The Occurrence of Mycorrhizas in Halophytes, Hydrophytes and Xerophytes, and of Endogone Spores in Adjacent Soils

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SUMMARY

The incidence of mycorrhizas in the roots and *Endogone* spores in rhizosphere soil of 52 xerophytes, 21 halophytes and 16 hydrophytes from Pakistan was investigated. Vesicular-arbuscular mycorrhizas were of general occurrence in all plants examined except hydrophytes and members of the families Urticaceae, Casuarinaceae, Nyctaginaceae, Portulacaceae, Caryophyllaceae, Amaranthaceae, Chenopodiaceae, Capparaceae, Oleaceae, Elaeagnaceae, Zygophyllaceae, Tamaricaceae, Euphorbiaceae and Palmae. Mycorrhizas were found mainly in the surface and subsurface horizons of the soil, and they were much less abundant in the deeper layers, although the abundance of *Endogone* spores did not decrease with depth. *Endogone* spores were rare in permanently waterlogged soils, which suggested that soil moisture affected spore number. Most other soil samples contained *Endogone* spores, including some from rhizospheres of non-mycorrhizal plants. In some soils an increase in spore numbers was recorded in the autumn and winter and a decrease in the spring and summer.

INTRODUCTION

Present information suggests that most plants, growing under natural conditions, possess vesicular-arbuscular (v.a.) mycorrhizal infection caused by species of the phycomycetous fungus genus *Endogone*, a regular and universal component of the rhizosphere microflora (Mosse & Bowen, 1968*a*; Khan, 1971). Despite its ubiquitous occurrence in most soils and its significance in plant nutrition, very little is known about the distribution of *Endogone* and variations in the degree of development of v.a. mycorrhiza in different habitats. There is, however, some evidence that the number of *Endogone* spores in the soil is affected by land usage (Nicolson, 1967; Mosse & Bowen, 1968*b*), soil type (Khan, 1971) and seasons (Mason, 1964; Hayman, 1970).

A survey of some Pakistani halophytes, xerophytes and hydrophytes was undertaken to study the occurrence of mycorrhizas and *Endogone* spores in their rhizospheres. A comparison between numbers of *Endogone* spores in the rhizospheres of some plants during summer and winter was made to determine the relationship of spore numbers to season.

METHODS

Collection of Materials. Plants and their rhizospheres were collected from the plains, the Salt Ranges, the coastal regions and the deserts of Panjab, Sind and Baluchistan Provinces of Pakistan. They were growing on sand and sand dunes, on gravelly soil, on soils impregnated with salt, in ditches and ponds, in crevices of limestone rock, or on rocks, in silt or on silt banks along freshwater creeks (Tables 1 to 4). The plant species sampled were typical

Table 1. *Occurrence of mycorrhizas in halophytes and of Endogone spores in adjacent soil*

Family, genus, species	Soil sites	Root pieces infected (%)	Range and mean of Endogone spore counts/100 g soil* (5 replicates)		
Chenopodiaceae	Salt-range (clayey)	{	{		
<i>Suaeda fruticosa</i> Forssk.				0	0
<i>Suaeda nudiflora</i> Moq.				0	0
<i>Kochia odontoptera</i> Schrenk.				0	0-4 (2)
<i>Haloxylon griffithii</i> Bunge ex Boiss.				0	0-2 (1)
<i>Salsola foetida</i> Delile.				0	0
<i>S. kali</i> L.				0	1-7 (4)
Tamaricaceae				0	5-13 (10)
<i>Tamarix dioica</i> Roxb.					
Papilionaceae				41	40-60 (50)
<i>Astragalus psilacanthus</i> Boiss.					
<i>Alhagi camelorum</i> Fisch.	59	42-69 (61)			
Sapindaceae	33	41-82 (59)			
<i>Dodonaea viscosa</i> Jacq.					
Zygophyllaceae	Sea coast (sand or dune)	{	{		
<i>Peganum harmala</i> L.				0	12-29 (19)
<i>Zygophyllum simplex</i> L.				0	1-15 (10)
<i>Fagonia cretica</i> L.					
Salvadoraceae	Salt range (clayey)	{	{		
<i>Salvadora oleoides</i> Dcne.				0	0-9 (6)
<i>Gymnosporia montana</i> Benth.				49	3-11 (7)
Apocynaceae	Salt range (clayey)	19	21-52 (40)		
<i>Rhazya stricta</i> Dcne.				65	3-10 (5)
Solanaceae					
<i>Withania coagulans</i> Dun.	(Sandy)	{	{		
Gramineae				44	45-74 (57)
<i>Saccharum munja</i> Roxb.				72	70-91 (80)
<i>S. spontaneum</i> L.				51	77-104 (89)
<i>Sporobolus arabicus</i> Boiss.				60	62-111 (95)
<i>Cenchrus pennisetiformis</i> Hochst. & Steud				39	30-56 (47)

* Values in parentheses represent means.

of desert, salt range and aquatic habitats. The samples for Tables 1 to 3 were collected during summer (July to August).

Extraction of Endogone spores. Endogone spores were extracted and counted as numbers/100 g soil, according to the previously described method of wet sieving and decanting (Khan, 1971). Five soil samples from around five plants all growing on the same site were examined for each species.

Measurement of extent of infection. The extent of mycorrhizal infection was measured by recording the percentage of root pieces infected after clearing fifty 1 cm root segments for 30 min in KOH (10 % at 90 °C) and then staining them with 0.5 % trypan blue in lactophenol (Phillips & Hayman, 1970).

Table 2. Occurrence of mycorrhizas in hydrophytes and of *Endogone* spores in adjacent soil

Family, genus, species	Soil sites	Root pieces infected (%)	Range and mean of <i>Endogone</i> spore counts/100 g soil* (5 replicates)
Nymphaeaceae			
<i>Nelumbium speciosum</i> Willd.	Pond	0	0
<i>Nymphaea lotus</i> L.	Pond	0	0
Ranunculaceae			
<i>Ranunculus aquatilis</i> L.	Ditch (clayey mud)	0	3-14 (10)
Cruciferae			
<i>Nasturtium officinale</i> R. Br.	Ditch (clayey mud)	0	0
Onagraceae			
<i>Trapa bispinosa</i> Roxb.	Ditch (clayey mud)	0	0
Alismaceae			
<i>Sagittaria guayanensis</i> H. B. & Khan	Muddy banks of canals	0	15-27 (19)
Hydrocharitaceae			
<i>Hydrilla verticillata</i> (L.f) L. C. Rich	Pond	0	0
<i>Vallisneria spiralis</i> L.	Streams and ponds	0	0
Potamogetonaceae			
<i>Potamogeton crispus</i> L.	Swamp	0	0-9 (3)
<i>P. indicus</i> Roxb.	Ditch	0	0
<i>Najas graminea</i> Delile	Pond (salty water)	0	2-15 (7)
Pontederiaceae			
<i>Eichornia crassipes</i> (Mart.) Schlecht	Pond (clayey mud)	0	20-41 (30)
Juncaceae			
<i>Juncus bufonius</i> L.	On pond margins (sandy)	0	23-54 (40)
Cyperaceae			
<i>Cyperus eleusinoides</i> Kunth.	Marsh	0	0
<i>C. difformis</i> L.	Marsh	0	0
Gramineae			
<i>Phragmites karka</i> Trin.	Swamp	0	51-71 (63)
Lemnaceae			
<i>Lemna polyrrhiza</i> L.	Pond	0	0
Typhaceae			
<i>Typha angustata</i> Bory & Chaub.	Marsh	0	13-38 (25)

* Values in parentheses represent means.

RESULTS

Types and numbers of Endogone spores

The results of this survey are set out in Tables 1 to 4. Most of the soils contained *Endogone* spores as regular components of their microflora. The majority of spores in clayey soils were of the yellow, vacuolate, non-endosporic type while those in sandy soils belonged to the white and bulbous reticulate and honey-coloured sessile types (Mosse & Bowen, 1968a). This observation is consistent with the previous one (Khan, 1971). The spore population of any one sample of rhizosphere soil from plants growing on sand and sand dunes was usually uniform, whereas that from plants growing on clayey soils contained two to three spore types; the yellow, vacuolate, non-endosporic type predominated.

Spores were very rare in permanently waterlogged and saline soils (Tables 1 and 2). In muds of marshes and swamps, however, sporocarps of yellow, vacuolate, non-endosporic type *Endogone* spores were found between the sheaths of the lowermost leaves of *Phragmites*, *Typha*, *Juncus* and *Eichornia* (Table 2). During the monsoon season many plants

Table 3. Occurrence of Mycorrhizas in Xerophytes and of Endogone spores in adjacent soil

Family, genus, species	Soil sites	Root pieces infected (%)	Range and mean of Endogone spore counts/100 g soil* (5 replicates)
Urticaceae			
<i>Ficus religiosa</i> L.	Clayey	0	8-13 (10)
<i>F. bengalensis</i> L.	Clayey	0	0-8 (3)
Casuarinaceae			
<i>Casuarina cunninghamiana</i> Miq.	Sandy	0	23-31 (25)
Nyctaginaceae			
<i>Boerhaavia coccinea</i> Mill.	Clayey	0	0
Portulacaceae			
<i>Portulaca oleracea</i> L.	Clayey	0	0
Caryophyllaceae			
<i>Acanthophyllum squarrosum</i> Boiss.	Sandy	0	0-5 (2)
Amaranthaceae			
<i>Amaranthus viridis</i> L.	Clayey	0	0
Chenopodiaceae			
<i>Chenopodium murale</i> L.	Clayey	0	0
<i>C. botrys</i> L.	Clayey	0	0
<i>C. foliosum</i> (Moench) Aschers.	Sandy	0	0
<i>Atriplex griffithii</i> Moq.	Sandy	0	0
Capparidaceae			
<i>Capparis decidua</i> Edgew.	Clayey	0	0-7 (3)
Tamaricaceae			
<i>Tamarix troupii</i> Hole.	Sandy	0	0
<i>T. aphylla</i> (L.) Karst.	Sandy	0	0-10 (6)
Euphorbiaceae			
<i>Euphorbia nivulia</i> Ham.	Sandy	0	0-5 (2)
<i>E. caducifolia</i> Haines.	Sandy	0	0
Mimosaceae			
<i>Acacia senegal</i> Willd.	Clayey	60	0-7 (3)
<i>A. arabica</i> Willd.	Clayey	29	11-22 (17)
<i>Prosopis spicigera</i> L.	Silty	37	27-58 (44)
Papilionaceae			
<i>Astragalus tribuloides</i> Delile	Silty	22	13-29 (19)
<i>Alhagi maurorum</i> Medic.	Silty	11	48-70 (59)
Zygophyllaceae			
<i>Tribulus alatus</i> Delile	Silty	0	10-27 (17)
<i>T. terrestris</i> L.	Clayey	0	11-28 (23)
<i>Zygophyllum atriplicoides</i> Fisch.	Silty	0	43-68 (51)
<i>Fagonia bruguierii</i> DC.	Clayey	0	0-19 (10)
Rhamnaceae			
<i>Ziziphus jujuba</i> Mill.	Clayey	6	11-29 (19)
<i>Z. nummularia</i> (Burm.f.) Wight & Arn.	Clayey	41	61-79 (69)
<i>Z. rotundifolia</i> Lam.	Clayey	23	32-47 (41)
<i>Rhamnus pentapomica</i> Parker	Silty	0	70-89 (77)
Oleaceae			
<i>Fraxinus xanthoxyloides</i> (Wall. ex G. Don) DC.	Clayey	0	0
<i>Olea ferruginea</i> Royle	Clayey	0	0
Elaeagnaceae			
<i>Elaeagnus angustifolius</i> L.	Clayey	0	0
<i>E. umbellata</i> Thunb.	Clayey	0	0
Asclepiadaceae			
<i>Periploca aphylla</i> Dcne	Sandy	19	11-28 (19)
<i>Calotropis procera</i> R. Br.	Silty	29	8-18 (13)

Table 3 (cont.)

Family, genus, species	Soil sites	Root pieces infected (%)	Range and mean of <i>Endogone</i> spore counts/100 g soil* (5 replicates)
Apocynaceae			
<i>Nerium indicum</i> Mill.	Sandy	21	21-38 (28)
Convolvulaceae			
<i>Convolvulus spinosus</i> Burm.	Crevices of lime rock	9	8-13 (11)
<i>Ipomoea pes-caprae</i> (L.) Sweet.	Sandy	68	12-20 (17)
	Sandy	30	30-47 (41)
Boraginaceae			
<i>Heliotropium ophioglossum</i> Boiss.	Clayey	5	12-27 (19)
Scrophulariaceae			
<i>Verbascum erianthum</i> Benth.	Clayey	14	21-32 (27)
Solanaceae			
<i>Solanum surattense</i> Burm.f.	Clayey	20	41-61 (50)
<i>Withania somnifera</i> Dunal.	Clayey	21	35-48 (41)
Labiatae			
<i>Eremostachys leasifolia</i> Benth.	Silty	31	51-91 (67)
Compositae			
<i>Artemisia maritima</i> L.	Sandy (salt range)	27	2-12 (9)
<i>Launaea procumbens</i> (Roxb.) Ramayya & Rajagopal	Clayey	51	19-47 (32)
<i>Vernonia cinerea</i> Less.	Clayey	47	50-89 (66)
<i>Hertia (Othonnopsis) intermedia</i> (Boiss) O. Ktze.	Clayey	11	50-82 (71)
<i>Inula grantioides</i> Boiss.	Clayey	32	33-81 (49)
<i>Echinops echinatus</i> Roxb.	Clayey	19	18-30 (22)
Iridaceae			
<i>Iris stocksii</i> (Baker) Boiss.	Clayey	92	51-94 (69)
Palmae			
<i>Phoenix dactylifera</i> L.	Sandy	0	10-41 (30)

* Values in parentheses represent means.

such as *Ipomoea carnea* Jacq. become temporarily waterlogged and the mud around their roots lacked spores, whereas the rhizosphere soil of adjacent plants of the same species, growing on drier soils, contained many. This suggested that soil moisture affects spore number.

Most of the soil samples from xerophytic plants contained *Endogone* spores except those belonging to families of the orders Urticales, Caryophyllales, Capparales, Tamaricales, Euphorbiales, Oleales and Elaeagnales (Table 3), the rhizospheres of which contained no or very few spores.

Mycorrhizal infection

Vesicular-arbuscular mycorrhizas were of general occurrence in all families except Urticaceae, Casuarinaceae, Nyctaginaceae, Portulacaceae, Caryophyllaceae, Amaranthaceae, Chenopodiaceae, Oleaceae, Elaeagnaceae, Zygophyllaceae, Tamaricaceae and Euphorbiaceae (Tables 1 and 3). Hydrophytic plants did not possess mycorrhizas, although groups of *Endogone* spores were present in the swamp muds (Table 2). Similarly, *Endogone* spores were present in the rhizospheres of plants in the family Zygophyllaceae, but there was no mycorrhizal invasion of their roots. These were entangled by many septate as well as aseptate fungal hyphae, but no internal infection was observed nor were root nodules, recorded in literature on Zygophyllaceae, observed. Similarly *Endogone* spores were present in the

Table 4. *Seasonal changes in the number of Endogone spores in soils adjacent to some xerophytes and halophytes*

Name of plant	Number of endogone spores/100 g soil during months of:			
	April (spring)	July (summer)	October (autumn)	January (winter)
<i>Acacia senegal</i>	9	3	5	7
<i>A. arabica</i>	31	17	49	55
<i>Prosopis spicigera</i>	11	44	89	88
<i>Alhagi maurorum</i>	9	59	77	91
<i>Astragalus tribuloides</i>	32	19	99	67
<i>Periploca aphylla</i>	6	19	50	72
<i>Calotropis procera</i>	17	13	37	41
<i>Phoenix dactylifera</i>	29	30	34	25
<i>Dodonaea viscosa</i>	35	59	80	104
<i>Salvadora oleoides</i>	0	7	3	4
<i>Gymnosporia montana</i>	1	5	2	5
<i>Saccharum munja</i>	42	80	110	150
<i>S. spontaneum</i>	31	89	134	171
<i>Sporobolus arabicus</i>	53	95	147	158

rhizospheres of *Rhamnus pentapornica* and those of plants in the family Zygophyllaceae, but there was no mycorrhizal invasion of their roots. They were entangled by many septate as well as aseptate fungal hyphae but no internal infection was observed nor were root nodules, recorded in literature on Zygophyllaceae and Rhamnaceae, observed. *Alnus*-type symbiotic root nodules were present on *Elaeagnus* and *Casuarina* species. In contrast, although many root segments of *Salvadora oleoides*, *Acacia senegal*, *Gymnosporia montana* and *Ipomoea pes-caprae* contained a well-developed v.a. endophyte in their cortices, very few spores have been recovered from their rhizospheres (Tables 1 and 3). The mycorrhizas in these plants possessed many thick-walled vesicles, a characteristic of endomycorrhiza produced by *Endogone fasciculata*. Mycorrhizas were found mainly in the surface and subsurface horizons of the soil and they were much less abundant in the layers at a depth of 4 to 5 ft, although the abundance of *Endogone* spores did not decrease with depth.

Seasonal fluctuations in Endogone spore numbers

Seasonal fluctuations in *Endogone* spore numbers were noted (Table 4). Usually there was an increase in spore numbers during the months of October, November, December and January, followed by a fall from the beginning of March until the end of August.

DISCUSSION

The present survey supports the contention that most plants growing under natural conditions possess v.a. mycorrhizas and that *Endogone* spores are a regular component of the soil microflora. It is also evident from this study that the degree of v.a. infection varies under different habitat conditions.

This survey suggests that the distribution of *Endogone* spores in the rhizosphere and v.a. infection of roots is affected by soil moisture and seasons. Mycorrhizas were absent in hydrophytes, as previously noted by several authors (Asai, 1934; Stahl, 1949; Maeda, 1954). The observation that mycorrhizal *Ipomoea carnea* plants growing on drier soils become non-mycorrhizal when temporarily waterlogged during the monsoon suggests that wet growing conditions result in the absence of mycorrhizas. This conclusion is supported by the observations of Maeda (1954) that non-mycorrhizal plants growing in wet places became

mycorrhizal when transplanted to well-drained soils. Also, Shuja, Gilani & Khan (1971) observed that on canal banks the roots of *Populus euroamericana* which are growing towards the water are non-mycorrhizal while those growing away from it possess both ectomycorrhizas and endomycorrhizas. Although *Endogone* spore masses were recovered from the swamp muds, species of *Phragmites*, *Typha*, *Juncus* and *Eichornia* did not possess mycorrhizas. This is in contrast with the observations of Dowding (1959) who noted a v.a. endophyte within the roots of four common swamp plants of Central Alberta as well as in swamp mud. According to Rayner (1927) mycorrhizal fungi do occur in bogs.

Although halophytes are reported to possess mycorrhizas (Mason, 1928; Fries, 1944; Stahl, 1949; Nicolson, 1960), no mention is made of *Endogone* spore numbers in saline soils. The present survey indicates that most of the halophytes contained spores in their rhizospheres and v.a. endophyte in their root cortices. However, no mycorrhizal invasion has been seen in roots of plants belonging to families of the order Centrospermae, in the rhizospheres of which *Endogone* spores were either absent or rare. Members of the families Urticaceae, Casuarinaceae, Capparidaceae, Tamaricaceae and Euphorbiaceae that were examined were found to be non-mycorrhizal. These observations agree with those of Gerdemann (1968) and Khan (1972) who also reported plants in the Centrospermae to be non-mycorrhizal. Most probably the plants regarded as non-mycorrhizal would be found to be mycorrhizal under certain conditions if an extensive search were made, or some fungitoxicant or antibiotic substance(s) such as sulphur, copper or betacyanin, reported to be present in Centrospermae, might be associated with their defence mechanism against mycorrhizal invasion.

The absence of *Endogone* spores in rhizosphere soils but the presence of v.a. mycorrhiza in some plants can perhaps be attributed to the fact that the roots may be infected by species of endophytes that do not produce many spores, or if they do, spores that are too small to be recovered by the technique used. Such an occurrence, for instance, is reported by Nicolson (1960) who recorded high endophyte activity but no *Endogone* spores in sand dunes. *Endogone fasciculata* may be involved in such instances because it is a species which forms small chlamydospores, always under 100 μm (Gerdemann, 1969), which are not recoverable by sieving. The flotation adhesion technique (Sutton & Barron, 1972) is effective for the recovery of such small spores.

Recovery of considerably more spores of *Endogone* from rhizosphere soils of xerophytes and halophytes during autumn and winter than summer showed the strong influence of season. This could be attributable either to an increase in spore formation or to a decrease in spore germination. Seasonal fluctuation were also noted by Mason (1964), Hayman (1970) and Sutton & Barron (1972). These variations appear to be related to a change in root production, which is strongly affected by season.

The finding that *Endogone* mycorrhizas hasten recovery from incipient wilting by decreasing the resistance to water transport in soybean (Safir, Boyer & Gerdemann, 1971, 1972) suggests the possible role of v.a. mycorrhiza under adverse soil water conditions, especially in physiologically dry soils which are impregnated with high concentrations of salt. *Endogone* infection may help halophyte roots tolerate salt better under such conditions. There is a great need for more work on the effect of the complex of external environmental factors, such as water, light, temperature, nutrient supply and soil microflora, on the development of v.a. mycorrhiza.

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