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Diversity of soil fungal communities in *Alnus nepalensis* and *Castanopsis hystrix* dominated plantation forest stands of Northeastern India

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Fungi are important members of soil microbial communities with a crucial role in biogeochemical processes. Very few studies have addressed the diversity of fungi in subtropical forests of Northeast India. In this study an attempt has been made to compare the species composition of culturable filamentous fungi and their seasonal occurrence in mineralized surface soils of *A. nepalensis* and *C. hystrix* dominated plantation forest stands located adjacently on hill slopes in the eastern Himalayan region. A total of 58 fungal species belonging to 29 genera and 1 sterile mycelia form were isolated by soil dilution plating during 12 months period. Month of sampling and study sites influenced the species composition of soil fungi. Total species richness of soil fungi was higher in *A. nepalensis* stand than the *C. hystrix* stand. *Cladosporium cladosporioides*, *Fusarium oxysporum*, *Mucor heimalis*, *Penicillium purpurogenum*, *Trichoderma viride* and white sterile mycelia were the dominant soil colonizers from both the sites with mean Relative Abundance (%) values ≥3. Different fungal species showed differential seasonal preferences at two study sites. Highest similarity index among the soil fungi of both stands was recorded during winter season. The present investigation suggests that soil environment and vegetation factors mainly influenced the fungal diversity and community composition.

Key words: Soil microfungi, seasonal variations, *A. nepalensis* and *C. hystrix* stands, Northeastern India

INTRODUCTION

Soil microbes are the essential components of biotic community in natural forests and are largely responsible for ecosystem functioning because they participate in nutrient transformations and biogeochemistry (Hackl *et al.*, 2004). Among different groups of soil microbiota, saprobic fungi represent the largest proportion of soil biomass in terms of diversity and physiological activities and perform the crucial roles in decomposition of plant structural polymers, thereby contributing to the maintenance of global carbon cycle (Kjøller and Strewe, 1982). Christensen (1989) described around twenty functions of soil fungi along with one being their significant role as primary degraders. Seasonal variations in climatic regimes, soil texture, nutrient and water availability therein and the vegetation type are the major factors affecting the spatial distribution and diversity of fungi in soil-litter interface (Arunachalam *et al.*, 1997; Sharma *et al.*, 2011a). Understanding the fungal community structure and patterns in various habitats is one of

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the central issues in soil microbial ecology (Green and Bohannan, 2004).

From the late 1940s, there has been a growing interest in soil mycology which has motivated towards such studies (Subramanian, 1986). In recent years, several investigations have been carried out on the species richness of soil fungi in different forest ecosystems of India (Satish *et al.*, 2007; Saravanakumar and Kaviyarasan, 2010; Panda *et al.*, 2010; Bhattacharyya and Jha, 2011; Sharma *et al.*, 2011a; Devi *et al.*, 2012). Evidences suggest that the fungal diversity is much greater in the tropics than that in temperate regions (Manoharachary *et al.*, 2005). However, defining the number of fungi on earth has always been a point of discussion and several reports have focused on enumerating the global fungal diversity which vary from 0.7 to 9.9 million species (Hawksworth, 2004) but only 80,000 species have been described to date worldwide (Schmit and Mueller, 2007). In addition to tropical forests, the number of unexplored habitats including subtropical ecosystems which have proven rich in specialized and unique fungi is still enormous (Lodge and Cantrell, 1995). Given the key roles that fungi play in nutrient cycling in tropical plantation forests there is a clear imperative to better understand the structure of soil fungal community in natural habitats.

North East India, being an important portion of Indo-Burma Biodiversity hot spot region (Myers *et al.*, 2000), is blessed with a wide range of physiography and ecoclimatic conditions. Himalayan alder (*Alnus nepalensis* D. Don - Family Betulaceae) and chinkapins (*Castanopsis hystrix* A. DC. - Family Fagaceae) are the parts of evergreen subtropical plantation forests trees in Manipur, North East India and are confined to lower and middle altitudes forming a climax vegetation type (Kayini and Pandey, 2010; Sharma *et al.*, 2011b). The subtropical forests of the region that follow the foot hills of the Himalaya to the west and extend into South East Asia in the east, still remains systematically unexplored in relation to fungal diversity (Bhattacharyya and Jha, 2011; Sharma *et al.*, 2011a; Devi *et al.*, 2012).

Therefore, the aim of the present study was to investigate the diversity, abundance and seasonal distribution of filamentous fungi in surface soils of *A. nepalensis* and *C. hystrix* dominated plantation forest stands of Manipur, Northeastern India.

MATERIALS AND METHODS

Study site

The study was conducted in two mature mixed subtropical plantation forest stands located adjacently on gentle slopes of the hillock having elevations between 1132 to 1154 m. a.s.l. at Pudunamei Taphou (Location: 25° 17' 13" - 25° 17' 26" N Latitude and 94° 01' 25" - 94° 01' 44" E Longitude), along the Taphou Naga hill range of Senapati District, 62 km north of Imphal, the capital city of Manipur. Climate of the area is monsoonic and the year is divisible into three distinct seasons viz. summer (April to June), rainy (July to September) and winter (November to February). March and October are the transitional months between winter and summer and rainy and winter seasons, respectively. Mean minimum and maximum temperature during the study period ranged between 1.1 to 14.2 °C and 24.4 to 34.1 °C, respectively (Fig. 1). Maximum relative humidity (RH) varied from 51.7 to 89.4% with an average RH of 35.8 to 62.2%. Monthly rainfall ranged from 0.4 to 235.3 mm. Soils of both stands were loamy sand in texture and slightly acidic in nature ranging from 5.1- 6.1pH in *A. nepalensis* dominated stand A and 4.2 - 5.5 for *C. hystrix* dominated stand B. Surface soil of Stand A was 10-15 cm deep, rocky type and blackish in colour while, that of Stand B was 20-25 cm deep and reddish in colour. Temperature and moisture contents of Stand A soil ranged from 13.3 to 22.7 °C and 8.5 to 49.8%, respectively and 14.1 to 23.6 °C and 10.6 to 48.5%, respectively for Stand B. Soil organic carbon varied between 3.21 to 5.64% and 2.4 to 3.96% in *A. nepalensis* and *C. hystrix* stands, respectively. The vegetation of Stand A and B was mainly dominated with *A. nepalensis* and *C. hystrix*, respectively along with other woody associates i.e. *Quercus serrata, Schima wallichii, Albizia lebbeck, Emblica officinalis* and *Ficus hispida*. Ground flora of both sites was formed by abundant herbaceous cover and woody species seedlings. Details of vegetation characteristics and range of soil properties of both stands are shown in Table 1.

Sampling

Surface soil samples (0-10 cm depth) were collected randomly in sterile polythene bags from 5 different locations of each study site at monthly intervals, separately and brought to the labora-

tory. Collected samples from each site and during a month were pool together for further analysis. A total of 12 collections were made from both stands during June, 2010 to May, 2011.

Fungal isolation

For qualitative estimation of fungi from both study sites, the soil dilution plate technique was adopted as described by Parkinson *et al.* (1971). Ten gram freshly collected ground surface soil was suspended into 100 ml sterilized distilled water kept in a 250 ml Erlenmeyer conical flask and thoroughly shaken for 15 min on a horizontal mechanical shaker (120 throws min^{-1} and 1.5 cm displacement) to get a homogeneous suspension. Suspension was further diluted to 10^{-4} by using sterile distilled water. One ml aliquot was inoculated separately into each of five replicated Petri dishes. Twenty ml molten and cooled (40°C) Martin's agar (Martin, 1950) medium supplemented with streptomycin (100 mg/l) was poured separately into each Petri dish. The dishes were rotated clockwise and anticlockwise to mix the homogenates. After solidifying, the dishes were incubated in the dark at 25±1°C for 7 days. Fungal colonies that developed after incubation were identified based on keys and descriptions provided by Domsch *et al.*, (2007), Ellis (1971, 1976), Subramanian (1971) and Watanabe (2002). The identities of several fungal isolates were confirmed at ITCC, IARI, New Delhi (ITCC 8248 to 8267) and NFCCI, ARI, Pune (NFCCI 2036, 2040, 2042 and 2873 to 2877). Non-sporulating white coloured strains were grouped into sterile white mycelia.

Based on the number of months and the seasons in which soil fungi of the two sites occurred were categorized into ubiquitous (recorded in 6 or more months of study period), summer-rainy (isolated in 3 or more months during March to September), winter (isolated in 3 or more months during October to February), non-specific (occurred in 3 or more months but not included in any of above categories) and accidental (recorded in less than 3 months) species.

Calculations

Per cent relative abundance (RA) of each fungal species was calculated as: (Number of colonies of a fungal species/Total number of fungal colonies) × 100. Mean RA per cent of each fungus were calculated by dividing the sum of RA of individual species by the number of observation i.e.12. Similarity index (SI, %) was calculated as described by Sørensen (1948) using the formula: SI = 2C/(A+B) × 100, where A is the total number of species in one study site, B is the total species number in other site and C is the sum of species common to both sites. The Shannon-Wiener biodiversity index (H2) was calculated according to the formula:

$H' = \Sigma - \left(\frac{n_i}{N}\right) \log_e \left(\frac{n_i}{N}\right)$ where, H^1 is the Shannon index of general diversity, n_i is the importance index value of each fungal species and N is the total importance value of all the species. The overlap of microfungi from two stand soils were calculated using the Sørenson's quotient: Overlap (%) = (Number of taxa shared between stand A and B/Total number of taxa observed in stand A and B) ×100.

RESULTS AND DISCUSSION

Qualitative nature of fungi isolated from surface soils

A total of 58 fungal species including one non-sporulating sterile form were isolated by soil dilution plating from *A. nepalensis* (Stand A) and *C. hystrix* (Stand B) dominated sites during 12 months of study period. Of the total, 41and 38 species were recovered from the soils of Stands A and B, respectively (Tables 2 & 3). Out of these, 21 species were common to both sites, while 20 and 17 species were exclusively isolated from Stand A and B soils, respectively. A class-wise distribution of microfungi, isolated from the soils of two study site, revealed that the members of Deuteromycetes, Mastigomycetes, Zygomycetes and sterile mycelia were represented by 86.21%, 1.72%, 10.34% and 1.72%, respectively. Deuteromycetous members were the most widely isolated fungal group with 50 species belonging to 23 genera and were represented by 17 species of *Penicillium*, 4 species of *Trichoderma,* 3 species each of *Aspergillus* and *Gliocladium*, 2 species each of *Cladosporium, Paecilomyces, Spicaria* and *Verticillium* and 1 species each belonging to *Aureobasidium, Cephalosporium, Colletotrichum, Cylindrocladium, Fusarium, Gongronella, Monodictys, Oedocephalum, Pestalotiopsis, Purpureocillium, Scopulariopsis, Sporormia, Scytalidium, Trichothecium* and *Zygorhynchus*. From the class

Mastigomycetes only one species belonging to genus *Pythium* was recorded. Whereas, the Zygomycetous members belonged to 5 genera, out of which *Absidia*, *Cunninghamella*, *Mortierella* and *Rhizopus* were represented by a single species each while, *Mucor* was represented by 2 species. Non-sporulating fungal mycelia bearing white colour was the only representative of the sterile group.

winter (25.13) and summer months (19.88), respectively (Fig 2). Species diversity (Shannon Index, H□) of soil fungi was highest (2.45) during winter season at Stand A and during rainy season (2.51) at Stand B. Lowest H□ values were recorded in summer season for both sites i.e. Stand A (2.18) and Stand B (2.13) soils (Fig. 4).

The numbers of ubiquitous, summer-rainy, win-

Table 1 : General characteristics of vegetation and soil at *A. nepalensis* and *C. hystrix* forest stands

Parameters	*A. nepalensis* stand	*C. hystrix* stand
Vegetation*		
Tree age (years)	55-60	35-40
Range of tree height (m)*	10-18	6-13
Mean girth (cm)	65.3±2.2	67.9±3.1
Density (tree ha^{-1})	1370	1430
Tree basal cover ($m^{-2} ha^{-1}$)	76	94
Soil**		
Soil type	Loamy sand	Loamy sand
Organic Carbon (mg g^{-1})	32.1 - 56.4	24 - 39.6
Total N (mg g^{-1})	21.6 - 24.8	14.1 - 19.0
Available P (mg g^{-1})	1.08 - 1.42	0.53 - 0.81
Exchangeable K (mg g^{-1})	40.8 - 84.9	28.9 - 52.8

* Height of *A. nepalensis* and *C. hystrix* only.
** Values of soil properties are reported as the range of variations during the study period in upper 10 cm soil depth

Dominant soil colonizers from both sites with mean Relative Abundance (RA %) values of ≥ 3 were *Cladosporium cladosporioides*, *Fusarium oxysporum*, *Mucor hiemalis*, *Penicillium purpurogenum*, *Trichoderma viride* and white sterile mycelia. *Cladosporium herbarium*, *Penicillium decumbens*, *P. rugulosum*, *Trichoderma koningii* in Stand A soil were the site specific species with mean RA (%) values 3 or more (Table 2) whereas, *Penicillium javanicum*, *Pestalotiopsis* sp. and *Trichoderma longibrachiatum* were exclusively isolated from Stand B soil with mean RA percentage above 3 (Table 3). The figures of several microfungi isolated from two stand soils during the present investigation are shown in Figs. 1 and 2.

Similarity index between fungal communities of both stands soils varied during different sampling periods revealing highest and lowest values in

ter, non-specific and accidental species in Stand A soil were 9, 13, 3, 10 and 6, respectively (Table 4). Corresponding numbers of fungal species in Stand B soil were 12, 6, 2, 6 and 12, respectively (Table 5). Different fungal species showed differential seasonal preferences at the two study sites. For example, *C. cladosporioides* was recorded as summer-rainy species at Stand A, while at Stand B it was ubiquitous species. *Aspergillus candidus*, *A. fumigatus* and *Spicaria divaricata* were isolated during summer-rainy months at Stand A but they were accidental species at Stand B. *Spicaria elegans* was found as winter species from *A. nepalensis* dominated forest soil whereas, it was observed as ubiquitous fungus in *C. hystrix* stand soil. *F. oxysporum*, *M. hiemalis*, *P. purpurogenum*, *T. viride* and white sterile mycelia were recorded as ubiquitous species at both sites. Similarly, *Verticillium terrestre* occurred as season non-

Table 2 : Relative abundance (%) of microfungi isolated from surface soil of *A.nepalensis* dominated plantation forest site

Fungi	Months											
	J'10	J	A	S	O	N	D	J'11	F	M	A	M
Absidia repens Tiegh.	0.0	0.0	0.0	0.0	3.6	0.0	9.9	14.1	4.2	0.0	0.0	0
Aspergillus candidus Link	5.5	8.5	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A. fumigatus Fresen.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	3.9	6.0
A. niger Tiegh	2.8	0.0	4.7	0.0	2.9	7.2	0.0	0.0	3.2	0.0	7.4	4.5
Aureobasidium pullulans (De Bary) G. Arnaud ex Cif., Ribaldi & Corte	7.3	3.8	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cladosporium cladosporioides (Fresen.) G.A. de Vries	2.8	0.9	24.8	3.5	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
C. herbarum (Pers.) Link	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	13.3	22.6	0.0	0.0
Colletotrichum gloeosporioides (Penz.) Penz & Sacc.	0.0	0.0	6.7	7.0	0.0	6.3	0.0	0.0	0.0	0.0	8.6	0.0
Cunningamella echinulata (Thaxt.) Thaxt. ex Blakeslee	0.0	8.2	0.0	0.0	0.0	0.0	6.0	13.0	0.0	0.0	0.0	0.0
Cylindrocladium parvum P.J. Anderson	0.0	4.7	0.0	0.0	10.3	0.0	0.0	0.0	0.0	0.0	13.3	7.5
Fusarium oxysporum Schltdl.	3.7	7.5	0.0	8.8	13.2	4.6	10.0	11.7	15.0	12.6	0.0	0.0
Gliocladium penicillioides Corda	0.0	0.0	1.3	13.2	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G. virens (Miller, Giddens & Foster) von Arx	0.0	0.0	0.0	0.0	7.4	5.4	0.0	0.0	0.0	0.0	0.0	5.9
Gongronella butleri (Lendn.) Peyronel & Dal Vesco	0.0	0.0	0.0	0.0	0.0	3.6	0.0	7.2	6.2	0.0	0.0	0.0
Mucor genevensis Lendn.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	8.6	21.6
M. hiemalis Wehmer	0.0	0.0	6.9	2.6	5.9	0.0	4.0	10.4	16.2	0.0	2.9	0.0
Paecilomyces variotii Bainier	0.0	0.0	6.8	0.0	6.8	10.3	0.0	0.0	0.0	0.0	0.0	0.0
Penicillium citrinum Thom	0.0	0.0	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9
P. decumbens Thom	43.1	4.7	0.0	15.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. diversum Raper & Fennell	3.7	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	9.5	15.0
P. frequentans Westling	0.0	0.0	6.2	1.8	0.0	0.0	0.0	0.0	0.0	9.9	3.8	0.0
P. italicum Wehmer	0.0	0.9	0.0	0.0	0.0	0.0	12.9	0.0	0.0	0.0	0.0	0.0
P. lividum Westling	0.0	0.0	4.7	0.0	0.0	0.0	0.0	7.3	19.4	0.0	0.0	0.0
P. nalgiovense Laxa	0.0	10.4	0.0	0.0	0.0	0.0	0.0	0.0	3.5	11.4	0.0	0.0
P. purpurogenum Stoll	0.0	9.4	6.1	7.9	0.0	0.0	0.0	18.9	8.9	17.9	0.0	0.0
P. rubrum Stoll	3.7	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. rugulosum Thom	7.3	15.6	0.0	6.1	14.0	0.0	10.9	0.0	0.0	0.0	4.3	0.0
P. thomii Maire	1.8	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	0.0	6.9
P. vermiculatum P.A. Dang	0.0	0.0	0.0	0.0	2.6	0.0	7.8	0.0	0.0	0.0	0.0	0.0
Purpureocillium lilacinum (Thom) Luangsa-ard, Houbraken, Hywel-Jones & Samson	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	5.7	5.9
Pythium rostratum E.J. Butler	0.0	0.0	0.7	5.3	14.0	3.6	5.1	5.0	0.0	0.0	0.0	0.0
Rhizopus sp.	0.0	0.0	0.0	0.0	0.0	7.2	0.0	6.7	0.0	0.0	0.0	0.0
Spicaria divaricata (Thom) J.C. Gilman and E.V. Abbott	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	7.7	8.8
S. elegans (Corda) Harz	0.0	0.0	0.0	0.0	0.0	4.6	3.0	7.5	12.0	0.0	0.0	0.0
Scytalidium lignocola Pesante	0.0	0.0	1.3	0.0	4.4	0.0	0.0	0.0	4.5	0.0	5.7	11.0
Trichoderma koningii Oudem.	6.4	0.0	3.4	8.8	2.2	22.5	0.0	0.0	0.0	0.0	16.1	7.9
T. viride Pers.	6.4	11.3	8.1	4.4	7.4	0.0	17.7	0.0	8.2	0.0	0.0	9.7
Verticillium lateratium (Ehrenb.) Rabenh.	0.0	0.0	0.0	0.0	3.4	0.0	10.0	0.0	0.0	0.0	0.0	0.0
V. terrestre (Pers) Sacc.	0.0	0.0	0.0	8.8	0.0	0.0	13.8	5.7	0.0	0.0	0.0	0.0
Zygorhynchus vuilleminii Namysl.	0.0	0.0	0.7	0.0	0.0	9.0	0.0	0.0	0.0	5.3	0.0	0.0
White sterile mycelia	5.5	0.0	9.4	6.1	6.6	6.3	0.0	0.0	0.0	2.1	6.4	7.7
Total no. of species	13	14	18	14	16	14	13	12	12	12	14	15

Table 3 : Relative abundance (%) of microfungi isolated from surface soil of *C. hystrix* dominated plantation forest site

Fungi	Months											
	J'10	J	A	S	O	N	D	J'11	F	M	A	M
Aspergillus candidus Link	0.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	8.2	0.0	0.0	0.0
A. fumigatus Fresen.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.9	7.5
Cephalosporium coremioides Raillo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	0.0
Cladosporium cladosporioides (Fresen.) G.A. de Vries	3.0	0.0	0.0	14.5	3.9	0.0	6.6	12.9	10.0	15.5	5.7	0.0
Cunninghamella echinulata (Thaxt.) Thaxt. ex Blakeslee	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	3.2
Cylindrocladium parvum P.J. Anderson	0.0	0.0	9.2	4.6	0.0	5.4	0.0	0.0	0.0	5.8	0.0	0.0
Fusarium oxysporum Schltdl.	1.1	0.0	0.0	7.0	9.3	6.7	12.3	21.9	0.0	0.0	5.7	5.4
Gliocladium fimbriatum J.C. Gilman & E.V. Abbott	0.0	0.0	0.0	0.0	0.0	8.3	4.7	0.0	9.0	0.0	0.0	0.0
G. virens J.H. Mill., Giddens & A.A. Foster	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	7.5
Monodyctis fluctuala (Tandon & Bilgrami) M.B. Ellis	0.0	0.0	6.1	4.7	5.4	0.0	2.8	0.0	0.0	3.9	0.0	0.0
Mortierella renispora Dixon-Stew.	5.3	0.0	0.0	0.0	0.0	10.7	0.0	7.0	0.0	1.9	0.0	0.0
Mucor hiemalis Wehmer	3.2	5.6	8.2	2.9	9.3	16.1	3.8	3.0	0.0	0.0	7.5	0.0
Oedocephalum lineatum B.K. Bakshi	0.0	0.0	0.0	3.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Paecilomyces javanicus (Friedrichs & Bally) A.H.S. Br. & G. Sm.	0.0	9.3	5.1	4.5	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Penicillium decumbens Thom	0.0	9.3	3.4	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
P. diversum Raper & Fennell	0.0	0.0	0.0	0.0	7.0	8.9	6.6	0.0	0.0	0.0	0.0	0.0
P. erhlichii Kleb.	2.1	4.7	14.5	3.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0
P. herquei Bainier & Santory	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	4.0	0.0	0.0	0.0
P. italicum Wehmer	0.0	0.0	6.1	5.3	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. janthinellum Biourge	15.8	0.0	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. javanicum J.F.H. Beyma	3.2	2.8	0.0	3.0	0.0	0.0	4.7	0.0	11.3	8.7	4.7	6.5
P. primulinum Pitt	5.3	8.4	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P. purpurogenum Stoll	21.2	10.3	0.0	2.9	0.0	4.5	6.6	0.0	0.0	13.6	0.0	0.0
P. rubrum Stoll	3.2	6.5	2.0	5.8	6.2	0.0	8.5	0.0	0.0	0.0	0.0	0.0
P. thomii Maire	0.0	12.1	0.0	3.7	2.3	6.3	0.0	15.7	0.0	3.9	11.3	0.0
P. vermiculatum P.A. Dang	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.6	0.0	5.4
Pestalotiopsis sp.	2.1	8.4	9.2	6.1	3.9	0.0	0.0	4.0	0.0	4.6	3.8	7.5
Pythium rostratum Butler	0.0	0.0	0.0	0.0	15.5	6.3	11.3	0.0	6.4	0.0	0.0	0.0
Scopulariopsis asperula (Sacc.) S. Hughes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	6.2	6.8	0.0	0.0
Spicaria divaricata (Thom) J.C. Gilman & E.V. Abbott	0.0	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.4
S. elegans (Corda) Harz	4.2	0.0	5.1	0.0	0.0	8.9	4.7	0.0	18.2	8.3	0.0	0.0
Sporormia intermedia Auersw.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	11.3	9.7
Trichoderma harzianum Rifai	0.0	0.0	0.0	5.1	0.0	0.0	0.0	4.9	0.0	0.0	4.7	0.0
T. longibrachiatum Rifai	0.0	0.0	0.0	4.5	3.1	11.6	9.4	4.0	13.3	0.0	0.0	9.7
T. viride Pers.	14.7	15.9	6.1	8.9	0.0	0.0	3.8	10.0	0.0	0.0	12.3	7.5
Trichothecium roseum (Pers.) Link	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	5.4
Verticillium terrestre (Pers.) Sacc.	0.0	4.7	7.1	0.0	0.0	11.9	14.2	0.0	0.0	0.0	0.0	0.0
White sterile mycelia	13.7	0.0	0.0	4.5	13.2	7.1	0.0	0.0	7.2	5.8	0.0	5.4
Total no. of species	14	14	14	18	14	14	14	12	11	13	13	13

specific species in both stand soils.

This is the first report of a comparative study on microfungal diversity and their seasonal occurrence in mineralized surface soils of *A. nepalensis* and *C. hystrix* dominated stands of Northeastern India. In the present study, we found evidence for a highly diverse soil fungal community in subtropical plantation forest with clear differences in species composition among the two sites located adjacently showing 36.21% species overlapping. The qualitative differences in fungal species composition at two sites indicate that surface vegetation and soil nutrient status influences the microfungal population. Plantations are often linked to a strong increase in the total soil organic matter content and microorganisms of the soil (Manlay *et al.*, 2000). In ecological context, stability of edaphic factors is important in governing the activity and diversity of fungi and therefore, mycoflora differ in its composition from an ecological niche to the other (Christensen, 1969; Manoharachary *et al.*, 2008).

Our findings revealed that species diversity of resident fungal community in *A. nepalensis* dominated stand soil was higher than that of *C. hystrix* stand soil. Earlier investigations have reported the major changes in organic carbon and

Table 4 : Seasonal occurrence of soil fungi at *A. nepalensis* stand

Ubiquitous species	Summer-rainy species	Winter species	Non-specific species	Accidental species
Aspergillus niger	*Aspergillus candidus*	*Absidia repens*	*Cladosporium herbarum*	*Penicillium citrinum*
Fusarium oxysporium	*A. fumigatus*	*Gongronella butleri*	*Colletotrichum gloeosporioides*	*P. rubrum*
Mucor hiemalis	*Aureobasidium pullulans*	*Spicaria elegans*	*Cunninghamella echinulata*	*P. vermiculatum*
Penicillium purpurogenum	*Cladosporium cladosporioides*		*Gliocladium virens*	*P. italicum*
P. rugulosum	*Cylindrocladium parvum*		*Paecilomyces variotii*	*Rhizopus* sp.
Pythium rostratum	*Gliocladium penicillioides*		*Penicillium lividum*	*Verticillium lateritium*
Trichoderma koningii	*Mucor genevensis*		*P. nalgiovense*	
T. viride	*Penicillium decumbens*		*P. thomii*	
White sterile mycelia	*P. diversum*		*Verticillium terrestre*	
	P. frequentans		*Zygorhynchus vuilleminii*	
	Purpureocillium lilacinum			
	Spicaria divaricata			
	Scytalidium lignocola			

nitrogen contents of soil in alder dominated plantation forests because *Alnus* community adds significant amount of nitrogen, due to actinorrhizae, and organic matter to the soil with consequent changes in aggregate structure, porosity and aeration (Maggi *et al.*, 1990; Sampò *et al.*, 1997) and these factors might have contributed higher fungal species richness in *A. nepalensis* dominated stand soil. Several fungi viz. *Absidia* sp., *C. cladosporioides*, *C. herbarum*, *F. oxysporum*, *M. hiemalis*, *Paecilomyces* sp., *Penicillium* spp. *Pythium* sp., *Trichoderma* spp., *Verticillium* sp. and *Zygorhynchus* sp. isolated in the present study from *A. nepalensis* stand soil were also reported from the soil of old *Alnus viridis* coenosis (Sampò *et al.*, 1997). The preferential distribution of several fungal taxa in one community type or the other could be due to their adaptations to particular nutritional strategy and the abiotic and biotic conditions that occur in the different alder coenoses. Similarity in soil fungal community of the two sites indicates that while species composition may differ in response to alder community, the major structure of the soil fungal reservoir remain unaffected because most of the species identified in the present study have also been reported as the common inhabitants of different soil types (Sammson and Frisvad, 2004; Domsch *et al.*, 2007).

Table 5 : Seasonal occurrence of soil fungi at *C. hystrix* stand

Ubiquitous species	Summer-rainy species	Winter species	Non-specific species	Accidental species
Cladosporium cladosporioides	*Cylindrocladium parvum*	*Gliocladium fimbriatum*	*Mortierella renispora*	*Aspergillus candidus*
Fusarium oxysporum	*Monodyctis fluctuala*	*Pythium rostratum*	*Penicillium decumbens*	*A. fumigatus*
Mucor hiemalis	*Paecilomyces javanicus*		*Scopulariopsis asperula*	*Cephalosporium coremioides*
Penicillium javanicum	*Penicillium erhlichii*		*Sporormia intermedia*	*Cunninghamella echinulata*
P. purpurogenum	*P. italicum*		*Trichoderma harzianum*	*Gliocladium virens*
P. rubrum	*P. primulinum*		*Verticillium terrestre*	*Oedocephalum lineatum*
P. thomii				*Penicillium diversum*
Pestalotiopsis sp.				*P. herquei*
Spicaria elegans				*P. janthinellum*
Trichoderma longibrachiatum				*P. vermiculatum*
T. viride				*Spicaria divaricata*
White sterile mycelia				*Trichothecium roseum*

Table 4 : Seasonal occurrence of soil fungi at *A. nepalensis* stand

Ubiquitous species	Summer-rainy species	Winter species	Non-specific species	Accidental species
Aspergillus niger	*Aspergillus candidus*	*Absidia repens*	*Cladosporium herbarum*	*Penicillium citrinum*
Fusarium oxysporium	*A. fumigatus*	*Gongronella butleri*	*Colletotrichum gloeosporioides*	*P. rubrum*
Mucor hiemalis	*Aureobasidium pullulans*	*Spicaria elegans*	*Cunninghamella echinulata*	*P. vermiculatum*
Penicillium purpurogenum	*Cladosporium cladosporioides*		*Gliocladium virens*	*P. italicum*
P. rugulosum	*Cylindrocladium parvum*		*Paecilomyces variotii*	*Rhizopus* sp.
Pythium rostratum	*Gliocladium penicillioides*		*Penicillium lividum*	*Verticillium lateritium*
Trichoderma koningii	*Mucor genevensis*		*P. nalgiovense*	
T. viride	*Penicillium decumbens*		*P. thomii*	
White sterile mycelia	*P. diversum*		*Verticillium terrestre*	
	P. frequentans		*Zygorhynchus vuilleminii*	
	Purpureocillium lilacinum			
	Spicaria divaricata			
	Scytalidium lignocola			

nitrogen contents of soil in alder dominated plantation forests because *Alnus* community adds significant amount of nitrogen, due to actinorrhizae, and organic matter to the soil with consequent changes in aggregate structure, porosity and aeration (Maggi *et al.*, 1990; Sampò *et al.*, 1997) and these factors might have contributed higher fungal species richness in *A. nepalensis* dominated stand soil. Several fungi viz. *Absidia* sp., *C. cladosporioides*, *C. herbarum*, *F. oxysporum*, *M. hiemalis*, *Paecilomyces* sp., *Penicillium* spp. *Pythium* sp., *Trichoderma* spp., *Verticillium* sp. and *Zygorhynchus* sp. isolated in the present study from *A. nepalensis* stand soil were also reported from the soil of old *Alnus viridis* coenosis (Sampò *et al.*, 1997). The preferential distribution of several fungal taxa in one community type or the other could be due to their adaptations to particular nutritional strategy and the abiotic and biotic conditions that occur in the different alder coenoses. Similarity in soil fungal community of the two sites indicates that while species composition may differ in response to alder community, the major structure of the soil fungal reservoir remain unaffected because most of the species identified in the present study have also been reported as the common inhabitants of different soil types (Sammson and Frisvad, 2004; Domsch *et al.*, 2007).

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Fusarium oxysporum	*Monodyctis fluctuala*	*Pythium rostratum*	*Penicillium decumbens*	*A. fumigatus*
Mucor hiemalis	*Paecilomyces javanicus*		*Scopulariopsis asperula*	*Cephalosporium coremioides*
Penicillium javanicum	*Penicillium erhlichii*		*Sporormia intermedia*	*Cunninghamella echinulata*
P. purpurogenum	*P. italicum*		*Trichoderma harzianum*	*Gliocladium virens*
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P. thomii				*Penicillium diversum*
Pestalotiopsis sp.				*P. herquei*
Spicaria elegans				*P. janthinellum*
Trichoderma longibrachiatum				*P. vermiculatum*
T. viride				*Spicaria divaricata*
White sterile mycelia				*Trichothecium roseum*

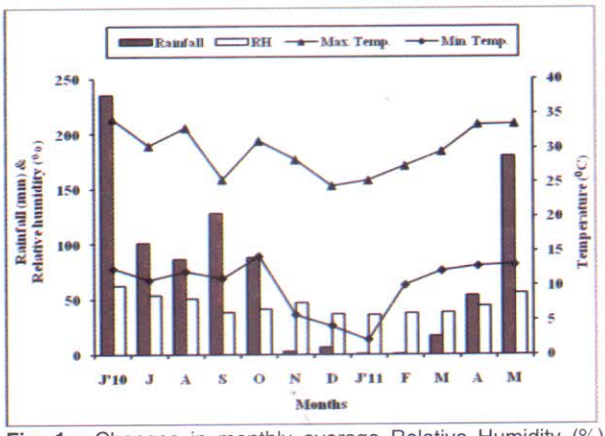

Fig. 1 : Changes in monthly average Relative Humidity (%), Rainfall (mm) and Maximum and Minimum Temperature (°C) during the study period

Fungal communities in both stand soils were predominantly the cosmopolitan anamorphic species frequently encountered in different forests elsewhere (Pandey *et al.*, 1991; Panda *et al.*, 2010; Bhattacharyya and Jha, 2011; Sharma *et al.*, 2011a; Devi *et al.*, 2012). Presence of these mitosporic fungi reflect the dynamics and complexity of the abiotic factors affecting these soils, while certain species would be expected to be specific to a particular soil conditions (Lodge and Cantrell, 1995). Major proportions of soil micromycetes is active only in low-stress habitats, and predominate wherever readily assimilable carbon sources are available. Lauber *et al.* (2008) have observed that soil fungal community are closely associated with soil nutrient sta-

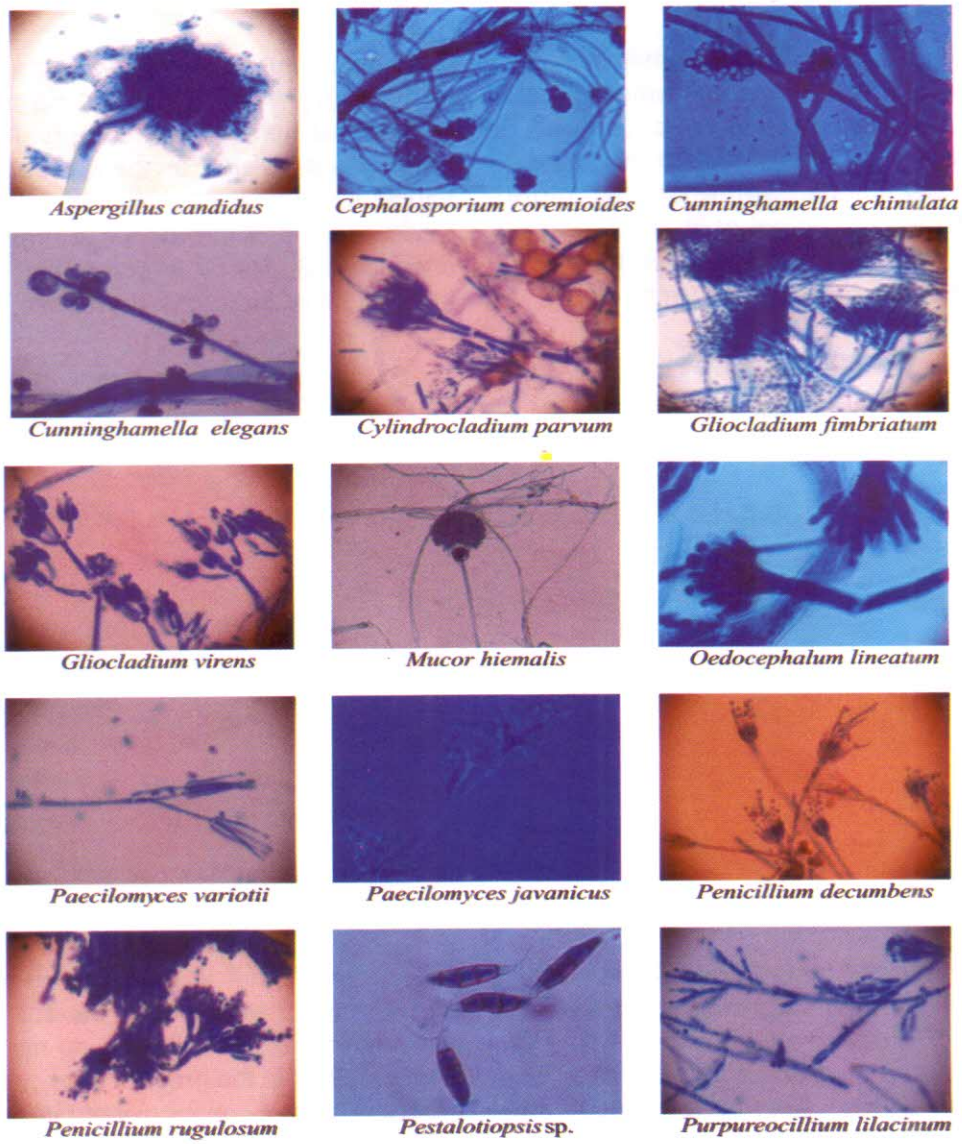

Fig. 2 : Microfungi isolated from two stand soils

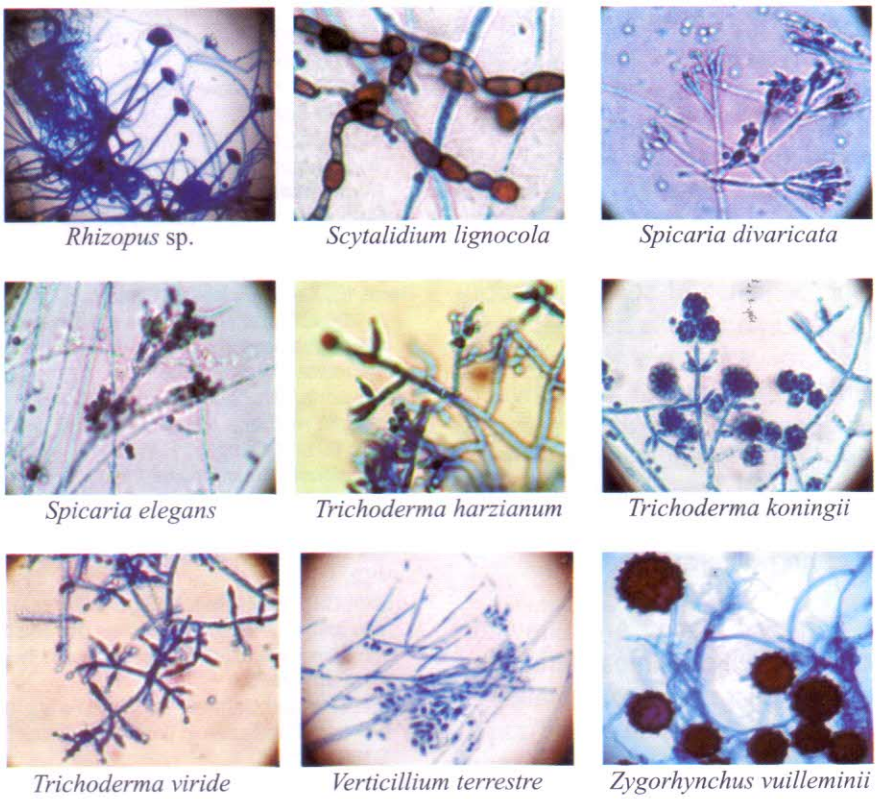

Fig. 3 : Microfungi isolated from two stand soils

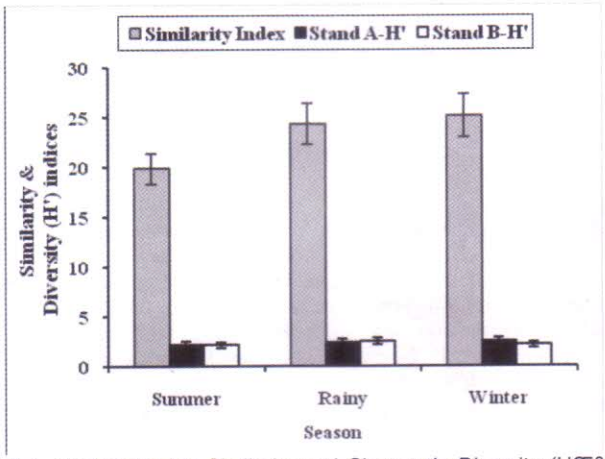

Fig. 4 : Sorensen's Similarity and Shannon's Diversity (HŒ§) indices of microfungi isolated from surface soils of *A. nepalensis* and *C. hystrix* forest stands during different seasons. Bars indicate SE

tus, and the specific changes in edaphic properties can alter microbial compositions across a given landscape. Additionally, not all of the fungi present in a soil sample may grow on the culture media offered, while others could be favoured by a particular growth medium. In the present study, several species of the fungal genera i.e. *Fusarium, Gliocladium, Penicillium* and *Trichoderma* usually appeared abundantly in both stand soils that might have dominant adoptive features as primary colonizers probably due to their capacity for rapid invasion of the available substrate (Frankland, 1981) besides their enzymatic flexibility, rapid growth and sporulation patterns in the soil milieu, and these combinations of factors can account for their broad ecological range (Cabello and Arambari, 2002). *Mortierella renispora* was isolated from *C. hystrix* dominated stand soil as season non-specific Zygomycetous fungus. Osorio and Habte (2001) have reported one *Mortierella* isolate that was an important solubilizer of immobile soil phosphorus hence, *M. renispora* may be related to phosphorus cycling in *C. hystrix* stand. White sterile mycelia were frequently isolated from both stand soils in this study which perhaps belong to monokaryotic Basidiomycetes that do not form fruiting bodies on culture media and remain sterile (Sharma *et al.*, 2011a).

Fungal species richness was higher during rainy months which indicate that sufficient soil moisture favoured the growth of microfungi and has pronounced effect on their distribution (Behera and Mukerji, 1985). Both stand soils were acidic in nature that facilitates the prolific growth of soil fungi.

Our findings revealed that some fungal species were abundantly present in a particular season while others were predominant in all seasons. Seasonality may influence the microbial biomass directly by inducing microbial community responses to soil moisture and temperature (Berg *et al.*, 1998). Seasonal variations also have an indirect effect on plant productivity and the patterns of organic matter release in natural ecosystem which, in turn, influence the densities of soil fauna populations and thereby, the interactions between grazers and the microflora. Widden and Parkinson (1973) have concluded that the soil microenvironment, in itself, is a special microcosm possessing a characteristic microbial community made up of populations coexisting and interacting with each other, though the fungal species composition does not change much during different seasons.

Overall, as suggested by Prescott and Grayston (2013) comparisons at multiple times during the year with periodical samplings and combination of isolation methods and culture media would assist in developing a more complete image of maximum soil fungal communities and their seasonal occurrence in an ecosystem.

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