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SOIL FUNGI ARE AN ACTIVE PARTNER OF OUR ECOSYSTEM. THEIR BIODIVERSITY AND ACTIVITIES SHOULD BE APPRECIATED*

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فطريات التربة شريك فاعل في نظامنا البيئي ، ومن الضروري التعريف بتنوعها البيولوجي والتوعية بنشاطاتها

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تلعب فطريات التربة دوراً أساسياً في صيانة وتسيير النظم البيئية التي تحيط بالإنسان ، والتي تؤثر بكل تأكيد - بطريق مباشر أو غير مباشر - على خير ورفاهية الإنسان . والهدف من هذا البحث هو التعريف بتنوعها البيولوجي والتوعية بنشاطاتها على المستويين العالمي والعربي .

Key Words: Soil fungi, Activities and biodiversity

ABSTRACT

Soil fungi play an active role in the maintenance and functioning of ecosystems around man. This paper is an appreciation of their biodiversity and activities at the global and Arab world levels.

Microorganisms merit more respect from "macroorganism" conservationists and ecologists. It is myopic to consider the maintenance of birds, mammals, fish, trees or flowers in natural ecosystems, without according due attention to the functioning of their life-support systems. [1].

My lecture objective is an appreciation and stimulation of more awareness of the biodiversity and the active role played by soil fungi, for the maintenance and functioning of ecosystems around man which certainly affect, directly or indirectly, man's welfare.

What are fungi?

Fungi are achlorophyllous, eukaryotic, filamentous microorganisms, provided, in the majority, with a chitinized cell wall. They are widespread in nature, in soil, water and air. They extensively deteriorate food and other organic materials. Frequently they invade living organisms causing serious diseases; you may remember the famous Irish famine, which occurred last century, between 1845-1849, in which about one million people died from starvation, and one further million emigrated. This was because of a fungus (*Phytophthora infestans*) which destroyed their main crop....potato. Also, according to one report, European and tropical agriculture may lose 30-50% of total crop yields annually, because of microbial diseases, among which fungal diseases are probably the most important.

Fungi also widely live in association with the roots of the majority of flowering plants to form mycorrhizae with green algae or cyanobacteria to form lichens.

About 69,000 species of fungi are known to science, comprising almost half of the known total number of microorganisms. The following table (1) shows the numbers of the known and conservatively estimated total number of microorganisms in the world [1]. These numbers do not in-

* Invited Lecture .

clude unculturable bacteria and mollicutes or mycoplasmas (bacteria-like organisms without a cell wall). The table reveals that only 5% of fungal species are known to science.

Table 1

Group	Known Species	Total Species	Percentage Known (%)
algae	40.000	60.000	67
bacteria	3.000	30.000	10
fungi	69.000	1.500.000	5
protozoa	40.000	100.000	40
viruses	5.000	130.000	4
Total	157.000	1.820.000	9

Soil fungi (on which my talk will focus) represent a major component of soil-inhabiting microorganisms, and their biomass even regularly exceeds that of bacteria by more than ten times [2]. Their role in soil is immense, and they are responsible for much of the disintegration of plant and animal debris, thus enriching the soil fertility.

My talk is divided into two parts: the first one surveys the main activities of soil fungi at the global level and the second deals with their biodiversity and activities in the Arab world.

A) AT THE GLOBAL LEVEL

1 - Soil fungi play an active role in:
A. Building up and maintenance of soil fertility through their ability to decompose animal and plant remains, thus, contributing to recycling ofnutrient elements

Fungi are able to make use of all components of these remains. It is impossible to enumerate all the natural substrates that fungi can decompose, but four of the most common insoluble components of such substrates are: cellulose which is probably the most abundant organic compound in nature, lignin whose content in plant may range from 3%, on a dry-weight basis in young plants, to about 35% in woody plants, chitin which forms the major part of the insect exoskeleton and of the wall of most fungi, and keratin which forms the main part of animal hair, nail, hoof and feather.

A peculiar nutritional ability is that executed by *Amorphotheca resinae* (teleomorph of *Cladosporium resinae*). It is a common soil fungus and widespread in nature. It can utilize creosote and other hydrocarbons, which are not available to the great majority of bacteria and fungi. During recent years, *A. resinae* has become a nuisance in the petroleum industry, and in the fuel tanks of aircraft. Most storage tanks contain a small amount of water under fuel. The fungus grows at the water-fuel interface. This presents an obvious potential danger because supply pipes and valves may be blocked by its tangled masses of mycelium, and the organic acids liberated may cause the corrosion of tank walls made of aluminum alloy. Tank cleaning programmes are very expensive and the addition of biocides such as ethylene glycol and diethylene glycol ether gave promising results [3].

Also, *Saccharomyces cerevisiae*, the baking yeast has been successfully grown on paraffins with the aim of production, on a commercial scale, of single-cell protein. These successful results have not been much appreciated because of the hazards of the carcinogenic effect of hydrocarbons.

B. Degradation and persistence of agriculture pesticides which reach soil
C. Modification and destruction of environmental pollutants which reach soil

2 - Many soil fungi are root-infecting and cause many serious plant diseases.

For example the wilt diseases which sometimes completely destroy crops of economic plants, such as cotton, banana and tomato. Their interrelationships with other soil fungi, as related to incidence of these diseases, should be emphasized.

There are three main types of these interrelationships:
1- Mycoporasitism In which a fungus parasitizes another one, thus limiting its activity. We have isolated from Egyptian soil *Melanospora zamiae* parsitizing *Fusarium acuminatum* and *Myrothecium cinctum* parsitizing *F. equiseti.*

2 - Antagonism Many soil fungi antagonized root-infecting fungi and this may inhibit their pathogenicity e.g. *Trichoderma harzianum* antogonizes *Rhizoctonia solani.* We have isolated several fungal species from the sclerotia of *Sclerotium cepivorum,* the causal agent of white rot of onions, and from the soil around the infected roots of onions which are strongly antagonistic in vitro to the mycelial growth of *S.cepivorum,* namely *Penicillium chrysogenum, P. frequentans, P. janthinellum, P. jensenii* and *Paecilomyces variotii.* These fungi may be also antagonistic in soil.

3- Synergism Some soil fungi promote the pathogenicity of some root-infecting fungi e.g. foot-rot of pea caused by *F. solani* is promoted by *Pythium* sp., and foot-rot of water melon caused also by *F. solani* is promoted by *F. oxysporum* and *F. semitectum* [4]

Understanding these phenomena can be a prelude to a successful biological control.

3- Many human and animal fungal pathogens are soil

inhabitants or geophilic as termed by medical mycologists.

Some are dislodged from the soil surface by wind, and are transmitted by air currents to be inhaled or alight on vulnerable parts of the body. Others are introduced with soil into injured areas of feet or other parts of the body.

The most common fungal diseases of human are those of the skin. Although these diseases may be irritating and even disfiguring, they are rarely, if ever, fatal.

Other fungal diseases affect internal body organs. These are less frequent but may be fatal. The most common of these diseases are coccidioidomycosis and histoplasmosis which involve lungs, but may move to other organs [5].

4- Soil is an unlimited reservoir of fungi producing chemical substances which can be of medical, agricultural, and industrial values, such as antibiotics, organic acids, enzymes, gibberellins, etc.

These fungi can represent vast genetic resources, and genes with desired properties can be introduced, or engineered, into other microorganisms, to facilitate commercial production of these substances.

5- About 85% of the world's flowering plants and trees form intimate root associations with fungi called mycorrhizae, which play a crucial role in the absorption of nutrients most limiting their growth [6].

In this association the root supplies the fungus with sugar requirements. In return, the fungus provides the root with mineral nutrients.

It was estimated that the uptake of mineral nutrients from the soil by mycorrhizal roots, takes place at 2-5 times the rate found in comparable non mycorrhizal roots.

In some cases, the mycorrhizal fungi produce chemicals which render the plants resistant to insect pests [7].

There are two types of mycorrhizae [5] :

a-Ectomycorrhizae In which the fungal mycelium is well-developed and forms a sheath around the root, from the interior of which hyphae arise and pass into the root, growing between its cells.

About 3% of the total number of plant species have ectomycorrhizae. The majority of such plants are deciduous or evergreen forest trees.

It has been reported that large ectomycorrhizal fungi are affected by acid rain [8] and thus can be used as bioindicators.

b - Endomycorrhizae Which have their external mycelium is poorly developed, and is not aggegated into a sheath. Its hyphae pass into the root, grow between cells, and also penetrate cells by sending haustoria.

There are two widespread endomycorrhizae:
1 - Ericaceae mycorrhizae
2 - Vesicular-Arbuscular mycorrhizae.

Vesicular arbuscular mycorrhizae are not restricted to wild plants, but are also characteristic of a wide range of crop species, including cereals and legumes.

Desert truffles which widely occur in the Gulf Countries and almost all Arab Countries, live in association with the roots of some desert plants and I shall refer in some detail to this point at the end of this paper.

6-Lichenized fungi are widespread in nature. They respond to gaseous pollutants and can be used as early bioindicators for ecosystem health.

This is another type of association in which a fungus lives symbiotically with a green alga or cyanobacterium. The fungus provides the shelter, water and mineral requirements and in return the alga provides the organic requirements.

About 13,500 species of fungi are involved in lichen associations [9].

This association qualifies lichens to occupy nutrient-poor substrates. They are also able to tolerate water stress and extremes of cold and heat. For these reasons, they dominate the ground in the Arctic tundra and the bare rocks of some deserts.

Most of them are sensitive to gaseous pollutants, especially SO_2 and most of them are killed by levels in excess of 0.01 ppm SO_2 . This is a level at which most higher plants are unaffected.

Under some conditions, they also provide useful forage for mammals.

Knowledge of lichens in the Arab World is fragmentary. Pioneer work in Saudi Arabia, and probably in the Arab World, has been achieved by Abu-Zinada and Hawksworth [10] and Abu-Zinada, Hawskworth and Bokhary [11]. They identified, in rather limited collection trips, to only a few areas of Saudi Arabia, 67 lichen species belonging to 38 genera.

7- Food pyramids of many animals rest on wide fungal bases.

For example, numerous beetles feed on fungi and in one study, of 6,236 beetle species trapped, 24% were fungus feeders [12]. A variety of microorganisms, including fungi, start to break down wood even before it is ingested and subjected to termite's gut biota, which also includes fungi; without these microorganisms, the food web could not exist [13]. There would not only be no termites, but the food chain onwards to dependent termite-eating mammals and birds would also be broken.

Herbivorous mammals, such as cows, giraffes, or reindeer could not function alone to digest the cellulosic and other materials on which they depend. They rely on the microorganisms, including fungi, resident in their guts [14].

Many soil fungi are predators of protozoa and nematodes, thus limiting their numbers and activities.

B) AT THE ARAB WORLD LEVEL

The main conclusions here reached are extracted from the investigations accomplished by the lecturer, his collaborators, and his former research students on soil fungi in Qatar, Egypt, Jordan, Saudi Arabia, Kuwait and Syria, which extended for about 30 years (refer to Moubasher, [15]).

I - Unlike the higher plants, there is no specific distribution of soil fungi in the various soil types and habitats, i.e. fungi isolated from agricultural soils are basically similar to those of desert and salt marsh soils.

This conclusion reveals that soil fungi are adaptable and can survive and live actively under the conditions prevailing in the various habitats, but the degree of adaptability certainly differs among various soil fungi.

Fusarium is more frequently isolated from agricultural and newly reclaimed soils than from salt marsh soils. Dark-coloured fungi are more prevalent in desert than in agricultural soils.

II - Comparison between the composition of soil fungi inQatar, Egypt and other Arab countries reveals basic similarities between them, and the commonest species are almost the same.

In most Arab countries soil and atmospheric conditions are essentially similar. The substantial part of the Arab World is arid with scanty water and vegetation, and receives less than 200 mm of precipitation per annum. Agricultural land is limited and represents mostly a very low percentage. In Qatar, it is about 0.2% and in Egypt is about 4%.

III - Soil fungi show seasonal periodicities. The months with moderate temperature are regularly the richest in counts and spectra, while the summer months are the poorest.

In summer, fungi are subjected to unfavourable conditions, the soil dries up quickly and the temperature becomes so high as to affect the inhabitants of soil severely. *Aspergillus* tends to prevail in months with average temperatures exceeding those of *Penicillium*. Also *Aspergillus* species predominate in sustrates stored at relatively high temperatures, whereas *Penicillium* species predominate at low temperatures.

IV - *Aspergillus fumigatus* exhibited an interesting behaviour in the surveys of soil fungi in Egypt.

Table 2
Frequency of Occurence of *Aspergillus fumigatus* in the different surveys

Year of survey	No. of casses of isolation	Total number	Percent	Reference
	-	12	0	[16]
1964	7	32	22	[17]
1966-67	3	19	16	[18]
1972	83	100	83	[19]
1972/73	57	72	79	[20]
1977	54	100	54	[21]
1977	88	100	88	[22]
1978	85	99	86	[23]
1987	26	30	86	[24]

As shown in table (2), *A. fumigatus* was absent in the survey made by Sabet [16]. In the sixties it showed low percentage of frequency. In the seventies and eighties, its percentage frequencies jumped to extremely high levels.

These observations may raise two questions:
1 -Is there a long-cycled or multi-annual periodicity in the occurrence of this organism, in addition to the seasonal one?

2 -Is there some change in the environment which affects positively this organism?

The proper answer is left to future investigations.

A. fumigatus has a special ecological and medical significance. It is able to grow in the range between 12° and 57°C with an optimum between 37° and 43°C. It is one of the most important agents of sytemic mycoses. The most common sites are the lungs and the respiratory tracts, where it can cause acute or chronic infections in cattle, lambs and poultry. In man, infection is rarely acute. It may also attack the cardiovascular system, the urinary system, brain and eye [25].

V -Soil fungi are generally orosmotolerant (recovered on up to 50% sucrose aga) or halotolerant (recovered on

5% or more sodium chloride agar).

Some of them are osmophilic or halophilic (growing better on media contain high concentrations of sucrose (up to 50%) or sodium chloride (up to 25%).

An interesting example of halophilism is *scopulariopsis halophilica* which can grow in media containing up to 25% sodium chloride, with no or little growth in sodium chloride free-media. Examples of osmophilism are *Eurotium* species.

It is reasonable to postulate that these fungi possess a mechanism that enables them to tolerate and live actively under the water stress conditions to which they are subjected. They may increase the concentration of sodim and chloride ions, and accumulate proline as an osmoregulator [26]. This amino acid is also known in higher plants as an osmoregulator. They may also accumulate glycerol [27,28].

VI -Most soil fungi are cellulolytic, but with various-abilities. Many soil fungi are chitinolytic.

As mentioned before, cellulose and chitin are abundant in nature, and hence these abilities are of significant ecological importance.

VII-Keratinolytic ability is restricted to a relatively narrow spectrum of soil fungi.

These fungi include *Chrysosporium* spp., *Microsporum gypseum* complex (a casual agent of Tinea capitis, which infects head's hair and skin, especially in children), *Arachniotus dankaliensis, Auxarthron zuffianum* and *Scopulariopsis brevicaulis* (a causal agent of onycomycosis which infects nails). Usually these fungi are abundant in situations where keratin substrates are common. They also form a characteristic mycbiota in bird's nests, the pellets of birds of prey and the long spine quills of living and dead hedgehogs [5].

VIII-Thermotolerant and thermophilic fungi were estimated at 45 ^{o}C and 55^{o}C.

Thermotolerant fungus *sensu* Cooney & Emerson [29]: is one that has a maximum temperature for growth near 50^{o}C, but a minimum well below 20^{o} C. Thermophilic fungus: is one that has a maximum temperature for growth at or above 50^{o} C, but a minimum at or above 20^{o} C.

The thermotolerant fungi are mainly *Aspergillus* spp.

The list of thermophilic includes *Malbranchea sulfurea, Thrmomyces lanuginosus, Malanocarpus (Myriococcum) albomyces, Chaetomium thermophilum, Thermoascus aurantiacus, Talaromyces dupontii and Rizomucor pusillus.*

IX -The succession of fungi during composting of wheat and broad bean straws was also studied.

This is a thermogenic process. The temperature rises sharply up to 70^{o} C between 4-11 days, then falls down gradually. These fluctuations of temperature initiate patterns of colonizing fungi of the composted straw in succession, from one period to another. Thermotolerant and thermophilic fungi gain a better access to this substrate than the mesophilic ones.

X -The application of pesticides to soil induces selective effects on soil fungi as well as on the rhizosphere and rhizoplane fungi, and the effect may be extended to the phyllosphere and phylloplane fungi.

These effects may be deleterious or beneficial on total fungal flora or on individual species, depending upon the chemical composition of the pesticide, dose and length of experiment which is influenced by the degree of persistence of the pesticide.

Generally the persistence period of herbicides and insecticides is considerably shorter than that of fungicides. For instance, the toxicity of the fungicide Dithane M-45 when applied to dry soil at 4.43 mg active ingredient per kg dry soil persisted for 15 weeks. The insecticide phosphamidon was of initiative effect on total soil fungi which persisted till after 20 days at 0.4 and 1.6 mg active ingredient; after a longer period this effect was alleviated. Also, a higher dose of 3.2 mg active ingredient was totally of no significant effect.

XI -Air-borne fungal spores show regular seasonal periodicities, and exhibit their peaks in spring and autumn and their trough in summer.

Study of air-borne fungal spores is of considerable significance. some fungal diseases of plant and man are spread by air. Spoilage of food materials and are frequently caused by fungi which reach them from the air. Spores of several fungi act as allergins and cause in some persons allergy diseases such as bronchial asthma and rhinitis.

They show high numbers in spring and autumn, and it is possible that the mild conditions of these seasons are of two-fold effect:

1 -Do not affect seriously the viability of fungal spores suspended in the air.

2 -Induce their flourish in or on the sources from which they originate.

Their numbers also show diurnal periodicities, and in one experiment they showed a double-peaked pattern at 6 a.m. and 6 p.m.

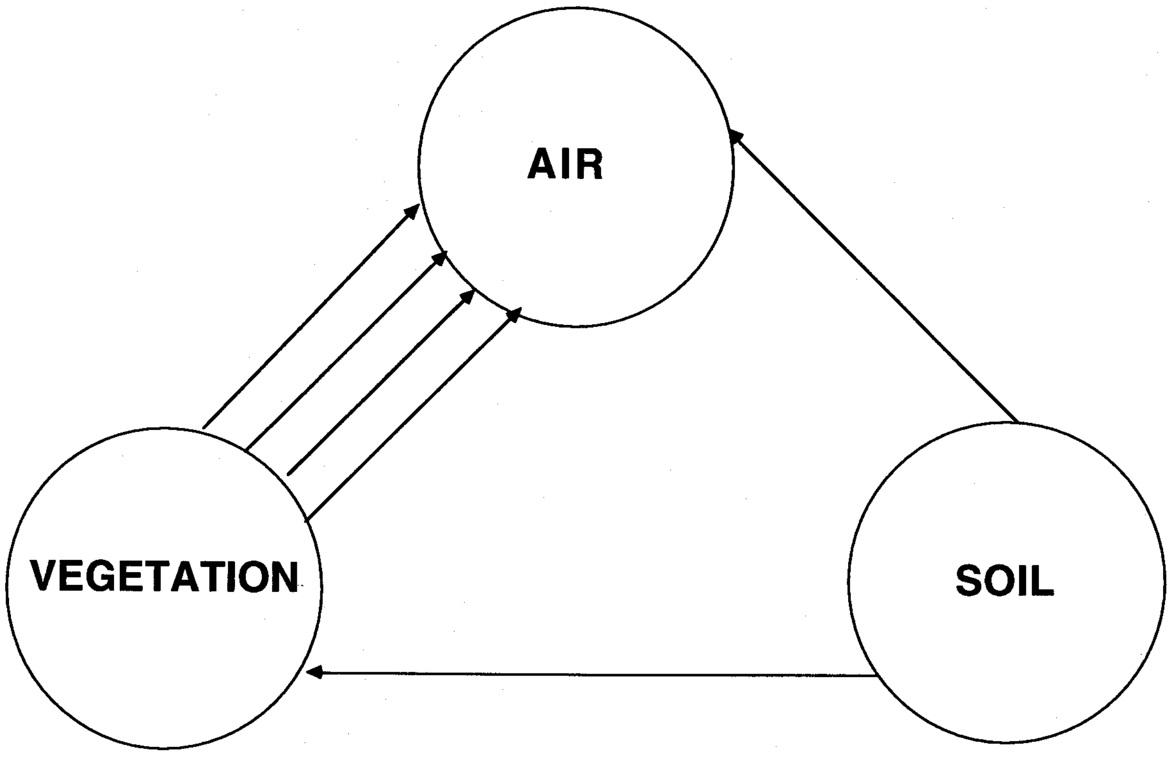
In some exposures, you may have tens or even hundreds of colonies of one species developing in one exposure plate. This is termed spore shower. There is no satisfactory explanation of this phenomenon.

Comparison between the composition of air-borne fungal spores and soil mycobiota, and between air-borne spores and phyllosphere fungi reveal basic similarity between air- and phyllosphere-borne fungi, which suggest that air-borne spores are mainly contributed by fungi developing on plant surface.

This lends further support to Gregory's [30] hypothesis that air-borne spores are basically a contribution from the vegetation rather than from the soil itself. This observation may show that some fungi such as *Cladosporium* spp. are strong competitive colonizers of plant material in the air unlike the case in soil where they are weak competitive colonizers of plant material in soil and hence they are more prevalent in air than soil. *Cladosporium* the commonest organism in the air where it contributed about 50% of the total fungal catch, retreated to the fifth place in soil where it donated 5.5% of the total count of soil fungi. *Alternaria* the second commonest organism in air where it contributed 17.2% of the total fungal catch, represented 0.3% of the total count of soil fungi only.

It is suggested that fungal spores are dislodged from soil by air currents. A part of them remains suspended in air and the others alight or are sedimented on vegetation surface where a new substrate or niche is initiated. In this niche the conditions are substantially different from those in soil. Competition for the colonization of this substrate is less severe. Atmospheric conditions are more drastic, high light intensity, and deep diurnal fluctuations of temperature and humidity. Consquently, the mycobiota developing in this niche has a basically different pattern from that of soil. The dark-coloured fungi, or the melanin-containing, are predominant over the hyaline ones, contrasting the pattern in the soil.

Similarity between this pattern and the pattern of air-fungal spores suggests that vegetation is the main contributor of these spores, and the soil is a minor one as shown in the following figure.



Suggested pathways of air-fungal spores

XII- Seed-borne fungi were studied in wheat, maize, sorghum, barley and peanut.

The study of seed- and grain-borne fungi is also of significant importance. Some of them are root-infecting. Others are toxigenic and when they flourish during storage, especially under humid conditions, they become potentially hazardous to the health of feeding human and animal.

Fungi deteriorating these seeds during storage under different conditions of temperature and moisture content were determined. The type of seed, temperature, moisture content and storage period selectively affect the pattern of the deteriorating fungi.

For instance, in peanuts where the well-known mycotoxins called aflatoxins, were first recognized in these seeds moulded with *aspergillus flavus*, this organism was represented in 80% of the dry seeds and predominated in seeds conditioned to 13.5% moisture content and stored at 15°C for one month.

XIII-Production of mycotoxins by fungi isolated from-human food and animal feedstuffs was also investigated.

The list of fungi screened included species of *Fusarium, Aspergillus, Penicillium, Stachybotrys* and *Trichoderma* in addition to *Acremonium strictum, Trichoderma roseum, Myrothecium verrucaria* and *Memnoniella etchinata.* The list of mycotoxins identified includes fusararenon-x, aflatoxins, satratoxins, roridins, trichodermin, verrucarin and others.

XIV - DESERT TRUFFLES

These truffles usually grow in calcareous, well-aerated, loose soil, associated in Qatar with the roots of a *Helianthemum* species. Personal preliminary observation reveals that their harvest season in Qatar is the second half of January and the whole of February and a good harvest is usually preceded by an early and suitable amount of rainfall as shown in table (3).

There are two types of truffles, white and dark-coloured. White one locally called "Zobaidi" (in literary Arabic means white), is more demanded and valuable than the dark-coloured. It belongs to *Tirmania.* The dark-coloured is locally called "Khlasi" (in literary Arabic means dark-coloured) and belongs to *Terfezia.*

Collaborative investigations between the Gulf and other Arab universities and research centres are much needed to determine: the host range, the real interrelationship with the host, whether beneficial or detrimental, and possible means of increasing its harvest. These means may include artificial irrigation in dry seasons, propagation of the host and increase of the fungus inoculum potential in the soil, assessing at the end the feasibility of these means.

Table 3
Monthly total rainfall (mm)
at Doha during the years 1981-1983 and 1988-1990

Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Type of harvest
		1981		1982		
0	0	0		2.6	18.8	poor
		1982		1983		
trace	trace	20.3	21.2	8.1	5.1	good
		1988		1989		
0	0	0	0	0	01.0	poor
		1989		1990		
0	0	14.6	66.8	10.6	1.8	good

Knowledge on their biodiversity in the Gulf and the other Arab countries is sparse. Two species of *Terfezia* and two of *Tirmania* were identified in Kuwait, Saudi Arabia and Qatar [31,32,33,15].

RECOMMENDATIONS

1 -Establishment of a Regional Culture Collection and Herbarium of fungi and other microorganisms for the purpose of research and training.

It is essential that this collection should be under the supervision of fungal and other microbial taxonomists.

2 -Establishment of satellite Culture Collections in the Universities and Research Centres.

3 -Encouragement of Gulf and Arab research students to do research in fungal and microbial taxonomy and ecology.

4 -Study of biodiversity of mycorrhizae (including desert truffles) and lichens in the Gulf and Arab countries is much needed.

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