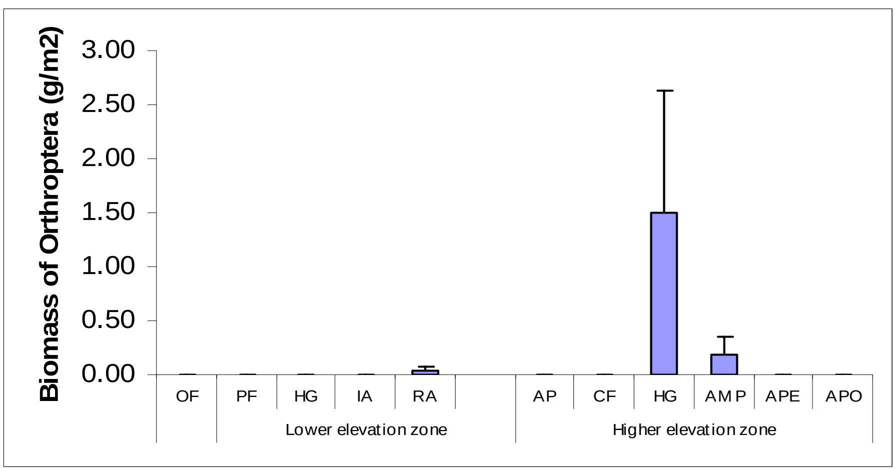


Figure 4.18. Mean biomass and SEM of Orthoptera in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

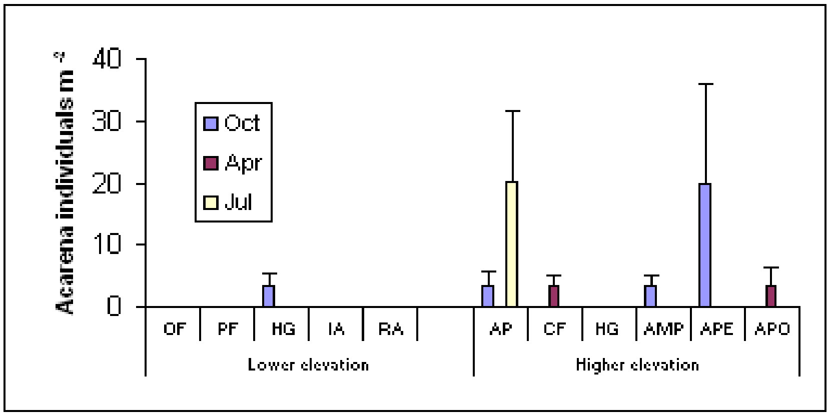


Figure 4.19. Numerical abundance of Acarena (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

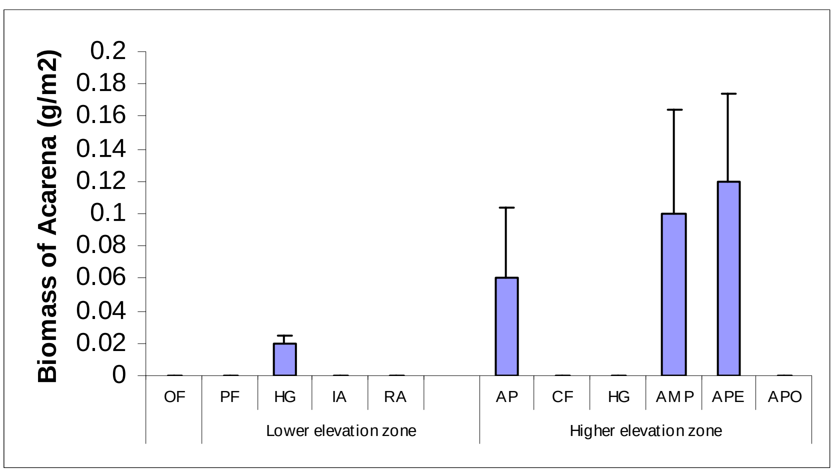


Figure 4.20. Mean biomass and SEM of acarena in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

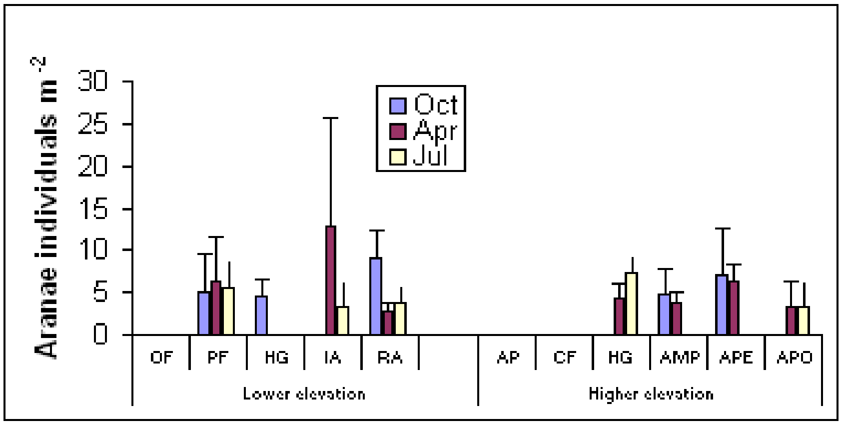


Figure 4.21. Numerical abundance of Aranae (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

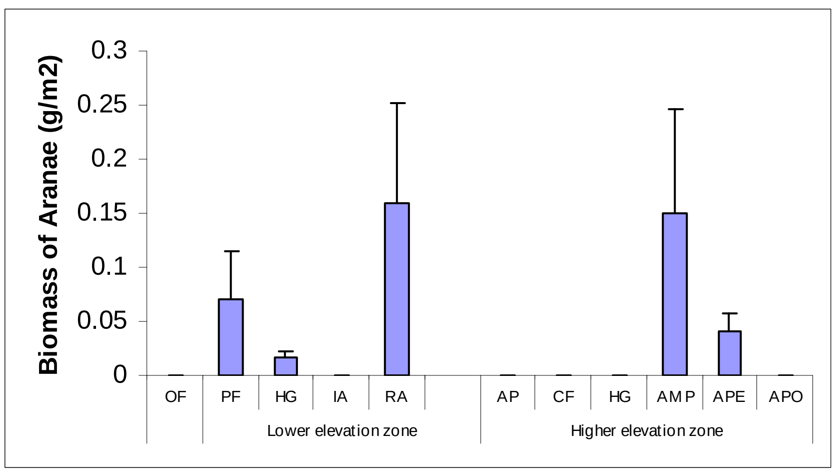


Figure 4.22. Mean biomass and SEM of Aranae in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

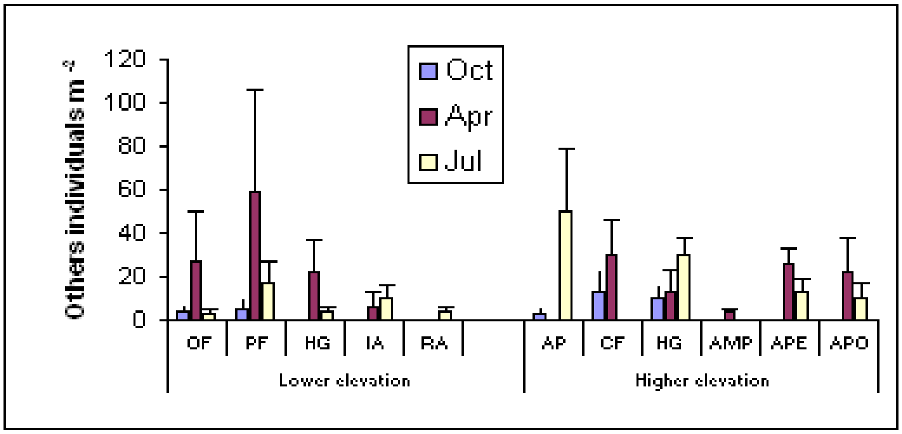


Figure 4.23. Numerical abundance of Others (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during three seasons (October, winter; April, early summer; July, Rainy season) in different land use types. Sampling in April was not done in alpine pasture because of snow cover.

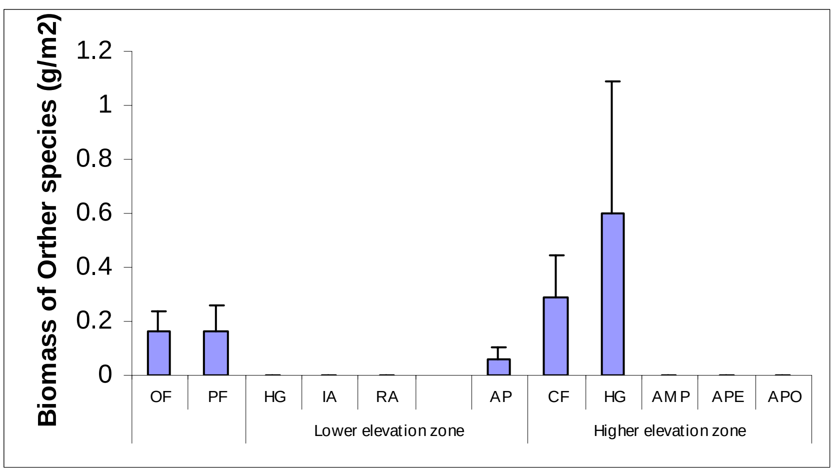
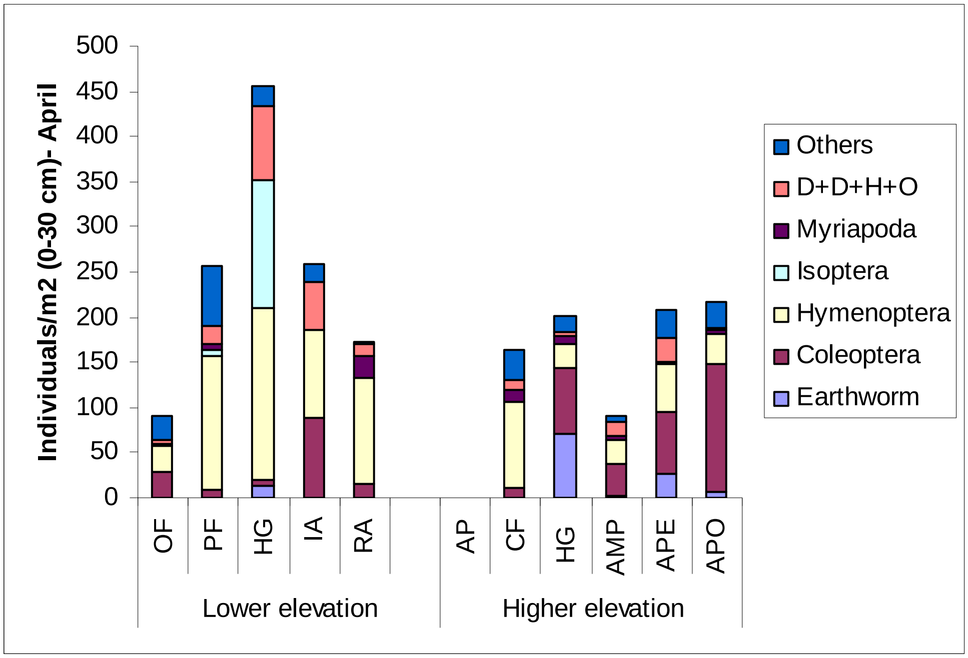


Figure 4. 24. Mean biomass and SEM of other organisms in different land uses in lower and higher elevation landscapes during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields



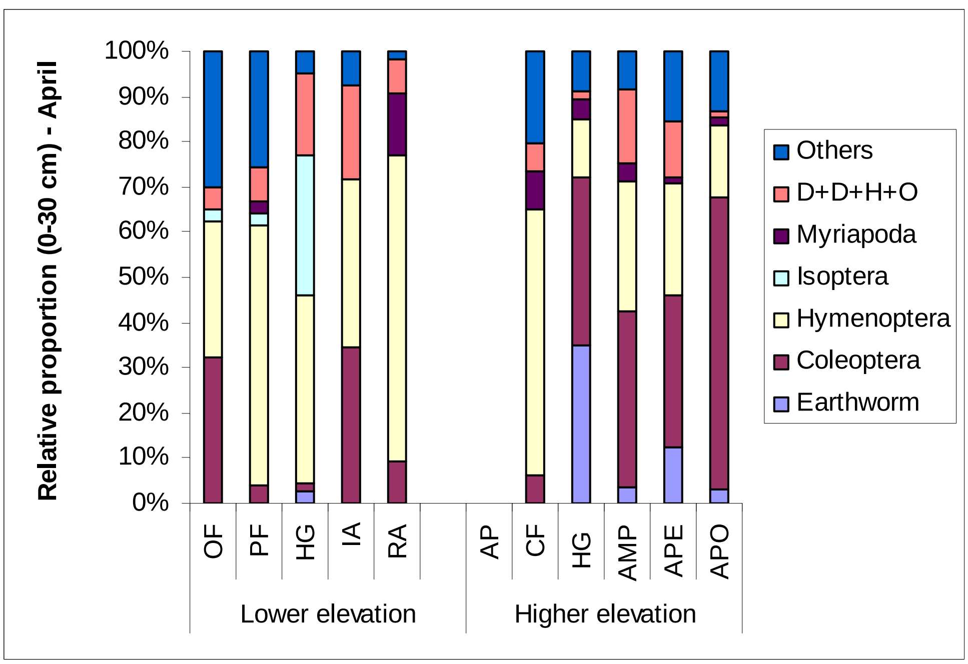


Figure 4.25. Absolute and relative abundance of soil fauna (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during April in different land use types. Sampling in was not done in alpine pasture because of snow cover.

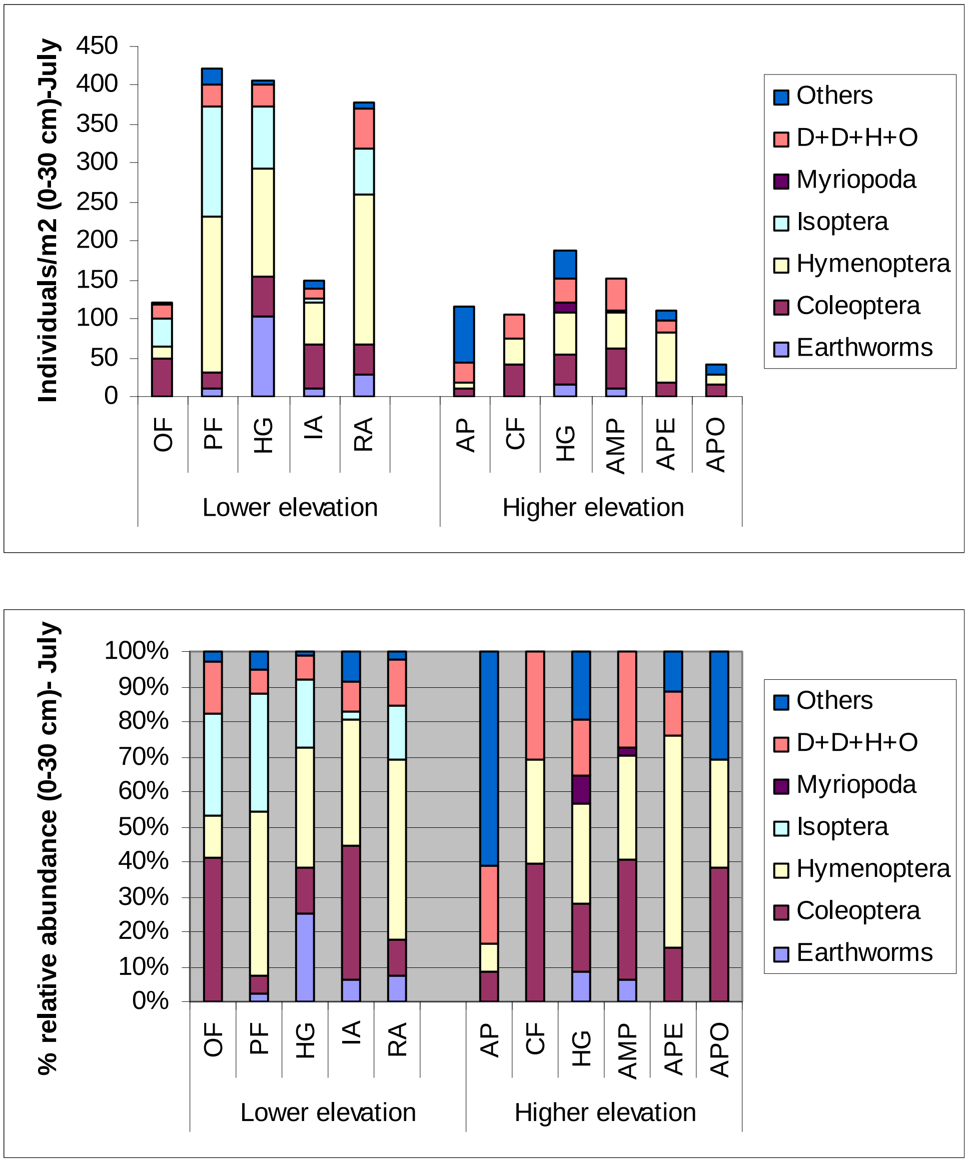


Figure 4.26. Absolute and relative abundance of soil fauna (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during July in different land use types. Sampling in was not done in alpine pasture because of snow cover.

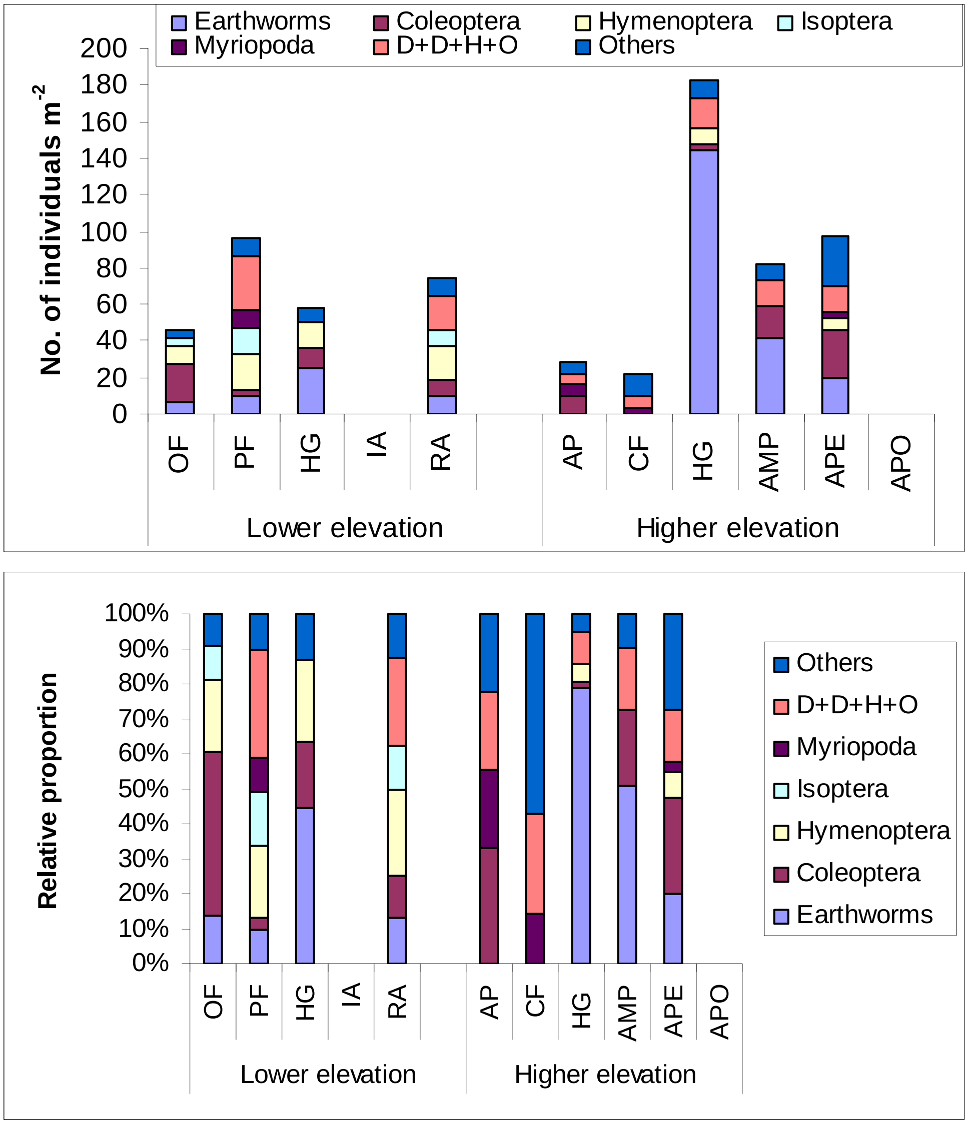
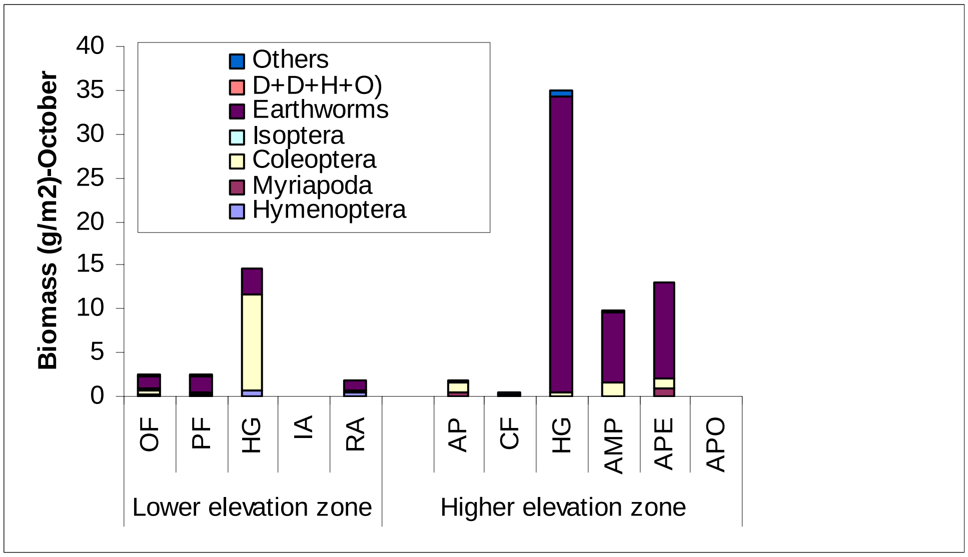


Figure 4.27. Absolute and relative abundance of soil fauna (individuals / m^2 in 0-30 cm soil layer, mean & SEM) during October in different land use types. Sampling in was not done in alpine pasture because of snow cover.



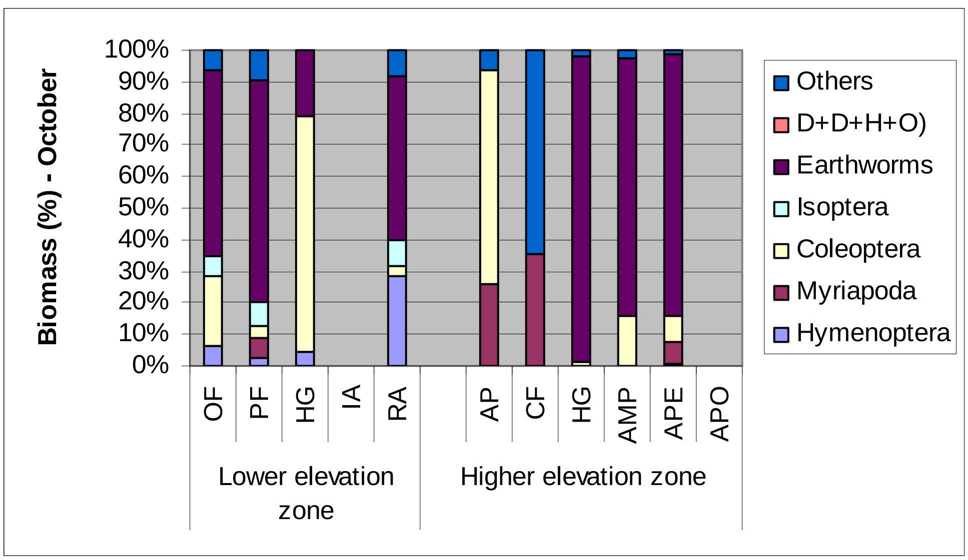


Figure 4.28. Absolute and relative biomass of soil fauna (0-30 cm) in different land uses during post monsoon period (October). Farmers didn't allow sampling in irrigated agricultural fields.

Table 4.1. 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 4.2. 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 4.3. 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 4.4a. 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 4.4b. A summary of studies carried out on earthworm diversity and abundance in the Himalayan region and other areas in India

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 (Montly sampling)	Five species: *Drawida willsi,* *Drawida calebi,* *Ocnerodrilus occidentalis,* *Lampito mauritii,* *Octochaetona surensis*	1399 worms per m^2 during August – Sept., 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):	Five species *Amynthas diffringens,* *Drawida assamensis,*	Population of *Amynthas diffringens* peaked during winter months and of other species during rainy season

shifting agriculture in Shillong	*Eutyphoeus festivus, Nelloscolex strigosus, Tonoscolex horaii*	4-47 mature individuals per m^2 in cropping phase and upto 50 individuals per m^2 in fallow phase
Senapati and Dash (1981). Grassland in Sambalpur, Orrisa(montly sampling).	Five species *Drawida calebi, Drawida willsi, Lampito mauritii, Octochaetona suremis, Ocenerodrilus occidentalis*	Maximum 78 gm per m^2 (20 to 78g/m^2) peaked during winter.
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): as here grasslands in Sambalpur, Orissa(monthly sampling).	Two species *Lampito mauritii, Ocnerodrilus occidentalis*	-Maximum density of (18 to 88/m^2) individuals per m^2 (i.e., 860,000 individuals/ha) -(6 to 61 g/m^2) (peak density in winter)
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 drydeciduous woodland of western Orissa (montly)	Four species: *Lampito mauritii, Drawida calebi, Rameila bishambari, Pellogaster bengalensis*	131 individuals per m^2 (7-28.5 g/m2) in October (24-131) Peaket in October.
Present study (Nanda Devi, Himalayan region)	Eight species: *Lennogaster pusillus, Metaphire houlleti, Metaphire anomala, Ocnerodrilus occidentalis,*	

	Dendrodrilus rubidus, Aporrectodea caliginosa(endogeic), Amynthas cortices, Drawida nepalensis	

Table 4.5. Coefficient of variation of Hymenoptera population (0-30 cm) in different land use types.

Lower elevation zone	October	April	July
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 4.6. Coefficient of variation of Isoptera population (0-30 cm) in different land use types.

Lower elevation zone	October	April	July
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 4.7. 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 4.8. 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 4.9. 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 4.10. 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 4.11. 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 4.12. 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 4.13. 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 4.14. 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 4.15. 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 4.16. 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	-	-	-	-	-	149.9

indica						(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 4.17. 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.

Forest types	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 4.18. 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		

Chapter 5

Mesofauna around Nanda Devi Biosphere Reserve

1. Introduction

Nematodes, mites and collembola are suitable bioindicators of soil health as ecosystem management practices invariably affect their food source and/or micro-environment, they are placed at an intermediate level in the food chain and their generation time long enough making them temporally stable unlike microbes which fluctuate with ephemeral nutrient flushes (Ferris and Ferris, 1974; Bongers, 1990; Frampton, 1997; Ruf, 1998; Dombos, 2001; Culik et al., 2002). However, in many situations some of these communities have been found to exhibit a wide range of tolerance. Zaitsev et al. (2002) did not find any prominent change in orbatid mite diversity in spruce forest stands varying in age from 5 to 95- years. Mites in this case thus constitute a conservative element of decomposer fauna providing buffering mechanisms against strong environmental change. Because of substantial information available on taxonomy and feeding habits of nematodes as compared to mites and collembola , nematodes are often argued to be more practical for biomonitoring as compared to mites and collembola (Gupta and Yeates, 1997). Soil nematodes interact in ecosystems directly as herbivores on plants and indirectly as consumers of microflora (Dash and Pradhan,1984). They regulate nutrient availability to plants through excretion and by maintaining bacteria in a logarithmic growth phase (Coleman et al., 1984; De Ruiter et al., 1993; Bardgett et al., 1999).

Classification of nematodes into trophic groups is a useful way of looking at the functional diversity of nematode community but there are some limitations in application of this approach (Table 5.1). First, taxa are generally assigned trophic groups based on buccal structures rather than the actual feeding habits (Freckman and Caswell, 1985; Juma and Mishra, 1988; Yeates et al., 1992). Second, there may be subtle differences between species placed within a functional group which are not taken into account in the existing trophic group classification (Yeates et al., 1999; Duffy, 2002). Third, trophic groups may not be necessarily mutually exclusive, e.g., *Tylenchus* spp. are often regarded as fungal-feeders in ecological studies but several species do feed and reproduce on plant roots (Neher, 2001), some "predaceous" *Mesodorylaimus* sp. can grow and reproduce by feeding on bacteria (Russell, 1986).

Table 5.1. Trophic group classification of nematodes (Wasillewska, 1971).

Trophic group	Families
Microbivores	Rhabditidae Diplogasteridae Panaigrolaimidae Cephalobidae
Fungivores	Tylenchida
Parasites	Tylenchida Dorylaimida
Omnivores	Dorylaimida Enoplida
Predators	Monochida Seinura Dorylaimids
Algivores* /unicellular eukaryotic (diatoms and algae) feeders	
Plant associates*	
Substrate ingestors	
Entomopathogenic	

* trophic groups given by Yeates et al. (1993)

A number of studies have been carried out on evaluating the abundance, impacts and management of nematodes in India (Senapati and Dash, 1976; Dash and Pradhan ,1984; Pradhan and Dash, 1987; 1988; Pradhan et al.,1988; Akhtar and Alam, 1992; Akhtar, 1998; Anver and Alam, 1989; Siddiqui and Mahmood, 1994; Shukla and Akhtar, 1996; Pandey et al., 1999; Siddiqui and Mahmood, 1998; Siddiqui and Alam, 1989; Tiyagi and Alam, 1995; Siddiqui and Alam, 1987; Akhtar and Malik, 2000; Jothi et al., 2004). However, most efforts have laid stress on plant parasitic nematodes in agroecosystems and there have been no systematic studies on inventory of nematodes and other soil fauna on a landscape scale. The objective of this study was to compare the abundance and diversity of nematodes in a landscape around Nanda Devi Biosphere in the Central Himalaya.

Bongers (1990) based on his work in high input agroecological regions in Netherlands proposed and tested the Maturity Index (MI). Nematode taxa were placed in the continuum of colonizer, the r-strategists to the persisters, the K-strategists (Table 5.2).

Table 5.2. A comparative account of the ecological attributes of r-strategist and K-strategist nematodes (Bongers and Ferris, 1999).

r-strategists	K-startegists
Numerically dominant in samples	Never belong to dominant species in samples
High fluctuation in population densities	Hardly fluctuate in numbers during the year
High rate of metabolic activity	a corollary of low metabolic activity
Voluminous gonads	Small gonads
Release large numbers of small eggs	Produce large eggs
Often viviparous	

As all families are composed of more or less related genera which tend to show morphological as well as ecological similarities, it seems unlikely that within a putative monophyletic family both colonizers as well as persisters occur. All genera within a family and all species within a genus are not likely to have exactly the same colonizing/persistence ability. Fiscus and Neher (2002) differentiated nematode taxa based on their sensitivity to tillage and alterations in soil chemistry. These ratings often conflicted with *cp* ratings implying limitations to the use of MI and PPI which take into account colonization-persistence abilities of nematodes. As MI may show seasonal fluctuations (Bongers, 1990), one time assessments may lead to erroneous conclusions. Building on the concepts pioneered by Bongers (1990), a number of indices quantify diversity of nematode community (Table 5.3).

Table 5.3. Indices used for characterizing nematode communities

Index	Proposed use and limitations	Formula
Diversity indices based on taxa diversity	Qualitative differences between taxa are not taken into account (e.g., absence of any differentiation of exotic species and endemic species)	H’ = - Σ *pi* (log *pi*) Pi is the proportion of the taxa in the total population

	Some indices are more sensitive to rare species (e.g., Shannon Weaver Index (H')) and others to more common species (e.g., Simpson Index (D))	$D = 1/\Sigma\, (ni/N)^2$ ni is the number of individuals of species *i*, and *N* is the total number of individuals in the community
Diversity index based on trophic group abundance/diversity	As above	
Fungivore/bacterivore ratio	Indicator of decomposition pathway in ecosystem – dominance of bacterivore indicates dominance of high quality organic matter	
Nematode channel ratio (NCR)	(Abundance of bacterial feeding nematodes/Abundance of bacterial feeding nematodes+ Abundance of fungal-feeding nematodes)	NCR = B/B+F B and F are the relative contributions of bacterial and fungal nematodes to total nematode abundance respectively
Maturity index (Bongers et al., 1990)	Incorporates ecological characteristics of families based on colonizers to persisters scale of 1-5. A lower index indicates disturbance Only free living nematodes with c-p value ranging from 1 to 5 were included.	$MI = \sum_{i=1}^{n} v(i) . f(i)$ where *v(i)* is the colonizer-persister (c-p) value assigned to taxon *i*, and *f(i)* is the frequency (dominance) of taxon *i* in the sample.
Plant parasite index (PPI) (Bongers, 1990)	Consideration of only plant parasites with cp values from 2 to 5; A higher index reflects increased plant production. Opportunistic taxa (cp = 1) are considered as enrichment opportunists which rapidly multiply following nutrient additions and hence, their high population densities may not necessarily reflect long-term changes in soil conditions. This group is excluded. The index is based on taxa with cp values of 2 to	PPI is similar to MI formula based on a scale of 1-5, but excludes free-living taxa. Here, plant feeding taxa are assigned a c-p value from 2-5

	5 as they are more stable	
Total maturity index (Yeates, 1994)	Consideration of both free living and parasitic nematodes	$\Sigma MI = \sum_{i=1}^{n} c\text{-}pi \cdot pi$ c-p is the c-p value, p is the proportion of individuals in the *i*th taxon and n is the number of taxa in the sample
Ratio of the total nematode population to the population of phytophagous tylenchids	An index found to be related to forest disturbance	
Enrichment Index (EI) (Ferris et al., 2001 ; Ferris, 2004)	Provides an indicator of resources available to the soil food web and the response of primary decomposers to those resources	EI = 100 (e/(e+b)), e is the abundance of individuals in guilds in the enrichment component weighted by their respective k_e values and b is the abundance of individuals in the basal component weighted by their k_b values
Structure Index (SI) (Ferris et al., 2001 ; Ferris, 2004)	A higher SI value results from the presence of omnivore and predator nematodes; it suggests a food web with more trophic linkages	SI = 100 (s/(s+b)) S is the abundance of individuals in the structure component weighted by their k_s values and b is the abundance of individuals in the basal component weighted by their k_b values
Channel Index (CI) (Ferris et al., 2001)	A high index indicates that fungal decomposition pathway dominates.	CI = 100 $(k_{fu2}Fu_2)/(k_{Ba1}Ba_1+ k_{fu2}Fu_2)$ the coefficients are the enrichment weightings for the Fu_2 fungivore guild and Ba_1

		enrichment-opportunist bacterivore guild
(Bacterial feeders + Hyphal feeders)/Obligate plant parasites		
Obligate plant parasites/plant feeders		
Statistic "R" (Kermarrec and LaMassese, 1972)	Ratio of the total nematode population to the population of phytophagous tylenchids and found this ratio to be sensitive to forest disturbance	
Trophic structure (T) (Yeates, et al., 1992)	Describes diversity of functional groups within the nematode community	$T = 1/\Sigma\, pi^2$ *p(i)* is the proportion of trophic group *i* in the nematode community

2. Methods

Soil samples from 0-10 and 10-20 cm depths were collected from each of seven land use-land cover types differentiated in the Langasu village landscape (n = 5 per land use) covering all the three seasons. Efficiency of nematode extraction through the two common methods viz., Cobb's sieving and sucrose centrifugation methods were compared in composite samples (0-20 cm depth) collected towards the end of winter seasons (March) covering all land uses Table 5.4.

Table 5.4. Description of methods

Steps	Sucrose centrifugation method	Cobb's sieving and decantation method
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
2	Waited for 2 minutes for sedimentation of soil, then passed the suspension 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.	Stirred the suspension, waited for 40 seconds and passed the supernatant through 250 micrometer (60 mesh size) sieve inclined at about 45 degree angle; this process was repeated for the residue left behind in the bowl. Larger nematodes trapped on the sieve taken in beaker for further observations.
3	The soil remain on the 32 micrometer sieve was taken in centrifuge tubes with about 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..
4	Discarded the supernatant water and added 48% sucrose solution and centrifuged again at 3000 rpm for 2 minutes.	Suspension passed through 32 um was discarded and the residue was suspended in 30-40 ml of water. This suspension was poured over two layers of tissue paper mounted on a stainless steel mesh temporarily laid over a pertri plate. This arrangement of tissue paper in contact with the suspension was kept for 48 hours. Nematodes remained on tissue paper were mixed with 250 micrometer nematode fraction (step 2 above). Nematodes that moved down to the Petri plate were collected in a separate beaker for further observation.
5	The supernatant sucrose solution was poured on 32 micrometer sieve and nematodes trapped on the sieves washed with a jet of water.	Nematodes were in 2 ml suspension each of the two suspensions, one containing the nematodes trapped on sieves and the other containing the smaller ones that migrated away from

		tissue paper.
6	The nematodes were suspended in 10-15 ml of water in a beaker.	
7	Nematodes were counted in 5 ml of suspension and abundance per 100 g soil calculated.	

Cobb sieving method, though more laborious as well as time-taking, was more efficient compared to sucrose centrifugation method in that it recovered markedly higher number of nematodes ($P < 0.01$) (Table5.5). Assuming that higher recovery in terms of abundance also implied advantage of recovering higher number of taxa, Cobb sieving method was followed. Another advantage of Cobb sieving method was reduction in amount of debris that posed problems in identification of nematodes. Attributes viz., root biomass, surface litter, herbaceous biomass,

Table 5.5. Abundance of nematodes (SEM in parentheses) enumerated from Cobb sieving and Sucrose centrifugation methods.

Method	Nematode abundance
Cobb's method	439 (101)
Sucrose centrifugation method	105 (12)

3. Results

3.1. Family-wise abundance

In all 12 families, two of bacterivores, one each of fungivore, predators and saprofagous, and seven of parasitic nematodes, were represented in the landscape. Thus, parasitic nematodes showed the highest level of taxonomic diversity. Except for Tylenchulidae which was present only in deeper soils, all other taxa were present in surface soil or at both soil depths. Only a few families showed land use specific occurrence. Tylenchulidae was present only in homegardens and rainfed agriculture, Heteroderidae only in irrigated agriculture, Meloidogynidae in all land uses except oak forests and home gardens, Longidoridae in all land uses except home gardens and scrubland, and Mononchidae in all land uses except irrigated agriculture and scrub land. With a few exceptions, abundance of a family decreased with depth within a given land use. Of the two bacterivore families, Cephalobidae was more abundant compared to Araeolaimidae, while parasitic Hoplolaimidae and Tylenchidae were more abundant than other parasitic families in all land uses (Table 5.6). A summary of studies carried out on mesofauna particularly on nematode diversity and abundance in Himalayan region and other areas in India is presented in Table 5.12.

Table 5.6. Nematode abundance (disaggregated by families; functional groups specified within parenthesis) in 0-10 cm and 10-20 cm soil layers in different landuses in Chamali villages (n=5). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland; B, Bacterivore; F, Fungivore; S, saprofagous; PP, plant parasite; P, predator

Family (Functional group)	c-p values	OF		PF		HG		IA		RA		AA		SL	
		(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)
Aphilenchidae (F)	2	5	5	15	0	35	30	28	10	113	23	5	35	15	18
Araeolaimidae (B)	1	40	0	13	0	15	13	13	8	13	8	8	0	0	18
Cephalobidae (B)	1	95	20	135	20	130	53	113	45	153	25	38	10	70	33
Criconematidae (PP)	3	35	30	28	3	3	0	8	0	23	0	0	0	5	0
Dorylaimidae (S)	4	93	10	145	0	50	0	58	8	120	43	48	20	100	80
Heteroderidae (PP)	3	0	0	0	0	0	0	13	0	0	0	0	0	0	0
Hoplolaimidae (PP)	3	48	10	110	5	85	30	48	75	205	65	155	80	58	0
Longidoridae (PP)	5	3	0	3	0	0	0	5	0	3	0	3	3	0	0
Meloidogynidae (PP)	3	0	0	0	15	0	0	25	60	23	0	8	0	15	13
Mononchidae (P)	4	15	0	3	10	0	13	0	0	3	3	0	3	0	0
Tylenchidae (PP)	2	55	10	125	8	60	35	55	23	180	20	80	20	50	35
Tylenchulidae (PP)	2	0	0	0	0	0	10	0	0	0	5	0	0	0	0

Relative abundance of families differed with depth and land use. Relative dominance of bacterivore Cephalobidae in home gardens and irrigated agriculture, saprofagous Dorylaimidae in scrub land and plant parasitic Hoplolaimidae in abandoned agricultural land was markedly higher than the next dominant family in 0-10 soil layer of respective landuse types. Bacterivore Cephalobidae and saprofagous Dorylaimidae in oak forest and these two families as well as parasitic Tylenchidae in pine forests showed almost similar values of relative dominance. In 10-20 cm layer of soil, plant parasitic Criconematidae in oak forest, bacterivore Cephalobidae in pine forest and home gardens, Hoplolaimidae in irrigated, rainfed and abandoned agricultural lands and saprofagous Dorylaimidae in scrub lands showed significantly higher relative abundance compared other families that occurred in respective landuses (Table5.7).

Table 5.7. Relative abundance of nematode families disaggregated in village landscape in different landuses (n=5). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland; B, Bacterivore; F, Fungivore; S, saprofagous; PP, plant parasite; P, predator.

	OF		PF		HG		IA		RA		AA		SL	
Family (Functional group)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)	(0-10 cm)	(10-20 cm)
Aphilenchidae (F)	1	6	3	0	9	16	8	4	14	12	1	21	5	9
Araeolaimidae (B)	10	0	2	0	4	7	3	3	2	4	2	0	0	9
Cephalobidae (B)	25	24	23	33	34	29	31	20	18	13	11	6	22	17
Criconematidae (PP)	9	35	5	4	1	0	2	0	3	0	0	0	2	0
Dorylaimidae (S)	24	12	25	0	13	0	16	3	14	22	14	12	32	41
Heteroderidae (PP)	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Hoplolaimidae (PP)	12	12	19	8	23	16	13	33	25	34	45	47	18	0
Longidoridae (PP)	1	0	0	0	0	0	1	0	0	0	1	1	0	0
Meloidogynidae (PP)	0	0	0	25	0	0	7	26	3	0	2	0	5	6
Mononchidae (P)	4	0	0	17	0	7	0	0	0	1	0	1	0	0
Tylenchidae (PP)	14	12	22	13	16	19	15	10	22	11	23	12	16	18
Tylenchulidae (PP)	0	0	0	0	0	5	0	0	0	3	0	0	0	0

3.2 Similarity between nematode communities in different landuses

Nematode communities in different land use types differed more in 10-20 cm soil layer compared to 0-10 cm layer. In the community inhabiting the entire depth (0-20 cm) sampled, maximum contrast was observed between oak forest and rainfed agricultural land/abandoned agricultural land (only 53% of species being common) and minimum between home garden and irrigated agriculture (Table 5.8).

Table 5.8. Index of Similarity for different landuses considering total nematodes. OF, Oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

Landuses		PF	HG	IA	RA	AA	SL
	0-10 cm						
OF		71.3	70.8	76.0	55.4	54.8	77.4
PF			74.8	66.8	77.7	63.7	67.2
HG				83.8	62.1	67.8	71.3
IA					58.4	60.4	77.3
RA						58.7	54.7
AA							63.2
	10-20 cm						
OF		49.7	33.6	33.9	40.0	35.3	32.1
PF			35.5	33.4	28.8	22.6	32.2
HG				56.6	61.2	52.8	52.5
IA					65.1	61.9	45.0
RA						78.3	59.2
AA							37.3
	0-20 cm						
OF		73.7	66.2	65.1	53.8	53.2	73.9
PF			77.0	76.7	75.3	64.1	77.4
HG				80.3	68.2	67.1	65.2
IA					63.8	67.8	70.7
RA						66.7	63.5
AA							60.4

3.3. Functional groups of nematodes and community indices

At 0-10 cm soil depth, total nematode abundance showed the trend: rainfed agriculture > pine forests > oak forests = home garden = irrigated agriculture = abandoned agricultural land = scrub land. The land uses with similar total nematode abundance differed in terms relative dominance of different functional groups: predators showed higher relative dominance in oak forests, fungivores in home gardens and irrigated agriculture, plant parasitic nematodes in abandoned agricultural land and saprofagous nematodes in scrub land. In all land uses, nematode abundance decreased with depth, this trend being more marked in pine forests (> 10-fold decrease in total nematode abundance) compared to other land uses (2-4-fold decrease). Nematode abundance in 10-20 cm soil layer was significantly lower in the two forest land uses (with insignificant differences between them) compared to non-forest land uses (with insignificant differences between them). As in the case of 0-10 cm soil depth. The land uses with similar nematode abundance in 10-20 cm layer, did differ in terms of relative abundance of different trophic groups. Oak forests differed from pine forests in terms of higher relative abundance of fungivorous and saprofagous nematodes but lower of predators. Among the non-forest land uses, home gardens showed a higher relative density of predators and bacterivores, irrigated agriculture of plant parasitic nematodes and scrublands of saprofagous nematodes, while rainfed agriculture and abandoned agricultural lands showed lower relative dominance of bacterivores. If the data of the two depths are pooled, nematode abundance was significantly higher in rainfed agriculture compared to other land uses with insignificant differences between them. Parasitic group in irrigated agriculture, rainfed agriculture, abandoned agriculture and pine forests, bacterivores in home gardens and saprofagous in scrub land and were more abundant compared to other trophic groups (Fig. 5.1.).

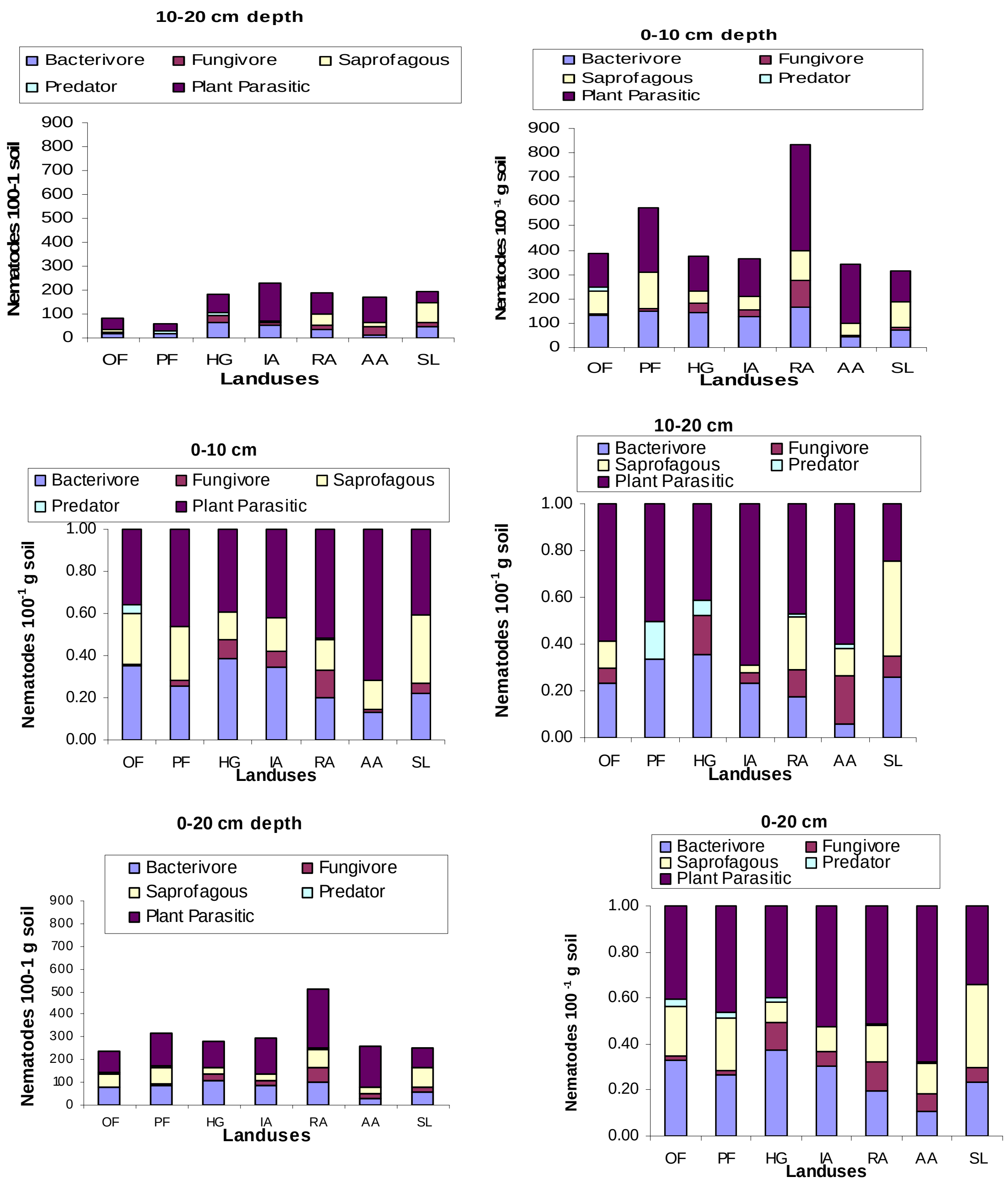


Fig. 5.1. Absolute and relative abundance of nematodes disaggregated by functional groups in 0-10 cm and 10-20 cm soil layers in different landuse types in Langasu landscape around Nanda Devi Biosphere Reserve). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

Home gardens showed the lowest values of maturity indices, but only the mean index for 0-20 cm layer was significantly different from all other land uses with insignificant differences between them. Home gardens and scrublands showed the lowest values of PPI. Diversity index did not differ significantly between different land use types except rainfed agriculture with abandoned agriculture at 0-10 cm soil layer, pine forest with rainfed agriculture at 10-20 cm soil layer, and oak forest, irrigated and rainfed agriculture with abandoned agriculture (Table5.9).

Table 5.9. The Maturity Index (MI), Plant parasitic Index (PPI), Bacterivore/Fungivore ratio (B/F) and Diversity Index (H) of various landuses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

	OF	PF	HG	IA	RA	AA	SL	LSD
MI (0-10 cm)	2.46	2.51	2.12	2.40	2.46	2.66	2.62	0.48
MI (10 -20 cm)	2.55	2.00	1.89	2.46	2.61	2.92	2.61	0.53
MI (0-20 cm)	2.45	2.49	2.04	2.44	2.48	2.69	2.68	0.36
PPI (0-10 cm	0.99	1.13	1.03	1.31	1.39	2.08	1.13	0.75
PPI (10-20 cm)	1.69	1.30	0.81	1.95	1.17	1.29	0.56	0.45
PPI (0-20 cm)	1.13	1.14	1.01	1.59	1.34	1.97	0.90	0.62
B/F (0-10 cm)	0.40	1.85	1.21	4.7	3.06	0.5	1.7	3.70
B/F(10-20 cm)	0.20	0.00	2.42	1.86	0.5	0.27	2.3	2.28
B/F (0-20 cm)	0.30	2.05	5.52	5.28	3.21	1.45	4.37	3.90
H (0-10 cm)	1.51	1.43	1.31	1.47	1.59	1.09	1.46	0.43
H (10-20 cm)	1.31	0.71	1.21	1.14	1.41	1.03	1.14	0.64
H (0-20 cm)	1.63	1.53	1.55	1.63	1.66	1.22	1.60	0.39

3.4 Variability

There was a high degree of within-class variability in abundance. Bacterivore Cephalobidae, saprofagous Dorylaimidae and parasitic Hoplolaimidae and Tylenchidae showed a lesser degree of within-land use variability compared to other taxa (Table5.10). Pooled abundance data showed the lowest degree of within-class variability for parasites in land uses. Coefficient of variation decreased from finer scale of observation at family and individual depth to coarser level of observation, i.e., aggregation by trophic groups, total abundance, community indices and all pooled soil depths (Table 5.11).

Table 5.10. CV of Nematode families disaggregated in different landuses in different soil layers in Chamali villages (n=5). OF, Oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland;

Family (Functional group)	OF		PF		HG		IA		RA		AA		SL	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Aphilenchidae (F)	224	224	149	0	170	48	75	163	54	114	224	111	137	64
Araeolaimidae (B)	41	0	141	0	224	141	224	224	224	149	224	0	0	120
Cephalobidae (B)	79	34	109	95	55	20	82	99	114	50	78	163	63	120
Criconematidae (PP)	186	23	177	224	224	0	224	0	138	0	0	0	224	0
Dorylaimidae (S)	95	56	85	0	73	0	76	91	56	71	112	105	74	74
Heteroderidae (PP)	0	0	0	0	0	0	224	0	0	0	0	0	0	0
Hoplolaimidae (PP)	118	56	85	224	54	140	80	33	42	84	65	85	36	0
Longidoridae (PP)	224	0	224	0	0	0	137	0	224	0	224	224	0	0
Meloidogynidae (PP)	0	0	0	224	0	0	154	120	149	0	224	0	137	224
Mononchidae (P)	137	0	224	163	0	173	0	0	224	224	0	224	0	0
Tylenchidae (PP)	34	224	60	91	74	73	151	194	90	144	110	157	66	92
Tylenchulidae (PP)	0	0	0	0	0	224	0	0	0	224	0	0	0	0

Table 5.11. CV of Nematodes disaggregated by feeding groups in different landuses at different soil layers in Chamali villages (n=5). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland;

	OF		PF		HG		IA		RA		AA		SL	
Functional Groups	0-10 Cm	10-20 Cm	0-10 Cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 Cm	10-20 Cm	0-10 cm	10-20 cm
Bacterivore	65	34	96	95	50	34	79	88	104	70	58	163	63	116
Fungivore	224	0	149	0	170	0	75	0	54	0	224	0	137	0
Saprofagous	95	56	85	0	73	0	76	91	56	71	112	105	74	74
Predator	137	0	224	163	0	173	0	0	224	224	0	224	0	0
Plant Parasitic	40	31	60	134	36	81	57	70	33	70	42	70	48	57

Table 5.12. A summary of studies carried out on mesofauna – nematodes diversity and abundance in Himalayan region and other areas of India.

S.N.	Author of study area	Nematode species diversity	Major trends, abudance and biomass
1.	Dash and Pradhan (1984). Distribution and population dynamics of soil nematodes in a tropical hill ecosystem of Sambalpur, Orissa.	Plant parasitic forms (6 spp.) Microbivores (1 spp.) Miscelllabeous feeders (4 spp.) Predators (5 spp.)	- Population diversity was found maximum during November (171.85 mg fresh mass m^{-2}/month) and minimum during may (48.71 mg fresh mass m^{-2}/month). - The fresh biomass ranged between 47.9 mg m^{-2} to 169.7 mg m^{-2}.
2.	Dash and Mishra (1986). Effect of moisture in intrinsic rate of increase and net reproductive rate of soil nematodes.		- Significant positive coorelation existed between the soil moisture with plant parasitic nematodes and total nematodes (r = 0.69 and r = 0.41) respectively. Net reproductive rate (RO) in general for nematodes ranged from 1 to 2, at how value in comparison to other invertebrates.
3.	Senapati and Dash (1978). A comparison of three methods of extraction of soil nematodes in trhee grassland sites, Orissa.		- More than 90% of the nematodes occur in the top 6 cm of the soil propile in all sites. Maximum nematodes number was 22.224 x $10^6/m^2$ (9 cm deep) in the grassland sites. - Among the three extraction methods used Millipore filter method is found most suitable for quantitative estimation of nematodes number.
4.	Pradhan and Dash (1987). Distribution and population dynamics of soil nematodes in tropical forest ecosystem from Sambalpur, Orissa, India.	17 species of nematodes were identified of which *Rotylenchus* spp. was the dominant plant parasitic form and *Acrobeloides* spp. was the dominant microbiovore species.	- Of the total nematodes 88.4% occurred in the top 10 cm soil. - Total nematode diversity ranged from 15.1 x 104/m^2 (May) to 66.1x104/m^2 (Nov.). - Monthly mean nematode biomass was 18.86$\pm$8.36 mg

			dry wt/m^2.
5.	Pradhan and Dash (1988). Soil nematodes in tropical hill slopes of Sambalpur, India.	Eight species of plant parasitic nematodes occurred in both north and south facing footslopes. *Helicotylenchus indicus* Siddiqui was the dominant plant parasitic form recorded from all the slope positions.	- Most plant parasites occurred on the footslopes and increased to greatest biomass in January (32.2 mg dry wt./m2) and lowest in may (5.3mgdry.wt./m2).
6.	Pradhan, Senapati and Dash (1988). Relationship of soil nematodes population to carbon: nitrogen ……….. laboratory decomposition of litter anendments.	Plant parasites (5 spp.) Microbivores (2 spp.) Miscellaneous feeders (4 spp.) Predators (8 spp.)	- Changes in trophic structure of soil nematodes were observed in relation to losses of organic matter during the decomposition of littre in the laboratory. - Soil nematodes could enhance degradation of organic matter by about 16.1% in the field soil, 29.8% in 5% litter, 23.4% in 10% litter, 29.5% in 20% litter indicating their role as a decomposer.
7.	Dash, Senapati and Mishra (1980). Nematode feeding by tropical earthworms.		- The nematode population in the pole containing a single earthworm decreased by 20.7, 28.8, 53.7, 21.0 and 24.3% in 1,2,3,4 and 6 week old cultures. - Gut content analysis showed that earthworms fed mainly on non-parasitic nematodes. These decreased by max. 90% during the six week period as compared with a decrease of max. 47% in the parasitic forms.

4. Landuse Characteristics

4.1. Litter Content

Litter biomass in oak forests was about 1.5 times higher compared to that in pine forests and about 5 times higher compared to that in other land uses (with insignificant difference between them) (Fig. 5.2).

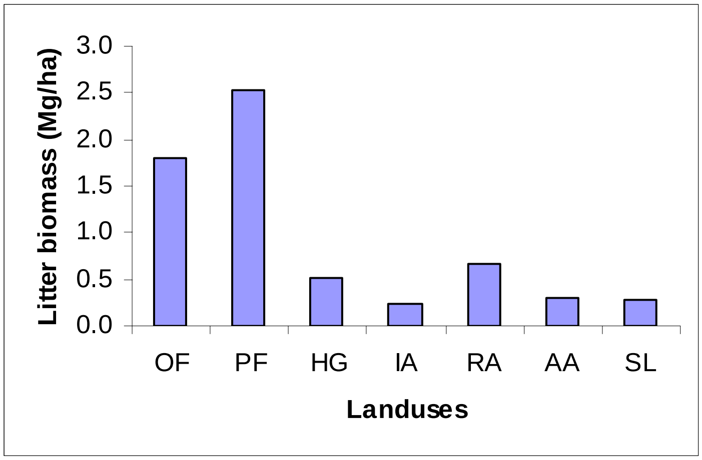


Fig 5.2. Litter biomass (Mg/ha) of different landuses in village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

4.2. Herbaceous Biomass

After winter crop harvest herbaceous biomass in crop fields is negligible. It showed highest values in oak forests and abandoned agricultural land (about 1 Mg/ha) followed by 0.7 Mg/ha in scrub lands, 0.5 Mg/ha in pine forests and 0.4 Mg/ha in home gardens (Fig.5. 3).

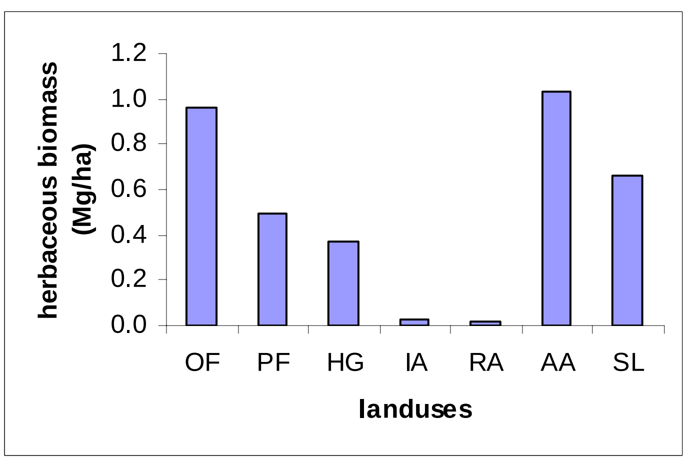


Fig 5.3. Herbaceous biomass (Mg/ha) of different landuses in village landscape. OF, Oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

4.3. Root biomass

Home garden and all agricultural land uses had insignificant root biomass in 10-20 cm soil layer. Root biomass in 10-20 cm layer accounted for about 40% of total root biomass in pine forests, 30% in scrublands and abandoned agricultural land, 10% in oak forests and <4% in agricultural land uses and home gardens. In all land uses, coarse root biomass in 10-20 cm layer was equal or higher than that of fine root biomass. In 0-10 cm layer, fine root: coarse root biomass ratio varied from about 30 in home gardens to about 2 in abandoned agricultural land, 1 in forests and croplands and 0.5 in scrublands. Total root biomass varied from 10.5 Mg/ha in oak forests to 0.8 Mg/ha in home gardens. Pine forest and irrigated agriculture, and rainfed agriculture and abandoned agricultural land did not differ significantly in terms of total root biomass in 0-20 cm soil layer (Fig. 5.4).

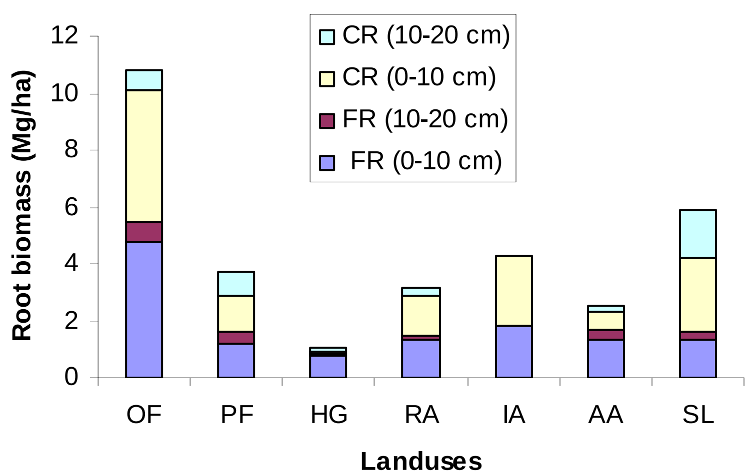


Fig 5.4. Root biomass (Mg/ha) of different landuses in village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland; CR, Coarse roots; FR, Fine Roots.

4.4 Moisture Content

Moisture content showed a narrow range of variation across land uses, from 13 to 21% at 0-10 cm depth and from 9 to 15% at 10-20 cm depth. Moisture content decreased with depth but this trend was not significant in rainfed agriculture, irrigated agriculture and abandoned agricultural land. Home gardens showed the highest and rainfed agriculture and pine forest the lowest soil moisture levels while other land uses showed intermediate values with insignificant differences (Fig.5. 5).

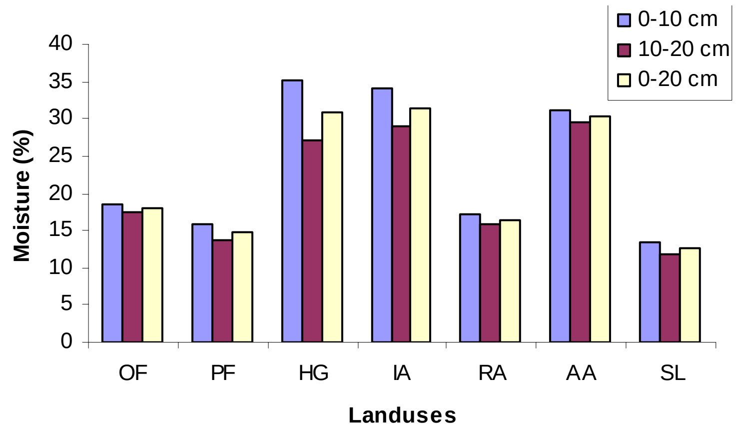


Fig 5.5. Moisture (%) content of soils in different landuses in village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

4.5. Chemical Properties

Soil pH showed the trend oak forest = pine forest < irrigated agriculture = rainfed agriculture < abandoned agricultural land = scrubland = home gardens. The two soil depths showed similar pH in all land uses (Fig. 5.6). Soil organic carbon concentration in the two depths considered together or separately in home gardens and irrigated agriculture was about 2 times higher than that in forests, rainfed agriculture and scrubland, with non-significant differences between the latter land uses (Fig.5.7). Exchangeable Ca concentration in home gardens and irrigated agriculture was about 3-times higher than that of forest, rainfed agriculture and scrubland soils. Ca content did not change with depth in all land uses except in oak forests where it decreased significantly (Fig.5.8). Exchangeable Mg decreased with increase in soil depth in all land uses except in oak forests where it increased and abandoned agricultural land where it did not change with increase in soil depth. Mean concentrations in 0-20 cm layer in home gardens and abandoned agricultural land was about 3 times higher compared to oak forests and 2-times compared to other land uses (Fig.5.9). Exchangeable K decreased in forests, home gardens and abandoned agricultural land, increased in irrigated/rainfed agricultural land and did not change in scrublands with increase in soil depth. Average concentration in 0-20 cm depth showed the trend: home gardens > irrigated agricultural land =

rainfed agricultural land > oak forests = pine forests = abandoned agricultural land > scrublands (Fig.5.10).

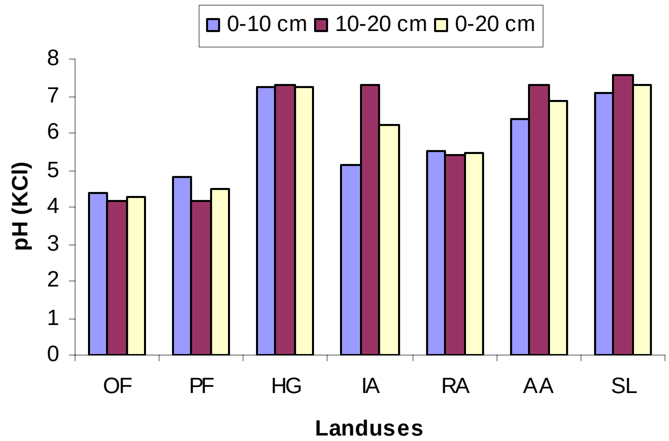


Fig. 5.6. pH (KCl) of soils of different landuses in village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

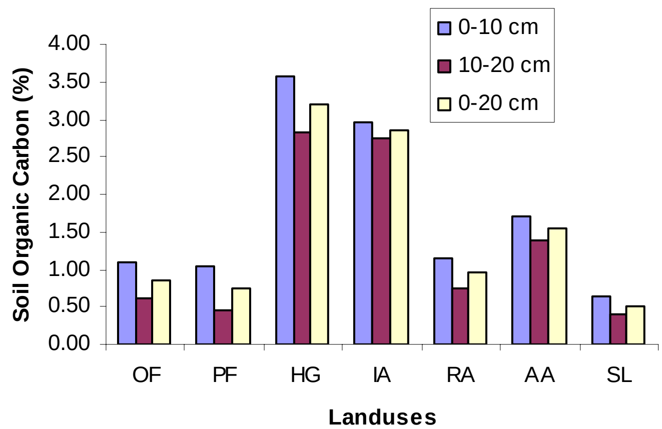


Fig 5.7. Soil Organic Carbon (%) of soils of different landuses in village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

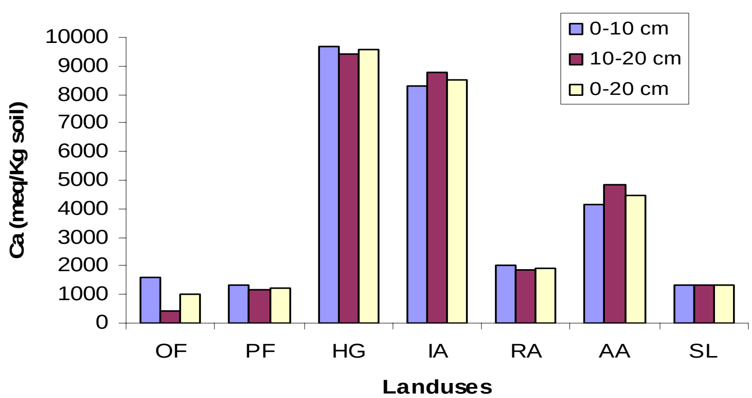


Fig 5.8. Ca (meq/Kg soil) of soils of different landuses in village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

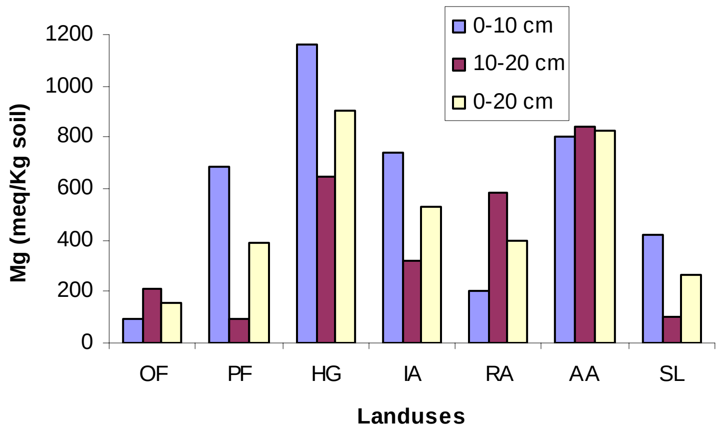


Fig 5.9. Mg (meq/Kg soil) of soils of different landuses in village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

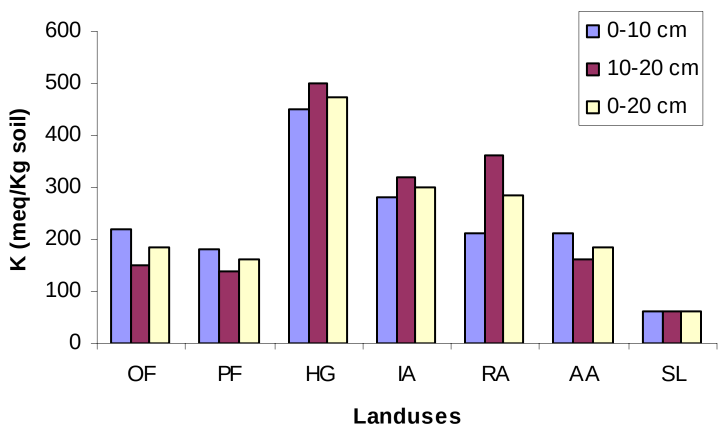


Fig 5.10. K (meq/Kg soil) of soils of different landuses in village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland.

Nematode abundance did not show any significant relationship with individual land use attributes stated above.

5. Discussion

5.1. Total nematode abundance in relation to land use and ecosystem attributes

Freckman and Ettemma (1993) observed a significant relationship between total nematode population and land use intensification/disturbance intensity, while Panesar et al., (2000) observed nematode abundance to be significantly influenced by clear-cutting, shelter wood and extended rotation forest management treatments.

On the other hand, several workers have observed nematode abundance to be a rather stable feature. Insignificant differences in nematode abundance was noted in comparison of the conventional and no-tillage agriculture by Hendrix et al. (1986), of corn and sorghum cropping systems in Florida by Gallaher et al. (1991), of clear-cut and other conifer forests in Finland by Huhta et al., (1967), of less disturbed forests with Rhododendron (*Rhododendron maximum*) removal and hurricane windthrow disturbances by Wright and Coleman (2002) southern Applachians, and of crop fields, fallow lands and woodlands by Ou et al., (2005). Insignificant differences in total nematode abundance in diverse land use/cover types such as pine forests, oak forests, abandoned agricultural land and scrublands observed here also suggest that total nematode abundance may not be a very powerful attribute reflecting impact of land use/land cover change on soil biota.

5.2. Effect of moisture/water-logging

Nematodes needing moisture to remain active are stressed more by drought than by low temperatures (Huhta et al., 1967) but such an effect of moisture may not be evident if oxygen and food are limited (Weaver and Smolik, 1987; Ruess et al., 1996). Sulfate reducing bacteria get activated in oxygen deficient conditions and produce sulfur compounds toxic to nematodes (Porazinska et al., 1999). Higher nematode abundance in rainfed agriculture devoid of any waterlogging compared to irrigated agriculture where fields flooded and hence are waterlogged for some time during the year reported in this study has also been reported by Ou et al. (2005) in Chinese agricultural systems. Amelioration of water stress but absence of waterlogging together with adequacy of food may be associated with high nematode abundance (McSorley, 1997; Matlack, 2001). Minor variations in soil moisture associated with different land uses may not show any signification correlations with nematode abundance as observed in the present study and also elsewhere (Freckman and Ettemma, 1993).

5.3. Effect of soil depth

A decline in nematode abundance with in increase in soil depth within a given land use and its correlation with soil organic carbon and nitrogen has been reported by Pradhan and Dash,(1987) and Pradhan et al., (1988) in pasture and agricultural land, Ou et al., (2005) in diverse land uses in aquatic brown soil, Yeates et al., (1980) in *Pinus radiata* plantations and grazed pastures, by Gould et al. (1979) in short grass prairies and Wall et al., (2002). We also observed a decline in nematode abundance with soil depth but this trend was not explained by soil chemical properties. Preference of Tylenchulidae members to deeper layers has also been reported by the studies of Popovici and Ciobanu (2000) in grassland ecosystems

5.4. Mulching

Mulching has been found to increase the population of nematodes with a relative contributors of bacterial feeders reported in the range of 46% to 76% of soil nematofauna (Porazinska et al., 1999; Bulluck et al., 2002). However, such a stimulation effect may be masked by extreme moisture stress and water-logging (????) or specific crop effects sustained with chemical fertilizer inputs (Garcia-Alvarez et al., 2004). In the present case, rainfed agriculture, irrigated agriculture and home gardens represent a 'positive mulching effect' (huge amount of forest leaf litter mixed with livestock excreta are added to crop fields) and other landuses a 'negative mulching effect'. The proportion of bacterial feeders in the present land uses with a positive mulch effect were towards the lower limit of the reported range. A very high abundance of nematodes in rainfed agriculture but not in home gardens and irrigated agriculture or insignificant difference between nematode abundance in forests where litter from forest floor is collected and irrigated agriculture/home gardens where the forest litter is applied point to a multitude of factors regulating nematode abundance.

5.5. Community indices

Panesar et al., (2000) did not find any significant change in trophic structure and taxonomic richness of nematode community under varied forest management systems. Urzelai et al., (2000) observed that diversity or maturity indices were not as sensitive as trophic composition to variation in perturbation in agroecosystems. Wright and Coleman (2002) did not find any change in nematode community composition following Rhododendron (*Rhododendron* *maximum*) removal and hurricane windthrow disturbances in the southern Applachians and Hanel (2004) following disturbances like those due to bark-beetle and clear cutting in spruce forests in Sumava mountains. Hoschitz and Kaufmann (2004) found maturity index to be stable in alpine Austrian landscape. In contrast, Yeates and Bird (1994) observed a change in some indices of community structure following in increase in intensity of agricultural land use from shrubland to pasture to wheat cultivation and McSorley (1997) with change in land use from pasture to Citrus groves. A positive impact of irrigation and negative of mulching on maturity index has been reported (Porazinska et al., 1998b; Porazinska et al., 1999). Hanel (2003) compared nematofauna in meadows derived from original oak-hornbeam and beech forests long back, meadow fields cultivated for over 25 years period and 2 year old abandoned fields derived from these meadows and concluded that land use change was coupled with a change in indices of diversity and maturity of nematode community. The data presented here show a mix of trends. Pine and oak forests, the former being an early-mid successional state and the latter the climax state did not differ in respect of maturity index. Our results support the conclusion drawn by Matlack (2001) that variation in abundance, species richness and diversity of nematode communities is linked more strongly to the soil properties than to the descriptors of aboveground vegetation such as canopy openness, herb cover and litter depth and (Popovici and Ciobanu (2000)) that no single soil chemical property has an overriding control on regulating nematode communities.

5.6. Nematodes and crop yields.

Plant parasitic nematodes are considered to be harmful and bacterivores beneficial for obtaining higher crop yields. A higher degree of diversity in parasitic nematodes compared to other functional/trophic groups reported in this study has also been observed elsewhere (Matlock, 2001). Lower populations of parasitic nematodes in the highly degraded and stressed scrublands is supported from the observations of Hanel (2003) and (Dmowska, 2001). It will be the relative abundance of harmful and beneficial organisms that will determine crop yields rather than mere presence or absolute abundance of parasitic taxa. Further, yield responses of susceptible crops to plant-parasitic nematodes are often a function of parasite densities at the time of planting (Kimpinski and McRae, 1988; Olthof and Potter, 1973). Porazinska et al. (1999) found that despite higher density of citrus root rot fungus

(*Phytophthora*) and higher weed abundance, productivity of mulch-treated trees was always greater possibly because mulch stimulated growth and activity of beneficial organisms lime bacterivore nematodes to an extent that far exceeded the crop loss due to the pathogenic fungus and weeds. Though, parasitic nematodes were present in large numbers in rainfed agriculture compared to home gardens and irrigated agriculture, crop loss due to nematode diseases is not observed in the regions suggesting an effective control of parasitic populations.

6. Conclusions

Efforts made on relating nematodes with land use intensification/disturbance have, by and large focused, on comparison of ecosystems which differ in respect of one type of disturbance (e.g., forest management systems differing in terms of intensity of tree removal) or one dimension of land use intensification (gradient of increasing agricultural inputs in crop lands, increase in grazing intensity in pastures) in temperate regions. Further, the experimental designs were such that the different treatments constituted independent land use systems with no or a very low level of interconnections between them in the landscape. The major conclusions arising from this study carried out in a landscape where the different ecosystems are intimately interconnected are (a) Cobb sieving method, though is more cumbersome and time-consuming, enables a better recovery and inventory of nematofauna (b) nematode abundance decreases with decrease in soil depth but this trend is not correlated with the trend in soil physico-chemical properties (c) plant parasite functional/trophic group is the most diversified nematode group (d) variability in nematode attributes decreases from finer scale of observation to coarser scale or synthetic indices but it remains to be investigated as to which variable is the best descriptor or predictor of land uses, soil health and disturbances (e) nematode community similarity/dissimilarity is not correlated with aboveground similarity/dissimilarity (f) abundance of parasitic nematodes is not an indicator of crop yield losses due to nematodes. These conclusions, however, may not be generalized too far in view of analysis of one-time data.

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Chapter 6

Abundance and Diversity of AM Fungi at Different Depths of Soil as Affected by Different Land Use Types in NDBR in Himalayas of Indian Sub-Continent

The abundance and diversity of arbuscular mycorrhiza (AM) fungi in different land use types was studied at different soil depths in the NDBR of Himalayas in the Indian Sub-continent. Thirty-four species of AM fungi were isolated from seven land use types. 13 of them belonged to the genus *Acaulospora*, three of them to the genus *Gigaspora*, eight of them to the genus *Glomus* and 10 of them to the genus *Scutellospora*. Most of the AMF species were confined to 0-10 species. They are; four species from the genus *Acaulospora viz., A. lacunose, A. rugosa, A. sporocarpia, A. tuberculata*, one species from the genus *Glomus i.e. G. manihotis*, and six species of *Scutellospora* (*S. carolloidea, S. cerradensis, S. dipurpurascea, S. gregaria, S. rubra* and *S. scutata*) but were absent in 10-20 cm soil depth. Only one species *viz. S. erythropa* was present in 10- 20 cm depth soil. These species confined to only one depth and belonged to the rare or occasionally frequent class (1-20% and 21-40% frequency of occurrence). At the landscape level, only one species of *Scutellospora* was dominant compared to three species of *Glomus*, five species of *Acaulospora* and none from *Gigaspora*. Twenty three species were isolated from 10-20 cm depth soil compared to 34 species in the 0-10 cm soil depth indicating a decline in species richness with increasing depth of the soil. Out of thirty-four species recorded from seven land use types, nine species were common to all the land use types but the land use types differed in terms of relative abundance of several species. *Glomus intraradices* was the most dominant species in scrubland, *G. aggregatum* in rain fed agriculture and *Glomus tenebrosum* in pine forest, oak forest, home gardens, irrigated agriculture and abandoned agricultural land. The pooled spore abundance in 0-20 cm soil depth showed a trend of pine forests > oak forests = rain fed agriculture = scrubland > irrigated agriculture > home gardens = abandoned agricultural land.

1. Introduction

Arbuscular mycorrhizal (AM) fungi are ubiquitous root-symbiotic fungi in the phylum Glomeromycota formerly Glomales within the Zygomycota (Schussler *et al*. 2001). They form mutualistic associations with roots of the majority of higher plants, including crop plants. AM fungi exist in two different phases, inside the root and in the soil. The intraradical mycelium consists of hyphae and other fungal structures, such as arbuscules and vesicles; the extraradical mycelium forms spores, explores soil and new areas for colonization and absorbs nutrients (Tommerup and Sivasithamparam, 1990).

They have a variety of important influences on ecological processes at several scales. At the individual plant host level, the AMF role in nutrient acquisition has historically been emphasized (Smith and Read, 1997) and they are also important in defense against soil-borne pathogens (Newsham *et al*. 1995). At the plant community level they have been shown to be important co-determinants of plant species diversity (van der Heijden *et al.*, 1998) and at the ecosystem level AM fungi are of recognized importance in processes such as nutrient cycling and play a role in the formation of stable soil aggregates, building up of macro porous structure of soil that allows penetration of air and water (Miller and Jastrow, 2000; Rilling, 2004).

Among the micro-organisms those interacting with land flora, AM fungi represents an important component by their ubiquity in soil microbial biomass and direct involvement in essential processes at plant-soil interface (Harley and Smith, 1983; McGee *et al.,* 1989). Mycorrhizal associations are important factors determining plant diversity in ecosystems; they modify the structure and functioning of a plant community in a complex and unpredictable way (Grime *et al.,* 1987; Read, 1990). Any shift in the mycorrhizal fungal population could have consequences for the composition of plant communities, causing changes in the biology of natural ecosystems (Miller and Allen, 1992; Molina *et al.*, 1992). On the other hand, the composition of the plant community could also affect the AM fungal community causing differential reproduction and survival of AM fungi which will operate as a selective force on the species composition (Giovannetti *et al.,* 1988; Sanders and Fitter, 1992).

However, not much work has been conducted on the inventory and establishing species diversity that too in the Indian sub-continent. But, a few studies made so far throw very little information on the ecology and diversity of these fungi. Venkataraman *et al.* (1990) while studying the distribution of AM fungi in acid soils of North Eastern India found that the hilly soils contained a fewer spores, *Scutellospora nigra, Sclerocystis rubriformis* and *Glomus macrocarpum* being the most abundant species. Bhadauria *et al.* (1998) found spores of five species of *Glomus*, eighteen of *Gigaspora* and one of *Slerocystis* sp. in barren low vegetation soil with pH ranging from 9.0-10.4. Sharma *et al*. (1987) reported, eight species of AM fungi belonging to the genera *Glomus*, *Gigaspora* and *Sclerocystis* in the rhizosphere of trees in a sub-tropical evergreen forest of North East India.

Modern intensive farming practices like application of fertilizers and pesticides, tillage practices, crop rotation and other soil management practices have consequences for the dynamics and diversity of AM fungi (Strzemska, 1975; Ocampo and Hayman, 1980; Mulligan *et al.*, 1985; Tisdall, 1994; Douds and Millner, 1999; Mader *et al.*, 2000). Though, there has been some work carried out on these aspects for cultivated plants, very little is available for natural ecosystems and their comparison to agro-ecosystems. Apart from this, very little is known about AM fungal diversity in relation to change in management practices in cultivated lands and natural ecosystems. However, a few studies have been conducted in temperate countries on species richness of AM fungi in different land use systems (Oehl *et al*., 2003). Work on this aspect is lacking in tropical countries. Hence, this study was undertaken to know the impact of land use intensity on the abundance and diversity of AM fungi at different soil depths in the Nandadevi Biosphere in Himalayas in the Indian Sub-continent.

2. Materials and Methods

The present study site is located in the Karanpryag Block of Chamoli district of Garhwal in the NDBR in the northern part of the western Himalayas. The sampling sites for BGBD and related studies are located in the lower zone of Garhwal Himalaya (500-1000 m asl) with 77 sampling points The area receives 70 per cent 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). Rain fed and irrigated land use systems are important agriculture ecosystems in this area with the former as a predominant form. 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 peas.

The vegetation structure comprises of mainly the oak forest 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 *Hedychium spicatum, Carea cruciata, Roscoea procera, Artimisia vulgaris* are dominating herbaceous species. 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.* Rain fed and irrigated land use systems are important agriculture ecosystems in this area. The farmers grow paddy during Kharif and wheat and mustard during Rabi season under rain fed land use at low altitude. The important feature of this land use is the mixed cropping which includes 12-15 varieties of pulse crops grown with other crop associates. Two crops, pure paddy during Kharif season and wheat and mustard during Rabi season are cultivated in the irrigated land. The kitchen gardens are maintained mainly to grow vegetables that include *Cucurbita maxima, Coriandum sativum, Capsicum annum Oleracea juncia, Rhaphanus sativas, Solanum melongana, Allium ceapa A. sativum Trigonella viridis etc.*

Soil sampling procedure to study soil properties and AM fungi: A triangle of 50 x 50 x 50 m was laid at each sampling point. The center point of the triangle was marked and from this central point at a distance of 3 m three soil cores of 0-10 cm and 0-20 cm depth were taken using a soil core avoiding the litter above the ground. Similarly, at a distance of 6 m from the center, another three soil cores of 0-10 cm and 0-20 cm depth were taken as explained above. Thus, at each sampling point six soil cores for 0-10 cm and 10-20 cm were collected and these six soil core samples for each depth were mixed together separately to form a composite sample per sampling point. The soil samples were stored in polythene bags in the refrigerator at 5^0 C for microbiological analysis. Samples were collected at nine sampling points each from oak forests, pine forests, home gardens, irrigated agriculture, rain fed agriculture, abandoned agriculture and scrub lands.

2.2. Microbiological Analysis

The extramatrical chlamydospores in the soil samples were determined by wet sieving and decantation procedure as outlined by Gerdemann and Nicolson, 1963. 25 g of soil sample was taken in a beaker containing 250 ml of water, mixed using a glass rod and blended for 20 seconds. After two minutes of sedimentation the suspension was passed through a series of 450µm, 125µm, 45 µm and 32µm sieves placed one above the other. The contents present on 125µm, 45µm and 32µm sieves were taken in centrifuge tubes with 25 ml of water and centrifuged at 2000 rpm for 10 minutes. The supernatant solution in the tubes was centrifuged with 40-60% sucrose solution again at 2000 rpm for 2 minutes. The supernatant was then poured on to a 32 µm sieve and the spores on the sieve were washed with a jet of water. The spores were then washed into a beaker and made-up to 10-15 ml of water. The use of 450µm sieve in the procedure however did not help much but use of 32µm sieve enabled retaining of spores, which were smaller than 45µm. The spores were then surface sterilized with an aqueous solution containing 200-ppm streptomycin sulphate and 2% chloramines- T. The spores were then mounted on a glass slide in lacto- glycerol. They were later identified, with the help of "Manual for identification of VA mycorrhizal fungi" by Schenck and Perez (1990) and the INVAM website by Joe Morton.

2.3. Statistical Analysis

The data collected from the field experiments were subjected to statistical analysis. The Co-efficient of variance was worked out by the procedure outlined by Sundararaj *et al.* (1972).

3. Results

3.1. AMF species spore abundance at different soil depths in various land use types:

Out of thirty-four species recorded from seven land use types, the species of AMF *viz*., *A. delicata, A. dilatata, A. morroiae, A. trappei, G. intraradices, G. aggregatum, G. tenebrosum* and *S. heterogama* were present in all the land use types at both the soil depths but the land use types differed in terms of relative abundance of several species (Table-1). The abundance of spores of *G. intraradices, G. aggregatum* and *G. tenebrosum* was very high in all the land use types particularly at 0-10 cm soil depth. Further, the spores of these AMF species were more abundant in pine forests compared to all other land use types in 0-10 cm soil depth. However, their numbers decreased with increase in depth (10-20 cm depth) except in case of *G. tenebrosum* that was more abundant in 10-20 cm soil depth in oak forests, abandoned agriculture and scrub lands, *G. aggregatum* in rain fed agriculture. They were also more abundant in rain fed agriculture compared to irrigated agriculture while the population of all other AMF species was lower in all the land use types either in the 0-10 cm or 10-20 cm soil depth. Further in terms of land use types *Glomus intraradices* was the most dominant species in scrubland, *G. aggregatum* in rain fed agriculture and *Glomus tenebrosum* in pine forest, oak forest, home gardens, irrigated agriculture and abandoned agricultural land (Table-4.1.).

Some species of AM fungi *viz., S. cerradensis* and *S. dipurpurescens* were present only in irrigated agriculture and abandoned agriculture in 0-10 cm, *S. erythropa* in 10-20 cm and *S. scutata* in 0-10 cm in irrigated agriculture and, *S. carolloidea* and *A. lacunosa* were present only in 0-10 cm in pine forests at 0-10 cm. Most of the other species were present in 0-10 cm and some species were present in 10-20 cm soil depth and their population varied to different levels. Three species of *Glomus viz., Glomus aggregatum*, *G. intraradices* and *G. tenebrosum* accounted for more than 50% of spores in almost all land use types, considering 0-10 cm and 10-20 cm horizons together or separately. Coefficient of variation differed by species and depth but in none of the cases; it exceeded a value of 190% (Table 4.2).

3.2. Total spore abundance in 0-20 cm soil depth: The total spore abundance at different soil depths decreased with increase in soil depth in all land use types except in rain fed agriculture and scrub lands where no change or a marginal increase was observed. There was a significant interaction of land use type and soil depth. Oak and pine forests did not differ in terms of spore abundance in 10-20 cm soil depth but the latter showed markedly higher abundance in spores compared to the former in 0-10 cm soil depth. Abandoned agricultural land had comparably higher spore density in 0-10 cm depth but about 50 per cent lower in 10-20 cm soil depth compared to the rain fed agriculture or scrublands. The pooled spore abundance in 0-20 cm soil depth showed a trend of pine forests > oak forests = rain fed agriculture = scrubland > irrigated agriculture > home gardens = abandoned agricultural land (Figure 4.1).

The coefficient of variation in most of the cases was lower for pooled abundance in 0-20 cm soil depth compared to that in 0-10 cm and 10-20 cm soil depths 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 per cent (Table-4).

3.3. Frequency of occurrence in the landscape: In all 34 species, 13 belonging to the genus *Acaulospora*, three to *Gigaspora*, eight to *Glomus* and ten to the genus *Scutellospora* could be identified in the soil samples collected from different land uses in the lower elevation village landscape. It may be noted that about three per cent of spores in abandoned agricultural land to 13 per cent 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 per cent and 21-40 per cent frequency of occurrence) (Table 4.3.). In the landscape, only one species of *Scutellospora* was dominant compared to three of *Glomus*, five 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.

4. Discussion

Out of 34 species of AMF fungi *A. delicata, A. dilatata, A. morroiae, A. trappei, G. intraradices, G. aggregatum, G. tenebrosum* and *S. heterogama* were present in all the land use types at both the soil depths but the land use types differed in terms of relative abundance of several species. Schenck and Kinloch (1980) reported such a variation in AMF species composition with different land use types. He recorded the highest number of species (12) from sorghum fields and least from woodlands. In the present study also the number of specie at 0-10 cm depth in home gardens, irrigated agriculture, abandoned agriculture and scrublands were high. Certain studies have indicated that the number of species in undistributed areas was more than in the distributed areas. Picone (2000) reported AMF species composition in Nicaragua and Costa-Rican forests and pastures. Even in this study, similar observations are made where in higher number of AMF species were present but in pine forests. Oehl *et al.* (2003) while studying the impact of land use types have also reported that the AMF species composition was highest in the grasslands, lower in the low and moderate input arable lands and lowest in the lands with intensive continuous maize mono-cropping. Several workers have reported that the grasslands contained higher number of AMF species than the cultivated fields (Mendez *et al.,* 2001; Skinner and Bowen, 1974; Schenck *et al.*, 1989). These fungi show a preferential colonization to host, and thereby, the extent to which these fungi are associated depends on the host plants in the ecosystem (Mc Graw and Schenck, 1981; Bagyaraj *et al*., 1989; Abbot and Robson, 1982). Therefore, these variations in species composition in different land use types could be attributed to the preferential colonization of AM fungi to different host plants. This could be one of the reasons why species of AM fungi in this study have shown a wide association irrespective of the land use types in this study.

Most of the AMF species were present in 0-10 cm and some species in 10-20 cm soil depth and their population varied to different levels. Some species of AM fungi *viz.*, *S. cerradensis* and *S. dipurpurescens* were present only in irrigated agriculture and abandoned agriculture, *S. erythropa,* and *S. scutata* only in irrigated agriculture and, *S. carolloidea* and *A. lacunosa* only pine forests. Such a variation in spore abundance of different AM fungi, in different land use types was observed even in the earlier studies. Schenck and Kinloch (1980) noticed changes in AM fungal species with different crops. *Gi.margarita, Gi.gigantean* and *Gi.gregaria* were dominant in soybean fields while *G.fasciculatum* and *G.clarum* in bahia grass and *Acaulospora spp*. in cotton and peanut fields and Lakshmipathy *et al.* (2004) reported *G.etunicatum* as the most abundant AM fungi from cashew plantations. Mendez *et al.* (2001) studied the AMF abundance in different field sites of Buenus Aires province (Argentina) and found that *G.pellucida* was the most dominant species in grasslands and wheat fields and in clover, *G.mosseae* being the dominant species.

In the present study, three species of *Glomus viz., Glomus aggregatum*, *G. intraradices* and *G. tenebrosum* accounted for more than 50 per cent of spores in almost all land use types, considering 0-10 cm and 10-20 cm horizons together or separately. Coefficient of variation differed by species and depth but in none of the cases; it exceeded a value of 190 per cent (Table 4.2.). Similarly, Blaszkowski (1994) observed variations in AMF species abundance in the rhizosphere of different plant species of Hel peninsula in Poland and observed that the most frequently occurring AMF species in majority of plant species was *G. tenue*. Further, it is quite evident that AMF generic distribution pattern varies with the soil type, vegetation, season and change in land use types. This is in accordance with the earlier studies made so far by several workers who have reported the preponderance of species of *Glomus* and *Acaulospora* in Indian soils under tropical conditions. (Raghupathy and Mahadevan, 1993; Muthukumar and Udaiyan, 2000). Several surveys made by other workers in other parts of Western Ghats also recorded *Glomus* and *Acaulospora* as the dominant genera of AM fungi (Muthukumar and Manian, 1993; Vasanthakrishna *et al*., 1994). Venkataraman *et al.* (1990) while studying the distribution of AM fungi in acid soils of North Eastern India found that the hilly soils contained a fewer spores, *Scutellospora nigra, Sclerocystis rubriformis* and *Glomus macrocarpum* being the most abundant species. Bhadauria *et al.* (1998) found spores of five species of *Glomus*, eighteen of *Gigaspora* and one of *Slerocystis* sp. in barren low vegetation soil with pH ranging from 9.0-10.4. (Sharma *et al*. (1987) reported, eight species of AM fungi belonging to the genera *Glomus*, *Gigaspora* and *Sclerocystis* in the rhizosphere of trees in a sub-tropical evergreen forest of North East India.

Totally thirty-four species of AM fungi were isolated, of which thirteen belonging to *Acaulospora*, three to *Gigaspora*, eight to *Glomus* and ten to the genus *Scutellospora.* Further, it may be noted that about three per cent of spores in abandoned agricultural land to thirteen per cent in oak forests could not be identified to species level. Four species of *Acaulospora* (*A. lacunose, A. rugosa, A. sporocarpia, A. tuberculata*), one from *Glomus* (*G. manihotis*), and six from *Scutellospora* (*S. carolloidea, S. cerradensis, S. dipurpurascea, S. gregaria, S. rubra* and *S. scutata*) were present in 0-10 cm surface but absent in the 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 per cent and 21-40 per cent frequency of occurrence). In the landscape, only one species of *Scutellospora* was dominant compared to three of *Glomus*, five 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 the soil (Table 4.8.). The information on differential sporulation of AM fungi at different soil depths is scarce or limited. Janos and Read (1992) have reported that root densities in the top five centimeters of tropical species favoured mycorrhization in soils.

The present study suggests that the abundance as well as species diversity decreases with increase in the depth of the soil.

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Table 6.1. Abundance (No. of spore g^{-1} soil) of AMF species in different land use types at different soil depths

AM fungi	Oak forest		Pine forest		Home garden		Irrigated agriculture		Rainfed agriculture		Abandoned agriculture		Scrub land	
	0-10 Cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Acaulospora delicate	0.10	0.35	0.75	0.35	0.60	0.19	0.44	0.97	1.09	0.29	0.24	0.65	2.21	1.20
Acaulospora dilatata	0.18	0.16	1.01	0.21	0.35	0.08	0.52	0.60	0.73	0.27	0.05	0.37	0.39	1.79
Acaulospora morrowiae	1.97	1.97	0.85	1.23	2.06	0.24	1.30	1.68	1.38	1.88	0.37	0.59	0.64	2.05
Acaulospora trappei	0.84	0.24	1.70	0.23	0.23	0.21	0.63	0.33	1.49	0.51	0.59	0.12	0.39	0.76
Glomus intraradices	4.76	2.65	10.31	1.45	2.49	2.17	5.48	2.48	6.73	2.52	4.19	1.07	6.57	6.22
Glomus aggregatum	4.91	1.60	10.22	2.87	1.80	1.48	4.39	2.61	4.99	6.12	2.80	0.96	4.53	4.26
Glomus tenebrosum	4.72	9.76	13.30	9.22	4.11	2.49	4.01	3.31	5.05	5.30	3.08	3.43	1.94	4.55
Scutellospora heterogama	0.82	1.17	1.47	0.67	0.55	0.60	0.53	1.77	1.76	1.91	0.32	0.51	0.17	2.25
Acaulospora mellea	0.09	0.07	0.42	0.55	0.23	0.11	0.14	0.19		0.12	0.31	0.03	0.17	
Acaulospora elegans	0.11	0.13	0.08		0.04	0.04	0.10						0.08	
Acaulospora rehmii	0.18	0.04	0.11	0.21	0.20	0.00	0.11			0.04	0.06	0.00	0.02	0.33
Glomus verruculosum	0.09	0.07	0.07	0.09	0.04	0.04	0.07		0.38	0.08	0.03		0.03	
Acaulospora myriocarpa	0.34	0.37	0.75	0.21		0.19	0.11	0.08	0.30	0.55	0.23	0.16	0.20	0.25
Glomus pansihalos	2.04		7.79		1.89	0.15	2.41		1.32		0.57		4.22	
Glomus manihotis	0.06		0.13		0.03		0.08				0.05			
Scutellospora calospora	0.30		0.62		0.37		0.27		0.26	0.44	0.87		0.02	
Scutellospora gregaria	0.33		0.27		0.57		0.52		0.43		0.16		0.91	
Acaulspora scrobiculata	0.06						0.18	0.05		0.17	0.08		0.07	
Acaulospora sporocarpia	0.72								0.09					
Scutellopora rubra	0.08		0.04										0.28	
Scutellospora pellucida	0.63	0.11	0.48		0.08	0.04			0.18	0.15		0.12	0.03	0.35
Gigaspora gigantean		0.04	0.15		0.04	0.05	0.11	0.40	0.32		0.30		0.03	
Glomus etunicatum		0.07	0.31		0.11	0.17	0.04		0.04					
Glomus viscosum		0.73	0.11		0.07		0.12		0.43					
Gigaspora albida			0.15	0.19	0.04	0.11	0.03	0.07	0.00	0.09	0.15		0.09	0.14
Acaulospora rugosa			0.04		0.04						0.11			
Acaulospora tuberculata					0.14		0.37		0.04		0.10		0.03	
Scutellospora carolloidea			0.12								0.07			
Acaulospora lacunosa			0.18											
Gigaspora geosporum										0.07	0.04			
Scutellospora cerradencis							0.05				0.08			
Scutellospora dipurpurescens							0.11							
Scutellospora erythropa								0.09						
Scutellospora scutata							0.05							
Others	3.45	0.19	6.34	0.44	1.36	0.55	1.23	0.29	1.21	0.26	0.48		1.36	
Total spores	26.77		57.76	17.93	17.43		23.41	14.93	28.24	20.76	15.34	8.00	24.37	24.15

Table 6.2. Coefficient of variation of different AMF species in different land use types at different soil depths

AM fungi	Oak forest		Pine forest		Home garden		Irrigated agriculture		Rainfed agriculture		Abandoned agriculture		Sscrub land	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Acaulospora delicate	124.9	173.2	66.3	88.8	115.4	173.2	67.0	29.7	137.5	53.3	173.2	54.9	154.0	101.7
Acaulospora dilatata	106.0	114.6	52.3	28.6	173.2	86.6	112.1	33.3	173.2	105.4	173.2	80.4	75.9	52.6
Acaulospora morrowiae	76.7	142.8	98.9	114.6	65.4	50.0	48.3	66.7	149.9	9.3	133.3	17.2	81.1	21.4
Acaulospora trappei	78.9	173.2	120.8	97.7	90.6	47.2	120.0	30.2	144.9	127.2	70.0	100.0	24.4	13.1
Glomus intraradices	63.8	86.3	77.9	29.2	31.0	94.0	41.4	79.7	58.9	102.4	48.8	27.6	24.4	55.9
Glomus aggregatum	25.1	78.9	75.6	67.8	61.7	35.8	44.1	85.1	58.1	67.8	51.5	43.9	39.9	48.7
Glomus tenebrosum	108.3	103.3	120.7	56.4	117.8	38.0	69.0	38.6	146.3	29.4	90.2	7.9	88.4	15.0
Scutellospora heterogama	89.0	118.1	86.6	78.9	93.3	173.2	116.4	36.7	173.2	55.9	42.7	74.6	121.6	18.1
Acaulospora mellea	173.2	173.2	126.6	173.2	106.4	173.2	173.2	173.2		100.0	173.2	173.2	89.6	
Acaulospora elegans	173.2	173.2	173.2		173.2	173.2	173.2						173.2	
Acaulospora rehmii	103.8	173.2	173.2	173.2	140.0		173.2			173.2	87.0		173.2	173.2
Glomus verruculosum	120.2	173.2	173.2	173.2	173.2	173.2	87.7		173.2	173.2	173.2		173.2	
Acaulospora myriocarpa	94.7	173.2	164.1	173.2		121.8	173.2	173.2	107.3	86.6	104.6	86.7	136.7	86.7
Glomus pansihalos	173.2		167.0		173.2	110.2	173.2		173.2		173.2		172.0	
Glomus manihotis	173.2		173.2		173.2		90.1				173.2			
Scutellospora calospora	96.8		79.9		173.2		173.2		173.2	173.2	173.2		173.2	
Scutellospora gregaria	173.2		173.2		173.2		142.9		173.2		173.2		173.2	
Acaulspora scrobiculata	173.2						87.8	173.2		173.2	173.2		173.2	
Acaulospora sporocarpia	146.5								173.2					
Scutellospora rubra	173.2		173.2										118.8	
Scutellospora pellucida	90.0	173.2	88.6		88.5	173.2			99.1	128.9		100.0	173.2	87.4
Gigaspora gigantea			128.9		173.2		173.2		39.9		67.7		173.2	
Glomus etunicatum		173.2	131.5		173.2	118.4	173.2		173.2					
Glomus viscosum		173.2	173.2		173.2		173.2		173.2					
Gigaspora albida			128.9	103.6	173.2	173.2	173.2	173.2		173.2	173.2		89.2	173.2
Acaulospora rugosa			173.2		173.2						173.2			
Acaulospora tuberculata					173.2		173.2		173.2		173.2		173.2	
Scutellospora carolloidea			97.4								173.2			
Acaulospora lacunosa	-	-	173.2	-	-	-	-	-	-	-	-	-	-	-
Gigaspora geosporum	-	173.6	-	-	-	173.2	-	34.6	-	173.2	173.2	-	-	-
Scutellospora cerradensis	-	-	-	-	-	173.2	-	-	-	-	173.2	-	-	-
Scutellospora dipurpurascens	-	-	-	-	-	173.2	-	-	-	-	-	-	-	-
Scutellospora erythropa	-	-	-	-	-	-	-	173.2	-	-	-	-	-	-
Scutellospora scutata	-	-	-	-	-	-	173.2	-	-	-	-	-	-	-
Others	75.1	173.2	137.4	110.2	99.0	142.7	67.6	173.2	48.1	33.2	128.4		61.9	-

Table 6.3. Frequency of occurrence of different AMF species in the Nanda Devi Biosphere landscape

Mycorrhizal species	0-10 cm	10-20 cm	0-20 cm
Acaulospora delicate	C	C	D
Acaulospora dilatata	C	D	D
Acaulospora elegans	O	R	O
Acaulospora lacunose	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 gigantean	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	?	?	?

Ab, absent; 1-20%, R, rare; 21-40%, O, occasional; 41-60%, F, frequent; 61-80%, C, common; 81-100%, D, dominant.

Table 6.4. Coefficient of variation of total spores in different land uses at variousdepths of soil

Land use	0-10 cm	10-20 cm	0-20 cm
Oak forest (OF)	43.5	73.4	24.0
Pine forest (PF)	71.1	55.1	46.7
Homegarden (HG)	47.4	46.1	23.8
Irrigated agriculture (IA)	21.0	55.2	31.1
Rainfed agriculture (RA)	67.4	44.7	25.3
Abandoned agriculture (AA)	55.4	19.5	37.9
Scrub land (SC)	39.2	15.4	13.2

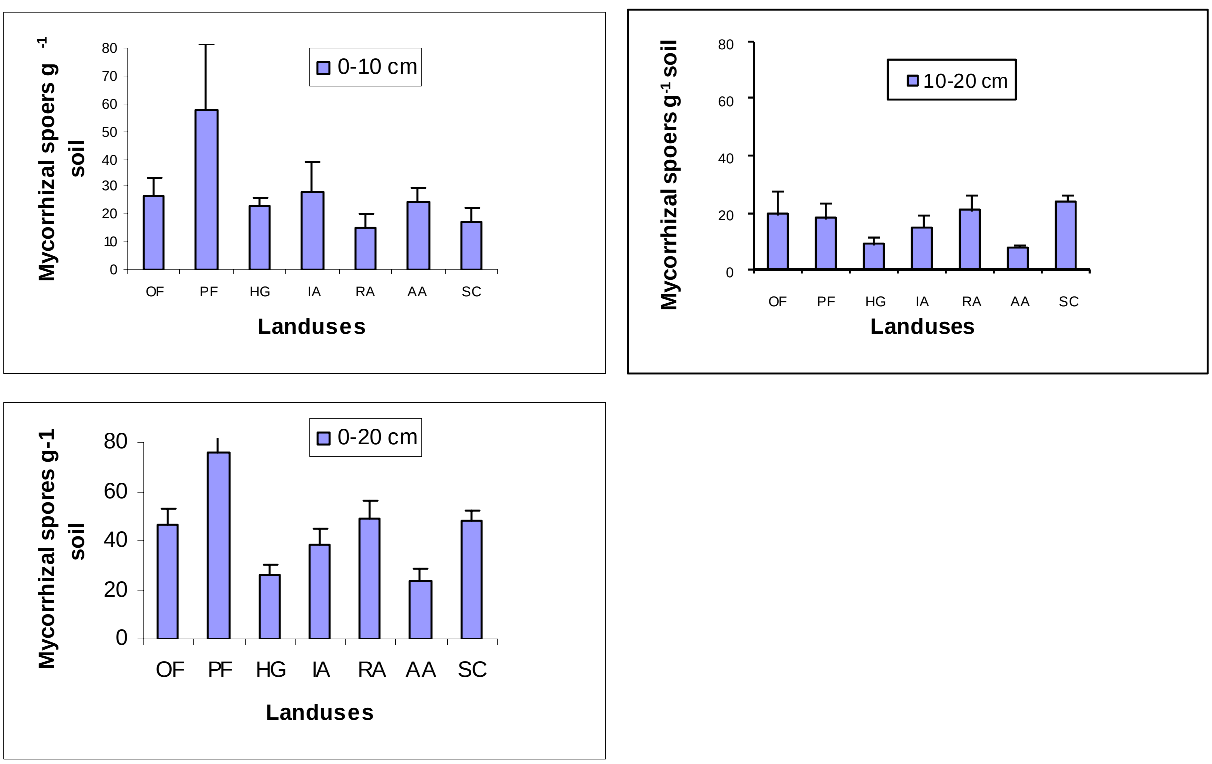

Figure 6.1. Numerical abundance of mycorrhizal spores in soil under various land uses at different depths.

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