4 Diversity, Ecology and Utilization of Soil Fungi: Indian Scenario

C. Manoharachary and D. Nagaraju

Abstract

Soil is a dynamic medium and complex ecosystem harbouring millions of microbes including fungi. Soil maintains a dynamic equilibrium of fungi and other microbes in spite of the constellation of physico-chemical factors. Vegetation along with multiple and minute habitats of varied physico-chemical setup influences the soil fungal communities. Soil fungi can be isolated by conventional, non-conventional and molecular methods. Interestingly, very little is known about the patterns of soil fungal diversity and their functional roles over large geographic scales. Most dominant fungi are Aspergilli and Penicilli followed by anamorphic fungi and others. There is a need to emphasize more on the ecological grouping of soil fungi. Soil and plant health is dependent on the functional activity of soil fungi. Soil fungi are known to play an important role in the cycling of elements, biogeographical demarcation, biogeochemical transformations, recycling of stored energy, degradation of organic matter, soil fertility and nutrient mobilization. The utility of fungi in the degradation of xenobiotic compounds, waste management, in medicine, agriculture, industry, carbon sequestration, biotechnological processes and other related activities, is very well known. Mother earth has been explored all over the world for fungi and microbes, still it harbours new and rare fungi and microbes which need to be discovered and classified accurately. Many soil fungi have been cultured artificially and are made available through germ plasm conservation centres. Further, in view of the importance attached to soil fungi, soil fungal floristics need to be surveyed and observed critically on individual capacity rather than en masse.

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4.1 Introduction

Soil is a complex ecosystem and is composed of multiple and minute habitats. Soil harbours almost all major groups of fungi. Stotzky (1997) has reported that the number of genera and species existing in soil is more than in any other environment. Soil being exposed to various conditions including extreme situations encases all microorganisms present on this planet. It is a known fact that fungi are the decomposing agents, help in biogeochemical transformations and recycle the stored energy and nutrients of organic matter which has been degraded by other microbes. Therefore, fungi have been considered as major players as recyclers of biosphere. It is established that physico-chemical composition of soil influences its fertility and also plays an important role in the distribution, seasonal variations and activity of fungi inhabiting the soil. However, it is also true that the soil fertility is dependent on the qualitative and quantitative structure and function of microbes and fungi inhabiting it. But for fungi being natural scavengers the planet could have been surrounded by piles of detritus and dead plant matter. Further geo-fungi are involved in the food chain cycle through their interaction with other living biota. Fungi are also known as recyclers of waste products, chemicals, transformers and biodegraders of xenobiotics. Soil is conglomerate of abiotic compounds with diversified microscopic organisms.

4.2 Soil as an Ecosystem, Fungal Diversity and Their Distribution in Soil

Soil is a natural medium in which diversified plant groups live, multiply and die which in turn becomes a perennial source of organic matter that gets recycled by microbes and fungi for plant growth and nutrition. A variety of fungi occurs in soil which range from lower (Chytrids) to higher fungi (Agarics), saprophytes to pathogens and predaceous to mutualistic mycorrhizal fungi. Fungi belonging to all groups occur in soil as hyphae, rhizomorphs, chlamydospores, sclerotia, asexual spores such as zoospores and conidia and sexual spores such as oospores, zygospores, ascospores and basidiospores.

The fungal diversities in soil have been studied by different workers (Watanabe 2011; Manoharachary et al. 2014) to know the fungi occurring in soil both quantitatively and qualitatively, ecologically, in relation to environmental variables, colonizing habitats and also to domesticate them effectively so as to use them in manufacturing nutritional, fermentative, pharmaceutical, agriculturally important materials, cosmetic materials and others. The diversity data also provides database on the available fungi and also about the invading or imported taxa in various habitats. The fungal diversities in soil can be understood readily by going through the list of the fungi reported in various soils of the world. More accurate, reliable and critical identification of soil fungi by both traditional and modern techniques is required. However, the modern system is still in the embryonic stage; therefore, the available gene data is in poor condition. Many morpho-taxonomists have been lost, some being endemic, and the classical taxonomy has received little attention due to shifting of mycologists towards molecular taxonomy. Many of the herbaria lack type species, which has created the lacunae in the fungal taxonomy. Therefore, confusion exists due to loss of traditional morpho-taxonomists and upcoming modern molecular taxonomists who are in the embryonic stage. Presently, the fungal taxonomy is now surrounded by morpho-taxonomists and gene analysis.

Soil is an ecosystem which comprises many microhabitats and harbours diversified groups of microbes and fungi. Most of the fungi are microscopic and some of them are macroscopic (*Agaricales*), and these microbiota are the decomposers, agents of mineral cycling, recycles stored energy and components of organic matter. Soil also includes symbiotic rhizobia, actinorhiza and mycorrhizae which serve the purpose of soil fertilization and uptake of nutrients to crops and forest plants. Fungi and other microbes play an important role as recyclers of biosphere. The quantitative and qualitative nature of microbes is of paramount importance in maintaining soil fertility along with chemical composition of soils. Soil fungi are also involved in food web through their interaction with other living biotic communities. Fungi are also involved as transformers and biodegraders of xenobiotics. The microphyte diversity of terrestrial ecosystems is dependent on below ground microbial diversity. Mycota is one of the diverse groups of organisms on the earth, which are the agents that govern carbon cycling, plant nutrition and plant disease production. These are distributed in different soil ecosystems but the distribution of different fungal groups has been less documented. Several edaphic factors, namely, pH, N, P, K, Ca and others, have greater impact on fungal distribution. Many fungal taxa are cosmopolitan in distribution but their endemicity is strong in tropical conditions. They also play an important role in driving carbon cycling in forest soils, mineral nutrition of plants and alleviate carbon utilization by other soil microbes.

Soil inhabits fungi and other microorganisms such as bacteria actinobacteria, cyanobacteria, protozoa and others. There are two groups of soil fungi which include indigenous fungi being isolated only from soil and other arrivals which are frequently isolated from surrounding habitats. Fungi colonizing underground parts considered as soil-borne appear to be typical soil fungi, sometimes fungi from air get contaminated into soil and are considered as casuals. Carris et al. (1989) have isolated 63 fungal species from the cyst *Heterodera schachtii* that causes disease in soybean and often the fungi associated with roots, decomposing litter fallen seeds and other plant parts and dead animals may get associated with soil. Fungal floras of various soil types have been studied worldwide. Thousands of research publications are available on soil fungi from all over the world, and some researchers might have described the fungi in detail while others might have listed without any descriptions. Therefore, numerous fungi have been described from different parts of the world; hence, it is almost impossible to list out all such soil fungi and also to refer all publications equally. Interestingly, isolation methods, media used, incubation conditions, soil types, soil physical conditions and other factors influence the quantitative and qualitative composition of fungi and microbes. It is possible that various species of *Pythium, Saprolegnia, Achlya* and others can be detected by means of baiting methods using boiled grass blades, cucumber seeds, hemp seeds, pollen grains, insect parts and others. Some ascomycetous fungi may get isolated including basidiomycetes by Warcup soil plate method but an overgrowth of fast-growing fungi such as *Rhizopus* and *Aspergillus* may not allow other fungi to grow. Waksman (1916) dilution plate method may yield a variety of fungi but did not yield perennating fungi. Majority of soil fungi remain unidentified because of non-sporulation. Identification of soil fungi with the adaption of appropriate scientific names is important for the study of soil fungi. In view of the importance attached to soil fungi, research activity on soil fungal floras has increased. Therefore, soil fungal floristics need to be observed more on an individual capacity rather than in en masse. Mother earth though has been explored all over the world, still it harbours new fungi which need to be discovered and classified accurately.

The global fungal estimate is 0.8 million to 5.1 million (Blackwell 2011), of which only 1 lakh fungal species are described. Around 29,000 fungi are reported from India. However, majority of such fungi are from soil. The diversity and distribution of soil fungi is shaped by macro-ecological and community assembly processes. Interestingly, very little is known about patterns of soil fungal diversity and their functional roles over large geographic scales. It is also known that soil fungi may exhibit strong biogeographical patterns. Based on the available data of fungal diversity (Manoharachary et al. 2014), it is indicated that the most dominant fungi are species of *Aspergillus* followed by *Penicillium*, hyphomycetes and some members of *Ascomycota*. This indicates the available techniques are inadequate to find out fungi that are present in different soil ecosystems.

Fungi are distributed worldwide in soils and are versatile. For example, Aspergilli are more common in tropical soils, while Penicilli are abundant in temperate soils. Among zygomycetes, *Rhizopus, Mucor, Absidia* and *Cunninghamella* have often been isolated. Zoosporic fungi such as *Pythium* and *Allomyces* have been isolated more frequently, and among the ascomycetous fungi, perfect states of *Aspergillus* and *Penicillium* besides *Chaetomium* are the most common ascomycetous fungi; basidiomycetous fungi have not been isolated commonly. Anamorphic fungi are frequently isolated fungi and are richly represented by asexual states of *Aspergillus, Penicillium*, *Alternaria, Drechslera, Curvularia* and others. Non-sporulating fungi are usually not identified; therefore, it is difficult to classify them in spite of using molecular tools as the sterile fungi show more than one perfect stage. However, it is hoped that with increasing knowledge and techniques, unidentified fungi on agar culture may get identified more readily together with the molecular studies. The authors have isolated 104 soil fungi from wild soils, cultivated soils, forest soils, pond muds, rhizosphere soils, etc. and are listed in Table 4.1. Similarly, soil fungi that are isolated in pure culture have to be named with right names on the basis of diversified characteristic features. Fungal diversities have to be widely acknowledged on the basis of voucher specimens such as holotype for the record and

Table 4.1 List of common soil fungi

Sl. no.	Fungal species	Substance	Year and place of collection	Collected by	Accession no.
1.	*Absidia cylindrospora* Hagem	Soil	2011, Hyderabad	Kunwar	OUFH 830
2.	*Acremonium chrysogenum* (Thirum. & Sukap.) Gams	Soil	2005, Mulugu	Kunwar	OUFH 574
3.	*Allomyces arbuscula* Butler, E.J. Butler	Forest soil	1981, Maha-Boobnagar	Madhusudan Rao	OUFHS 11
4.	*Alternaria alternata* (Fr.) Keissl	Soil (*Sesamum*)	1977, Hyderabad	Manohar.	OUFHS 12
5.	*Arthrobotrys foliicola* Matsuchima	Soil	2008, Narsapur	Kunwar	OUFH 572
6.	*Aspergillus awamori* Nakaz	Soil (Tamarind)	2005, Hyderabad	Kunwar	OUFH 340
7.	*Aspergillus candidus* Link	Pond mud	1979, Nizamabad	Manohar.	OUFHS 25
8.	*Aspergillus fumigatus* Fresen.	Forest, wild, cultivated soils	1974, Anantagiri hills	Manohar.	OUFHS 35
9.	*Aspergillus nidulans* (Eidam) G. Wint.	Mud soil	1996, Khammam	Manohar.	OUFHS 40
10.	*Aspergillus niger* Tiegh	Forest soil	1974, Anantagiri hills	Manohar.	OUFHS 42
11.	*Aureobasidium pullulans* (de Bary) Arnaud	Forest soil	1989, Amrabad	Manohar.	OUFHS 58
12.	*Beltrania rhombica* Penz.	Wild soil	2002, Narsapur	Narsimha charyulu	OUFHS 60
13.	*Blakeslea trispora* Thaxt.	Forest soil	1981, Amrabad	Reddy	OUFHS 64
14.	*Chaetomella raphigera* Swift	Forest, wild, cultivated soils	1984, Anantagiri hills	Manohar	OUFHS 72
15.	*Chaetomium abuense* Lodha	Soil	2004, Hyderabad	Kunwar	OUFH 237
16.	*Chaetomium aureum* Chivers	Pond mud	1983, Hyderabad	Manohar.	OUFHS 75
17.	*Chaetomium globosum* Kunze	Paddy field soil	1979, Nanded, Nizamabad	Manohar.	OUFHS 79

(continued)

Table 4.1 (continued)

Sl. no.	Fungal species	Substance	Year and place of collection	Collected by	Accession no.
18.	*Circinella muscae* (Sorokin) Berl. De Toni	Cultivated soil (castor)	1981, Hyderabad	Ramarao	OUFHS 93
19.	*Circinella simplex* Tiegh.	Silty, clay, loamy, cultivated soil	1979, Nanded, Nizamabad	Manohar.	OUFHS 94
20.	*Cladosporium herbarum* (Pers.) Link	Rhizosphere soil (*Ocimum abscendens*)	1975, Hyderabad	Manohar.	OUFHS 96
21.	*Cladosporium macrocarpum* Preuss	Polluted pond mud	1993, Hyderabad	Narendra Babu	OUFHS 97
22.	*Cochliobolus australiensis* (Tsuda & Ueyama) Alcorn (=*Drechslera australiensis*)	Forest, wild, cultivated soils	1984, Ananthagiri hills	Manohar.	OUFHS 102
23.	*Cochliobolus geniculatus* R. Nelson (=*Curvularia geniculata*)	Soil (cashew nuts)	1980, Hyderabad	Ramarao	OUFHS 103
24.	*Cochliobolus hawaiiensis* Alcorn (=*Drechslera hawaiiensis*)	Coastal soil	1969, Chirala	Lakshmi-narsim-ham	OUFHS 104
25.	*Cochliobolus lunatus* R.R. Nelson & Haasis (=*Curvlularia lunata*)	Pond mud	1974, Hyderabad	Manohar.	OUFHS 105
26.	*Colletotrichum capsici* (Syd.) E. J. Butler & Bisby	Rhizosphere, nonrhizo. Soil (Castor)	1981, Hyderabad	Ramarao	OUFHS 109
27.	*Cunninghamella blakesleeana* Lendner	Pond mud	1976, Hyderabad	Manohar.	OUFHS 114

(continued)

Table 4.1 (continued)

Sl. no.	Fungal species	Substance	Year and place of collection	Collected by	Accession no.
28.	*Cunninghamella echinulata* (Thaxt.) Thaxt. ex Blakeslee	Cultivated soil	1976, Nanded	Manohar.	OUFHS 115
29.	*Curvularia clavata* B.L. Jain	Soil (spinach)	1995,Hyderabad	Padma	OUFHS 117
30.	*Curvularia lunata* var. *aeria* (Bat. J.A. Lima & C.T. Vasconc.) M. B. Ellis	Forest, wild, cultivated soils	1984, Ananthagiri hills	Manohar.	OUFHS 118
31.	*Emericellopsis minima* Stolk	Forest, garden soil	1977, Khammam	Manohar.	OUFHS 128
32.	*Eurotium chevalieri* Mangin	Soil (cashew nut)	1980, Hyderabad	Ramarao	OUFHS 132
33.	*Fusarium chlamydosporum* Willenw. & Reinking	Riverbank soil	1984, Gadwal	Manohar.	OUFHS 134
34.	*Fusarium oxysporum* Schlecht	Forest, wild, cultivated soils	1984, Vikarabad	Manohar.	OUFHS 137
35.	*Fusarium poae* (Peck) Wollenw.	Rhizosphere, soil (castor)	1981, Hyderabad	Ramarao	OUFHS 138
36.	*Geotrichum candidum* Link	Polluted mud	1993, Karimnagar	Narendra Babu	OUFHS 141
37.	*Gibberella fujikuroi* (Sawada) Wollenw.	Rhizosphere soil, soils (cluster bean)	1978, Hyderabad	Manohar.	OUFHS 144
38.	*Gliocladium deliquescens* Sopp	Mud	2000, Karimnagar	Shantha Devi	OUFHS 150
39.	*Graphium terricola* Manohar. Rag. Rao, Rehana & Rama Rao	Sea shore soil	1975, Bheemilipatnam	Manohar.	OUFHS 154
40.	*Humicola fuscoatra* Traaen	Soil (cashew nut, castor)	1980, Hyderabad	Ramarao	OUFHS 158
41.	*Humicola grisea* Traaen	Riverbank, cultivated soils	1977, Gadwal	Reddy	OUFHS 159
42.	*Khuskia oryzae* H.J. Huds.	Deciduous forest soil	1981, Mannanur	Reddy	OUFHS 161

(continued)

Table 4.1 (continued)

Sl. no.	Fungal species	Substance	Year and place of collection	Collected by	Accession no.
43.	*Lasiodiplodia theobromae* (Pat.) Griffiths & Maubl.	Forest soil	1977, Hyderabad	Manohar.	OUFHS 162
44.	*Macrophomina phaseolina* (Tassi) Goid.	Rhizosphere, soils (cluster bean)	1978, Hyderabad	Manohar.	OUFHS 164
45.	*Magnaporthe grisea* (T.T. Hebert) M.E. Barr	Soil	1968, Nellore	Tilak	OUFHS 165
46.	*Monodictys putredinis* (Wall.) S. Hughes	Soil	2003, Hyderabad	Kunwar	OUFH 100
47.	*Mucor hiemalis* Wehmer	Soil (cluster bean)	1978, Hyderabad	Manohar.	OUFHS 176
48.	*Mucor laysanensis* Lendn.	Forest soil	2004, Vikarabad	Manohar.	OUFHS 178
49.	*Mucor racemosus* Fresen.	Pond mud	1976,Hyderabad	Manohar.	OUFHS 180
50.	*Mucor varians* Povah	Riverbank soil	1977, Gadwal	Reddy	OUFHS 181
51.	*Myrothecium cinctum* (Corda) Sacc.	Cultivated soil	1980, Hyderabad	Manohar.	OUFHS 182
52.	*Myrothecium roridum* Tode	Forest, cultivated soils	1984, Ananthagiri	Manohar.	OUFHS 185
53.	*Myrothecium verrucaria* (Alb. & Schwein.)	Rhizosphere soil (*Datura fastuosa*)	1975, Hyderabad	Manohar.	OUFHS 186
54.	*Nectria hematococca* Berk. & Broome	Forest, wild, cultivated soils	1984, Hyderabad	Manohar.	OUFHS 188
55.	*Nectria humicola* Rama Rao	Mazie field soil	1969, Narsapur	Ramarao	OUFHS 189
56.	*Neocosmospora vasinfecta* E. F. Sm.	Paddy field soil	1977, Karimnagar	Manohar.	OUFHS 191
57.	*Paecilomyces lilacinus* (Thom.) Samson	Pond mud	1983, Hyderabad	Manohar.	OUFHS 194

(continued)

Table 4.1 (continued)

Sl. no.	Fungal species	Substance	Year and place of collection	Collected by	Accession no.
58.	*Paecilomyces variotii* Bainier	Soil (cashewnut)	1980, Hyderabad	Ramarao	OUFHS 195
59.	*Penicillium chrysogenum* Thom	Forest soil	1981, Mahaboobnagar	Madhusudan Rao	OUFHS 198
60.	*Penicillium citrinum* Thom	Cultivated soil	1979, Nanded	Manohar.	OUFHS 200
61.	*Penicillium commune* Thom	Forest, wild, cultivated soils	1984, Ananthagiri	Manohar.	OUFHS 201
62.	*Penicillium digitatum* (Pers. & Fr.) Sacc.	Mud soil	1996, Karimnagar	Alivelu- manga-mma	OUFHS 204
63.	*Penicillium italicum* Stoll	Polluted soil	1993, Hyderabad	Narendra Babu	OUFHS 212
64.	*Penicillium rubrum* Stoll	Forest, wild, cultivated soils	1984, Ananthagiri	Manohar.	OUFHS 223
65.	*Penicillium variabile* Wehmer	Rhizosphere & nonrhizo. Soils (castor)	1981, Hyderabad	Ramarao	OUFHS 229
66.	*Periconia hispidula* (Pers.) E.W. Mason & M.B. Ellis	Forest soil	2004, Bhadrachalam	Manohar.	OUFHS 233
67.	*Pestalotiopsis glandicola* (Castagne) Steyaert	Rhizosphere soil (grape)	1964, Hyderabad	Ramarao	OUFHS 235
68.	*Pestalotiopsis mangiferae* (Henn.) Steyaert	Soil	1964, Hyderabad	Ramarao	OUFHS 236
69.	*Phoma eupyrena* Sacc.	Pond mud	1977, Gadwal	Reddy	OUFHS 238
70.	*Phoma fimeti* Brunaud	Pond mud soil	1975, Vikarabad	Manohar.	OUFHS 239
71.	*Phoma herbarum* Cooke	Fresh water tank mud	1996, Karimnagar	Alivelu- manga-mma	OUFHS 241
72.	*Phoma nebulosa* (Pers.) Berk.	Seashore soil (*Casuarina*)	1996, Anakapalli	Chandra Mohan	OUFHS 244
73.	*Phytophthora palmivora* (E.J. Butler) E.J. Butler	Field soil (*Colocasia*)	1980, Hyderabad	Satya Prasad	OUFHS 246

(continued)

Table 4.1 (continued)

Sl. no.	Fungal species	Substance	Year and place of collection	Collected by	Accession no.
74.	*Pseudeurotium ovale* Stolk	Rhizosphere soil (grape)	1965, Hyderabad	Rafia Mehdi	OUFHS 251
75.	*Pythium acanthicum* Dechsler, J. Wash.	Scrub jungle soil	1975, Vikarabad	Manohar.	OUFHS 255
76.	*Pythium aphanidermatum* (Edson) Fitzp.	Pond mud	1976, Hyderabad	Manohar.	OUFHS 256
77.	*Pythium butleri* subram.	Scrub jungle soil	1975, Vikarabad	Manohar.	OUFHS 257
78.	*Pythium carolinianum* Matthews	Pond mud	1983, Hyderabad	Manohar.	OUFHS 258
79.	*Pythium elongatum* Mathews	Pond mud	1978,Hyderabad	Manohar.	OUFHS 261
80.	*Pythium spinosum* Sawada	River bank soil	1981, Gadwal	Reddy	OUFHS 265
81.	*Rhizomucor miehei* (Cooney & R. Emers.) Schipper (=*Mucor miehei*)	Soil	1984, Warangal	Veugopal Rao	OUFHS 266
82.	*Rhizopus arrhizus* A. Fish. var. *arrhizus*	Rhizosphere soil (grape)	1965, Hyderabad	Rafia Mehdi	OUFHS 268
83.	*Rhizopus microsporus* var. *chinensis* (Saito) Schipper & Stalpers	Forest soil	2004, Vikarabad	Manohar.	OUFHS 269
84.	*Rhizopus stolonifer* var. *stolonifer* (Ehrenb.) Vuill.	Pond mud	1976, Vikarabad	Manohar.	OUFHS 270
85.	*Saprolegnia monoica* Pringsheim	Maize field soil	1964, Hyderabad	Ramarao	OUFHS 274
86.	*Scolecobasidium humicola* G.L. Barron & L. V. Busch	Soil (spinach)	1995,Hyderabad	Padma	OUFHS276
87.	*Scopulariopsis brumptii* Salv.-Duval	Rhizosphere soil (grape)	1965, Hyderabad	Rafia Mehdi	OUFHS 278

(continued)

Table 4.1 (continued)

Sl. no.	Fungal species	Substance	Year and place of collection	Collected by	Accession no.
88.	*Sordaria fimicola* (Oberge ex. Desm.) Ces. & De Not.	Pond mud	1977, Vikarabad	Manohar.	OUFHS 280
89.	*Stachybotrys atra* Corda	Soil (spinach)	1995, Hyderabad	Padma	OUFHS 288
90.	*Stachybotrys bisbyi* (Sriniv.) G.L. Barron	Forest soil	1981, Mahaboobnagar	Madhusudan Rao	OUFHS 289
91.	*Stachybotrys parvispora* S. Hughes	Soil (spinach)	1995, Hyderabad	Padma	OUFHS 292
92.	*Talaromyces funiculosus* (Thom) Samson, Yilmaz, frisvad & Seifert (= *Penicillium funiculosum*)	Soil	2010, Hyderabad	Kunwar	OUFH 688
93.	*Talaromyces trachyspermus* (Samson & Abdel-Fattah) Yaguchi	Forest soil	2004, Narsapur	Manohar.	OUFHS 299
94.	*Thermoascus aurantiacus* Miehe	Soil	1984, Rampachoda-varam	Venugopal Rao	OUFHS 301
95.	*Thielavia terricola* (Gilman & Abbott) Emmons	Forest soil	1981, Amrabad	Madhusu-dan Rao	OUFHS 303
96.	*Torula caligans* (Batista & H.P. Upadhyay) M.B. Ellis	Soil	1974, Adilabad	Singh	OUFHS 304
97.	*Trichoderma atroviride* karst.	Polluted soils	2003, Hyderabad	Satyavani	OUFHS 307
98.	*Trichoderma citrinoviride* Bisset	Forest soil	2002, Vikarabad	Narasimhacharyulu	OUFHS 309
99.	*Trichoderma hamatum* (Bonord.) Bainier	Soil	2002, Vikarabad	Kunwar	OUFH 059
100.	*Trichoderma harzianum* Rifai	Forest soil	2001, Chittor	Srilakshmi	OUFHS 312

(continued)

Table 4.1 (continued)

Sl. no.	Fungal species	Substance	Year and place of collection	Collected by	Accession no.
101.	*Trichoderma virens* (Miller, Giddens & Foster) von Arx	Forest soil	2004, Vikarabad	Nagamani	OUFHS 321
102.	*Trichoderma viride* Pers. (=*Trichoderma lignorum*)	Soil (*Datura fastuosa*)	1975, Hyderabad	Manohar.	OUFHS 322
103.	*Zygorhynchus moelleri* Vuill.	Cultivated soil	1979, Nanded	Manohar.	OUFHS 332
104.	*Zygosporium masonii* Hughes	Forest soil	2005, Vikarabad	Kunwar	OUFH 282

OUFHS Osmania University Fungal Herbarium–Soil, *Manohar* Manoharachary

description of new species. Cultures are always essential for their effective use in biotechnology. The original cultures need to be single source culture.

4.3 Methodology

Soil samples need to be collected from cultivated and uncultivated soils of diversified habitats along with soil passport card. The soil fungi can be isolated by various methods, but soil dilution plate method, soil plate method by direct soil inoculation and baiting methods are the best methods for isolation of various soil fungi. By single hyphal tip from germinating reproductive unit may be placed on full pledged agar mediam and the growth of colony be observed. Czapek's agar medium, plain water agar medium, PDA medium, soil extract agar medium and others are recommended. The main drawback for dilution plate method is that it neglects slow-growing fungi. The diluted soil suspensions are poured on to appropriate selective isolation media, and single-spore cultures are established later (Davet and Rouxel 2000).

Warcup soil plate method (1950) includes direct soil inoculation on to the sterile agar medium in a sterile Petri dish. The media include Czapek's agar, tomato agar, soil extract agar and others. The drawback of this method is that it tends to neglect fungi of qualitative nature and overgrowth of the fast-growing fungi. Bating method is often used for Zoosporic fungi. Immersion slide method (Chesters 1948) has also been found useful to isolate soil fungi as this also represents the soil fungi associated with soil profile. Molecular methods such as total fungal community DNA extraction, metagenomics, phylogenetic analysis of 18S, 16S rDNA sequences, understanding of genetic diversity, PCR and several other modern techniques are available to understand and evaluate soil fungal community.

4.4 Identification of Soil Fungi

Fungal taxa thus isolated have been identified on the basis of morpho-taxonomic criteria by comparing with known species; the morphologies that are observed through a stereomicroscope, compound microscope and electron microscope along with cultural characters have to be noted. Hyphal morphology, spore morphology, ontogeny, cultural characteristics, fruiting structures, etc. have to be noted down.

Experienced mycologists may identify some fungi at a glance; however, the most suitable taxon may be assessed after repeated observations and suitable literature survey. In case of new species, the Melbourne code 2013 has to be adopted and deposition be made at gene bank.

The morphologies of fungi be maintained continuously and molecular techniques may be employed for clarifying ambiguous and vague entities.

The available monographs on geo-fungi are many (Gilman 1957; Domsch et al. 1980; Watanabe 2002); however, different monographs are available for different groups of fungi (Raper and Thom 1949; Raper and Fennel 1965; Barron 1968; Ellis 1971, 1976; Subramanian 1971). Domsch et al. (1980) has listed 450 species, and Nagamani et al. (2006) have described 332 fungal species from India. The inventorization, monitoring and biodiversity status of soil fungi have been discussed by Bills et al. (2004).

4.5 Ecological Grouping of Soil Fungi

Fungi are known to colonize cultivated crop soils, wild forest soils, soils of highest mountain peaks, deep permafrost soils, geothermal and humid soils of the volcanic horizon, mine soils and highly alkaline soils. Cold-loving fungi are restricted to Polar Regions which can tolerate 0–16 °C, and examples of this group belong to *Leptomitus, Penicillium, Cryptococcus, Chrysosporium* and others. The fungi occurring in extreme environments may be of biotechnological importance as they have the potential for the production of extremozymes, secondary metabolites, bioremediation properties and others (Nonzom and Sumbali 2015). Desert soils contain a variety of yeasts that have been documented from hot and cold deserts. It seems that man-made contaminations of Antarctica might have added *Penicillium, Aspergillus* and other common fungi from soil and air. Endolithic conidial fungi are also common (Sterflinger et al. 2012). Halophilic fungi are considered as a major source of diverse and novel metabolites. The salt-loving fungi mainly belonging to *Ascomycota* do occur in marine soils. A distinctive group of fungi exist in marine waters and marine soils. Terrestrial aquatic hyphomycetes are associated with the litter fallen on to the soil.

Thermophiles are a group of extremophiles which require relatively high temperature (41–122 °C). Successful isolation of soil thermophiles requires incubation of soil on specified media at 45 °C/50 °C. Normally, thermopiles occur in compost, hay, wood chips and also in tropical desert soils. Some of the common soil thermophiles include *Aspergillus fumigatus, Scytalidium thermophilum, Chaetomium thermophilum, Thermomyces* sp., *Humicola* sp. and others. Thermophilic fungi possess valuable enzymes such as pectinase, cellulase, xylanase and also secrete a number of secondary metabolites of biotechnological importance (Rajasekaran and Maheshwari 1993). The voluminous literature that has accumulated on soil fungi (Manoharachary et al. 2014; Taylor and Sinsabaugh 2015; Taylor et al. 2000) indicates that a number of fungal species do occur in wild and forest soils consisting of rich diversified flora and medicinal plants. This clearly indicates that mesophiles dominate the soil fungal biotic community. Cultivated soils also support rich fungal flora. Quantitatively and qualitatively, the fungi are more and diversified in species composition with reference to wild and forest soils. However, the cultivated soils no doubt support quantitatively richness of fungi but qualitatively it is represented by few fungal species. The author's experience indicates that wild and forest soils have shown quantitatively and qualitatively richness of fungi in scrub jungle forest, deciduous forests and also in grassland soils than in cultivated crop soils. However, grassland soils have shown richness of fusarial fungi (Manoharachary and Ramarao 1978; Manoharachary et al. 1989; Madhusudhan Rao and Manoharachary 1981). Submerged mud soils were rich in melanin pigment containing fungi, such as Ascomycetes, dematiaceous hyphomycetes and others. Manoharachary et al. (2014) have isolated 340 fungal species and have also indicated that anamorphic fungi formed the bulk in soil fungal biota. Further, it has also been shown that *Aspergillus* and *Penicillium* species are predominantly followed by *Chaetomium* and anamorphic fungi than other groups. Many soil-borne and root-borne pathogenic fungi were also encountered; 18 species representing the genus *Trichoderma,* a well-known biocontrol agent, were isolated. In general, it has been shown that forest and wild soils followed by rhizosphere soils and cultivated soils harbour a more number of fungi and richness of fungal species than mud soils, riverbank soils, sea shore soils, herbicide-treated soils, polluted soils and poultry farm soils (Manoharachary et al. 2014).

Temperature, pH, moisture, soil texture, soil organic matter, soil NPK and gaseous composition are known to influence the distribution and composition of soil fungi. Plant communities existing in diversified soils may have a greater impact on the quantitative and qualitative composition of soil fungi.

4.6 Soil Fungi and Soil Health

Soil health depends on soil quality and fertility. Soil health is the resultant of the interaction between different processes, properties and activities of soil microbiota including soil fungi. Soil fungi are the biological controllers, ecosystem regulators, decomposers and compound transformers. Therefore, soil fungi serve as ecosystem regulators, responsible for soil structure formation and modification of the habitats. Mycorrhizal fungi are known to stabilize the soil structure and serve as biofertilizer for plant growth. Fungi present in the soil also participate in hormone production, biological control, stress management, stabilization of soil organic matter and biodegradation of residues. Thus, soil health maintained by soil fungi is directly connected with the production of healthy food which has an impact on public and animal health (Frac et al. 2018).

Certain soils are not congenial to live for plant pathogens by limiting their survival or growth of the pathogen. The suppressive soils reduce fungal attack and are often effective against only one or two pathogens. Suppressiveness is of two types: (1) long-standing suppression which is a biological condition and appears to survive in the absence of plants and (2) inclusive suppression is initiated and sustained by crop monoculture by the addition of target pathogen. A number of soil-borne pathogens are represented by *Fusarium* sp., *Gaumannomyces* sp., *Phytophthora* sp. and *Pythium* spp. Few cause diseases in plants growing in conducive soils, and few other pathogens cause no disease in plants. Suppressiveness may be because of soil microflora and abiotic factors and may vary with the type of pathogen. Some studies have indicated that activities of antagonistic soil fungi, bacteria, actinomycetes and others are responsible for the suppression of pathogens. The formation of suppressive soils is due to the mechanisms envisaged by soil fungi and soil microbiota, namely, nutrient competition, amensalism, antagonism, parasitism and systemic-induced resistance. However, understanding of the exact mechanism in suppressive soil is still far from satisfaction and probably the application molecular assessment tools may bring more understanding of such activity (Garbeva et al. 2004).

4.7 Functions and Biotechnological Aspects of Soil Fungi

Fungi are known to play a role in organic matter production, decomposition, carbon sequestration, carbon mineralization and cycling of elements. Mycorrhizal associations in plants not only boost plant productivity but also the acquisition of water, phosphorus and nutrients. Fungal endophytes offer resistance to biotic and abiotic stress. Filamentous soil fungi promote macro-aggregate formation through soil particle binding with fungal hyphae and the fungal cell wall material as adhesive, while the most common activity of the soil fungi is the nutrient cycling. Most hydrolytic and oxidative capabilities are elaborated by soil fungi as they are principle degraders of plant cell wall material during decomposition. Production of cellulases, pectinases, laccases and others have been elaborated by many soil fungi. The potential use of chitin as a nitrogen source is widespread among fungi because the fungal cell wall includes chitin. Chitinase activity is used as an indicator of fungal biomass and metabolism. Further, the proteins get degraded by many fungi which is the largest source of nitrogen. The inorganic phosphate solubilizing fungi supply phosphorus to the plants. Mineral phosphates get degraded by *Penicillium, Aspergillus* and other soil fungi into organic soluble phosphate which then get transported to fungal hyphae and to the plants. A number of soil fungi are also known to play an important role in bioremediation. Fungi are linked to many other organisms in a complex soil food web. For example, wood decay fungi and nematodes live together. Fungal hyphae in soil secrete both extracellular and intracellular bacteria. Mycorrhizal helper bacteria help in the formation of ecto- and endo-mycorrhizas. Many insects consume fungal hyphae (Taylor and Sinsabaugh 2015).

Soil fungi are important in everyday affairs of human beings. Soil fungi are well-known degraders of raw or manufactured materials such as foodstuff, timber, textiles, leather, paint, glue, plastics, petroleum products, optical glasses and others. Some of the soil fungi such as *Aspergillus* are known to produce aflatoxins, ochratoxins and others. Soil yeasts are used in brewery industries, while mushrooms, truffles and morels are edible and some species like *Amanita, Clitocybe and Inocybe* are poisonous. Species of *Psilocybe* and *Paniolus* are hallucinogenic. Soil fungi are also used in food processing. Several antibiotics, growth hormones, organic acids, enzymes, mycoproteins and vitamins are extracted from soil fungi. Soil fungi play an important role in the biosphere by involving in the recycling of nutrients, afforestation programmes, wastewater treatments, detoxification, xenobiotics, biocontrol of diseases and in several other ways. Soil fungi are also involved in metabolic pathways and studying genetic mechanisms. However, some of the soil fungi such as *Phytophthora, Pythium, Rhizoctonia, Sclerotium, Macrophomina, Fusarium, Verticillium* and few others are also involved in causing soil-borne and root-borne diseases. Soil fungi are very successful organisms due to their great plasticity and physiological versatility. Some of the important soil-borne diseases include damping off seedlings, wilt diseases, root rot and several others.

The intense influence of soil microbes and fungi on human life and global biogeochemical cycles necessitates exploration of microbial and fungal genomes to expand our understanding of most microbial and fungal species on earth, particularly those showing low relative abundance. There is a need to understand the ecology of such rare microbes and fungal population and highlight molecular and computational methods for targeting taxonomic blind spots within the rare biosphere.

Soil fungi play an important role in pharmaceutical industries in the isolation of compounds such as penicillin, cyclosporine, lovastatin, etc. Some of the fungi such as *Trichoderma* spp. are considered as potential biocontrol agents to control parasites and predators as antagonists. Fungi such as *Arthrobotrys* have been considered as nematophagous fungi, while species of *Metarhizium* and *Beauveria* have been considered as insect pathogens. Soil fungi have gained importance in recent times and have been exploited for bioremediation of anthropogenic pollutants including pesticides, benzene, toluene, xylene, dyes, hydrocarbons and others. The unexplored soil fungi may become rich resource material for new genes and species valuable to biotechnology and medicine. Soil fungal biodiversity plays a pivotal role in sustaining growth and management of the ecosystem. In future, soil fungal diversity seems to be very challenging and advantageous to the biosphere. As on today, the number of species considered to be true soil fungi is around 15,000. It is estimated that a gram of soil may hold several thousand fungal species. The revised species in future will be additional new species which may get revealed under Genealogical Concordance Phylogenetic Species Recognition (GCPSR) programme (Taylor et al. 2000).

4.8 Rhizosphere Soil Fungi

The rhizosphere soil is the specialized ecological region, which is adjacent to the root system of the plant as influenced by the root exudates. The term rhizosphere was proposed by Hiltner (1904). The root exudates and root debris products attract many fungi and microbes. The interaction of fungi and plant root is essential for the nutrition and growth of the plant. The growth, development, productivity of many crop plants, forest plants, orchids, oilseed crops, horticultural plants, medicinal plants, cash crops and others are largely dependent on soil health, which is maintained by soil microbes, soil fungi and also rhizosphere microflora including fungi. Therefore, rhizosphere studies are of great interest to agriculturists, soil biologists, chemists, mycologists, microbiologists and molecular biologists. The rhizosphere microbes and fungi may influence the availability of nutrients, water and growth promoter and may also change the oxidation cum reduction potential. Mycorrhizae, a symbiotic association, are beneficial in the uptake of phosphorus, zinc and other minerals besides increasing the root surface area of the plant for effective ion absorption. The soil microbial and fungal interactions such as antagonism, competition, synergism occurring in soil and rhizosphere are of great importance in studying the microbial and fungal ecology of rhizosphere (Mukerji et al., 2006). The rhizosphere exudates include a wide range of organic and inorganic compounds that affect the microbial and fungal population. Therefore, the authors have studied the rhizosphere fungal flora employing soil plate, soil dilution and immersion methods. Selective media and enrichment techniques are used, which include CFU, MPN, particle counts, fluorescence microscopy, and biochemical methods such as assay for ATP, immunological and molecular techniques. The fungi isolated from rhizospheres of various plants are listed in Table 4.2.

4.9 Soil Fungi and Climate Change

Soil fungi play a critical role in the carbon cycle. Carbon which is essential for life on earth moves between air, soil and water. After the death of the plants, the carbon enters the soil, making the soil a reservoir of the carbon. The dead plant material is broken down by microbes and fungi in the soil, thus releasing the carbon into the air. The rate at which the carbon left the soil will have a major impact on the amount of atmospheric carbon, which is the key factor to drive climate change. One of the limiting factors to the growth of these decomposing fungi is the availability of nitrogen in the soil, which get solved by mycorrhizal fungi. The mycorrhizal fungi extract the nitrogen from the soil and make it available to the plants through their roots. Recently, it has been found by scientists that soils supporting ectomycorrhizal fungi contain 70 percent more carbon than the soils dominated by arbuscular mycorrhizal fungi. Thus, fungi have a greater role in the control of the global carbon cycle. Since the plants and mycorrhizae are interconnected, the future carbon cycling cannot be predicted without thinking about plants and mycorrhiza.

Table 4.2 Rhizosphere soil fungi

S. no.	Name of the fungal species
1.	*Acrophialophora fusispora* (S.B.Saksena) Samson
2.	*Alternaria alternata* (Fr.) Keissl
3.	*Aternaria humicola* Oudem
4.	*Aternaria longipes* (Elis & Everh.) E.W. Mason
5.	*Aternaria tenuissima* (Kunze) Wiltshire
6.	*Aspergillus caespitosus* Raper and Thom
7.	*Aspergillus chevalieri* Thom & Church
8.	*Aspergillus clavatus* Desm.
9.	*Aspergillus flavus* Link
10.	*Aspergillus foetidus* Thom & Raper
11.	*Aspergillus fumigates* Fresenius
12.	*Aspergillus nidulans* Eidam
13.	*Aspergillus niger* Tiegh
14.	*Aspergillus sydowii* Bainer & Sartory
15.	*Aureobasidium pullulans* (de Bary & Lowental) G. Arnand
16.	*Cephaliophora irregularis* Thaxt
17.	*Chaetomella raphigera* Swift
18.	*Chaetomium aureum* Chievers
19.	*Chaetomium globosum* Kunze
20.	*Chaetomium spirale* Zopf.
21.	*Cladosporium cladosporioides* (Fresen) G.A. de Vries
22.	*Cladosporium herbarum* (Pers.) Link
23.	*Cladosporium oxysporum* Berk. M.A. Curtis
24.	*Colletotrichum falcatum* Butler & Bisby
25.	*Cunninghamella echinulata*
26.	*Curvularia brachyspora* Boedijn
27.	*Curvularia clavata* Jain
28.	*Curvularia eragrostidis* Itenn & Mayer
29.	*Curvularia lunata* (Walker)Boedijn
30.	*Curvularia pallescens* Boedijn
31.	*Doratomyces microspores* (Sacc.) F.J. Marten & G.Sm.
32.	*Drechslera australiensis* (Bugnicourt) Subr. & Jain
33.	*Fusarium moniliforme* J.Sheld
34.	*Fusarium nivale* (Fr.) Sarauer
35.	*Fusarium oxysporum* Schltdl
36.	*Fusarium solani* Sacc.
37.	*Graphium penicillioides* Corda

(continued)

Table 4.2 (continued)

S. no.	Name of the fungal species
38.	*Humicola grisea* Traaen
39.	*Melanoma pomiformis* (Pres.ex. Fr.) Sacc
40.	*Memnoniella echinulata* (Rivolta) Galloway
41.	*Monodictys glauca* (Cooke & Harkn.) S.Hughes
42.	*Mucor racemosum* Fresen
43.	*Mucor sphaerospermum* Hagem
44.	*Mucor varians* (H.Mart.) Fr.
45.	*Myrothecium brachysporum* Nicot
46.	*Myrothecium gramineum* Lib.
47.	*Nigrospora oryzae*(Berk. & Broome) Petch.
48.	*Paecilomyces fusisporus* S.B. Saksena
49.	*Paecilomyces humicola* Onions & G.L. Barron
50.	*Penicillium chrysogenum* Thom.
51.	*Penicillium citreo-viride* Biourge
52.	*Penicillium fructigenum* Takeuchi
53.	*Penicillium funiculosum* Thom.
54.	*Penicillium oxalicum* Currie & Thom
55.	*Penicillium spinulosum* Thum
56.	*Penicillium tardum* Thom
57.	*Penicillium variabile* Wehmer
58.	*Penicillium varians* G.Sm.
59.	*Periconia atropurpurea* (Berk. M.A. Curtis) M.A. Litv.
60.	*Pestalotiopsis mangiferae* (Henn.) Steyaert
61.	*Phoma feckelli* Brackel
62.	*Phoma humicola* J.C. Gilman & E.V.Abbott
63.	*Pithomyces atro-olivaceus* (Cooke & Harkn.) M.B.Ellis
64.	*Pithomyces flavus* Berk. & Broome
65.	*Rhinocladiella basitona* (de Hoog) Arzanlou & Crous
66.	*Rhinocladiella mansonii* (Castell.) Schol-Schwarz
67.	*Rhizoctonia bataticola* (Taubenth.) E.J. Butler
68.	*Rhizopus nigricans stolonifer* (Ehrenb.) Vuill
69.	*Rhizopus nodosus arrhizus* A. Fisch.

(continued)

Table 4.2 (continued)

S. no.	Name of the fungal species
70.	*Scolecobasidium constrictum* E.V. Abbott.
71.	*Scolecobasidium humicola* G.L. Barron & L.V. Busch
72.	*Scopulariopsis brevicaulis* (Sacc.) Bainier
73.	*Scytalidium lignicola* Pesante
74.	*Spicaria elegans* (Corda) Harz.
75.	*Spicaria fumosorosea* (Wize) Vassiljevsky
76.	*Spicaria griseola* Sacc.
77.	*Spicaria helothis* Charles
78.	*Sporotrichum roseolum* Oudem. & Beij.
79.	*Stachybotrys chartarum* (Ehrenb.) S. Hughes
80.	*Stachybotrys parvispora* S.Hughes
81.	*Stachylidium bicolour* Link
82.	*Thielaviopsis paradoxa* (De Seynes) Hohn.
83.	*Torula herbarum* (Pers.) Link
84.	*Trichocladium canadense* S. Hughes
85.	*Trichoderma koningii* Oudem.
86.	*Trichoderma viride* Pers.
87.	*Trichuris spiralis* Hasselbr.
88.	*Veronaea apiculata* (J.H. Mill., Giddens &A.A. Foster) F.B. Ellis
89.	*Verticillium puniceum* Cooke & Ellis,
90.	*Wardomyces inflatus* (Marchal) Hennebert
91.	*Zygorhynchus moelleri moelleri* Vuill.

4.10 Conclusions

1. Soil is a dynamic medium for fungi and microbes and maintains balance in spite of constellation of physico-chemical factors.
2. Soil harbours diversified groups of fungi belonging to zoosporic fungi, zygomycota, *Ascomycota* and *Basidiomycota*.
3. Soil is a rich nutrient medium for the sustenance of fungi.
4. Diversified soils such as desert soils, temperate soils, tropical soils, forest soils, crop soils sand dunes, submerged soils, saline and mangrove soils, soils of high attitude and low attitude, and others support not only specific fungal taxa but also fungi common to all soils.
5. Soil physico-chemical factors, plant vegetation, altitude, meteorological conditions and other related factors influence the soil fungi both quantitatively and qualitatively.

6. There is a definite seasonal variation among soil fungi. Some fungal species are characteristically associated with one or the other soils. Further fungi like Aspergilli are distributed widely in tropics, while the Penicilli are associated with temperate soils.
7. Soil fungi are the fastest decomposing agents, help in biogeochemical transformations and recycle stored energy and nutrients. Soil fungi also help in carbon sequestration besides serving as natural scavengers, and are useful in industry, medicine, agriculture, waste management, and in biotechnology and other activities.
8. Some fungi exhibit antagonistic activity and plant growth promotion.

There is a need for in-depth studies on soil fungi, their diversity, ecology, conservation and utility for human welfare.

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