IMPACT OF LAND USE – LAND COVER ON SELECTED SOIL ORGANISMS IN A VILLAGE LANDSCAPE OF GARHWAL HIMALAYA

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CERTIFICATE

The research work embodied in this dissertation entitled "Impact of land use-land cover on selected soil organisms in a village landscape of Garhwal Himalaya" has been carried out at the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi – 110 067. This work is original and has not been submitted in part or in full for any other degree or diploma of any university.

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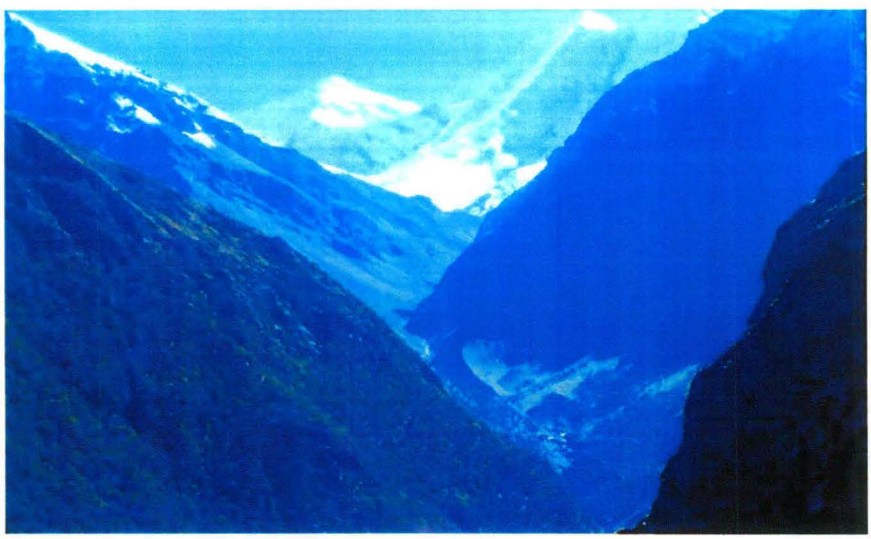
Dedicated To

The Beauty Of Garhwal Himalaya



May
the nature and the people of Garhwal
retain their identity forever

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1. Introduction

Structure, composition and functions of belowground biodiversity are influenced by soil type and land use. The diversity of organisms involved in nutrient cycling may be substantially reduced under agricultural intensification. However, there is little evidence to show that this depletion of soil biodiversity is coupled with any significant effects on decomposition and mineralization processes, possibly because of a high level of functional redundancy among decomposers (Swift *et al.*, 2004).

Soil organisms are conveniently grouped into three categories based on size of the organisms:

(a) The microfauna are small (< 0.2 mm body width), live in the water filled pore space, and are comprised mainly of protozoa and nematodes. They feed on bacteria and fungi, leading to nutrient release from microbial biomass. Microfauna can affect the nutrient mineralization directly, by excreting mineral nutrients and indirectly by causing shifts in the microbial community structure and growth rates. Grazing by nematodes and protozoa can increase microbial turnover by stimulating growth of surviving microbial populations by reducing microbial competition and increasing nutrient availability. These trophic interactions are influenced by soil physical and chemical properties (Savin *et al.*, 2001).

(b) The mesofauna include organisms larger than microfauna but smaller than macrofauna (average size < 2 mm) and include organisms such as mites (acarids), springtails (collembolans), and the small oligochaeta and the enchytraeidae.

(c) The macrofauna include termites, earthworms, and large arthropods. They have the ability to dig the soil and are some time called 'ecosystem engineers' because of their impact on soil structure (Kladivko, 2001).

1.1 Land use-land cover

Land is classified according to the most suitable sustained use that can be made of it Land use describes how a piece of a land is managed or used by humans and land cover is the observed physical/biological cover of land such as vegetation or man-made features. Several land use classification systems have been developed around the world (Brady, 1990). The majority of agricultural landscapes in the tropics, in contrast to northern temperate zones, are mosaics of varied agricultural and semi-natural ecosystem types. Landscape heterogeneity is more pronounced in mountains which occupy a three dimensional space in contrast to the two dimensional spatiality of low lands. Variability in terrain features such as slope and altitude gets manifested as landscape heterogeneity/diversity. Unique geographical location of the Himalaya and geographical processes influencing the region, further magnify the effects of slopes and altitudes (Rao and Saxena, 1994).

1.2 Mycorrhiza

Mycorrhizae are symbiotic associations that form between roots of most plant species and a group of fungi. These symbioses are characterized by bi-directional movement of nutrients where carbon flows to the fungus and inorganic nutrients move to the plant, thereby providing a critical linkage between the plant root and soil. Most of the vascular plants and crops in tropics are dependent on vesicular arbuscular mycorrhizal (VAM) fungi or arbuscular mycorrhizal (AM) fungi (Hart and Reader, 2004).

Mycorrhizae are of two kinds:

(a) Ectomycorrhizal fungi are mostly basidiomycetes that grow between root cortical cells of many tree species of the families Pinaceae, Fagaceae, Betulaceae, Myrtaceae, Dipterocarpaceae and Fabaceae (Leguminosae).

(b) Endomycorrhizae, called VAM or AM belong to the order Glomales and form highly branched structures called arbuscules, within root cortical cells of many herbaceous and woody plant species.

Some tree species of Casuarinaceae, Myrtaceae and Leguminosae form both EM and AM. Haselwandter and Bowen (1996) observed that EM predominated in organic matter rich parts of soil profile and AM dominated in other parts.

1.2.1 Distribution of Mycorrhizal Fungi

AM fungal communities are influenced by plant species composition, soil properties, climatic conditions and management practices. Management practices such as fire, tillage, crop rotation and fallowing adversely affect populations of mycorrhizal fungi in the field (Rashid *et al.,* 1997; Lovelock *et al.,* 2003; Muthukumar and Udaiyan, 2002). Natural ecosystems dominated by perennial trees and shrubs, spores had fewer compared to the adjacent agricultural soils, but some virgin grasslands showed higher spore numbers than the adjacent wheat crop field. In some environments, cultivation (tillage and fertilizer application) reduces VAM diversity, while in others it enhances VAM diversity (Abbott and Robson, 1991).Vertebrates and invertebrates act as potential vectors of VAM. Earthworms concentrate VAM propogules in their casts. Thus, agricultural soil management can greatly influence the population size and activity of both VAM fungi and earthworms (Lee *et al.,* 1996).

The population of mycorrhizal spores in agricultural fields depend on sampling time, crop and management practices, e.g., tillage regime (Douds *et al.,* 1995). Different management practices introduce different types of disturbances, which may influence microbial communities in different ways. Tillage causes a physical disruption of fungal mycelia and may change soil physico-chemical properties and soil-crop relations (Johansson *et al.,* 2004). Disturbance can decrease mycorrhizal infection and may be associated with decreased phosphate uptake after ploughing compared to the uptake in 'no tillage' scenario (O'Halloran *et al.,* 1986). The fallowing of agricultural lands may result in a decline in the abundance of propogules of AM fungi (Moutoglis and Widden, 1996). This forms the basis of the recommendation (Thompson, 1987) that farmers should avoid planting mycorrhizal dependent crops following periods of fallow or after cultivation of non-mycorrhizal crops, which lead to reduction in AM propogules. The

addition of phosphate fertilizers has shown either no effect or to decrease in the level of mycorrhizal infection in a range of agricultural crops (Abbott and Robson, 1991).

1.2.2 VAM functions in the soil

Mycorrhizal fungi have been shown to be effective in reducing stresses to crops caused by water/nutrient deficiency and diseases. Since the external mycelium extends several centimeters from the root surface, it can by-pass the nutrient depletion zone surrounding the roots. Mycorrhizal fungi increase the uptake of mineralized P by occupying the micro-sites of active litter decomposition. Mycorrhizal hyphae have the capacity to extract nitrogen and transport it from soil to plant because of the enhanced absorptive surface area. Mycorrhizal fungi equalize resource allocations such that less competitive species are able to co-exist with the more competitive ones (Kumar *et al.,* 1999). Growth of external VAM hyphae into soil matrix creates the skeletal structures that hold primary soil particles (i.e., salt, silt and clay) together via physical entanglement (Miller and Jastrow, 1992). The functioning of the plant-mycorrhiza system depends on interactions with other organisms. VAM fungi are likely to be affected by fungivorous animals such as nematodes and collembola. A laboratory experiment showed that fungal feeding soil invertebrates can affect the interactions between mycorrhizal fungi and saprotrophic soil microorganisms (Tiunov and Scheu, 2005).

1.2.3 Mycorrhizal spore abundance and VAM-crop-land use interrelations

Cardoso *et al.,* (2003) studied distribution of mycorrhizal fungal spores in oxisols (spores extracted from 0-1, 2-3, 5-7.5, 10-15, 20-30, 40-60 cm soil layers) under agroforestry and monocultural coffee plantations of different age groups (young, medium and old) in Brazil. Spore abundance was significantly higher in the surface layers of soil (0-1, 2-3 and 5-7.5 cm depth) in the monocultural coffee fields compared to those in the agroforestry coffee fields. Carrenho *et al.,* (2002) evaluated the influence of peanut, maize and sorghum crops grown in acidic poor substrate on the sporulation and diversity of AM fungi. Rhizpspheric soils of peanut, maize and sorghum showed 548, 415 and 350 spores per 100 g soil, respectively. In these fields Acaulosporaceae was the most dominant family (81.8% of total spores) followed by Glomaceae (17.4%) while

Gigasporaceae (0.8%) was the least. Guadarrama and Alvarez-Sanchez (1999) compared mycorrhizal abundance and diversity in sites with different regimes of disturbance in a tropical rainforest of Mexico. AM spores were recorded in closed canopy and gaps in the forest. It was observed that abundance and diversity of AM fungi were influenced by seasonality but not by disturbance. The spore abundance ranged from 0.4 to 2.6 spores g^{-1} soil. The highest number of species and spores were observed during the dry season, with a marked decrease during the rainy season. *Glomus* was the most dominant genus followed by *Sclerocystis* (Glomaceae) and *Acaulospora*. The genus *Gigaspora* was the least abundant genus in the area. Muthukumar and Udaiyan (2000) studied the influence of organic manures on AMF associated with *Vigna unguiculata*. The soil at the start of experiment had a spore density of 2.5 spores g^{-1} belonging to *A. scrobiculata, G. aggregatum, S. calospora* and *Sclerocystis sinuosa*. The addition of farmyard manure, green manures of sunhemp and *Pongamia pinnata* showed increase in soil N, P and K levels as well as spore density after 90 days of enrichment. Zhang *et al.,* (2004) studied the diversity of AM fungi in deforested and natural forest land in the subtropical region of Dujiangyan, southwest China. They did not observed any significant difference in the total AM spore density between natural forest (284 ± 50 spores 100^{-1} g air-dried soil) and the deforested land (349 ± 37 spores 100^{-1} g air-dried soil). *Gigaspora* was significantly higher in the deforested land (6 ± 2 spores 100^{-1} g air-dried soil) than in the natural forest land (0.2 ± 0.2 spores 100^{-1} g air-dried soil). *G. versiforme, Acaulospora sp.* and *Gigaspora. rosea* were more abundant in the deforested land than in the intact natural forests . The dominant genus *Glomus* had the highest spore density in both the deforested (293 ± 34 spores 100^{-1} g air-dried soil) and natural forest (244 ± 47 spores 100^{-1} g air-dried soil). *Glomus* was followed by the genus *Acaulospora*, which had 48 ± 9 spores 100^{-1} g air-dried soil in the deforested land and 38 ± 9 spores 100^{-1} g air-dried soil in natural forest land. However, there are studies reporting AM fungal diversity (spore formation, distribution and mycorrhiza development) to be dependent on plant diversity in natural ecosystems (Gange *et al.,* 1993). Gupta *et al.,* (2002), in their short communication revealed that the use of *G. fasciculatum* inoculation significantly increased the productivity and reduced the fertilizer input required to sustain production of mint crop under field conditions.

Lovelock *et al.,* (2003) studied the AM fungal communities in a tropical wet forest of Costa Rica. In 100 cm^3 of rhizospheric soil, the mean number of spores was 55.4 and the number of species was 3.53. The mean number of AM fungal species per host tree species was 7.0 and the genus *Acaulospora* was the most dominant one. *Acaulospora mellea* was more abundant in the dry season compared to wet season.

Mohammad *et al.,* (2004) looked at the effectiveness of the introduced *G. intraradices* on wheat growth and observed that mycorrhizal growth effect was higher at low input of P (5 kg/ha and 10 kg/ha) compared to higher P input (20 kg/ha). Number of AM spores decreased significantly with increase in P application. In field soils, spore numbers appear to reach maximum in conditions where phosphate availability is less than that required for maximum shoot growth (Abbott and Robson, 1991).

Taylor and Harrier (2000) evaluated the effects of different AM fungi on growth, development and mineral nutrition of micro-propagated raspberry plantlets. The species of *Glomus* were the most extensive colonizers, with *G. intraradices* having the highest colonization percentage. This species significantly increased the P and Cu concentration in the shoot tissue. *Scutellospora* species like *S. heterogama* and *S. persica* significantly decreased Na, S and K uptake as compared to *S. calaspora*. The growth parameters like dry weights, plant height and the number of side shoots per plant were not influenced by *Glomus,* increased by *Scutellospora*, and reduced by *Gigaspora*. Rajan *et al.,* (2000) studied the efficiency of nine arbuscular mycorrhizal fungi on growth of *Tectona grandis* under nursery condition. Teak plants grown in the presence of AM showed a general increase in plant growth parameters like plant height, stem girth, leaf area and total dry weight.

1.2.4 Effect of seasonal variation

Root length colonized, spore numbers and infectivity may vary during the year (Abbott and Robson, 1991). Giovannetti (1985) studied seasonal variation in VAM fungi associated with perennial grasses on sand-dunes. Gemma and Koske (1988) observed that

abundance of spores was poorly related to seasonal differences in infectivity. Spore density has been found to be lower during the growing season (Hayman, 1970; Smith, 1980).

1.3 Nematodes

The phylum Nematoda comprises the classes Secernentea and Adenophora. The Secernentea are almost exclusively terrestrial, only rarely being freshwater or marine, where as Adenophora occupy niches in all three habitats (Bongers and Ferris, 1999). Soil food webs comprise a great variety of organisms, ranging from single celled bacteria, algae and protozoa to multicelled mites, earthworms, collembola and nematodes. Nematodes, mites and collembola have been viewed as suitable bioindicators of soil health as 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 is long enough making them temporally stable unlike microbes which fluctuate with ephemeral nutrient flushes (Ferris and Ferris, 1974; Bongers, 1990; Dombos, 2001; Culik *et al.,* 2002). However, there are studies showing these organisms to be relatively insensitive to some ecological factors. 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 appropriate bioindicator than mites and collembola (Gupta and Yeates, 1997). Soil nematodes interact in ecosystems directly as herbivores on plants and indirectly as consumers of microflora. They regulate nutrient availability to plants through excretion and by maintaining bacteria and fungi they feed on in a logarithmic growth phase (Coleman *et al.,* 1984; Freckman and Ettema, 1993). Nematodes can be used as indicators of soil quality (Neher, 2001; Schloter *et al.,* 2003), since these form a dominant group and occur in all soil types, have a high abundance and high biodiversity and play an important role in soil functioning (Schloter *et al.,* 2003). Several characters of soil

nematodes make them good candidates for bioindicators of the status and processes of an ecosystem. Nematodes posses the most important attributes of any prospective bioindicator: abundance in virtually all environments, diversity of life strategies and feeding habits, short life cycles, and relatively well defined sampling procedures (Porazinska *et al.*, 1999).

During the long course of evolution, morphological and biochemical modifications led to diverse feeding types/habits of nematodes. Thus, trophic groups make a useful classification of nematode communities (Norton and Niblack, 1991). In ecological studies, functional groups of terrestrial nematodes are generally treated synonymous to feeding groups. Nematodes are transparent; their diagnostic internal features can be seen without dissection. There is a clear relationship between structure and function; the feeding behaviour is easily deduced from the structure of the mouth cavity and pharynx. As, in addition to feeding on the roots of higher plants, nematodes feed on bacteria and fungi, changes in relative abundances of bacterial or fungal feeding nematodes mirrors the changes in the decomposition route and width of energy channels. Nematodes occupy key positions in soil food webs. They feed on most soil organisms and are food for many others (Bongers and Ferris, 1999). Characterization of nematode community of a site at a given point of time provides a snapshot of current environmental conditions, whereas sequential assessments allow analysis of environmental degradation or remediation.

1.3.1 Distribution of Nematodes

The existing knowledge of the distribution and diversity patterns of soil organisms in relation to ecosystem processes remains quite inadequate, partly due to extremely high species richness, diversity and complexity of belowground communities (Wall and Virginia, 1999). Soil nematodes live in capillary water; they are readily influenced by the environmental conditions because of their permeable cuticle, they do not migrate from stressful conditions and many species survive dehydration, freezing or oxygen stress (Bongers and Ferris, 1999). Many nematodes have a wide host range, occur in a wide range of environment, and are cosmopolitan, e.g., *Meloidogyne incognita,* the southern root-knot nematode, and *Meloidogyne hapla,* the northern root-knot nematode (Norton

and Niblack, 1991). Some plant nematodes, such as *Xiphinema* and *Longidorus* spp., are long lived, and their densities may vary little within a year. Differences in temporal distributions may reflect inherent differences among nematode species, or be associated with seasonal changes in the quantity of quality of plant material, or both. Yeates, *et al.,* (1985) found sequential and complementary distributions of M*eloidogyne, Heterodera,* and *Pratylenchus* on white clover sampled over several months.

The largest numbers of plant nematodes are found in the top 15-20 cm of soil, but some may be found at depths as high as 240 cm. *Criconemella xenoplax* is found to a depth of 1m on peach roots, whereas *C. ornate* is found mostly in the upper 15 cm on peanut. Vertical migration/distribution in soil profile is largely controlled by temperature, moisture tensions, and root distribution, but often evidence of migration is circumstantial. The availability of specific nematodes may differ with land use and field conditions, For example, *Pratylenchus* was detectable in significant numbers at 40 cm depth in Italian field (Norton and Niblack, 1991).

Nematode populations are influenced by the fecundity, fertility, length of life cycle, longevity and survival capabilities as influenced by the physical, chemical and biological environments (Kimpinski and Sturz, 2003). Nematodes are poikilothermic organisms. A temperature range of 25 – 30^0 C is ideal for activity of most nematodes in tropical and subtropical climates. The upper elevations of the tropics, where cooler weather slows downs development, have different kinds of nematode communities than the lowland areas (Ferris and Ferris, 1974). In temperate areas, the nematode abundance ranged from 175000 to 20000000 per m^2 in surface soil (5-10 cm). The highest numbers were found in grass fields and lowest in extremely dry habitats. Some available sources recorded soil nematodes in a Puerto Rican tropical rain forest to be a maximum of 2×10^4 individuals m^{-2} (Ferris and Ferris, 1974).

1.3.2 Functional groups of Nematodes

Classification of the thousands of species that have been described is based largely on morphology, life history, and habitat. The life cycles and breeding habits of many

nematodes are unknown. The allocation of nematodes to feeding groups is an effective method to condense taxonomic information (Yeates and Bogers, 1999). Both carbon and nitrogen mineralization increase with temperature up to about 35^0 C. Microbes mineralize nitrogen at a rate of proportional to respiration when growing on a substrate with C:N ratio less than the microbial C:N ratio (Savin *et al.,* 2001). Nematodes contribute to N mineralization indirectly by grazing on decomposer microbes, excreting N in live biomass. Under filed conditions, bacterivores and predatory nematodes are estimated to contribute about 8-19% of N mineralization in conventional and integrated farming systems (Neher, 2001).

Classification of nematodes into trophic groups is a useful way of looking at the functional diversity of nematode community but there are limitations in application of this approach. 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.,* 1993). 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* spp. can grow and reproduce by feeding on bacteria (Russell, 1986). According to Siddiqi (1986), the Tylenchidae are algal and moss feeders and parasites of lower and higher plants. Yeates *et al.*, (1993) classified nematodes as follows:

1. Plant feeding

Plant feeding nematodes feed on vascular plants using a tylenchid stylet, dorylaimid stylet or onchiostyle.

a. Sedentary parasites

Females of *Globodera, Heterodera, Meloidogyne, Verutus, Sphaeronema* come under this category.

b. Migratory endoparasites

Members of Pratylenchidae, Anguinidae are the migratory endoparasites.

c. Semi-endoparasites

Hoplolaimidae, Telotylenchus are considered to semi-endoparasites.

d. Ectoparasites

Some nematodes are migratory and few are sedentary ectoparasites. *Cephalenchus*, *Pungentus*, members of Dolichodoridae, Pratylenchidae, Longidoridae are migratory ectoparasites. Members of Criconematidae, Hemicycliophoridae, Trichodoridae are sedentary ectoparasites.

e. Epidermal cell and root hair feeders

Members of Tylenchidae, Psilenchidae, Atylenchidae are associated with roots and generally referred as plant associated nematodes by Yeates *et al.*, (1993).

f. Algal and moss feeders

Algal, lichen or moss feeders which feed by piercing; Nematodes like *Tylenchus*, *Laimaphelenchus* and members of Anguinidae were put under this category.

g. Feeders on above-ground plant tissue

Few nematodes feed on aboveground parts like stem, leaves etc.

2. Fungal feeding

Fungal feeding nematodes penetrate fungal hyphae by a stylet with a narrow lumen. Members of family Aphelenchidae like *Aphelenchoides, Aphelenchus* are classified as fungal feeders.

3. Bacterial feeding

This category includes species that feed on any prokaryotic food source, whether through narrow (*Rhabditis*, *Alaimus*) or broad (*Diplogaster*) stoma. Members of Cephalobidae, Araeolaimidae were classified in this category.

4. Substrate ingestion

Some Diplogasterids and marine nematodes usually be passive and incidental to bacterial feeding and predation; however, when more than a pure food source is actively ingested, the feeding activity may be classified here.

5. Animal predators

Some nematodes feed on invertebrates such as protista, nematodes, rotifers, and enchytraeids.

a. Ingesters

Diplogaster, Mononchus, Nygolaimus, Apocelaimus, where the anterior opening is large and distinct parts of prey may be found in the intestine.

b. Piercers

Seinura, Laimaphelenchus and Labronema, where the body contents of the prey is sucked through a relatively narrow stylet.

6. Unicellular eucaryote feeding

Various nematodes have been reported to feed on diatoms and other algae but the typical lack of marker structures in the food, and the globules and pigmentation which obscure intestinal contents, make interpretation

7. Dispersal or infective stages of animal parasites

8. Omnivorous

Some nematodes appear to feed on a range of food resources, it is usual restrict term omnivore to some dorylaimids.

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. Within nematodes several life strategies have developed. Colonizers (r-strategists, in the broad sense) produce many small eggs and exploit a nutrient-rich habitat rapidly. In contrast, persisters (K strategists, in the broad sense) hardly react at transient conditions of high food availability.

Table 1: A comparative account of the ecological attributes of r-strategist and K-strategist nematodes (from Bongers and Ferris, 1999)

r-strategists	K-strategists
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	Oviparous

The MI incorporates ecological characteristics of families based on a colonizer to persister (cp) scale of 1-5 (Bongers and Bongers, 1998):

cp-1

Nematodes with a short generation time, producing many small eggs resulting in an explosive population growth under food-rich conditions are placed in this group. These nematodes are relatively tolerant to pollution-induced stress. In a petri dish, in water or on agar, these nematodes are always active; for example, Rhabditidae are continuously pulsing with their oesophagus. Obviously, they have a high metabolic activity. These enrichment opportunists show a phoretic relation with insects and other vectors and are only active under transient conditions of high microbial activity. They form dauerlarvae as microbial activity decreases. This group is composed of rhabditid, diplogastrid and panagrolaimid bacterial feeders.

cp-2

Nematodes placed in this group have a short generation time and a high reproduction rate, but they do not form dauerlarvae. They occur under food-rich as well as food-poor conditions and are very tolerant to pollutants and other disturbances. This group is composed of the smaller tylenchids, mainly feeding on epidermal cells, the fungal feeding aphelenchoids and anguinids, and the bacterial feeding cephalobids, plectids and monhysterids.

cp-3

The nematodes placed in this group have a longer generation time and are relatively sensitive to disturbances. This group includes bacterial feeding teratocephalids, the Araeolaimida and Chromadorida, the larger tylenchid nematodes that feed on deeper cell layers of plant roots, the diphtherophorids, assumed to feed on fungi, and the carnivorous tripylids.

cp-4

Small dorylaimids and large non-dorylaimids placed in this group are characterized by a long generation time, permeable cuticle and sensitivity to pollutants. The non-carnivorous nematodes in this group are relatively sessile, whereas carnivorous have to move. This group is composed of larger carnivores, the bacterial feeding Alaimidae and Bathyodontidae, the smaller dorylaimid nematodes and the plant feeding trichodorids.

cp-5

Large dorylaimid nematodes placed in this group have a long life span, low reproduction rate and low metabolic activity. They produce few but large eggs and show low motility. With a permeable cuticle they are very sensitive to pollutants and other disturbances. This group is composed of the larger dorylaimids: omnivores, predators and plant feeders.

In a complex soil ecosystem any nutrient flush is assumed to be rapidly used by bacteria, protozoa, nematodes and other consumers and converted to biomass. Nematodes and other soil biota play an important role in releasing nutrients from bacterial biomass for uptake by plant roots. Those nematodes that respond first are enrichment opportunists, their biomass continues to increase as long as the bacterial activity is high. As the soil dehydrates, some species cannot survive. However, *Plectus* is present in almost all soils and can easily recover. Rhabditidae are an important buffer against high flushes of nutrients, *Acrobeloides* of flushes resulting in a microbial level below the carrying capacity for Rhabditidae. Some soil pores will be too narrow for *Acrobeloides*. In a sustainable system, high soil biota diversity is required to prevent leaching and to reduce local multiplication of soil-borne plant pathogens.

Bongers (1990) have suggested that the PPI, in heavily fertilized agronomic crops with greater root production than in natural systems, would increase and the MI decrease. The MI has proved useful in assessing disturbance of terrestrial, freshwater (Bongers, 1988; 1990) and marine (Bongers *et al.*, 1991) ecosystems, but has not been assessed in

agricultural systems. This index was developed to monitor colonization and succession based on the characteristics of the constituent species, such as length of life cycle (Bongers, 1990). 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. Yet, 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 Maturity Index (MI) and Plant Parasitic Index (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.

1.3.3 Nematode abundance in different ecosystems

Porazinska *et al.,* (1999) studied nematode communities in soils exposed to different management practices in Florida and recorded total number of nematodes in the range of 359-1396 per 100 cm^3 soil. The study showed organic inputs trigger quick increase of bacterial populations followed by a quick increase of some of the bacterivorous nematodes. As soon as easily decomposable substrates diminishes, bacterial and then nematode populations decline usually reaching previous or even lower population levels and this study evidenced contributions of bacterivore nematode species to N mineralization.

Nematode community structure and function are known to change in response to land management practices such as nutrient enrichment through fertilization by organic and inorganic N, tillage, liming, drainage, plant community composition and age, and application of toxic substances such as heavy metals, pesticides, and polycyclic aromatic hydrocarbons (Neher, 2001).

Akhtar (1998) conducted a field study to see the effects of compositae plant species and fertilizer on nematodes in an alluvial soil. The field had been previously cultivated and

ploughed by chisel thoroughly to a depth of 25-30 cm. The soil had a pH of 8.3 and organic matter 1%. The field was treated with synthetic fertilizer and organic fertilizer at two dosages of 110 and 220 kg N/ha. The initial population of nematode was found to be 1119, 215 and 2249 of plant parasitic, predators and free living nematodes 100^{-g} soil, respectively. Plant parasitic nematodes decreased with the application of synthetic fertilizers while organic fertilizers did not have any significant effect in this respect. Soils treated with compositae family members such as marigold and sunflower showed decrease in plant parasitic, predatory and free living nematodes. Organic fertilizers coupled with *Tagetes* plant species led to greatest reduction in plant parasitic nematodes. The study showed that plants such as marigold and sunflower were highly effective in maintaining low populations of plant parasitic nematodes and these can be useful in intercropping or crop rotations to reduce plant parasitic nematodes.

Neher (1999) observed that density of plant-parasitic and bacterivorous nematodes were higher in soils managed organically than conventionally. Fungivore:bacterivore ratios observed in this study were relatively small (median = 0.10), indicating a predominance of bacterivorous nematodes in both management systems. No differences in values of maturity indices for free-living nematodes were observed between soils managed organically or conventionally. It reflects similar frequencies of disturbance in both management systems even though the type of management differed. Neher (1999) suggested that organic farms were not useful as a reference base for maturity and trophic diversity indices. Differences observed in plant-parasitic nematode communities can be attributed primarily to the different host crops present in the contrasting management practices. Physical disturbances such as cultivation may influence soil ,nematode community structure and function as much or more than applications of synthetic chemicals such as fertilizers and pesticides.

Nematode communities in relation to microclimatic variability over an elevation range of 1900–2250 masl were studied in the calcareous Alps of Austria (Styria) by Hoschitz and Kaufmann (2004). Total nematode abundance and diversity were very similar. Maturity indices (3.0–3.3) and the plant parasite indices (2.4–2.6) were also within a narrow range.

Wright and Coleman (2002) assessed the effects of rhododendron removal and hurricane windthrow on nematode abundance and community structure in a riparian forest of chestnut oak (*Quercus prinus* L.) and tulip poplar (*Liriodendron tulipifera* L.). Nematode abundance and community composition varied widely within and between sample replicates. Bacterivore nematodes were the most dominant accounting 50-60% of all nematodes followed by fungivores and Tylenchidae. Storm plots showed total nematode abundance of 18-48 and 14-32 nematodes g $soil^{-1}$ in the 0-5 and 5-10 cm soil, respectively, and cut plot showed total nematode abundance of 17-54 and 13-34 nematodes g $soil^{-1}$ in the 0-5 and 5-10 cm soil, respectively. There were no significant differences in total nematode abundance in response to disturbance events.

A number of studies have been carried out on evaluating the abundance, impacts and management of nematodes in India (Akhtar and Alam, 1992; Akhtar, 1998; Anver and Alam, 1989; Siddiqui and Mahmood, 1994; Shukla and Haseeb, 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. A number of efforts have been made to study mycorrhiza (Gupta *et al.*, 2002; Kumar *et al.*, 1999; Lee *et al.*, 1996; Mohammed *et al.*, 2004; Pande and Tarafdar, 2004; Pandey *et al.*, 1999; Rajan *et al.*, 2000; Ragupathy and Mahadevan, 1993; Rashid *et al.*, 1997), however, efforts on inventorying VA mycorrhizae on a landscape scale are lacking.

1.4 Objective

The objective of this study was to look into the diversity and abundance of VA mycorrhizal spores and nematodes in different land use-land cover types in a mountain village landscape.

2. Materials and Methods

2.1 Study area

The Garhwal Himalaya, spread over a geographical area of 29698 km^2 comprises five districts of Uttaranchal state of India viz. Uttarkashi, Chamoli, Pauri, Tehri and Dehradun. The study was carried out in and around the Chamali village landscape in Chamoli district (30^0 27^1 N latitude and 79^0 5^1 E longitude). The landscape covers an elevation range of 800-1400 m above mean sea level (amsl). The year consists of three seasons: dry summer season (April-June), warm rainy season (July-September), and winter season (October-March). Annual average rainfall is about 1200 mm and about 80% of total rainfall is received during rainy season. The parent material is represented by feldspathic quartz schists, quartz muscovite schists and quartz chlorite schists, and can be classified as Dystric cambisol according to FAO soil classification system.

The village landscape is differentiated into seven land use-land cover types: a) Oak (*Quercus leucotrichophora*) Forest, b) Pine (*Pinus roxburghii*) Forest, c) Home Garden, d) Irrigated agricultural land, e) Rain-fed agricultural land, f) Abandoned agricultural land and g) Scrub land.

2.1.1 Oak Forest

Oak forests are socially valued and face high biotic pressure due to their high quality fuel wood, fodder and leaf litter used as a component of farmyard manure and minor forest products. Oak forests are considered best for soil and water conservation and soil fertility enhancement. Oaks fail to survive in soils with poor moisture and nutrient. The sustainability of these forests depends greatly on their productivity, resilience and human activities (Awasthi *et al.*, 2003).

2.1.2 Pine Forest

Pine forest is also a major forest type in the Garhwal Himalayas. Pine leaves are unpalatable and pine wood is an inferior quality fuel wood. However, economic benefits from pine forests such as resin and minor timbers are considerable. The pine forest also gives better ground forage. Pine forests are accused for promotion of forest fire, depletion

of soil moisture and degradation of soil quality. Pine is a stress tolerant - fast growing conifer and can survive in poor soil moisture and fertility conditions.

2.1.3 Home Garden

Home gardens multi-species small tiny plots located close to dwellings and comprising a variety of tree species like citrus, mango, guava, papaya, walnut etc. were the dominant species and vegetables like onion, chillies, brinjal, rye, cauliflower and leafy vegetables..

2.1.4 Irrigated Agricultural Land

Irrigation is practiced on very small scale, particularly in the valleys along the streams. Here, two crops are harvested in a year: rice (*Oryza sativa*) being the major crop of summer season and wheat (*Triticum aestivum*) of winter season. No fallowing is done in irrigated agricultural fields.

2.1.5 Rainfed Agricultural Land

Rainfed agriculture on terraced slopes is common in Garhwal Himalayas. Maintenance of soil fertility and soil moisture in the mountain rainfed farming is a challenging task. Traditionally massive amount of leaf litter collected from nearby oak and pine forests is allowed to decompose alongwith livestock excreta and the farmyard manure is transferred to crop fields and incorporated at the time of ploughing. The rainfed terraces are often left uncultivated and sometimes become probe for the invasion of weeds such as *Lantana camara.*

2.1.6 Abandoned Agricultural Land

Some of the agricultural lands were abandoned due to uneconomic production from inconveniently located agricultural plots. Migration of people from hilly areas to plain lands and unwillingness of the absentees owners (non-residents) to leese their lands are the other reasons for fallowing. These abandoned agricultural lands are used as grazing lands in some cases.

2.1.7 Scrub Land

The scrub lands are barren lands comprising grasses, weeds and shrubs. These strips of lands were situated in the valleys of main streams and subjected to unregulated and intensive grazing.

2.2 Sampling

Soil samples from 0-10 and 10-20 cm depths were collected in rainy (September-October) and winter seasons (February-March) from each of seven land use-land cover types differentiated in the Chamali village landscape (n = 5 per land use), but analysis of all replicants could not be completed for various reasons. Root mass was sampled in the entire soil profile. However, processing of all samples could not be completed because of time constraints. Data pertaining to only one point of time and two soil depths (0-10 cm and 10-20 cm) are presented in this study.

2.3 Biomass studies of litter, herbs and roots

The litter and herbs were collected in $1m^2$ quadrats, oven dried at 65^0 C for 24 hours and weighed. The dry weight of litter was computed as Mg of litter per ha. The roots were collected in 30 × 30 × 100 cm sample areas, separated as fine roots (< 2mm diameter) and coarse roots (>2 mm diameter), washed to remove adhered soil particles and oven-dried..

2.4 Moisture (%)

From each sample, 50 g of fresh soil was oven-dried for about 24 hours. The percentage of moisture was calculated as:

$$\text{Moisture (\%)} = \frac{\text{Moisture content (wet weight – dry weight) of the soil}}{\text{Dry weight of the soil}} \times 100$$

For analyzing chemical parameters, the soil samples were air-dried and ground using pestle and mortar. The samples were passed through 250 μm sieve. A composite sample was prepared by mixing the soils belonging to the same horizon of the same plot and preserved in a polythene pockets and neatly labeled for chemical analysis.

2.5 Soil pH

10 g of soil mixed with 50 ml of 1M KCl, the mixture was shaken using mechanical shaker for 30 minutes and pH was measured using a digital pH meter.

2.6 Organic Carbon

Soil organic carbon was estimated by Walkley and Black method (Walkley and Black, 1934). From each sample 0.3 g of soil was taken into a 250 ml conical flask and 5 ml of 1M Potassium dichromate solution and 10 ml of conc. H_2SO_4 were added. The solution was allowed to cool down and 50 ml of double distilled water was added. Again this solution was allowed to cool down to room temperature. After adding 2 to 3 drops of Orhto-phenantroline indicator, solution was titrated against 0.2 M Ferrous Ammonium Sulfate Solution. End point was observed by a change in colour from green to maroon. Blanks were also made and received the same treatment but no soil in them. Percentage of organic carbon was obtained by using the following calculation.

$$OC\ (\%) = \frac{T \times 0.2 \times 0.3}{\text{Sample weight}}$$

Where,

T = titre value (Vb – Vs)

Vb = Volume of FAS consumed by blank

Vs = Volume of FAS consumed by sample

Sample weight = 0.3 g

2.7 Potassium (K)

10 g of air-dried soil was mixed with 250 ml of neutral 1N ammonium acetate solution. The solution was shaken for one hour. The suspension was filtered and the filtrate was used to analyse K by flame photometer (Jackson, 1967).

2.8 Extraction of soil organisms

2.8.1 Mycorrhiza

Extraction of VAM spores from soil is based on isolating spores mixed with organic debris through wet-sieving from soil then separated from organic matter by centrifugation (Abbott and Robson, 1991).

25 g of soil was taken in a 1000 ml beaker, about 500 ml of water was added and stirred using glass rod. The mixture was blended gently for about 15 seconds, and then the solution was allowed for sedimentation for about 2 minutes. For a few samples, spores in in blended and non-blended soils were compared. As blending of soils resulted in recovery of larger number of spores (Table 2), all samples were blended. The suspension was passed through 125, 45 and 32 μm sieves The residue remained on the sieves was collected in a beaker separately and centrifuged with water at 2000 rpm for 10 minutes. Then, the supernatant was discarded slowly and the pellet was again centrifuged with sucrose solution (484 g sucrose in 1000 ml water). The supernatant was washed on a 32 μm sieve and mycorrhizal spores on the sieve were collected in glass vials and labeled. The solution was kept in a cold room at 10^0 C and mycorrhizal spores were counted and identified using INVAM key (http://invam.caf.wvu.edu/fungi/taxonomy/keyindex.htm).

2.8.2 Nematodes

A wide variety of methods for extracting nematodes from soil are available; all are imperfect and have various degrees of inefficiency. As a result, many laboratories choose a method that gives the most efficient and consistent results for local conditions and nematodes of particular concern or interest (McSorley and Frederick, 2004). Most of the available extraction techniques can be divided into active methods that rely on nematode activity (Baermann funnel incubation method) and passive methods that rely on nematode's specific gravity or sedimentation (McSorley and Walter, 1991).

a. Sucrose centrifugation method

25 g of soil was taken in a 1000 ml beaker, about 500 ml of water was added and stirred using glass rod. The solution was allowed for sedimentation for about 2 minutes. The suspension was passed through 500 and 32 μm sieves. The residue

remained on the 500 μm sieve was discarded and the residue over the 32 μm sieve was collected in a beaker and transferred to centrifuge tube and centrifuged with water at 3500 rpm for 10 minutes. Then, the supernatant was discarded slowly and the pellet was again centrifuged with sucrose (484 g sucrose in 1000 ml water) solution. The supernatant solution was poured over a 32 μm sieve and the nematodes on the sieve were washed and stored in glass vials in refrigerator till they were counted.

b. Cobb's decanting and sieving method (Cobb, 1918)

100 g of soil was placed in a container, soaked with water and lumps were broken slowly. The muddy mixture was stirred and poured through a 1mm-aperture sieve into a second container leaving behind the heavy material which had settled. The remaining material on the sieve was washed with a gentle jet of water and collected in container II. The residue on the sieve was discarded. After stirring the contents of container II, it was poured through the 60 mesh (250 μm) sieve into container I, again leaving behind the heavier debris. The sieve was rinsed as before, and then, the residue on the sieve was washed into a 250 ml beaker and labeled as 60 mesh. The operations were repeated for the remaining solution in the container I using 310 mesh (32 μm) sieve and the sievings were collected in another beaker.

The extraction from 310 meshes was filtered through bathroom tissue using a mesh support below the tissue paper in a Petri plate and labeled as 310 mesh. The nematodes moved down the tissue paper in Petri plate were collected and transferred to the vials. The residue upon the tissue were collected and transferred to 60 mesh extraction and observed for the detection of larger nematodes and cysts.

The collected nematodes were identified up to family level and were divided into 5 feeding types based on the feeding habits.

Comparison of nematode abundance based on the two methods showed recovery of higher number of nematodes through Cobb's sieving method (Table 3). Based on this conclusion all samples were analyzed following Cobb's sieving method.

2.8.3 Ecological (Community) Indices

a. Frequency of soil organisms

Frequency refers to the occurrence of a species in a sample is an improvement over a mere listing of species. It is a measure of distribution uniformly, not abundance.

Absolute frequency is expressed as a percentage:

$$\text{Absolute frequency} = \frac{\text{Number of samples containing a species}}{\text{Number of samples collected}} \times 100$$

On the basis of these frequencies five categories were recognized as follows: R – rare (1-20%); O – occasional (21-40%); F – frequent (41-60%); C – common (61- 80%); D – dominant (81-100%).

b. Density

Density (abundance) is a quantitative measure of entities in a sample or a group of samples per unit of soil.

Relative density is a measure of number individuals of a species in relation to total number of individuals of all species and is calculated as follows:

$$\text{Relative density} = \frac{\text{Number of individuals of a species in a sample}}{\text{Total of all individuals in a sample}} \times 100$$

c. Maturity Index (MI)

The MI is a measure based on the ecological characteristics of nematode taxa. Nematode taxa except for plant feeders, are classified on a scale of 1-5, with colonizers (short life cycle, high reproductive rates, tolerant to disturbance) = 1, and persisters (long life cycles, low colonization ability, few offspring, sensitive to disturbance) = 5. The MI is calculated as the weighted mean of the constituent nematode taxa values:

$$MI = \sum_{i=1}^{n} v(i) \,.\, f(i)$$

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. The resulting index is a measure of disturbance, with lower values indicating a more disturbed environment and higher values characteristic of a less disturbed site.

d. Plant Parasitic Index (PPI)

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, because according to Bongers (1990) there are no plant feeding colonizers designated as 1.

e. Index of Similarity (IS)

An index of similarity is used to compare the nematode fauna of two areas or test sites. One of the earliest in ecology, the index proposed by Jaccard (1912), is based on presence-absence of species (Norton, 1978). Sorenson's (1948) method, a modification of Jaccard's equation, is more widely used.

$$ISs = \frac{c}{½\,(a+b)} \qquad \text{or} \qquad IS\,s = \frac{2c}{a+b}$$

where c is the number of species that two samples or areas have in common

a and b are the number of species in samples or area a and b, respectively.

f. Diversity Index

Shannon–Wiener index (H') was calculated as follows

$$H' = - \Sigma\, pi\, (\log pi)$$

pi is the proportion of the taxa in the total population

2.9 Statistical tests

Student's t-test, one- way analysis of variance and least significant difference ($P = 0.05$) were used to compare means.

3. Results

3.1 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. 1).

3.2 Herbaceous biomass

After winter crop harvest, herbaceous biomass in crop fields was 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. 2).

3.3 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. 3).

3.4 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. 4).

3.5 Soil pH

Soil pH showed the trend oak forest = pine forest < rainfed agriculture = abandoned agricultural land = scrubland < home gardens = irrigated agriculture. Effect of depth was not significant in all land uses except in forests where deeper soils were more acidic (Fig 5).

3.6 Soil Organic Carbon

Average soil organic carbon concentration in 0-20 cm soil layer was highest in home gardens followed by irrigated agriculture and other land uses with insignificant differences between them. Surface soil was richer in organic carbon compared to the sub-surface one in all land uses but this depth effect was most pronounced in pine forests (Fig 6).

3.7 Potassium

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 7).

3.8 Mycorrhiza

3.8.1 Frequency of occurrence in the landscape

In all 34 species, 13 belonging to the genus *Acaulospora*, 3 to *Gigaspora*, 8 to *Glomus* and 10 to the genus *Scutellospora* could be identified. It may be noted that about 3% of spores in abandoned agricultural land to 13% in oak forests could not be identified at species level.

Four species of *Acaulospora* (*A. lacunose, A. rugosa, A. sporocarpia, A. tuberculata*), one of *Glomus* (*G. manihotis*), and six of *Scutellospora* (*S. carolloidea, S. cerradensis, S. dipurpurascea, S. gregaria, S. rubra* and *S. scutata*) were present in 0-10 cm surface but absent in sub-surface soil (10-20 cm). Only one species viz. *S. erythropa* was present in

sub-surface but absent in surface soil. These species confined to only one depth belonged to rare or occasional frequency class (1-20% and 21-40% frequency of occurrence). In the landscape, only one species of *Scutellospora* was dominant compared to 3 of *Glomus*, 5 of *Acaulospora* and none of *Gigaspora*. Twenty three species were sampled from the subsurface soil compared to 34 species in surface soil, indicating a decline in species richness with increasing depth of soil (Table 4).

3.8.2 Spore abundance in 0-10 cm soil layer

Acaulospora lacunosa was sampled only from pine forests, *Gigaspora geosporum* only from abandoned agricultural land and, *Scutellospora dipurpurascea* and *S. scutata* only from irrigated agriculture. Twelve species occurred in all land uses but the degree of abundance varied between sites. Thus, *Acaulospora delicate* and *G. tenebrosum* occurred in all land uses but were more abundant in scrub land. *Glomus pansihalos* and *G. tenebrousum* were more dominant in pine forests compared to oak forests, while *Acaulospora morrowiae* was more abundant in oak forests. Irrigated agriculture differed from rainfed agriculture in terms of higher density of *Acaulospora morrowiae, Glomus tenebrosum* and *Glomus pansihalos* spores but lower of *Glomus intrradices* and *Glomus aggregatum* (Table 5,8).

3.8.3 Spore abundance in 10-20 cm soil layer

Acaulospora elegans occurred only in oak forests, *Gigaspora geosporum* and *Scutellaspora calospora* only in rainfed agriculture, *Scutellospora erythropa* only in irrigated agriculture, *Glomus pansihalos* only in homegardens and *Glomus viscosum* only in oak forests. Nine species were common to all land uses. However, land uses differed in terms of relative abundance of several species. *Glomus intraradices* was the most dominant species in scrubland, *G. aggregatum* in rainfed agriculture and *Glomus tenebrosum* in pine forest, oak forest, homegardens, irrigated agriculture and abandoned agricultural land. (Table 6,9)

Three species of *Glomus* viz., *Glomus aggregatum, G. intraradices* and *G. tenebrosum* accounted for > 50% of spores in almost all land uses, considering 0-10 cm and 10-20 cm

horizons together or separately (Table 8, 9). Coefficient of variation differed by species and depth but, in none of the cases, it exceeded a value of 190% (Tables 11,12,13).

3.8.4. Soildepth, land use and spore abundance

Total spore abundance decreased with depth in all land use types except rainfed agriculture and scrub where no change or a marginal increase was observed. There was a significant interaction of land use and depth. Oak and pine forest did not differ in terms of spore abundance in 10-20 cm depth but the latter showed markedly higher abundance compared to the former in 0-10 cm horizon. Abandoned agricultural land had comparable spore density in 0-10 cm depth but about 50% lower in 10-20 cm depth compared to rainfed agriculture or scrubland. Pooled spore abundance in 0-20 cm horizon showed a trend of pine forests > oak forests = rainfed agriculture = scrubland > irrigated agriculture > homegardens = abandoned agricultural land (Figure 8).

3.8.5 Variability of distribution of mycorrhizal spores

Coefficient variation in most of the cases was lower for pooled abundance in 0-20 cm horizon compared to that in 0-10 cm and 10-20 cm layers separately. Coefficient of variation in total spore abundance was lower than that of species wise abundance. In none of the land uses, coefficient of variation for pooled spore abundance for 0-20 cm soil layer exceeded a value of 75% (Table 14).

3.9 Nematodes

3.9.1 Family-wise abundance

In all 12 families, two of bacterivores, one each of fungivore, predators and saprofagous nematodes, 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 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 home gardens 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 15).

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 land use 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 land uses (Table 16).

3.9.2 Similarity between nematode communities in different land uses

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 17).

3.9.3 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. 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 for 0-10 cm soil layer, 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 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. 9).

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. B/F ratio found to be quite low in oak forest. Diversity index did not differ significantly between different land use types except abandoned agricultural land and rainfed agricultural land in 0-10 cm soil layer, pine forest and rainfed agricultural land in 10-20 cm soil layer. In 0-20 cm soil layer, the diversity index of abandoned agricultural land significantly differed with rainfed agricultural land, irrigated agricultural land and oak forest (Table 18).

3.9.4 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 (Table 19). Pooled abundance data showed the lowest degree of within-class variability of parasites. 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 20).

Table 2: Abundance of mycorrhizal spores (SEM in parentheses) enumerated from blending and non-blending of soil (n=8) followed by wet-sieving and centrifugation method. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, Scrubland.

Wet-sieving and centrifugation method	Mycorrhizal spores (spores 100^{-g} soil)
Following blending of soil	231 (26)
Without blending of soil	177 (23)

Table 3: Abundance of nematodes (SEM in parentheses) enumerated from Cobb's sieving and sucrose centrifugation methods (n=8). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, Scrubland.

Method	Nematode abundance (individual of nematodes 100^{-g} soil
Cobb's sieving and decantation method	439 (101)
Sucrose centrifugation method	105 (12)

Table 4: Frequency of occurrence of different mycorrhizal species in 0-10 cm and 10-20 cm soil layers and mean values for 0-20 cm soil layer in the landscape. Species are classified in six frequency classes: Ab, absent; 1-20%, rare (R); 21-40%, occasional (O); 41-60%, frequent (F); 61-80%, common (C); 81-100%, dominant (D).

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

Table 5: Abundance (number of spores g^{-1} soil) of mycorrhizal species in different land uses in 0-10 cm soil layer. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

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

Table 6: Abundance (number of spores g^{-1} soil) of mycorrhizal species in different land uses in 10-20 cm soil layer. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

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

Table 7: Abundance (number of spores g^{-1} soil) of mycorrhizal species in different land uses in 0-20 cm soil layer (pooled data of 0-10 cm and 10-20 cm soil layers). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, Scrub land.

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SL
Acaulospora delicata	0.22	0.55	0.39	0.71	0.69	0.45	1.70
Acaulospora dilatata	0.17	0.61	0.21	0.56	0.50	0.21	1.09
Acaulospora elegans	0.12	0.04	0.04	0.05	0.00	0.00	0.04
Acaulospora lacunosa	0.00	0.09	0.00	0.00	0.00	0.00	0.00
Acaulospora mellea	0.08	0.48	0.17	0.16	0.06	0.17	0.09
Acaulospora morrowiae	1.97	1.04	1.15	1.49	1.63	0.48	1.35
Acaulospora myriocarpa	0.36	0.48	0.09	0.10	0.42	0.20	0.23
Acaulospora rehmii	0.11	0.16	0.10	0.06	0.02	0.03	0.18
Acaulospora rugosa	0.00	0.02	0.02	0.00	0.00	0.06	0.00
Acaulospora sporocarpia	0.36	0.00	0.00	0.00	0.05	0.00	0.00
Acaulospora trappei	0.54	0.97	0.22	0.48	1.00	0.35	0.58
Acaulospora tuberculata	0.00	0.00	0.07	0.19	0.02	0.05	0.02
Acaulspora scrobiculata	0.03	0.00	0.00	0.12	0.09	0.04	0.04
Gigaspora albida	0.00	0.17	0.08	0.05	0.05	0.08	0.12
Gigaspora geosporum	0.00	0.00	0.00	0.00	0.03	0.02	0.00
Gigaspora gigantea	0.02	0.07	0.05	0.26	0.16	0.15	0.01
Glomus aggregatum	3.25	6.54	1.64	3.50	5.56	1.88	4.39
Glomus etunicatum	0.03	0.16	0.14	0.02	0.02	0.00	0.00
Glomus intraradices	3.71	5.88	2.33	3.98	4.63	2.63	6.40
Glomus manihotis	0.03	0.07	0.02	0.04	0.00	0.03	0.00
Glomus pansihalos	1.02	3.89	1.02	1.21	0.66	0.29	2.11
Glomus tenebrosum	7.24	11.26	3.30	3.66	5.18	3.25	3.25
Glomus verruculosum	0.08	0.08	0.04	0.04	0.23	0.01	0.01
Glomus viscosum	0.37	0.05	0.04	0.06	0.22	0.00	0.00
Scutellospora calospora	0.15	0.31	0.19	0.14	0.35	0.44	0.01
Scutellospora carolloidea	0.00	0.06	0.00	0.00	0.00	0.04	0.00
Scutellospora cerradencis	0.00	0.00	0.00	0.03	0.00	0.04	0.00
Scutellospora dipurpurescens	0.00	0.00	0.00	0.06	0.00	0.00	0.00
Scutellospora gregaria	0.16	0.13	0.29	0.26	0.22	0.08	0.45
Scutellospora erythropa	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Scutellospora heterogama	1.00	1.07	0.57	1.15	1.84	0.42	1.21
Scutellospora pellucida	0.37	0.24	0.06	0.00	0.16	0.06	0.19
Scutellopora rubra	0.04	0.02	0.00	0.00	0.00	0.00	0.14
Scutellospora scutata	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Others	1.82	3.39	0.95	0.76	0.74	0.24	0.68
Total spores	23.25	37.85	13.17	19.17	24.50	11.67	24.26

Table 8: Relative abundance of different mycorrhizal species (spores g^{-1} soil) in 0-10 cm soil layer in different land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

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

Table 9: Relative abundance of different mycorrhizal species (spores g^{-1} soil) in 10-20 cm soil layer in different land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

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

Table 10: Relative abundance of different Mycorrhizal species (spores g^{-1} soil) in 0-20 cm soil layer (pooled data of 0-10 cm and 10-20 cm soil layer) in different land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

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

Table 11: Coefficient of variation of abundance of different mycorrhizal species in 0-10 cm soil layer in different land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

Mycorrhizal species	OF	PF	HG	IA	RA	AA	SL
Acaulospora delicata	124.9	66.3	115.4	67.0	137.4	173.2	154.0
Acaulospora dilatata	106.0	52.3	173.2	112.1	173.2	173.2	75.9
Acaulospora elegans	173.2	173.2	173.2	173.2			173.2
Acaulospora lacunosa		173.2					
Acaulospora mellea	173.2	126.6	106.4	173.2		173.2	89.6
Acaulospora morrowiae	76.7	98.9	65.4	48.3	149.9	133.3	81.1
Acaulospora myriocarpa	94.7	164.1		173.2	107.2	104.6	136.7
Acaulospora rehmii	103.8	173.2	140.0	173.2		87.0	173.2
Acaulospora rugosa		173.2	173.2			173.2	
Acaulospora sporocarpia	146.5				173.2		
Acaulospora trappei	78.9	120.8	90.6	120.0	144.9	70.0	24.4
Acaulospora tuberculata			173.2	173.2	173.2	173.2	173.2
Acaulspora scrobiculata	173.2			87.8		173.2	173.2
Gigaspora albida		128.9	173.2	173.2		173.2	89.2
Gigaspora geosporum						173.2	
Gigaspora gigantea		128.9	173.2	173.2	39.8	67.7	173.2
Glomus aggregatum	25.1	75.6	61.7	44.1	58.0	51.5	39.9
Glomus etunicatum		131.5	173.2	173.2	173.2		
Glomus intraradices	63.8	77.9	31.0	41.4	58.9	48.8	24.4
Glomus manihotis	173.2	173.2	173.2	90.1		173.2	
Glomus pansihalos	173.2	167.0	173.2	173.2	173.2	173.2	172.0
Glomus tenebrosum	108.3	120.7	117.8	69.0	146.3	90.2	88.4
Glomus verruculosum	120.2	173.2	173.2	87.7	173.2	173.2	173.2
Glomus viscosum		173.2	173.2	173.2	173.2		
Scutellospora calospora	96.8	79.9	173.2	173.2	173.2	173.2	173.2
Scutellospora carolloidea		97.4				173.2	
Scutellospora cerradensis			173.2		173.2		
Scutellospora dipurpurascens			173.2				
Scutellospora gregaria	173.2	173.2	173.2	142.9	173.2	173.2	173.2
Scutellospora heterogama	89.0	86.6	93.3	116.4	173.2	42.7	121.6
Scutellospora pellucida	90.0	88.6	88.5		99.0		173.2
Scutellospora rubra	173.2	173.2					118.8
Scutellospora scutata				173.2			
Others	75.1	137.4	99.0	67.6	48.0	128.4	61.9

Table 12: Coefficient of variation of abundance of different mycorrhizal species in 10-20 cm soil layer in different land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

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

Table 13: Coefficient of variation of abundance of different mycorrhizal species in 0-20 cm soil layer (pooled data of 0-10 cm and 10-20 cm soil layers) in different land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

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

Table 14: Coefficient of variation of abundance of mycorrhizal spores (all species pooled together) in 0-10 cm, 10-20 cm and 0-20 cm (pooled data of 0-10 cm and 10-20 cm soil depths) in different land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

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

Table 15: Nematode abundance (disaggregated by families; functional groups specified within parenthesis) in 0-10 cm and 10-20 cm soil layers in different land uses in Chamali village landscape (n = 5). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land; 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

Table 16: Relative abundance of nematodes disaggregated by families in in different land uses (n=5). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land; B, Bacterivore; F, Fungivore; S, saprofagous; PP, plant parasite; P, predator.

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)	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

Table 17: Index of Similarity between nematode communities of 0-10 cm, 10-20 cm and 0-20 cm soil layers in different land uses. OF, Oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrub land.

Land uses	OF	PF	HG	IA	RA	AA	SL
0-10 cm							
OF	100	71.3	70.8	76.0	55.4	54.8	77.4
PF		100	74.8	66.8	77.7	63.7	67.2
HG			100	83.8	62.1	67.8	71.3
IA				100	58.4	60.4	77.3
RA					100	58.7	54.7
AA						100	63.2
SL							100
10-20 cm							
OF	100	49.7	33.6	33.9	40.0	35.3	32.1
PF		100	35.5	33.4	28.8	22.6	32.2
HG			100	56.6	61.2	52.8	52.5
IA				100	65.1	61.9	45.0
RA					100	78.3	59.2
AA						100	37.3
SL							100
0-20 cm							
OF	100	73.7	66.2	65.1	53.8	53.2	73.9
PF		100	77.0	76.7	75.3	64.1	77.4
HG			100	80.3	68.2	67.1	65.2
IA				100	63.8	67.8	70.7
RA					100	66.7	63.5
AA						100	60.4
SL							100

Table 18: The Maturity Index (MI), Plant Parasitic Index (PPI), Bacterivore/Fungivore Ratio (B/F) and Diversity Index (H') calculated for nematode communities in 0-10 cm, 10-20 cm and 0-20 cm soil layers in various land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, Scrubland; LSD, least significant difference (P = 0.05).

	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

Table 19: Coefficient of variation of nematode abundance in 0-10 cm and 10-20 cm soil layers (disaggregated by families) in different land uses. 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)	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 20: Coefficient of variation of nematode abundance disaggregated by feeding/functional groups in 0-10 cm and 10-20 cm soil layers in different land uses. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, Scrub land.

	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 21: A profile of selected studies on mycorrhizal spore abundance

Study area/authors	Reported spore abundance	Other distinguishing points
Shaded/agroforestry and unshaded coffee system in Brazil: Cardoso *et al.*, (2003)	2-130 spores per g soil	
Neem-based Agroforestry systems in Rajasthan (arid-semi-arid region): Pande and Tarafdar (2004)	1.2 – 4.4 spores per g soil	Three genera viz. Glomus, Gigaspora and Sclerocystis with 15 species
Primary and secondary tropical seasonal rainforests in Xishuangbanna, China Muthukumar *et al.*, (2003)	0.3-0.9 spores per g soil	
Closed canopy and gaps in tropical rain forests in Mexico: Guadarrama and Alvarez-Sanchez (1999)	0.4 – 2.6 spores g soil	Four genera (Glomus, Gigaspora, Sclerocystis and Acaulospora) and 16 morpho-species
Field plots in Coimbatore: Muthukumar and Udaiyan (2000)	2.5 spores per g soil	Acaulospora Scutellospora Glomus Sclerocystis
Acacia farnesiana plantation and Acacia planifrons plantation near Coimbatore: Udaiyan *et al.*, (1996)	5-15 spores per g soil	Four genera with eight species: Acaulospora, Gigaspora, Glomus and Sclerocystis
Scrub vegetation around Islamabad: Rashid *et al.*, (1997)	3-3.8 spores per g soil	Three genera (Glomus, Gigaspora and Acaulospora) – also mentioned 'unknowns'
Maple forests in eastern Canada (Moutoglis and Widden, 1996)	27-1600 per g soil	Two genera – Glomus and Acaulospora
Tropical rain forests in Costa Rica: Lovelock *et al.*, (2003)	518-4794 per 100 cm3 soil	Acaulospora Scutellospora Gigaspora Glomus
Semiarid tropical alfisols/agricultural soils: Lee *et al.*, (1996)	14-26 spores per g soil	
P deficient soil in pot with Leucaena: Bagyarj *et al.*, (1989)	163-180 in 25 ml of unioculated and 212-312 per 25 ml of inoculated soil	

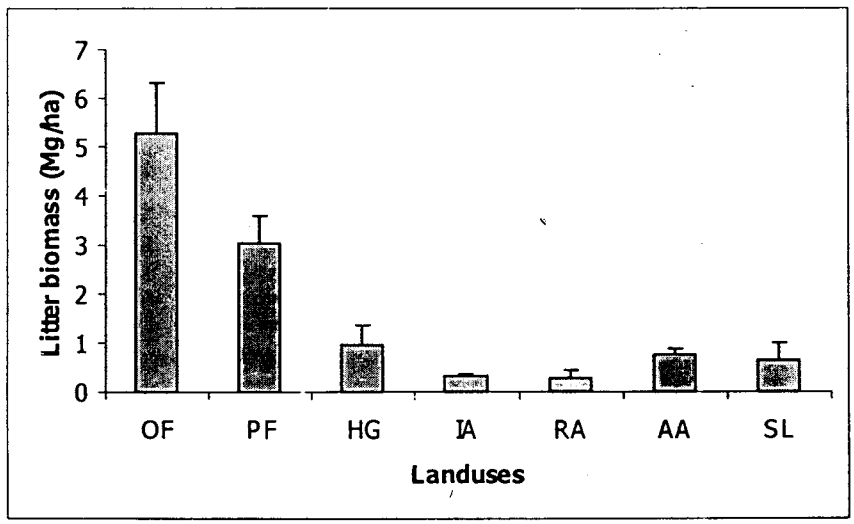

Fig 1. Litter biomass (Mg/ha) of different land uses in Chamali village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland. Bars represent SEM.

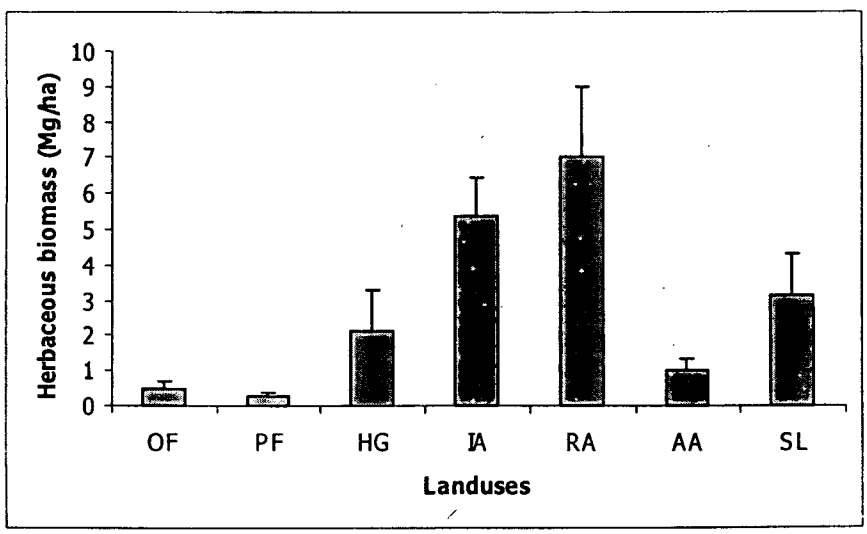

Fig 2. Herbaceous biomass (Mg/ha) of different land uses in Chamali village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland. Bars represent SEM.

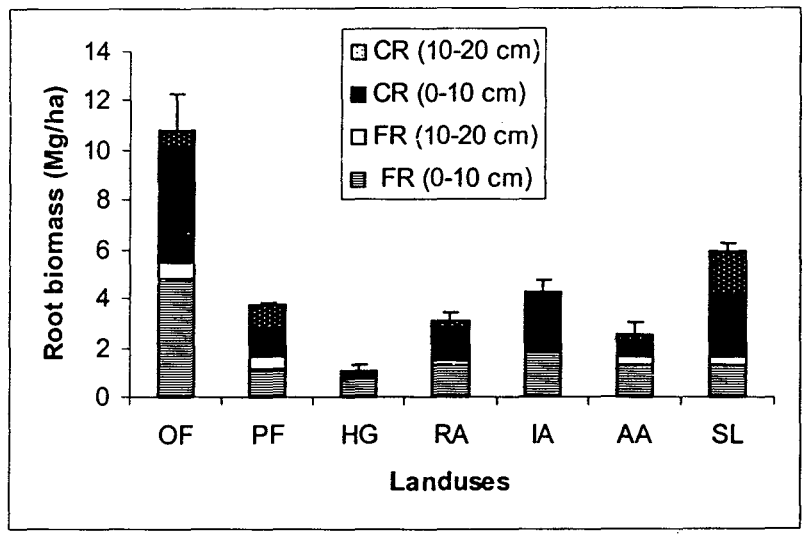

Fig 3. Root biomass (Mg/ha) of different land uses in Chamali village landscape (bars showing SE for total root biomass). OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland; CR, Coarse roots; FR, Fine Roots. Bars represent SEM for total root biomass.

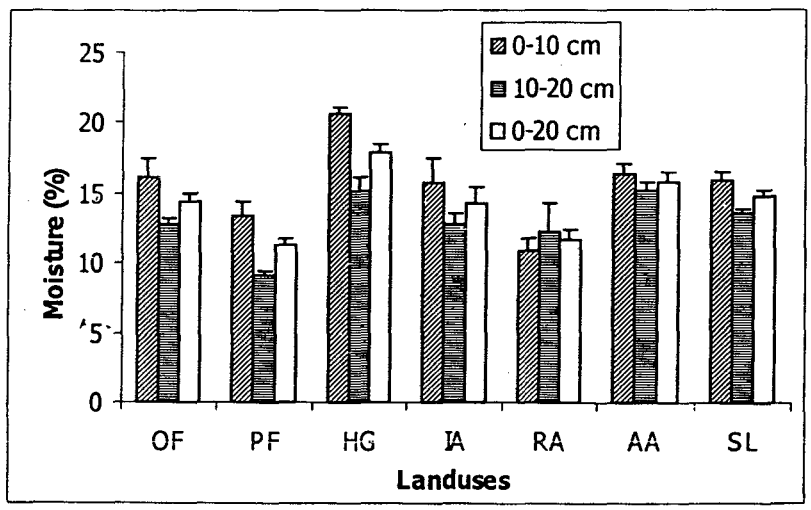

Fig 4. Moisture (%) content of soils in different land uses in Chamali village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland. Bars represent SEM.

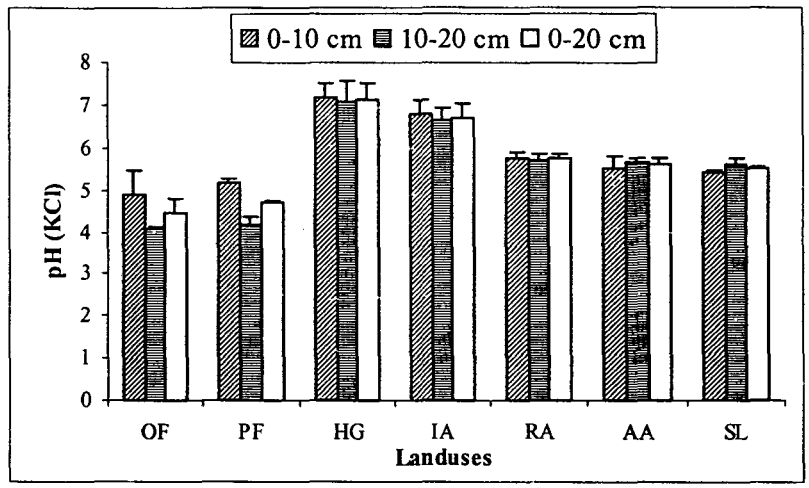

Fig 5. pH (KCl) of soils of different land uses in Chamali village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland. Bars represent SEM.

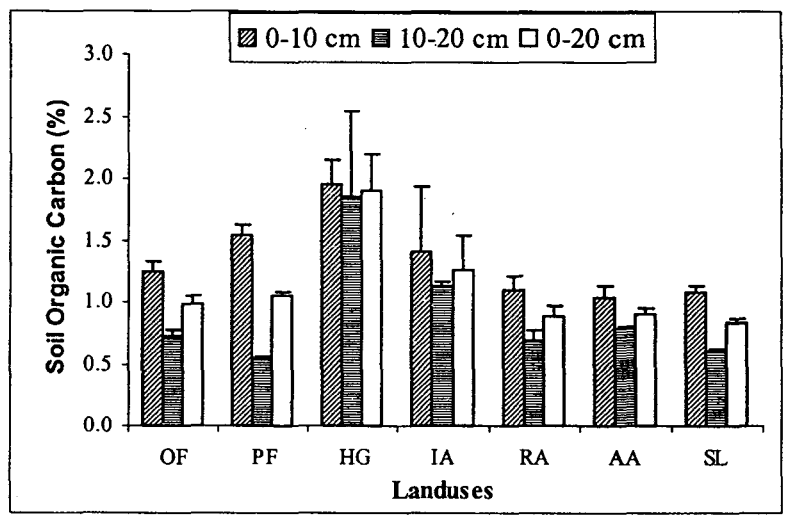

Fig 6. Soil Organic Carbon (%) of soils of different land uses in Chamali village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland. Bars represent SEM.

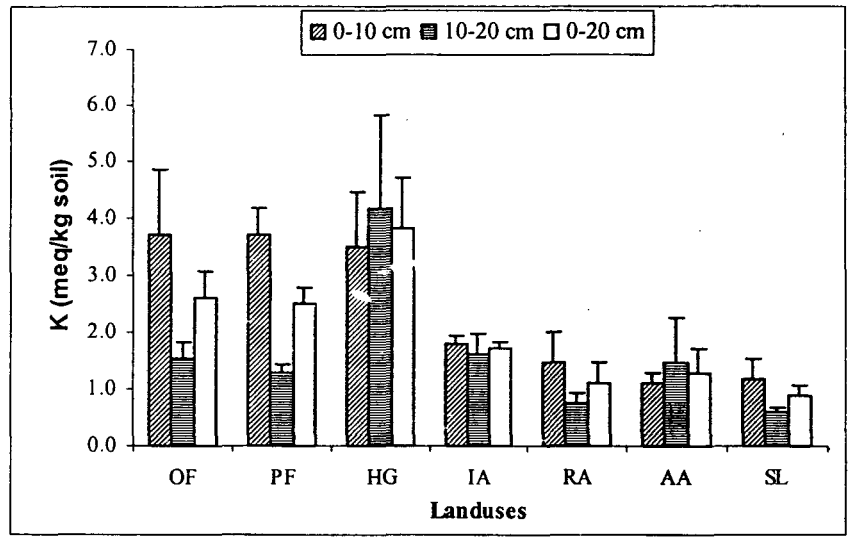

Fig 7. K (meq/kg soil) of soils of different land uses in Chamali village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland. Bars represent SEM.

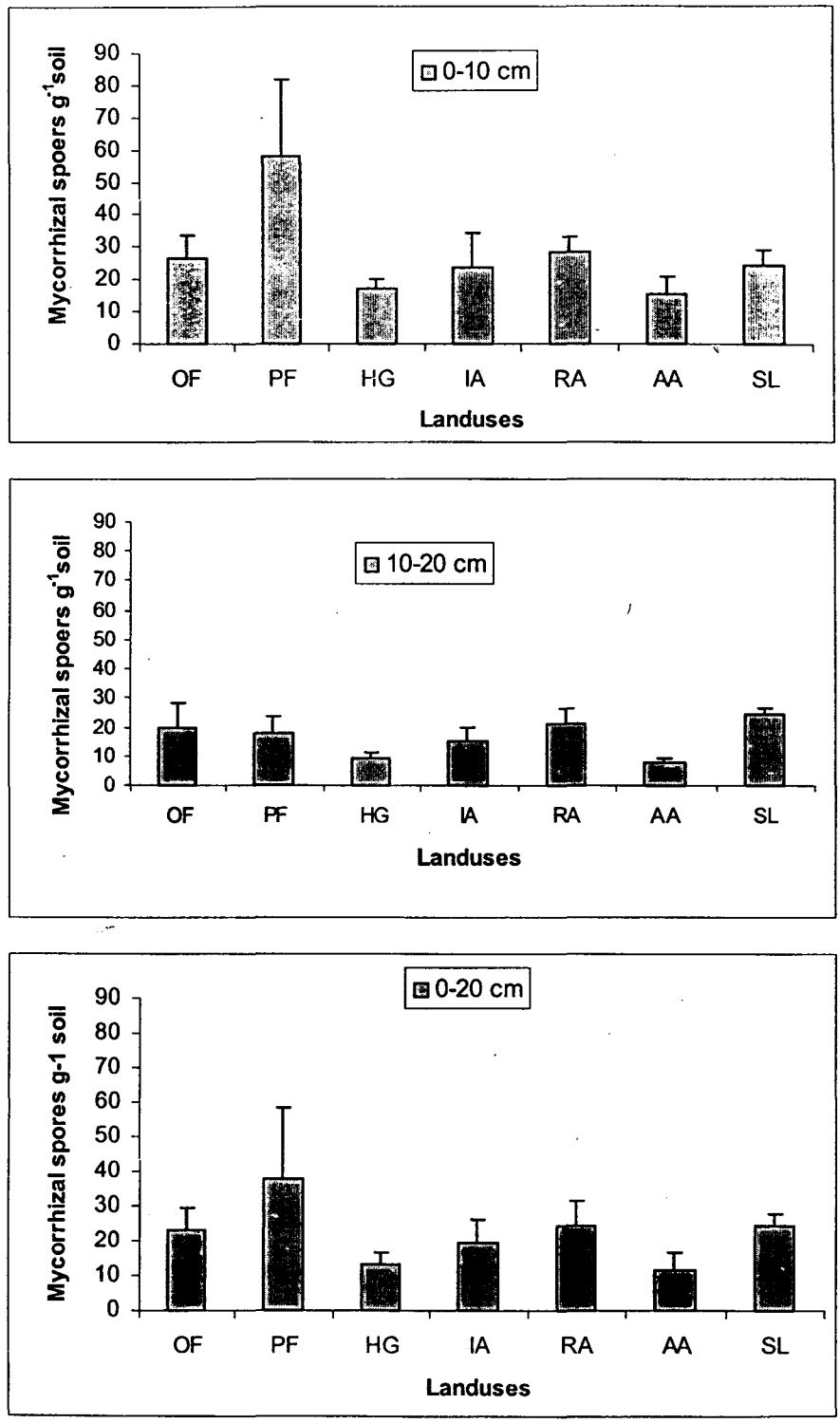

Fig 8. Numerical abundance of mycorrhizal spores (bars showing SE) in different landuses at different soil layers in Chamali village landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland. Bars represent SEM.

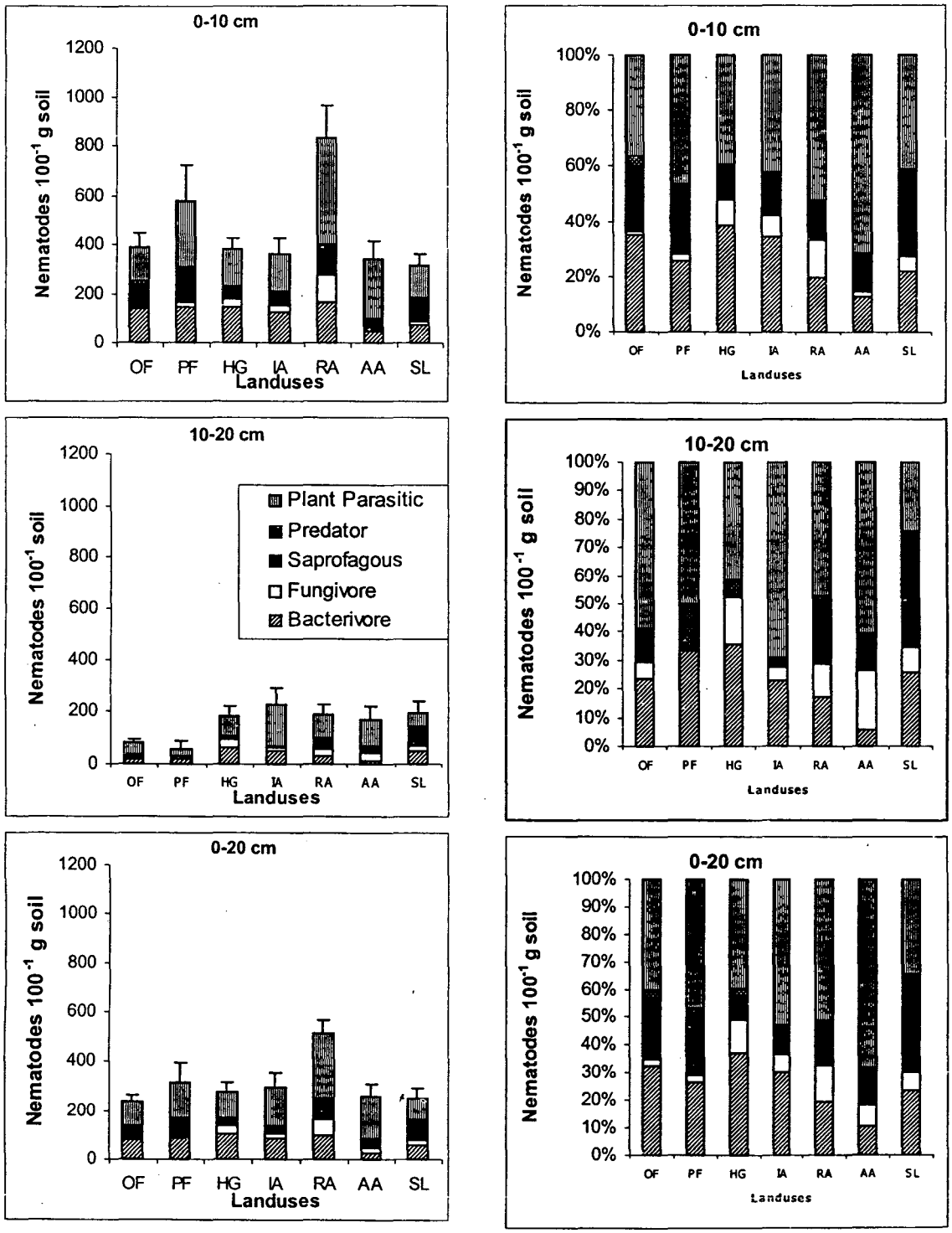

Fig 9. Absolute and relative abundance of nematodes (bars showing SE for total nematodes) disaggregated by functional groups in 0-10 cm and 10-20 cm soil layers in different landuse types in Chamali landscape. OF, oak forests; PF, pine forests; HG, home gardens; IA, irrigated agriculture; RA, rainfed agriculture; AA, abandoned agriculture; SL, scrubland. Bars represent SEM for total abundance.

Plate 1. Landscape view of rainfed agriculture land.

Plate 2. Rainfed agriculture land: terraces with wheat crop.

Plate 3. Homegarden harbour rich biodiversity of vegetables, fruit trees and fodder trees.

Plate 4. Oak forest: dense canopy sustains rich biodiversity.

Plate 5. Pine forest: *Pinus roxburghii* with sparse understorey vegetation.

Plate 6. Abandoned agriculture land: sheeps and goats exert grazing pressure.

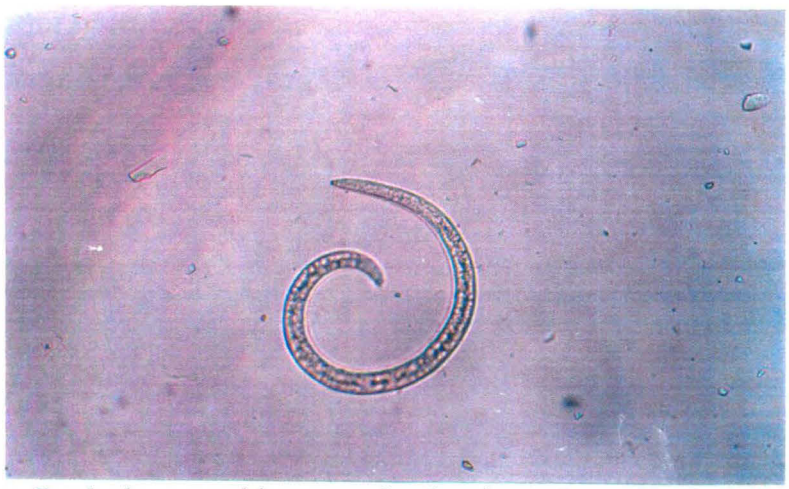

Plate 7. A plant parasitic nematode, showing stylet and helicoid body.

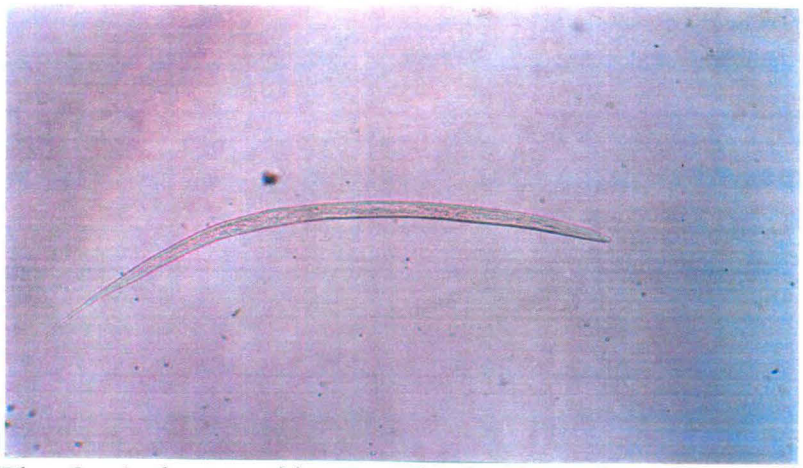

Plate 8. A plant parasitic nematode, showing stylet and taper tail.

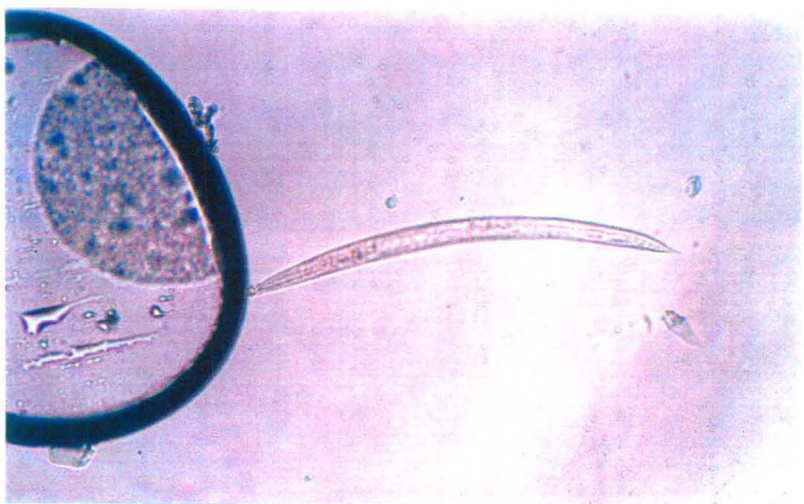

Plate 9. A bacterivore nematode, bearing feathered mouth parts.

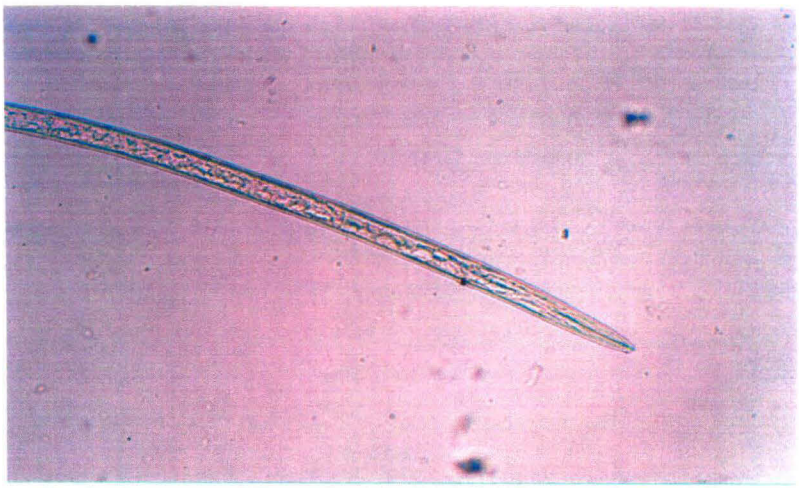

Plate 10. A plant parasitic nematode, bearing long stylet and linear body.

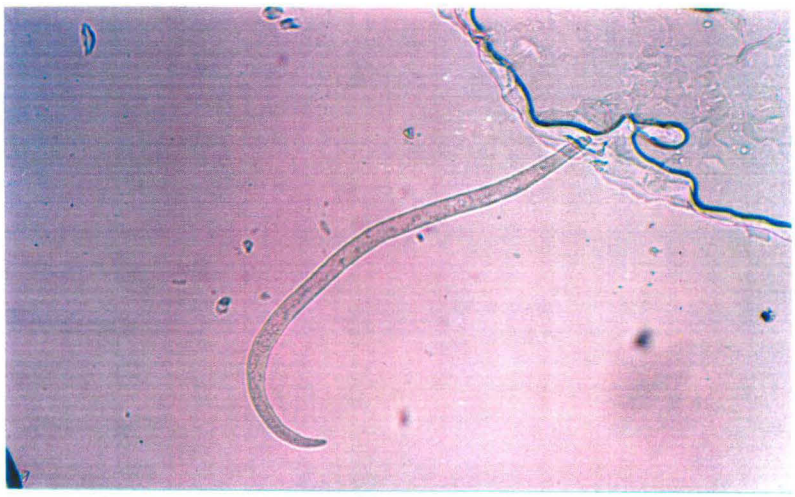

Plate 11. A plant parasitic nematode, showing stylet.

4. Discussion

4.1. Suitability of mycorrhizal spore count

Majority of arbuscular mycorrhizal fungi (AMF) produce soil-borne spores. The spores of AMF could be viewed as a surrogate or indicator of mycorrhizal incidence as spore numbers and root colonization have been found to be positively correlated (Fischer *et al.,* 1994; Onguene, 2000), sporulation is positively correlated with the growth of mycorrhizal plants (Hetrick and Bloom, 1986; Giovannetti *et al.,* 1988) and the factor that stimulate or inhibit sporulation inhibit colonization as well (Daft and Nicolson, 1972). Exceptions to these generalizations do exist, e.g., spore numbers and percent root colonization may not be necessarily correlated as wide range of factors related to host, fungus and environment determine VAM formation (Khalil *et al.,* 1992; Udaiyan *et al.,* 1996). The results presented here show that spore recovery is substantially improved if soil is blended in isolating spores using wet-sieving method.

Quantification of root colonization in a diverse plant community is difficult as the optimum treatments for staining roots may differ from species to species. Cardoso *et al.,* (2003) did not succeed in clearing and staining roots of some species, observed a high degree of variability in time required for clearing in others, and thus found it impossible to discriminate among roots that would need a different protocol. We also failed to succeed in decoloring and proper staining of roots of quite a few species including the dominant ones like oaks (unpublished work of Kritika Singh).

Spore count for evaluating diversity and abundance of mycorrhizae is advantageous in that spores are highly resistant to adverse conditions (Abbot and Robson, 1991) and spore community is likely to reflect the previous history of a mycorrhizal symbiosis (Harley and Smith, 1983). Further, spore count has an advantage over the MPN method in that assumptions concerning host specificity of VAM are not made, i.e., that trap plants might fail to reveal presence of many species as spores. However, difficulties in taxonomy based solely on the spore features and lack of differentiation of effective and ineffective spores in terms of their ability to develop mycorrhizal association remains a major limitation of characterizing mycorrhiza abundance and diversity based exclusively on spores.

4.2. Optimum time for mycorrhizal spore enumeration

Based on the work carried out in tropical rain forest in Mexico, Guadarrama and Alvarez-Sanchez (1999) concluded that higher species richness as well as abundance of spores is likely in dry season as also observed by Janos *et al.*, (1995) in Peru. Spore abundance decreases during rainy season, spore germination is favoured and intra- and extramatricial mycelium increases (Mason *et al.*, 1992; Ragupathy and Mahadevan, 1993). Exceptions to this general trend do exist (Moutoglis and Widden, 1996). In the present situations, it appears that there are significant effects of season, management practices and their interactions. This work, however, could not be completed for various reasons.

4.3. Species diversity of VAM

Glomus species have been found to be most common AM fungi occurring over a wide range of ecosystem types (Talukdar and Germida, 1993; Pande and Tarafdar, 2004; Hart and Reader, 2004; Taylor and Harrier, 2000) as also reported in this study. A cross section of studies summarized in table 21 shows that the spore abundance, species dominance and diversity data in the present case falls within the range of reported values. The differences between land use types were more marked in terms of relative abundance of different species and spore abundance in relation to soil depth rather than their presence/absence. Guadarrama and Alvarez-Sanchez (1999) also did not find a very significant effect of season but not of site on species richness or abundance of spores of AM fungi in tropical rainforest. Rashid *et al.*, (1997) did not find any significant difference in diversity or abundance of spores between control and burnt sites.

4.4. Effect of soil depth on mycorrhiza

Most of the studies on mycorrhiza in the tropics and sub-tropical region have concentrated on top 0-20 cm soil, though AMF at deeper depths may be equally important where trees have roots reaching the deeper soil layers. Cardoso *et al.*, (2003) observed that agroforestry system had greater numbers of AMF spores and as well as roots in deeper layers (40-60 cm) and lower values in the upper layers (0-7.5 cm) compared to unshaded coffee system. Muthukumar *et al.*, (2003) observed that root

density, AM colonization and AM fungal spore numbers decreased with soil depth in all forests in Xishuangbanna, southwest China and similar observation was made by Douds *et al.,* (1995). Thompson (1991) observed a gradual decline in spore numbers to soil depths of 120 cm in cropland, Jakobsen and Nielsen (1983) did not observe any change upto 20 cm depth, and Ananth and Rickeri (1991) found the highest concentration in 30-45 cm soil layer. An *et al.,* (1990) found some species in a soyabean field more prevalent at 0-15 cm depth and others at 30-45 cm depth. Surface soil had higher spore abundance in no-tilled agricultural system and tilled soil had higher abundance in deeper soils (Abbott and Robson, 1991). Douds *et al.,* (1995) observed that distributions of spores of VAM fungi with depth were affected by sampling date, tillage and farming system type. In the present study also, the effect of depth was more marked in more intensively ploughed homegardens and irrigated agricultural land use compared to less intensively tilled rainfed agriculture.

4.5. Correlation of mycorrhiza with edapho-climatic features

Spore populations have been found to decrease with increasing clay content, increase with increasing pH and carbon, and decrease with increasing soil phospohorus (Day, *et al.,* 1987). Pande and Trafdar (2004) found that AMF spore population was correlated with Fe and maximum temperature in both tree and crop rhizosphere, with Zn only in tree rhizosphere and with EC, Organic carbon, P, $CaCO_3$, rainfall and relative humidity only in crop rhizosphere and found a positive correlation of spore abundance and bulk density, moisture content, water holding capacity and pH of soil. Contrary to these results, we did not find any simple statistical relationship between soil physicochemical properties or root biomass with spore abundance.

4.6. How many spores are required for proper colonization

McGee *et al.,* (1997) while working on soils in eastern Australia used to grow cotton, considered a density of 4 to 212 spores^{-g} soil to be high, and assumed that 5 spores^{-g} soil would be required to initiate maximum levels of colonization taking spore germination rate as 5%. Bagyaraj *et al.,* (1989) added 12500 infective propagules to each test plant grown in 4 kg soil. If these conclusions are applied to the present study area, soil seems not to be very deficient in spore abundance. However, whether infective propogules of

the most advantageous mycorrhiza are present in sufficient numbers and the soil physicochemical characteristics are favorable for function of such mycorrhizal association are the aspects which need to be further investigated?

4.7 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.

4.8 Effect of soil depth on nematodes

A decline in nematode abundance with an increase in soil depth within a given land use and its correlation with soil organic carbon and nitrogen have been reported by Ou *et al.,* (2005) in diverse land uses in aquatic brown soil, 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.

4.9 Effect of moisture/water-logging on nematodes

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).

4.10 Mulching

Mulching has been found to increase the population of nematodes with a relative contributon 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 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 land uses a 'negative mulching effect'. The proportion of bacterial feeders in the present land uses with a positive mulch effect was 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.

4.11 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.,* 1998; 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. Bongers (1990) have suggested that the PPI, in heavily fertilized agronomic crops with greater root production than in natural systems, would increase and the MI decrease. 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.

4.12 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.

5. Conclusions

The major conclusions arising from this study carried out in a landscape where the different ecosystems are intimately interconnected are

(a) Blending of soil may improve recovery of mycorrhizal spores from Himalayan soils.

(b) Mycorrhizal spore density decreased with increase in soil depth, spores were correlated with moisture.

(c) Mycorrhizal spores vary with landuses depending on the management practices within the landuses and the crops grown in agricultural field.

(d) Cobb sieving method, though is more cumbersome and time-consuming, enables a better recovery and inventory of nematofauna.

(e) Nematode abundance decreases with increase in soil depth but this trend is not correlated with the trend in soil physicochemical properties.

(f) Plant parasite functional/trophic group is the most diversified nematode group.

(g) 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.

(h) Nematode community similarity/dissimilarity is not correlated with aboveground similarity/dissimilarity.

(i) 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.

Sequential assessments of mycorrhiza and nematodes allow analysis of environmental degradation or remediation, therefore, there is need to study mycorrhiza and nematodes adopting a more intensive sampling framework. One time assessment as presented here does provide only a snapshot view of current conditions. Further the conclusions on soil biota – land use and soil characteristics can not be generalized too far as processing of all samples could not be completed because of time constraints.

6. References

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