Comparative studies of the occurrence of arbuscular fungi and mycorrhizae (Glomales) in cultivated and uncultivated soils of Poland

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This paper presents results of 6-yaer studies on the occurrence of arbuscular fungi and mycorrhizae in cultivated and uncultivated soils of Poland. The comparisons include the incidence of spore and species densities, and the levels of mycorrhizal colonization. The relationship between the occurrence of arbuscular fungi and mycorrhizae and soil chemical properties was assessed based on analysis of correlation. The distribution of the fungal species found both in Poland and in the world is presented.

INTRODUCTION

Studies on arbuscular mycorrhizae of plants have been continuously conducted from the time of the discovery of this phenomenon (F r a n k, 1885). Arbuscular fungi (*Glomales*) probably belong to the most common soil fungi (G e r d e m a n n, 1968) and are associated with about 80 % of plants of the world (G i a n i n a z z i, G i a n i n a z z i - P e a r s o n, 1986). According to G e r d e m a n n (1968), only the families *Cruciferae* and *Chenopodiaceae* contain a large number of significant cultivated plants, which may be nonmycorrhizal. This suggestion has been supported by H a r l e y and H a r l e y (1987, 1990) in their check-lists of mycorrhizae in the British flora. In Poland pioneer and long term ecological studies on mycorrhizae have been conducted by Dominik and his co-workers (e.g., D o m i n i k, 1952, 1958; D o m i n i k, W o j c i e c h o w s k a, 1963), who have neither recovered nor recognized arbuscular fungi, however.

The occurrence of arbuscular fungi has been recognized best in the U.S.A. and Canada, as well as in Australia and New Zeland. In Europe they have been found in almost all countries, but sporadically. Arbuscular fungi have also been recorded in Taiwan, Cuba, India, Japan, Mexico, and in the Central and South America (B ł a s z k o w s k i, 1989 b; S i e v e r d i n g, 1986).

In Poland, up to 1982, no systematic studies have been conducted on the occurrence of arbuscular fungi. In literature, there are only two reports of specimens found during studies on the occurrence of other fungi. The first one refers to *G. versiforme* (Karsten) Berch found in the vicinity of Wrocław (B u c h o l t z, 1912), and the second one informs of the occurrence of *G. macrocarpum* (Ł a w r y n o w i c z, 1979). From 1982 to 1990, the occurrence of 39 additional species of arbuscular fungi has been recognized (B ł a s z k o w s k i, 1991 c).

Arbuscular fungi are sensitive to environmental conditions (S c h e n c k, K i n-l o c h, 1980; S t a h l, C h r i s t e n s e n, 1991). The most frequently mentioned factors affecting the occurrence of these fungi are plant species (H e t r i c k, B l o o m, 1986; S c h e n c k, K i n l o c h, 1980), the stage of plant development (G e m m a et al., 1989; S y l v i a, 1986), interactions with other soil organisms (B a a s et al., 1989; H e t r i c k et al., 1986), soil pH (G r e e n et al., 1976; K o o m e n et al. 1987), soil nutrition (H a y m a n, 1970; K r u c k e l m a n n, 1975; M e n g e et al. 1978), physical soil properties (D a n i e l s, T r a p p e, 1980; D a y et al., 1987; K o s k e, 1987; K o s k e, H a l v o r s o n, 1981), soil disturbance (E v a n s, M i l l e r, 1988; F a i r c h i l d, M i l l e r, 1988), and agrochemical practices (D o d d, J e f f r i e s, 1989; J a s p e r et al., 1989; S c h e n c k et al., 1989).

In contrast to uncultivated soils, in cultivated soils, most of the factors listed above undergo periodic changes that probably suppress or eliminate sensitive species, remaining those with physiological plasticity and/or with genetic adaptability to survive disparate local environmental conditions (S t a h l, C h r i s t e n s e n, 1991; S t a h l et al., 1988). Such species should theoretically be the most effective once in their further utilization in plant production (G i a n i n a z z i et al., 1989). The method of recognition of the range of responses of arbuscular fungi to environmental factors may be a comparative study of their occurrence in a range of cultivated and uncultivated soils (A b b o t t, R o b s o n, 1991). This was the aim of this study.

MATERIALS AND METHODS

Soil and root samples were collected from a depth of 5-30 cm using small trowel. About 2-litre samples were put into plastic bags and subsequently stored in a refrigerator at 4°C for 1-8 months. Soils and roots were sampled under well developed or maturing plants that grew in dense communities, as K o s k e and H a l v o r s o n (1981) suggested.

Spores of arbuscular fungi were recovered from soils by wet sieving and decanting (G e r d e m a n n, N i c o l s o n, 1963). Both intact and crushed spores in polyvinyl alcohol/lactic acid/glycerol (PVLG) (K o s k e, T e s s i e r, 1983) and Melzer's reagent were examined. Classification, spore wall characteristics, and spelling of scientific names are according to A l m e i d a (1989), M o r t o n (1986), M o r t o n and B e n n y (1990) and W a l k e r (1983, 1986, 1991). Nomenclature of plants follows that of F a l k o w s k i (1982) and S z a f e r, P a w ł o w s k i, K u l c z y ń-s k i (1969). Spore colour of fresh specimens immersed in water was determined under a dissecting microscope using the Methuen Handbook of Colour (K o r n e r u p, W a n s c h e r, 1983). Voucher specimens of recovered fungi have been deposited in the Department of Plant Pathology, Academy of Agriculture in Szczecin.

The mycorrhizal status of plant species examined was determined based on roots washed away during wet sieving of soils. Mycorrhizal colonization of 50 stained (P h i l l i p s, H a y m a n, 1970) root fragments of a length of about 1 cm was evaluated according to G i o v a n n e t t i and M o s s e (1980). The presence of *G. tenue* was determined in the same roots mounted on microscope slides.

Differences in the structure of arbuscular fungal communities were investigated by determining the frequency of occurrence of species, spore and species densities and by calculating dominance coefficients (G ó r n y, G r u m a, 1981). The variability in spore and species densities was expressed by the coefficient of variability. Frequency of occurrence was calculated by determining the percentage of samples from which spores of a particular species were recovered. Spore and species density was defined by determining the number of spores and species occurring in 100 g dry soil. Dominance coefficient expresses the proportion of the number of spores of a particular species in all spores of arbuscular fungi recovered. Coefficient of variability is a quotient of a standard deviation and a mean expressed in percentages.

RESULTS AND DISCUSSION

A r b u s c u l a r f u n g i. During 6 years of study, a total of 332 soil and root samples were examined, of which 173 and 159 came in cultivated and uncultivated plants, respectively. The samples represented 76 plant species from 21 families (Tab. 1). They were sampled in 113 localities in 22 voivodships (Fig. 1 a, b). The most numerously represented plants were those of the *Gramineae* (114 samples, 31 species), *Rosaceae* (37 samples, 8 species), *Leguminosae* (27 samples, 7 species), and *Cupressaceae* (25 samples, 3 species). The more rarely examined plants were from the *Umbelliferae* (6 samples, 4 species), *Juncaceae* (5 samples, 1 species), *Compositae* (4 samples, 3 species), *Liliaceae* (4 samples, 3 species), *Solananceae* (4 samples, 2 species), *Salicaceae* (4 samples, 3 species), and *Caryophyllaceae* (4 samples, 2 species). The other plant families were represented by 1-2 soil and root samples and single plant species.

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Arbuscular fungi were most frequently found in *T. aestivum* (43 samples),
Z. mays (25 samples), *A. arenaria* (23 samples), *T. occidentalis* (17 samples),
R. canina (15 samples), *C. monogyna* (13 samples), *H. vulgare* (12 samples),
T. pratense (9 samples), *V. faba* (6 samples), *J. communis* (6 samples), and
J. conglomeratus (5 samples) (Tab. 1). Mycorrhizal associations in the other plant
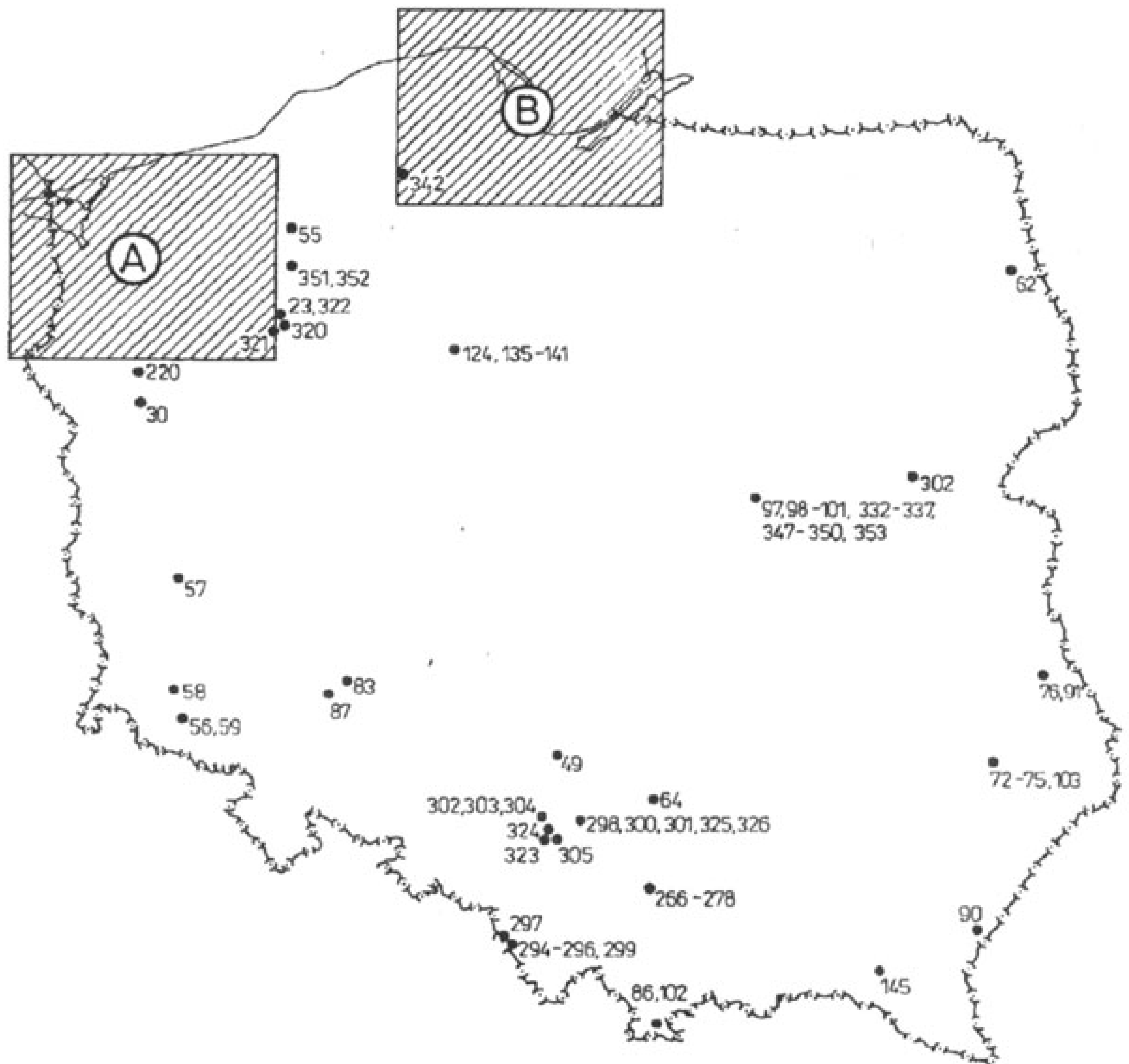species were tested rarely (1-4 samples).

Fig. 1 a. Sites at which soil and root samples were collected in Poland
(see list of localities and data of collection)
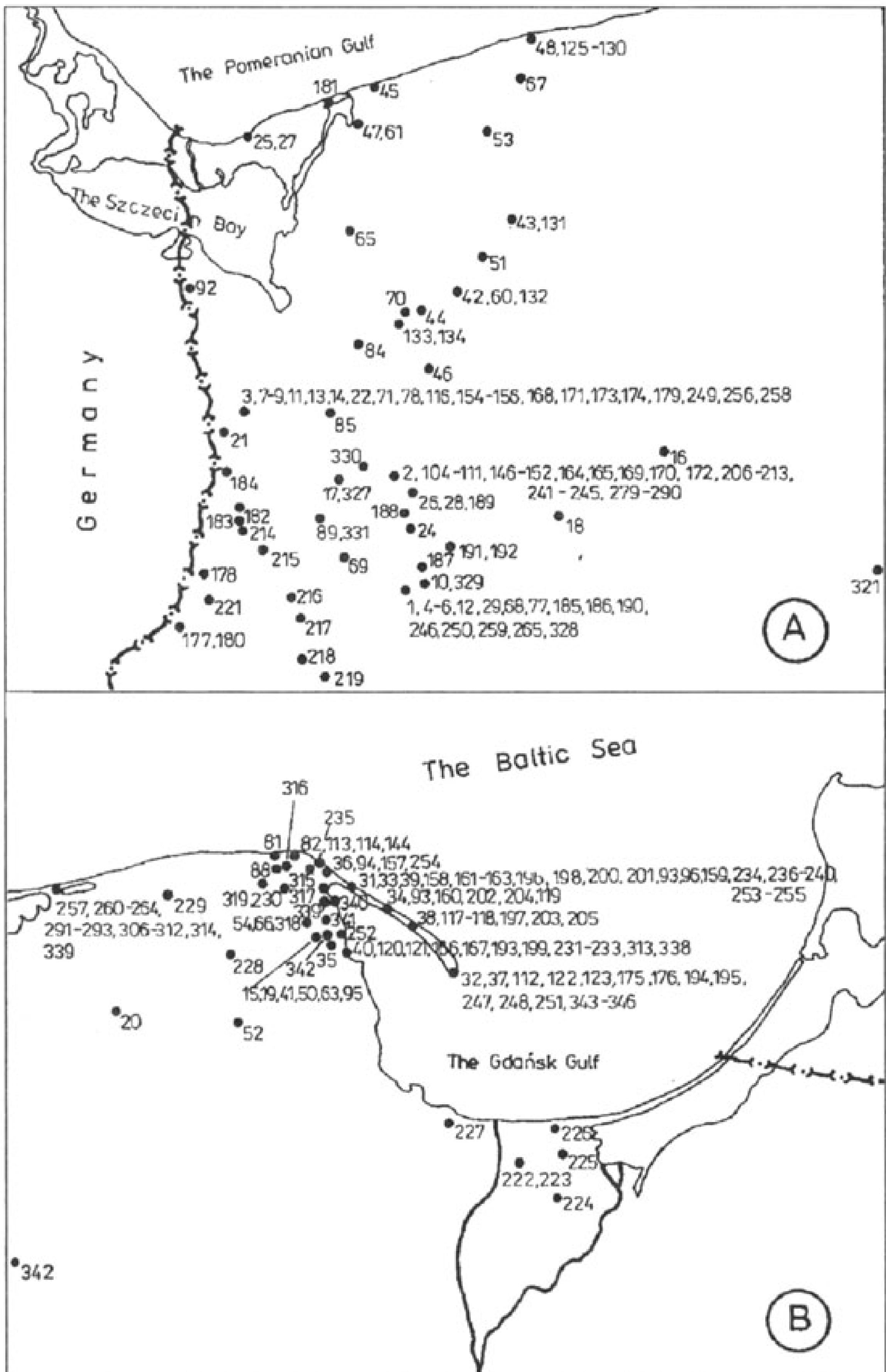A – Region of Szczecin, B – Region of Gdańsk

The Pomeranian Gulf

48,125-130

57

181 · 45

· 47,61

· 25,27

· 53

The Szczecin Bay

· 65

· 43,131

· 51

· 92

70 · 42,60,132

· 44

133,134

· 84

· 46

3,7-9,11,13,14,22,71,78,116,154-156,168,171,173,174,179,249,256,258

· 85

· 21

· 16

330 · 2,104-111,146-152,164,165,169,170,172,206-213,

17,327 241-245,279-290

184

· 26,28,189

188 · 24 · 18

183 · 182

214

89,331

215 · 69 187 · 191,192

· 178 · 10,329

· 221 · 216 1,4-6,12,29,68,77,185,186,190,

246,250,259,265,328

177,180 · 217 321

· 218

· 219

Germany

A

The Baltic Sea

316

235

81 82,113,114,144

88 36,94,157,254

315 31,33,39,158,161-163,19b, 198,200, 201,93,96,159,234,236-240,

257,260-264, 229 319 230 317 34,93,160,202,204,119 253-255

291-293,306-312,314, 54,66,318 38,117-118,197,203,205

339 252

228 342 35 40,120,121 6,167,193,199,231-233,313,338

15,19,41,50,63,95 32,37,112,122,123,175,176,194,195,

247,248,251,343-346

· 20

· 52 The Gdańsk Gulf

· 227 · 226

· 225

222,223

· 224

· 342

B

Fig. 1 b. Sites at which soil and root samples were collected in Region A (Szczecin)
and Region B (Gdańsk)

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Table 1

Plants and localities, in which the occurrence of arbuscular fungi and mycorrhizae was examined

Plant	Locality (see Fig. 1)
Aceraceae	
Acer palmatum Thunb.	29
Buxaceae	
Buxus sempervirens L.	137
Caryophyllaceae	
Dianthus carthusianorum L.	268, 270, 276
Gypsophila fastigiata L.	273
Chenopodiaceae	
Beta vulgaris L.	336, 342
Compositae	
Artemisia campestris L.	255
Helianthus annuus L.	320
Petasites officinalis Moench	168, 249
Cruciferae	
Brassica napus L.	336, 338
Cupressaceae	
Chamaecyparis lawsoniana (And.) Parl.	251
Juniperus communis L.	98, 101, 144, 235, 298, 300
Thuja occidentalis L.	4, 37, 77, 90, 102, 112, 116, 156, 185, 190, 194, 195, 246, 248, 250, 259, 265, 297
Cyperaceae	
Bulboschoenus maritimus (L.) Palla	237
Ericaceae	
Calluna vulgaris (L.) Salisb.	198
Geraniaceae	
Geranium sp.	3
Gramineae	
Agropyron repens (L.) P. B.	1, 186, 187, 189
Agrotis gigantea Roth.	131, 183, 275
Ammophila arenaria Link	127, 200, 204, 205, 236, 2578, 260-264, 291-293, 306-312, 314
Arrhenatherum elatius (L.) P.B.	191, 221
Avena sativa L.	25, 52, 337
Calamagrostis arundinacea (L.) Roth.	78, 179, 269
Corynephorus canescens (L.) P. B.	32, 76, 89, 160
Dactylis glomerata L.	188, 252
Deschampsia caespitosa (L.) P. B.	277
Elymus arenarius L.	31
Festuca arundinaceae Schreb.	201
Festuca polesica Zap.	75
Festuca rubra L.	73, 88
Festuca rubra subsp. *fallax* (Thuill.) Hack.	36
Festuca ovina L.	39, 50, 64, 87, 97, 157, 158
Festuca sp.	49
Glyceria aquatica (L.) Wahlb.	141, 154, 173, 174, 177, 178, 180-182, 184, 258
Helictotrichon pubescens (Hads.) Pilg.	163, 167
Holcus lanatus L.	162
Hordeum vulgare L.	24, 164, 165, 169, 170, 243, 244, 317, 321, 328, 333, 339
Lolium multiflorum Lam.	82
Molinia coerulea (L.) Moench	303
Nardus stricta L.	203

Phragmites communis Trin.	161
Poa chaixi L.	302
Poa pratensis L.	81, 95, 159, 304
Secale cereale L.	65, 331
Setaria italica (L.) P. B.	13
Sorghum sudanensis (Piper) Stapf	8, 11, 171
Triticum aestivum L.	21, 28, 30, 35, 58, 62, 70, 104-111, 145-152, 206-213, 279, 281, 283, 284, 286, 287, 316, 319, 320, 327, 332, 341
Triticum secalum	172, 280, 282, 285, 288-290, 318, 322, 330
Zea mays L.	10, 38, 40, 44-46, 56, 91, 133, 139, 214-216, 219, 222, 225, 226, 228, 229, 242, 323, 325, 329, 334, 340
Unrecognized grasses	83, 85, 94, 96, 99, 100, 126, 135, 176, 271
Juncaceae	
Juncus conglomeratus L.	199, 231-234
Leguminosae	
Glycine hispida Max.	9
Lupinus luteus L.	16, 60, 69, 245
Medicago sativa L.	2, 26, 51, 217, 224
Phaseolus vulgaris L.	48
Pisum arvense L.	61
Trifolium pratense L.	7, 17, 43, 57, 218, 223, 227, 296, 324
Vicia faba L.	335
Liliaceae	
Allium cepa L.	18
Allium porrum L.	41, 67
Allium schoenoprasum L.	22
Oenotheraceae	
Epilobium hirsutum L.	256
Polypodiaceae	
Dryopteris filix-mas (L.) Schott	27, 68
Ranunculaceae	
Ficaria verna Huds.	193
Rosaceae	
Crataegus monogyna Jacq.	113, 114, 117, 121, 130, 136, 140, 254, 294, 295, 299, 305, 313
Fragaria vesca L.	20, 42, 47, 53
Malus domestica Borb.	92
Malus x *purpurea*	12
Prunus domestica L.	74
Prunus serrulata Lindl.	6
Rosa canina L.	93, 118, 119, 123-125, 128, 129, 132, 134, 138, 238-240, 253
Rubus idaeus L.	120
Salicaceae	
Populus alba L.	86
Salix arenaria L.	301
Salix triandra L.	175, 247
Solanaceae	
Nicotiana tabacum L.	72, 103
Solanum tuberosum L.	59, 230
Umbelliferae	
Anthriscus sylvestris (L.) Hoffm.	14, 71
Apium graveolens L.	23
Eryngium maritimum L.	33, 166
Heracleum sphondylium L.	155
Unrecognized plants	266, 267, 272, 274, 278

The list of localities and collection data (Fig. 1 a)

Bielsko-Biała: Cieszyn: 297, 8.09.1989; Leszna Górna: 294-296, 299, 8.09.1989; **Bydgoszcz**: Bydgoszcz: 124, 135-141, 15.09. 19-87; **Chełm**: Rezerwat Bakus: 76, 91, 19.09.1986; **Częstochowa**: 49, 10.08.1985; **Gdańsk**: Chałupy: 31, 33, 39, 23.08.1985; 93, 30.07.1986; 96, 29.07.1986; 158, 159, 161-163, 4.06.88; 196, 198, 200, 201, 28.09.1988; 234, 7.07.1989; 236-240, 7.07.1989; 253-255, 27.08.1989; Chłapowo: 88, 20.11.1986; 235, 7.07.1989; Choczewo: 229, 30.09.1988; Hel: 32, 37, 21.08.1985; 112,122,123, 20.08.1987; 175, 176, 194, 195, 28.09.1988; 247, 248, 5.08.1989; Jastarnia: 38, 117, 118, 20.08.1987; 197, 203, 205, 28.09.1988; Jastrzębia Góra: 81, 82, 20.11.1986; 113, 114, 30.10.1987; 144, 2.11.1987; Kuźnica: 34, 23.08.1985; 119, 20.08.1987; 160, 4.06.1988; 202, 204, 28.09.1988; 251, 5.08.1989; Łebcz: 339, 15.091990; Kostkowo: 22, 30.09.1988; Nowy Dwór Gdański: 224, 30.09.1988; Osłonino: 35, 24.08.1989; 166, 167, 22.06.1988; 199, 3.04.1989; 231-233, 7.07.1989; 313, 5.08.1989; 338, 15.09.1990; Połczyno: 318, 3.08.1989; Puck: 54, 24.08.1985; 66, 29.08.1985; 341, 15.09.1988; Rekowo: 342, 15.09.1990; Rybina: 225, 30.09.1988; Rzucewo: 40, 24.08.1985; 252, 5.08.1989; Sławoszyno: 319, 3.08.1989; Starzyno: 317, 3.08.1989; Stegna: 226, 30.09.1988; Strzelno: 316, 3.08.1989; 340, 15.09.1990; Sulicice: 230, 30.09.1988; Swarzewo: 315, 3.08.1989; Trępnowo: 223, 30.09.1988; Władysławowo:36, 21.08.1985; 94, 29.07.1986; 157, 4.06.1988; Wiślanka: 227, 30.09.1988; Żelistrzewo: 15, 19, 2.11.1985; 41, 24.08.1985; 50, 25.06.1986; 63, 2.07.1986; 95, 29.07.1986; 120, 121, 22.08.1987; 193, 3.04.1989; Żóławki: 222, 30.09.1988; **Gorzów Wielkopolski**: Małyszyn: 30, 12.06.1985; **Jelenia Góra**: Bolesławiec: 58, 17.08.1985; **Katowice**: Góra Świętej Doroty: 305, 9.09.1989; Grodziec: 324, 9.09.1989; Kuźnica: 325, 326, 9.09.1989; Miasteczko Śląskie: 303, 304, 9.09.1989; Pustynia Błędowska: 298, 300, 301, 9.09.1989; Repty: 302, 9.09.1989; Siemianowice Śląskie: 323, 9.09.1989; **Kielce**: Miechów: 64, 16.05.1986; **Koszalin**: Grzmiąca: 55, 30.06.1986; Pomierzyn: 16, 9.08.1985; **Kraków**: Bolesław: 268, 270, 272, 278, 17.09.1989; Krążek: 266, 267, 271, 273, 274, 276, 17.09.1989; Ujków: 269, 275, 277, 17.09.1989; **Krosno**: Iwonicz Zdrój: 145, 28.07.1987; **Nowy Sącz**: Zakopane: 86, 20.07.1986; 102, 15.09.1986; **Piła**: Gostomia: 321, 8.07.1989; Różewo: 320, 8.07.1989; Wałcz: 23, 18.08.1985; 322, 8.07.1989; **Przemyśl**: 90, 26.09.1986; **Słupsk**: Lębork: 20, 15.08.1985; Łeba: 257, 260-264, 291-193, 306-312, 314, 1.08.1989; **Suwałki**: Brzozowo: 62, 25.07.1985; **Szczecin**: Dziwnówek: 45, 25.07.195; Glewice: 133, 134, 22.09.1987; Golenice: 219, 16.09.1988; Goleniów: 84, 15.09.1986; Gryfino: 182, 14.10.1988; Jarosławki: 46, 25.07.1985; Kamień Pomorski: 47, 61, 25.07.1985; Karsko: 220, 16.09.1988; Kikorze: 44, 5.08.1985; Kluczewo: 26, 14.05.1985; 28, 16.07.1985; 189, 25.08.1988; Kobylanka: 330, 13.07.1990; Kołbacz: 17, 4.08.1985; 327, 13.07.1990; Kołbaskowo: 184, 14.10.1988; Kosin: 10, 16.07.1985; 329, 13.07.1990; Krajnik Dolny: 177, 180, 14.10.1988; Krzywinek: 221, 16.09.1988; Lipnik: 2, 16.05.1985; 104-111, 10.08.1986; 146-152, 10.08.1987; 164, 1.06.1988; 165, 3.06.1988; 169, 170, 27.07.1988; 172, 25.05.1988;

206-213, 3.08.1988; 241-245, 19.07.1989; 279-290, 28.07.1989; Lubiatowo: 187, 25.08.1988; Międzyodrze: 181, 14.10.1988; Międzyzdroje: 25, 27, 14.07.1985; Moskorzyn: 191, 192, 25.08.1988; Mrzeżyno: 48, 5.08.1985; 125-130, 22.09.1987; Nowielice: 70, 5.08.1985; Nowogard: 42, 60, 5.08.1985; 132, 22.09.1987; Ostoja: 21, 10.07.1985; Piaseczno: 217, 16.09.1988; Płoty: 43, 5.08.1985; 131, 22.09.1987; Pniewo: 214, 16.09.1988; Prusinowo: 53, 5.08.1985; Przelewice: 1, 4, 10.05.1985; 5, 6, 29, 15.05.1985; 12, 68, 16.07.1985; 77, 1.10.1986; 185, 186, 190, 25.08.1988; 246, 20.07.1989; 250, 265, 29.09.1989; 259, 21.09.1989; 328, 13.07.1990; Przybiernów: 65, 25.07.1985; Rów: 218, 16.09.1988; Różnowo: 215, 16.09.1988; Rzepnowo: 69, 25.07.1985; Szczecin: 3, 11.05.1985; 7, 10.07.1985; 8, 11.08.1985; 9, 5.09.1985; 11, 20.09.1985; 13, 4.10.1985; 14, 18.10.1985; 22, 3.09.1985; 71, 15.09.1986; 78, 10.10.1986; 116, 22.10.1987; 154, 5.05.1988; 155, 156, 22.10.1987; 168, 2.08.1988; 171, 11.08.1988; 173, 174, 25.08.1988; 179, 12.09.1988; 249, 5.10.1989; 256, 258, 25.09.1989; Trzebiatów: 67, 5.08.1985; Wapnica: 18, 9.08.1985; Warnice: 188, 25.08.1988; Widuchowo: 178, 14.10.1988; Załom: 85, 15.09.1986; Żabów: 51, 5.08.1986; **Warszawa**: Hornówko: 97, 26.07.1986; 335-337, 9.08.1990; Kampinos National Park: 98, 26.07.1986; 99-101, 26.07.1986; Truskaw: 332-334, 9.08.1990; **Wrocław**: Bartkowo: 83, 15.09.1986; Makowice: 87, 12.10.1986; **Zamość**: Zwierzyniec: 72-75, 103, 18.09.1986; **Zielona Góra**: Czciradz: 57, 27.08.1985; Lasocin: 56, 59, 27.08.1985.

O c c u r r e n c e   o f   s p o r e s. Spores of arbuscular fungi were found in 330 soil samples. About 87 % of all spores recovered were of the genus *Glomus* (Tab. 2). Members of the genera *Acaulospora* and *Scutellospora* also occurred regularly, but were less numerous. Spores of *Entrophospora*, *Gigaspora* and *Sclerocystis* occurred irregularly and generally in low numbers.

The proportion of *Glomus* sp. was highest in samples taken under plants of the *Caryophyllaceae* (100.00 %), *Solanaceae* (98.60 %), *Leguminosae* (95.60 %), *Liliaceae* (93.57 %), *Umbelliferae* (93.55 %), and *Compositae* (91.00 %) (Tab. 2). In addition, spores of *Glomus* distinctly predominated among roots of members of the *Rosaceae* (79.02 %), *Gramineae* (78.35 %), and *Cupressaceae* (75.02 %). They were relatively rare in the *Juncaceae* (50.48 %) and *Salicaceae* (33.85 %). The soils from under the other plant families were also dominated by members of the genus *Glomus* (68.49-100 % participation in spore populations recovered), but these families were either represented only by single soil samples or the spore populations recovered were exceptionally rare.

Spores of *Acaulospora* were most numerously found among roots of plants of the *Salicaceae* (40.85 %) and *Juncaceae* (29.52 %) (Tab. 2). Their amount was relatively high in samples from under the *Gramineae* (7.20 %), *Rosaceae* (6.65 %), *Umbelliferae* (6.00 %), and *Cupressaceae* (4.03 %), as well as among roots of plants of the *Geraniaceae* (31.51 %), *Ericaceae* (4.40 %), and the *Ranunculaceae* (4.88 %). The three last families were, however, represented by only single soil samples.

Table 2

Frequency of occurrence* of 6 genera of arbuscular fungi in 21 palnt families (%)

Family	n	Acaulospora	Entropho- spora	Gigaspora	Glomus	Sclerocystis	Scutello- spora
Aceraceae	1	1.20 (0.0)	–	–	98.80 (0.0)	–	–
Buxaceae	1	–	–	–	94.10 (0.0)	–	5.90 (0.0)
Caryophyllaceae	4	–	–	–	100.00 (0.0)	–	–
Chenopodiaceae	2	–	–	–	100.00 (0.0)	–	–
Compositae	4	–	–	–	91.00 (17.3)	–	9.00 (173.2)
Cruciferae	2	–	–	–	100.00 (0.0)	–	–
Cupressaceae	25	4.03 (626.6)	11.55 (286.9)	0.08 (475.0)	75.20 (48.3)	0.40 (489.9)	8.92 (241.6)
Cyperaceae	1	–	–	–	100.00 (0.0)	–	–
Ericaceae	1	4.40 (0.0)	–	–	80.40 (0.0)	–	15.20 (0.0)
Geraniaceae	1	35.51 (0.0)	–	–	68.49 (0.0)	–	–
Gramineae	194	7.20 (252.0)	0.59 (933.1)	2.36 (502.3)	78.35 (47.4)	0.66 (1042.4)	9.36 (241.3)
Juncaceae	5	29.52 (86.5)	–	20.00 (200.0)	50.48 (66.2)	–	–
Leguminosae	27	1.70 (283.9)	0.02 (490.0)	–	95.57 (7.5)	–	2.71 (217.3)
Liliaceae	4	1.25 (173.2)	–	–	93.57 (8.0)	–	5.18 (146.5)
Oenotheraceae	1	–	–	–	100.00 (0.0)	–	–
Polypodiaceae	2	–	–	–	100.00 (0.0)	–	–
Ranunculaceae	1	4.88 (0.0)	–	–	95.12 (0.0)	–	–
Rosaceae	37	6.65 (294.3)	0.45 (422.2)	2.36 (426.7)	79.02 (41.6)	–	11.42 (217.8)
Salicaceae	4	40.85 (94.2)	–	–	33.85 (109.3)	–	25.30 (104.1)
Solanaceae	4	–	–	–	98.60 (2.5)	–	1.40 (172.9)
Umbelliferae	6	6.00 (139.7)	–	0.08 (224.5)	93.55 (8.7)	–	0.37 (221.6)
Mean		6.63 (92.9)	0.60 (101.5)	1.18 (87.1)	86.95 (17.0)	0.05 (73.0)	4.54 (82.7)

* – (Number of spores of a given genus divided by the number of all spores in samples of a given plant family) multiplied by 100; n – number of soil samples examined. Values in parentheses are coefficients of variation (%)

Table 2

Frequency of occurrence* of 6 genera of arbuscular fungi in 21 palnt families (%)

Family	n	Acaulospora	Entropho-spora	Gigaspora	Glomus	Sclerocystis	Scutello-spora
Agropyron repens	4	1.95 (173.2)	–	–	96.88 (4.0)	0.40 (173.2)	0.77 (172.1)
Agrostis gigantea	3	3.70 (141.4)	8.00 (141.4)	–	86.87 (11.4)	–	1.23 (141.8)
Ammophila arenaria	23	19.42 (140.9)	–	7.83 (270.8)	13.87 (196.3)	–	58.88 (69.4)
Avena sativa	3	0.30 (141.4)	–	–	98.30 (1.9)	–	1.40 (141.8)
Calamagrostis arundinacea	3	–	23.8 (141.4)	–	76.20 (44.2)	–	–
Corynephorus canescens	4	30.55 (79.5)	–	–	51.54 (50.5)	–	16.43 (137.0)
Crataegus monogyna	13	8.16 (283.3)	–	4.64 (475.0)	83.68 (40.2)	–	7.79 (266.8)
Dianthus carthusianorum	3	–	–	–	100.00 (0.0)	–	–
Festuca ovina	7	24.97 (94.1)	–	6.96 (244.9)	59.53 (244.9)	–	8.14 (215.1)
Fragaria vesca	4	0.95 (102.5)	–	–	76.95 (44.6)	–	22.10 (157.7)
Glyceria aquatica	11	–	1.19 (316.3)	–	98.81 (3.8)	–	–
Hordeum vulgare	12	0.09 (337.8)	–	–	99.74 (0.6)	–	0.17
Juncus conglomeratus	5	29.52 (86.5)	–	20.0 (200.0)	50.48 (66.2)	–	–
Juniperus communis	6	19.97 (176.4)	15.48 (218.2)	–	59.80 (69.1)	–	4.75 (163.5)
Lupinus luteus	4	5.38 (173.0)	–	–	94.62 (9.8)	–	–
Medicago sativa	4	2.70 (173.2)	–	–	88.20 (8.7)	–	9.10
Poa pratensis	4	0.25 (173.2)	–	–	64.80 (62.5)	22.48 (173.2)	11.47 (138.8)
Rosa canina	15	13.49 (210.5)	1.12 (255.0)	1.81 (343.1)	70.10 (48.8)	–	13.48 (190.5)
Sorghum sudanensis	3	0.20 (141.4)	0.10 (141.4)	–	89.10 (9.4)	–	10.60 (78.4)
Thuja occidentalis	18	11.98 (173.9)	3.98 (224.8)	–	73.12 (42.4)	–	10.92 (227.9)
Trifolium pratense	9	1.10 (282.8)	0.06 (261.9)	–	95.68 (6.5)	–	3.16 (177.9)
Triticum aestivum	43	1.89 (276.1)	–	0.22 (570.4)	97.07 (17.7)	–	0.82 (383.8)
Triticum secalum	10	10.60 (228.7)	–	–	88.60 (27.9)	–	0.80 (279.8)
Vicia faba	6	–	–	–	100.00 (0.0)	–	–
Zea mays	25	0.10 (489.9)	–	0.34 (495.7)	99.32 (2.4)	–	0.24 (400.0)

Explanations as in Table 2

Spores of *Scutellospora* occurred in greatest amounts in the zone of roots of the *Salicaceae* (25.30 %) (Tab. 2). They were additionally found in large numbers among members of the *Rosaceae* (11.42 %), *Gramineae* (9.96 %), *Compositae* (9.00 %), *Cupressaceae* (8.42 %), and *Liliaceae* (5.18 %). The roots of *C. vulgaris* (*Ericaceae*) (15.20 %) and *B. sempervirens* (*Buxaceae*) (5.90 %) also harboured relatively large numbers of spores of this genus, but only single soil samples were taken from under these plants.

Members of *Entrophorospora* achieved a distinctive amount only in the *Cupressaceae* (11.55 %), and those of *Gigaspora* in the *Juncaceae* (20.00 %) (Tab. 2).

Of the 25 plant species, from under of which at least three soil samples were collected, 75.1-100.00 % of spores of the genus *Glomus* occurred in 17 ones, among others in *V. faba* (100.00 %), *H. vulgare* (99.74 %), *Z. mays* (99.32 %), *A. sativa* (98.30 %), *T. aestivum* (97.07 %), *T. secalum* (88.30 %), and *F. vesca* (76.95 %) (Tab. 3). In seven other species, the proportion ranged from 50.48 to 73.12 %. Exceptionally low amounts of spores of this genus were found among roots of *A. arenaria* (13.87 %).

The proportion of spores of *Acaulospora* was highest in *C. canescens* (30.55 %), *J. conglomeratus* (29.52 %), and *F. ovina* (24.97 %), and lowest, e.g., in *H. vulgare* (0.09 %), *Z. mays* (0.10 %), *P. pratensis* (0.25 %), *A. sativa* (0.30 %), *F. vesca* (0.95 %), *T. pratense* (1.10 %), *T. aestivum* (1.89 %), and *A. gigantea* (3.70 %) (Tab. 3).

Spores of *Scutellospora* distinctly dominated among roots of *A. arenaria* (58.88 %) (Tab. 3). They occurred in large numbers in *F. vesca* (22.10 %) and *C. canescens* (16.43 %) as well. The lowest proportion of these spores was found, e.g., in *H. vulgare* (0.17 %), *Z. mays* (0.24 %), *T. secalum* (0.80 %), *T. aestivum* (0.82 %), *A. gigantea* (1.23 %), and *A. sativa* (1.40 %).

The fungi of the genera *Entrophospora*, *Gigaspora*, and *Sclerocystis* occurred in the zone of roots of 8, 7, and 2 plant species, respectively (Tab. 3). The genus *Gigaspora* was distinctly more numerously represented in spore populations derived from under *C. arundinacea* (23.80 %) and *J. communis* (15.48 %). Spores of *Sclerocystis* occurred in distinctly higher numbers among roots of *P. pratensis* (22.48 %).

Of the spore-forming arbuscular fungi, a total of 40 species in 6 genera and 7 unrecognized forms (one each in *Acaulospora* and *Scutellospora*, 2 in *Entrophospora*, 3 in *Glomus*) were found (Tabs. 4, 5). Additionally *G. tenue*, a nonsporulating species, was found in roots.

In the zone of roots of cultivated plants, 31 and 2 spore-forming species and forms occurred, respectively (Tab. 4). Thirty-six species in 6 genera and 5 forms in 3 genera were recovered from under wild plants (Tab. 5). *Glomus tenue* occurred, in roots of the both plant groups. In soil samples collected from under both cultivated and wild plants, spores of 6 genera were also found, whose properties did not fit any described species so far. For the both plant groups, 28 fungal species were in common. Four species and 3 forms were found only in the zone of roots of cultivated plants, and 4 species and 4 forms occurred only among roots of wild plants.

T a b l e 4

Arbuscular fungi isolated from under cultivated plants

Species	Frequency of occurrence (%)	Dominance (%)
Acaulospora bireticulata	0.6	0.07
Acaulospora capsicula	2.9	0.50
Acaulospora cavernata	2.9	2.11
Acaulospora lacunosa	1.7	0.05
Acaulospora paulinae	3.5	0.32
Acaulospra polonica	1.7	0.62
Acaulospora polylamina	1.7	1.16
Acaulospora thomii	0.6	1.01
Acaulospora 87	0.6	0.46
Enthropospora infrequens	2.3	0.03
Entrophospora 91	1.7	0.24
Gigaspora gigantea	2.3	0.03
Glomus aggregatum	8.7	0.72
Glomus caledonium	34.1	3.73
Glomus constrictum	43.9	5.51
Glomus deserticola	45.1	14.44
Glomus dominikii	18.5	4.27
Glomus etunicatum	17.9	2.45
Glomus fasciculatum	30.1	11.46
Glomus fuegianum	2.9	0.57
Glomus geosporum	31.8	5.13
Glomus heterosporum	6.9	6.20
Glomus hoi	0.6	0.36
Glomus macrocarpum	24.9	4.48
Glomus microcarpum	6.4	2.90
Glomus mosseae	59.5	11.82
Glomus occultum	5.8	0.91
Glomus pansihalos	2.9	0.74
Glomus przelewicensis	0.6	0.18
Scutellospora calospora	9.2	0.65
Scutellospora dipurpurascens	8.7	1.00
Scutellospora nodosa	0.6	0.05
Scutellospora pellucida	2.9	0.05
Unrecognized *Acaulospora*	11.6	0.65
Unrecognized *Gigaspora*	1.7	0.07
Unrecognized *Glomus*	34.1	9.00
Unrecognized *Scutellospora*	11.0	0.77

T a b l e 5

Arbuscular fungi isolated from under wild plants

Species	Frequency of occurrence (%)	Dominance (%)
Acaulospora bireticulata	0.6	0.03
Acaulospora capsicula	1.9	0.38
Acaulospora dilatata	5.0	0.38
Acaulospora gdanskensis	5.0	2.02
Acaulospora lacunosa	19.5	3.55
Acaulospora paulinae	10.1	1.28
Acaulospora polonica	1.9	0.05
Acaulospora polylamina	11.9	0.81
Acaulospora rugosa	0.6	0.21
Entrophospora infrequens	2.5	0.08
Entrophospora 95	0.6	1.20
Gigaspora gigantea	10.1	0.55
Glomus aggregatum	17.0	9.33
Glomus caledonium	7.5	0.99
Glomus constrictum	37.1	11.77
Glomus deserticola	15.7	4.83
Glomus dominikii	4.43	0.31
Glomus etunicatum	8.2	0.79
Glomus fasciculatum	27.7	7.95
Glomus fuegianum	1.9	1.70
Glomus geosporum	10.1	1.29
Glomus globiferum	1.3	0.19
Glomus heterosporum	11.9	9.42
Glomus hoi	3.8	2.25
Glomus laccatum	1.3	0.42
Glomus macrocarpum	18.9	3.31
Glomus microaggregatum	0.6	0.08
Glomus microcarpum	13.2	7.19
Glomus mosseae	18.9	1.51
Glomus occultum	4.4	0.81
Glomus pansihalos	7.6	4.86
Glomus pustulatum	0.6	0.06
Glomus versiforme	0.6	0.15
Glomus 81	4.4	1.43
Glomus 86	0.6	0.47
Glomus 93	0.6	0.94
Sclerocystis rubiformis	4.4	1.49
Scutellospora calospora	17.6	1.19
Scutellospora dipurpurascens	25.2	6.89
Scutellospora pellucida	3.1	0.35
Scutellospora 72	6.9	0.44
Unrecognized *Acaulospora*	6.3	0.59
Unrecognized *Entrophospora*	3.8	0.75
Unrecognized *Gigaspora*	5.7	0.29
Unrecognized *Glomus*	20.8	2.81
Unrecognized *Scutellospora*	6.9	0.63

In the conducted investigations, the most frequently occurring spores were those of *G. constrictum* (40.4 %) and *G. mosseae* (40.1 %) (Tabs. 4, 5). Other frequently recovered species were *G. deserticola* (31.0 %), *G. fasciculatum* (29.2 %), *G. macrocaprum* (22.0 %), *G. caledonium* (21.4 %), and *G. geosporum* (21.4 %). The proportions of soil samples derived from under cultivated plants to those taken under wild plants containing these species were 2.6:1 – for *G. caledonium*, 1.2:1 – for *G. constrictum*, 2.9:1 – for *G. deserticola* and *G. mosseae*, 1.1:1 – for *G. fasciculatum*, 3.4:1 – for *G. geosporum* and 1:2.8 – for *G. macrocarpum*.

Among cultivated plants, the most frequently occurring species were *G. mosseae* (59.0 %), *G. deserticola* (45.1 %) and *G. constrictum* (43.9 %) (Tab. 4). Relatively frequently found species also were *G. fasciculatum* (30.1 %), *G. geosporum* (29.5 %), *G. macrocarpum* (24.9 %), and *G. caledonium* (19.7 %). Six species were recovered in frequencies from 5.8 to 9.8 %, and 16 ones and 3 forms occurred in frequencies from 0.6 to 3.5 %.

Among roots of wild plants, the most frequently occurring species were *G. constrictum* (37.1 %), *G. fasciculatum* (27.7 %), *S. dipurpurascens* (25.2 %), and *G. mosseae* (20.1 %) (Tab. 5). Eleven species occurred in frequencies from 10.1 to 17.6 %, including, e.g., *G. deserticola* (15.7 %), *G. geosporum* (10.7 %), and *G. macrocarpum* (18.2 %). The frequency of occurrence of 4 other species and 1 form ranged from 6.9 (*Scutellospora* 72) to 7.5 % (*G. caledonium*). The other 18 species and 3 forms occurred in 0.6-5.0 % of the soil samples examined.

D o m i n a n c e. Considering together both plant groups, the highest dominance coefficient was achieved by *G. fasciculatum* (9.61 %), *G. deserticola* (9.17 %), *G. constrictum* (8.94 %), *G. heterosporum* (7.96 %), *G. mosseae* (6.16 %), *G. aggregatum* (5.45 %), and *G. microcarpum* (5.25 %). The dominance coefficients of *G. fasciculatum*, *G. deserticola*, and *G. mosseae* were 1.4; 3.0, and 7.8 times higher for cultivated than wild plants, respectively. In contrast, the proportions of dominance coefficients of the other species were advantageous to wild plants and were, e.g., 13.0:1 – for *G. aggregatum*, 2.1:1 – for *G. constrictum*, 1.5:1 – for *G. heterosporum*, and 1.1:1 – for *G. microcarpum*.

Among roots of cultivated plants, the distinctively dominating species were *G. deserticola* (14.44 %), *G. mosseae* (11.82 %), and *G. fasciculatum* (11.46 %) – an eudominant group, dominance coefficient D at and above 10.0 % (G ó r n y, G r u m a, 1981) (Tab. 4). The dominants (D = 5.1-10.0 %) were *G. heterosporum* (6.20 %), *G. constrictum* (5.51 %), and *G. geosporum* (5.13 %). Six species were subdominants (D = 2.1-5.0 %), among which were *G. macrocarpum* (4.48 %), *G. caledonium* (3.73 %), and *G. microcarpum* (2.90 %). The dominance coefficient of the other 19 species and 3 forms ranged from 0.03 to 1.16 %.

In the zone of roots of wild plants, the eudominant was only *G. constrictum* (11.73 %) (Tab. 5). The dominants were *G. heterosporum* (9.42 %), *G. aggregatum* (9.33 %), *G. fasciculatum* (7.95 %), *G. microcarpum* (7.19 %), and *S. dipurpurascens*

(6.89 %). Six species were classified as subdominants, including, e.g., *G. deserticola* (4.83 %) and *G. macrocarpum* (3.31 %). The dominance coefficients for the other 24 species and 5 forms ranged from 0.03 to 1.70 %.

S p o r e   d e n s i t y. Considering jointly cultivated and wild plants, the spore density of all genera of arbuscular fungi in 100 g dry soil averaged 101.6 and ranged from 0 to 1435 spores. Separately for cultivated and wild plants, the densities averaged 87.9 (range 0-1435) and 116.4 (range 0-695), respectively.

The richest in spores soil samples were those from under the *Cupressaceae* (137.8), *Umbelliferae* (126.3), *Rosaceae* (124.5), and *Caryophyllaceae* (119.3) (Tab. 6). Somewhat fewer spores were found in the root zone of plants of, e.g., the *Gramineae* (91.0), *Compositae* (78.3), *Leguminosae* (66.6), *Solanaceae* (51.0), and *Liliaceae* (42.3). Less numerous spore populations were those isolated from under members of the *Cruciferae* (16.5), *Polypodiaceae* (16.0), and *Chenopodiaceae* (2.5).

Table 6

Spore (a)* and species (b)* density of arbuscular fungi in 21 plant families

Family	n	a		b	
Aceraceae	1	245.0	–	6.0	–
Buxaceae	1	34.0	–	4.0	–
Caryophyllaceae	4	119.3	(66.7)	1.5	(33.3)
Chenopodiaceae	2	2.5	(20.0)	1.0	(0.0)
Compositae	4	78.3	(65.3)	3.3	(40.0)
Cruciferae	2	16.5	(87.9)	1.5	(33.3)
Cupressaceae	25	137.8	(72.9)	4.7	(52.2)
Cyperaceae	1	59.0	–	1.0	–
Ericaceae	1	46.0	–	3.0	–
Geraniaceae	1	75.0	–	3.0	–
Gramineae	194	91.0	(139.9)	3.5	(55.9)
Juncaceae	5	62.6	(72.0)	2.6	(57.6)
Leguminosae	27	66.6	(69.2)	4.1	(42.1)
Liliaceae	4	42.3	(38.0)	4.5	(40.1)
Oenotheraceae	1	282.0	–	3.0	–
Polypodiaceae	2	16.0	(87.5)	2.5	(60.0)
Ranunculaceae	1	1435.0	–	5.0	–
Rosaceae	37	124.5	(97.4)	4.7	(61.4)
Salicaceae	4	91.3	(114.5)	3.0	(40.8)
Solanaceae	4	51.0	(108.6)	3.5	(42.9)
Umbelliferae	6	126.3	(84.5)	5.0	(41.6)

* In 100 g dry soil; n – number of soil samples examined
Values in parentheses are coefficients of variation (%)

Spore densities in the other plant families ranged from 34 (*Buxaceae*) to 1435 (*Ranunculaceae*), but these families were represented only by single soil samples.

Of the 25 most frequently examined plant species, most spores were found in the zone of roots of *J. communis* (218.5 in 100 g dry soil), *S. sudanensis* (177.3), *D. carthusianorum* (158.7), *G. aquatica* (151.7), and *C. canescens* (151.5) (Tab. 7). The 100-150 density range included only *T. occidentalis* (112.8) and *F. ovina* (101.4). The density of spores in 9 other plant species ranged from 53.8 (*P. pratensis*) to 99.7 (*R. canina*). Among these species, there were additionally, e.g., *T. aestivum* (97.4), *L. luteus* (87.3), *T. pratense* (69.6), *Z. mays* (57.4), and *A. sativa* (54.0). The spore number in samples from under the other plant species ranged from 36.0 (*F. vesca*) to 46.8 (*M. sativa*); this group of plants also included, e.g., *T. secalum* (43.6), *V. faba* (43.4), and *H. vulgare* (40.7).

S p e c i e s   d e n s i t y. Considering jointly cultivated and wild plants, the species density of arbuscular fungi in 100 g dry soil averaged 3.7. In the root zone of cultivated plants, it averaged 3.9 in a range of 0-9, and an average of 3.5 species (range 0-11) were found among roots of wild plants.

Most species contained soils sampled under plants of the *Umbelliferae* (av. 4.5) and *Leguminosae* (av. 4.1) (Tab. 6). From 3 to 3.5 fungal species were recovered from under members of 4 plant families; e.g., this mean was 3.5 for the *Gramineae* and *Solanaceae*. The lowest number of species was isolated from under plants of the *Chenopodiaceae* (av. 1.0), *Caryophyllaceae*, and *Cruciferae* (av. 1.5), *Polypodiaceae* (av. 2.5), and *Juncaceae* (av. 2.6). Relatively heterogenous also were spore populations recovered from single samples representing the families *Aceraceae* and *Ranunculaceae* which contained 6 and 5 fungal species, respectively.

Most species were found in soils sampled under *C. canescens* (av. 6.8), *A. sativa* (av. 5.3), *T. occidentalis* (av. 5.1), and *S. sudanensis* (av. 5.0) (Tab. 7). Fifteen plant species harboured from 3.0 (*V. faba*) to 4.8 (*L. luteus*) fungal species, among which were, e.g., *T. secalum* (3.3), *F. vesca* (3.5), *Z. mays* (3.4), *T. aestivum* (3.7), *M. domestica* (3.8), and *T. pratense* (4.1). The remaining plant species were associated with 1.7-2.8 fungal species (*D. carthusianorum* vs. *H. vulgare*).

The presence of spores of arbuscular fungi in ca 90 % of soil samples collected under 76 plant species from 21 families confirms G e r d e m a n n's (1968) suggestion that *Glomales* belongs to the most common soil fungi in the world and is associated with almost all vascular terrestrial plants.

According to G e r d e m a n n and T r a p p e (1974) and M o s s e, S t r i b l e y, L e t a c o n (1981), members of the genus *Glomus* are the most widely distributed species and usually dominate in spore populations of arbuscular fungi. *Acaulospora* and *Scutellospora* sp. also have a worldwide distribution, but are secondary in populations. In contrast, spores of the genera *Entrophospora, Gigaspora,* and *Sclerocystis* occur infrequently and in low amounts. A similar conclusion may be drawn from the author's study.

Table 7

Spore (a) and species (b) density of arbuscular fungi among roots of 25 most frequently examined
plant species

Species	n	a		b	
Agropyron repens	4	98.8	(36.8)	4.5	(11.1)
Agrostis gigantea	3	160.7	(74.9)	4.0	(54.3)
Ammophila arenaria	23	37.1	(73.3)	2.6	(54.2)
Avena sativa	3	54.0	(78.6)	5.3	(46.8)
Calamagrostis arundinacea	3	35.0	(93.7)	2.3	(20.2)
Corynephorus canescens	4	151.5	(78.9)	6.8	(28.2)
Crataegus monogyna	13	147.5	(91.9)	4.2	(70.7)
Dianthus carthusianorum	3	158.7	(22.1)	1.7	(28.2)
Festuca ovina	7	101.4	(61.7)	3.3	(21.3)
Fragaria vesca	4	36.0	(53.1)	3.5	(31.9)
Glyceria aquatica	11	151.7	(124.9)	2.6	(25.7)
Hordeum vulgare	12	40.7	(82.6)	2.8	(49.6)
Juncus conglomeratus	5	62.6	(72.0)	2.6	(57.6)
Juniperus communis	6	218.5	(57.6)	4.0	(72.2)
Lupinus lùteus	4	87.3	(78.0)	4.8	(31.1)
Medicago sativa	4	46.8	(16.3)	3.8	(22.1)
Poa pratensis	4	53.8	(58.6)	3.3	(45.5)
Rosa canina	15	99.7	(86.8)	4.5	(71.6)
Sorghum sudanensis	3	177.3	(65.6)	5.0	(32.7)
Thuja occidentalis	18	112.8	(66.0)	5.1	(42.8)
Trifolium pratense	9	69.6	(72.5)	4.1	(49.3)
Triticum aestivum	43	97.4	(173.2)	3.7	(44.6)
Triticum secalum	10	43.6	(122.6)	3.3	(45.1)
Vicia faba	6	43.4	(54.9)	3.0	(29.8)
Zea mays	25	57.4	(92.3)	3.4	(56.4)

Expalnations as in Table 6

In the study discussed here, exept for the *Juncaceae* and *Salicaceae*, members of all the other families harboured spore populations with at least a 75 % proportion of fungi of the genus *Glomus*. A similar proportion of *Glomus* spores in recovered populations of arbuscular fungi has been found by, e.g., F e r r e r et al. (1989), G i a n i n a z z i - P e a r s o n et al. (1980), K o r m a n i k (1985), and S c h e n c k and S m i t h (1981). Among roots of plant species of the *Juncaceae* and *Salicaceae*, the dominant spores were those of *Acaulospora*; plant species of the *Salicaceae* were additionally associated with a large amount of spores of the genus *Scutellospora*. The fungi of these mycorrhizae may have suppressed secondary colonization of roots by *Glomus* sp., presuming the law of colonization priority (W i l s o n, T r i n i c, 1983). *Acaulospora* and *Scutellospora* sp. were more aggressive than fungi of the genus *Glomus*. Species, and even strains of arbuscular fungi may significantly differ in infectivity (S y l v i a, B u r k s, 1988). The aggressiveness of arbuscular fungi also depends on the soil conditions (K o o m e n, G r a c e, H a y m a n, 1987), which for

Acaulospora and *Scutellospora* sp. probably were more favourable in sites with the *Juncaceae* and *Salicaceae*.

According to N e m e c et al. (1981), the most common arbuscular fungi of cultivated soils are *Glomus* sp., which in the author's studies were twice as numerous among roots of cultivated plants as among those of to wild plants (618 vs. 380). Such proportions for the other fungal genera were advantageous for wild plants and were 45 vs. 100 for *Acaulospora*, 7 vs. 11 for *Entrophospora*, 7 vs. 25 for *Gigaspora*, 0 vs. 7 for *Sclerocystis*, 56 vs. 95 for *Scutellospora*. *Glomus mossesae*, the most frequently occurring species in cultivated soils of Poland, is mainly associated with fertilized soils, of fine texture and with neutral to alkaline pH (A b b o t t, R o b s o n, 1977; M o s s e, B o w e n, 1968 b). In contrast, *Acaulospora* sp. are favoured in coarse--grained and acid soils (A b b o t t, R o b s o n, 1977; K r u c k e l m a n n, 1975). The optimum temperature for germination of spores of *Gigaspora* and *Scutellospora* from two climatically different sites has been 25-35°C (D a n i e l s, T r a p p e, 1980; S c h e n c k et al., 1979). According to P i r o z y n s k i (1968), temperature is the main factor determining the occurrence of fungi. *Glomus versiforme* was more sensitive to drought than *G. gigantea* (D a n i e l s, T r a p p e, 1980). *Gigaspora* sp. have occurred more frequently in soils with a large amount of sand (D a y, S y l v i a, C o l l i n s, 1987). These data probably partly explain the distinctive dominance of members of *Scutellospora* and the related genus *Gigaspora* over *Glomus* sp. among roots of *A. arenaria* in maritime sand dunes, as well as the relatively low proportion of spores of the other genera in the zone of roots of cultivated plants examined by the author of this paper.

Of the species abundantly sporulating in soils of Poland, only *G. deserticola* and *G. mosseae* produced more spores in cultivated than uncultivated soils. *Glomus mosseae* is known to prefer cultivated sites (A b b o t t, R o b s o n, 1977; K h a n, 1974; M o s s e, B o w e n, 1968 b). A species of similar requirements probably is *G. deserticola*, whose sporulation was highly variable. High variability of sporulation was also distinctive in *G. macrocarpum*, a species which seems to be relatively well adapted to cultivated soils. *Glomus deserticola* and *G. macrocarpum* frequently from ecotypes differing in effectiveness in both root colonization of a plant and the influence on its growth (S t a h l, S m i t h, 1984; S y l v i a, B u r k s, 1988), and vigorously growing plants usually harbour more numerous spore populations of arbuscular fungi (H a y m a n, 1974; H e t r i c, B l o o m, 1986). Both the commonness of *G. constrictum* in soils of Poland and the relatively slight predominance of this species in the root zone of wild plants suggest that it also suffer environmental alternations induced by agricultural activities. In contrast, sporulation of, e.g., *G. aggregatum* was over 17-fold more abundant in uncultivated than cultivated soils. *Glomus aggregatum* forms extensive extramatrical hyphae (B ł a s z k o w s k i, 1991 b; K o s k e, 1985) that are probably easily damaged in cultivated soils, and this

makes the fungus to disappear (J a s p e r et al., 1989). S t a h l and C h r i s t e n-
s e n (1991) suggested that a broad distribution of species of arbuscular fungi mainly
results from their genetic adaptability which leads to genetic differentiation between
populations. Hence, the apparent tolerance to agrochemical practices of the fungal
species found in this study probably is relatively stable. Thus, they should theoreti-
cally be the most appropriate fungi which could be used in inoculations of agricul-
tural soils of Poland.

The density of spores of arbuscular fungi in soils of Poland (av. 101.6; range
0-1435 spores in 100 g dry soil) is comparable with densities found in many sites of
the U.S.A. (K o s k e, H a l v o r s o n, 1981; M e d i n a, K r e t s c h m e r,
S y l v i a, 1988; S c h e n k, K i n l o c h, 1980; S t a h l, C h r i s t e n s e n, 1982;
W a l k e r et al., 1982), Denmark (J a k o b s e n, N i e l s e n, 1983), Iran (K i a n-
m e r, 1981), and Australia and New Zealand (H a y m a n, 1978; H a y m a n,
S t o v o l d, 1979; K o s k e, 1975). Fewer spores have been recovered from 100 g of
soil taken under *T. aestivum* cultivated in Kansas – 0.5-23.4 (H e t r i c k, B l o o m,
1983) and from under actinorhizal plants in Oregon – 1-19 (R o s e, 1980). In
contrast, more numerous populations of arbuscular fungi have been harboured by
M. domestica in nurseries in 18 states of the U.S.A. – 62-2151 spores in 100 g dry
soil (M i l l e r, D o m o t o, W a l k e r, 1985), plants colonizing mine spoils in
Canada – 390-2070 (Z a k, D a n i e l s o n, P a r k i n s o n, 1982), *Rubus idaeus*
growing in France – 227-2386 (G i a n i n a z z i - P e a r s o n et al., 1980), and by
grasses and other plants in India, Pakistan, and New Zealand – 5000-10000 (K h a n,
1974; S a i f, I f f a t, 1976; S n i g h, V a r m a, 1981).

According to many investigators (B a y l i s, 1969; M o s s e, B o w e n, 1968 b;
R e a d et al., 1976; S c h e n c k, K i n l o c h, 1980; S c h e n c k et al., 1989),
cultivated soils contain more numerous spores of arbuscular fungi than those under
natural vegetations. B a y l i s (1969) suggested that production of spores is stimu-
lated by periods interrupting the growth of roots, which naturally occur only in
annual plants. However, this was not confirmed in the author's studies, since the
mean spore density was distinctly higher in the zone of roots of wild than cultivated
plants (116.4 vs. 87.9 spores in 100 g dry soil). Similar results have been obtained
by J o h n s o n (1977), H e t r i c k and B l o o m (1983), and by K o r m a n i k (1985).
The lower spore density of arbuscular fungi in cultivated than uncultivated soils may
be due to (1) higher soil N and P concentrations in cultivated soils that decrease
sporulation and infectivity of these fungi (H a a s, K r i k u n, 1985; K r u c k e l-
m a n n, 1975; J o h n s o n, P l a t t, 1978); and (2) mechanical treatments that
decrease the infectious potential of soil through the destruction of spores and
extramatrical hyphae (J a s p e r, A b b o t t, R o b s o n, 1989).

Except for the family *Caryophyllaceae*, high and mean spore densities harboured
families and species of plants that form regular associations with arbuscular fungi

(H a r l e y, H a r l e y, 1987). Exceptionally low numbers of spores were found in the root zone of plant species of the *Chenopodiaceae* and *Cruciferae*, which are known to be nonhost of these fungi (B e r c h, G a m i e t, D e o m, 1988; H a r l e y, H a r l e y, 1987). *Buxus sempervirens* (*Buxaceae*), *D. carthusianorum* (*Caryophyllaceae*), and *L. luteus* (*Leguminosae*) usually are autotrophic (H a r l e y, H a r l e y, 1987). Hence, spores recovered from soils sampled under these plants may have been formed on forecrops or neighbouring plants, as V o l k m a r and W o o d b u r y (1989) suggested.

The mean species density of arbuscular fungi in Polish soils (3.9 in 100 g dry soil; range 0-11) is similar to the densities found in other regions of the world. In 100 g dry soil 1-3 species have been found by K h a n (1974) and M o s s e and B o w e n (1968 b). From 3 to 5 species have been recovered in studies of A b b o t t and R o b s o n (1977), A m e s and L i n d e r m a n (1977), J o h n s o n (1977), K o s k e (1975), M o l i n a et al. (1978), and M o s s e and B o w e n (1968 a). Although H a y m a n (1978), K o s k e (1987), K o s k e and H a l v o r s o n (1981), M i l l e r, D o m o t o, W a l k e r (1985), R o s e (1980), and S t a h l and C h r i s t e n s e n (1982) isolated more than 5 species from single soil samples, mean species densities in those samples ranged from 2.7 to 4.9 with an overall range from 0 (H a y m a n, 1978) to 14 (K o s k e, 1987).

The higher density of species in cultivated than uncultivated soils (av. 3.9; range 0-9 vs. 3.5; range 0-11) found in the author's studies corresponds with the report of S c h e n c k and K i n l o c h (1980), but contradicts the results of S c h e n c k, S i q u i e r a, O l i v i e r a (1989). In both cases, the variability of composition of arbuscular fungal populations in adjacent sites, of which one had been covered with natural vegetation and the second one had been under cultivation, was investigated. S y l v i a (1986) and G e m m a, K o s k e, C a r r e i r o (1989) found that highest spore and species densities usually occur during plant maturation, whereas the peak of sporulation in wild plants (especially in perennial ones) may occur at a different time of a year; however, the species density is frequently unrelated with the density of spore population as a whole. A similar phenomenon was frequently observed in the author's studies.

The extended in time sporulation of arbuscular fungi probably minimizes the extent of simultaneous competition for host photosynthate or cortical cells. This strategy leads to the maintenance of high diversity of arbuscular fungal populations (G e m m a, K o s k e, K a r r e i r o, 1989), and this suggests their high stability (A l e x a n d e r, 1975).

Most species of arbuscular fungi were harboured by plants of the *Umbelliferae, Rosaceae, Cupressaceae, Liliaceae, Leguminosae, Gramineae,* and *Solanaceae,* which were also associated with the most numerous spore populations and which are good hosts of arbuscular fungi (H a r l e y, H a r l e y, 1987).
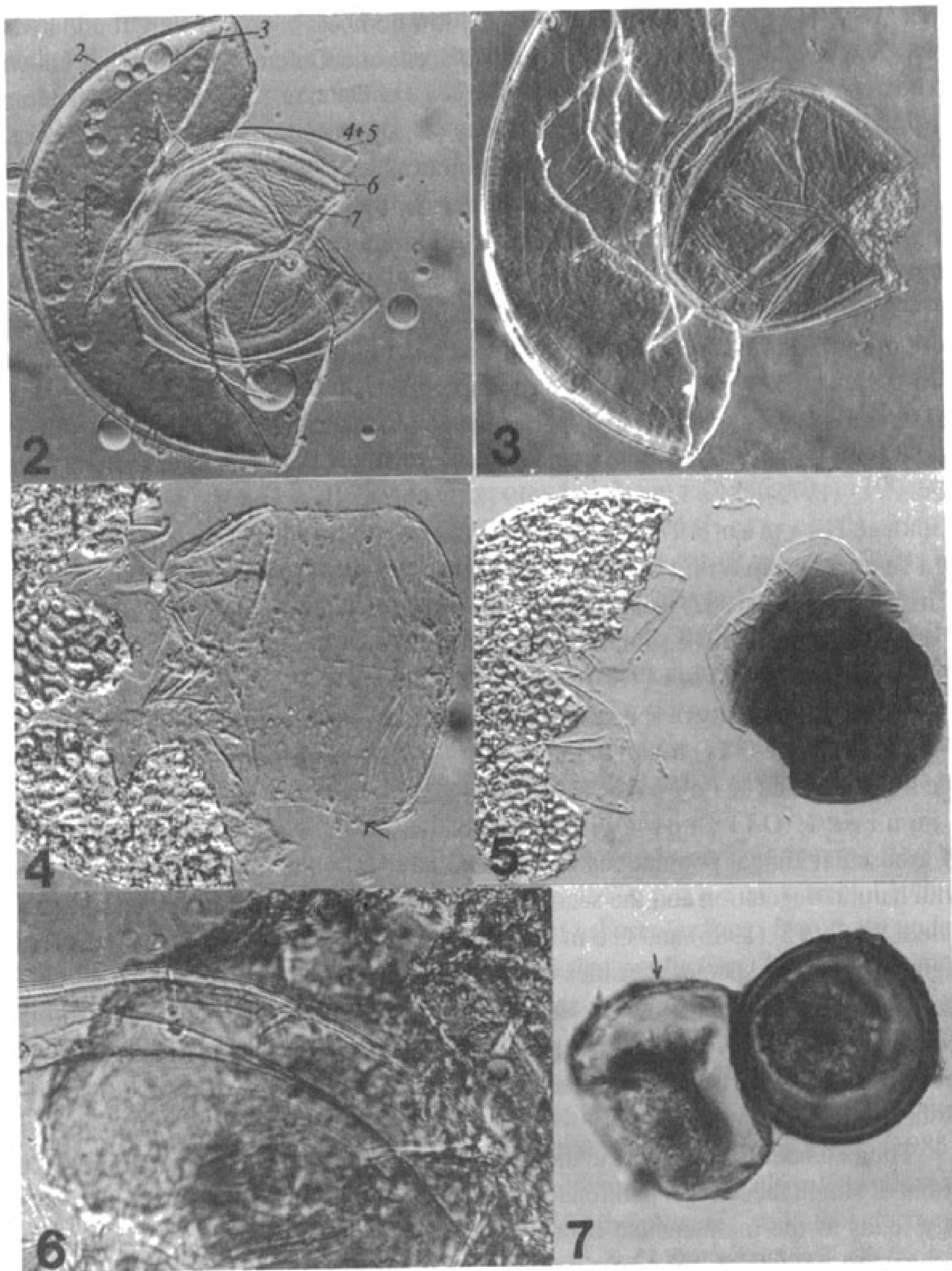
Figs. 2-7. 2-3 *Acaulospora polylamina*: 2 – Crushed spore in PVLG, numbers indicate spore wall arrngement (see description), differential interference contrast, DIC, X160, 3 – Crushed spore in Melzer's reagent (DIC), x 160; 4-5 *Acaulospora* 87: 4 – Crushed spore in PVLG, the innermost amorphous wall is arrowed, DIC, x 160, 5 – Crushed spore in Melzer's reagent, DIC, x160; 6 – *Entrophospora* 91, spore wall structure of a crushed spore in PVLG, DIC, x290; 7-8 *Entrophospora* 95: 7– Intact spore with sporiferous saccule (arrow), bright-field microscopy, x 110.
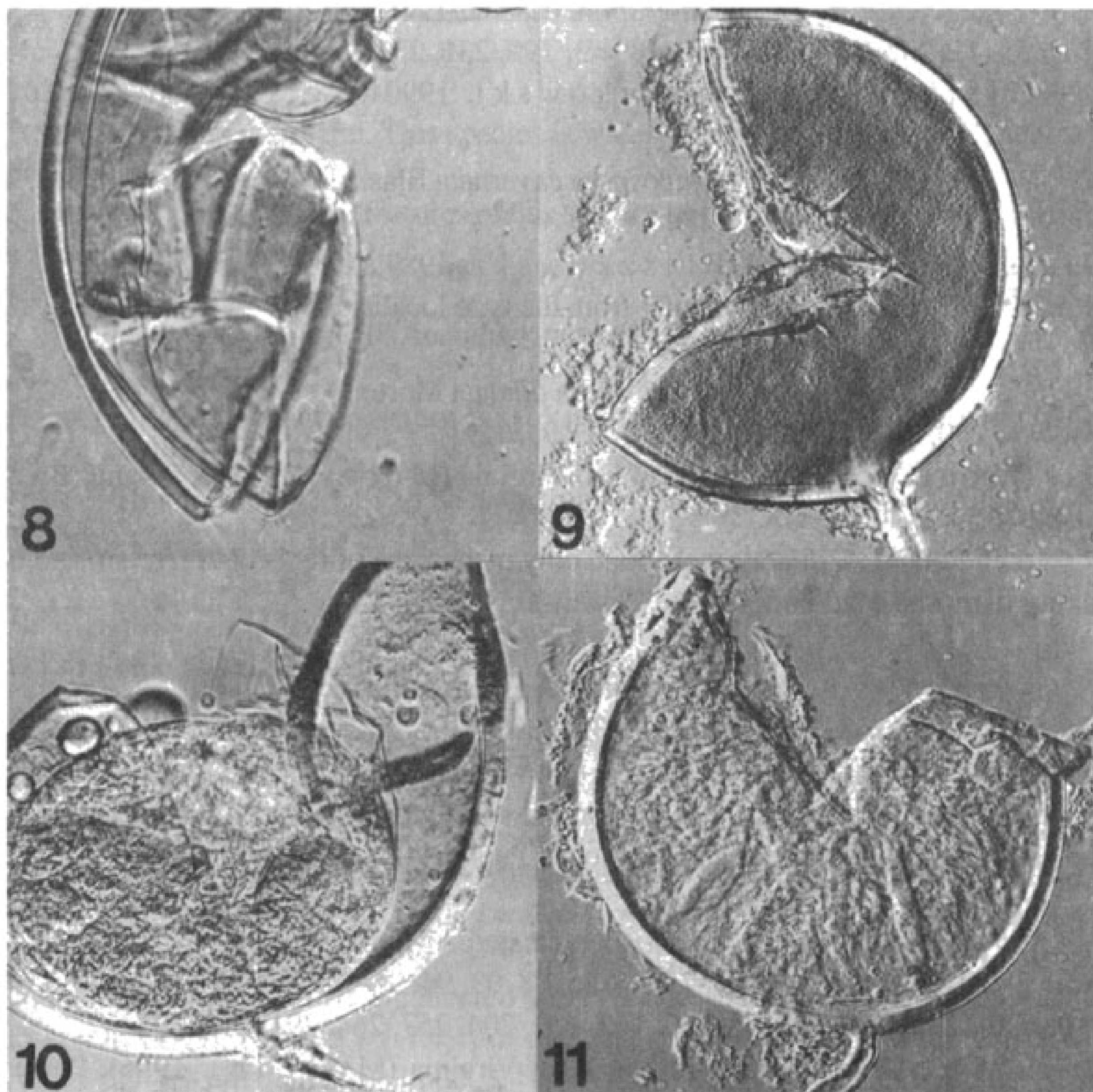
Figs. 8-11. 8 – Crushed spore in PVLG, DIC, x 160; 9 – *Glomus* 81, crushed spore in PVLG, DIC, x 160; 10 – *Glomus* 86, crushed spore in PVLG, DIC, x 160; 11 – *Glomus* 93, crushed spore in PVLG, DIC, x 160.

Distribution of arbuscular fungi notes on their general occurrence, an taxonomic remarks.

Nc (nw) – number of soil samples from under cultivated (wild) plants, in which a particular fungal species was found; subsequent numbers are those of sites presented in Table 1 and Figure 1, and mentioned in the list of localities and collection date.

1. *Acaulospora bireticulata* Rothwell et Trappe

Nc = 1: 58; nw = 1: 99 [44].

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1989 b), United States (M i l l e r et al., 1985; S c h e n c k, S m i t h, 1982).

2. *Acaulospora capsicula* Błaszk.

Nc = 5: 112, 175, 194, 195, 247; nw = 3: 199, 231, 233.

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1990 d).

3. *Acaulospora cavernata* Błaszk.

Nc = 5: 112, 175, 194, 195, 247.

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1989 a).

N o t e. This species is known only from the type locality.

4. *Acaulospora dilatata* Morton

Nw = 8: 260, 262, 263, 291, 293, 307, 309, 312.

D i s t r i b u t i o n: United States, West Virginia (M o r t o n, 1986), Poland (B ł a-
s z k o w s k i, in press).

N o t e. In Poland *A. dilatata* was found only in the zone of roots of *A. arenaria* colo-
nizing maritime sand dunes of the Słowiński National Park.

5. *Acaulospora gdanskensis* Błaszk.

Nw = 8: 39, 50, 163, 199, 231, 233, 235, 239.

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1988 b).

N o t e. This fungus is probably commonly associated with roots of plants colonizing
the Hel Peninsula and areas adjacent to the Puck Gulf.

6. *Acaulospora lacunosa* Morton

Nc = 3: 210-212, nw = 31: 73, 75, 83, 85, 88, 93, 94, 96-98, 100, 101,104, 113, 114,
119, 126-128, 131, 155, 157, 160, 162, 202, 204, 257, 264, 291, 292, 303.

D i s t r i b u t i o n: United States, West Virginia (M o r t o n , 1986), Poland
(B ł a s z k o w s k i, 1990 c).

N o t e. In Poland *A. lacunosa* is widely distributed, but preferred wild plants.

7. *Acaulospora paulinae* Błaszk.

Nc = 4: 69, 77, 190, 195; nw = 15: 76, 82, 89, 93, 98, 99, 101, 114, 157, 163, 166, 200,
201, 233, 310.

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1988 a).

N o t e. In Poland this species is probably widely distributed in different soils.

8. *Acaulospora polonica* Błaszk.

Nc = 3: 37, 112, 195; nw = 3: 119, 261, 264.

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1988 b).

N o t e. This fungus was found only on the Hel Peninsula and in soils sampled from
the root zone of *A. arenaria* growing on dunes in the Słowiński National Park.

9. *Acaulospora polylamina* Błaszk., sp. in edition, Figs. 2, 3

Nc = 3: 282, 285, 286; nw = 19: 19, 31, 32, 34, 81, 93, 113, 119, 128, 132, 134, 158, 163, 200-202, 240, 253, 254.

D i s t r i b u t i o n: Poland. This species is widely distributed in Poland. It seems to prefer wild plants.

N o t e. The morphological features of this species have been described earlier (B ł a-s z k o w s k i, in press).

10. *Acaulospora rugosa* Morton

Nw = 1: 89.

D i s t r i b u t i o n: United States, West Virginia (M o r t o n, 1986), Poland (B ł a-s z k o w s k i, 1990 a).

N o t e. This species is likely to be an extremely infrequent fungus in Poland.

11. *Acaulospora thomii* Błaszk.

Nc = 1: 58.

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1988 b).

12. *Acaulospora* 87, Figs. 4, 5

Nw = 1: 193.

N o t e. Spores of *Acaulospora* 87 are pale yellow (3A3) to cream (4A3); globose to subglobose, (95-) 104 (-120) μm diam, sometimes ovoid, 95-100 x 100-130 μm. Spore wall structure consists of five walls (1-5) in three groups (A, B, C). Group A consists of an evanescent, hyaline, 0.8-1.2 μm thick outermost wall (wall 1), usually completely sloughed in field-collected spores and of a laminated, pale yellow (3A3) to cream (4A3), (4.7-) 5.7 (-7.4) μm thick inner wall (wall 2), ornamented with round, 5.9-7.1 μm diam, or elliptic, 3.4-3.9 x 8.6-8.8 μm pits, 2.5-2.7 μm deep; pits separated by ridges of a width of 1.2-5.4 μm. A single, hyaline, (0.7-) 0.9 (-1.2) μm thick, unit wall (wall 3) forms group B. Group C is composed of a beaded membranous, hyaline, (0.5-) 0.9 (-1.2) μm thick wall (wall 4) and of an amorphous, hyaline wall (wall 5), of variable (10.0-22.5 μm) thickness in PVLG, 0.9-1.3 μm thick and dark purplish red (13E8) in Melzer's reagent.

The following species of *Acaulospora* form pitted spores: *A. cavernata, A. dilatata, A. foveata* Trappe & Janos, *A. lacunosa, A. paulinae, A. scrobiculata* Trappe, and *A. undulata* Sieverding (B ł a s z k o w s k i, 1988 a, 1989 a; J a n o s, T r a p p e, 1982; M o r t o n, 1986; S i e v e r d i n g, 1988; T r a p p e, 1977). Spores of *Acaulospora* 87 resemble most those of *A. paulinae* and *A. undulata* in having similar appearance, size, and colour. However, *Acaulospora* 87 produces somewhat greater spores than both *A. paulinae* and *A. undulata* (95-129 μm in diam vs. 60-95 μm and 55-85 μm in diam, respectively). In addition, the pits in *A. paulinae* are smaller in diameter (2.0-3.5 μm vs. 5.9-7.1 μm). *Acaulospora cavernata, A. foveata,*

and *A. scrobiculata* have darker (yolk yellow to light brown, yellowish brown to black, and olive to light brown, respectively) and larger spores (185-480 μm diam, 110-170 μm diam, and 100-240 x 100-220 μm, respectively). The pits in *A. dilatata* and *A. lacunosa* are irregularly distributed and have a different appearance. The ornamentation of the former consists of minute pits, and saucer-shaped pits with cone-shaped raised edges occur on the latter.

The distinctness of *Acaulospora* 87 most expresses its spore wall structure. The most closely related species in this respect are *A. dilatata*, *A. lacunosa*, and *A. paulinae*. They have the same number of walls of the same types both in the outermost and the innermost wall groups. However, the middle wall group (group B) of *Acaulospora* 87 spores consists of only a single unit wall, whereas group B of *A. dilatata*, *A. lacunosa*, and *A. paulinae* (B ł a s z k o w s k i, in press) is composed of two tightly adherent unit walls. The other species mentioned above significantly differ from *Acaulospora* 87 in the number, type, and position of walls in wall structure. The muronyms of *A. caverata*, *A. foveata*, *A. scrobiculata*, and *A. undulata* are A (ELoU) B (UU) C (MoCA), A (Lo) B (M), A (Uo) B (UM), A (EUo) B (U), respectively (B ł a-s z k o w s k i, in press; S c h e n c k, P e r e z, 1990).

13. *Entrophospora infrequens* (Hall) Ames et Schneider
Nc = 4: 7, 8, 188, 250; nw = 4: 88, 98, 99, 138.
D i s t r i b u t i o n: Australia (H a l l, A b b o t t, 1984), New Zealand (H a l l, 1977), Poland (B ł a s z k o w s k i, 1989 b), United States (A m e s, S c h n e i d e r, 1979; B l o s s, W a l k e r, 1987; H a l v o r s o n, K o s k e, 1987; H e t r i c k, B l o o m, 1983; K o s k e, H a l v o r s o n, 1989; P f l e g e r, S t e w a r d, 1989; S c h e n c k, S m i t h, 1982; S t a h l, C h r i s t e n s e n, 1982).
N o t e. *E. infrequens* is probably widely distributed in Poland, but usually forms a small number of spores.

14. *Entrophospora* 91, Fig. 6
Nw = 3: 246, 250, 259.
N o t e. This fungus probably occurs throughout Poland, but very infrequently.

Entrophospora 91 forms Persian orange (6A7) spores, 150-200 μm diam. Its spore wall structure expresses the following muronym: A (ULU) B (MC). The Persian orange colour of spores comes from the outermost wall, which only slightly sloughs and always occurs in field-collected specimens. This wall differs from a typical evanescent wall in being more rigid and pigmented and therefore is stated here to be of the unit type. All the other walls are hyaline.

Entrophospora 91 seems to be most closely related to *A. appendicula* Spain et al. because of similarities in colour and wall structure of spores (M o r t o n, 1989). Spores of both fungi have an outermost unit wall that flakes with age and an innermost coriaceous wall. However, walls 2 and 3 in *A. appendicula* are unit and

ornamented with regular depressions, whereas walls 2 and 3 in *Entrophospora* 91 are smooth and of the laminated and unit types, respectively. Additionally, the wall structure of *A. appendicula* spores lacks the membraneous wall of *Entrophospora* 91 spores.

15. *Entrophospora* 95, Figs. 7, 8

Nw = 1: 298.

N o t e. *Entrophospora* 95 was isolated from the root zone of *J. communis* growing on the Błędowska Desert.

This fungus forms golden yellow (5B7) to raw umber (5F8) spores, 80-120 μm in diam. Spore wall structure is composed of four walls in one group whose muronym is A (EL LM). The innermost wall sometimes resembles a coriaceous wall because of its somewhat greater thickness.

Of the three so far described species of *Entrophospora*, only *E. colombiana* Spain et Schenck is likely to be confused with *Entrophospora* 95 because of similarities in size and colour of spores. However, spores of the former have a quite different wall structure, which expresses the following muronym: A (EL) B (UU) C (MbA) (M o r t o n, 1989). Spores of the other two known species may easily be differentiated from those of *Entrophospora* 95, since *E. schenckii* Sieverding et Toro forms smaller and lighter spores (S i e v e r d i n g, T o r o, 1987), while those of *E. infrequens* are ornamented (A m e s, S c h n e i d e r, 1979). None of the two fungi has a spore wall structure of *Entrophospora* 95.

16. *Gigaspora gigantea* (Nicol. et Gerd.) Gerd. et Trappe

Nc = 4: 102, 108, 111, 149; nw=16: 34, 96, 98, 113, 118, 119, 121, 123, 234, 254, 257, 261, 262, 264, 291, 293.

D i s t r i b u t i o n: New Zealand (J o h n s o n, 1977), Poland (B ł a s z k o w s k i, 1990 f), United States (H e t r i c k, B l o o m, 1983; K o s k e, 1987; K o s k e, H a l v o r s o n, 1981; K o s k e, T e w s, 1987; M i l l e r, D o m o t o, W a l k e r, 1985; N i c o l s o n, G e r d e m a n n, 1968; P f l e g e r, S t e w a r d, 1989; S c h e n c k, S m i t h, 1982).

17. *Glomus aggregatum* Schenck et Smith emend. Koske

Nc = 15: 25, 37, 38, 41, 42, 48, 69, 74, 90, 91, 107, 116, 148, 193, 335; nw = 27: 71, 73, 75, 88, 93, 95, 99, 113, 121, 123, 128, 140, 141, 162, 163, 177, 180-182, 184, 237, 255, 267, 268, 275, 278.

D i s t r i b u t i o n: Canada (K o s k e, 1985), India (S u l o c h a m a, M o n o h a- r a c h a r y, 1989), Poland (B ł a s z k o w s k i, 1990 a, 1991 b), United States (B l o s s, W a l k e r, 1987; D a l p é, G r a n g e r, F u r l a n, 1986; H a l v o r- s o n, K o s k e, 1987; K o s k e, 1985, 1988; K o s k e, H a l v o r s o n, 1989; K o s k e, T e w s, 1987; S c h e n c k, S m i t h, 1982; Z a k, D a n i e l s o n, P a r k i n s o n, 1982).

N o t e. This fungus is frequently associated with dune plants in Poland and plants colonizing the banks of the rivers Odra and Vistula.

18. *Glomus caledonium* (Nicol. et Gerd.) Trappe et Gerd.

Nc = 59: 8-10, 38, 54, 58, 77, 91, 102-111, 164, 170, 192, 206, 207, 211-215, 218-220, 222, 224, 229, 241, 243, 246, 250, 259, 279, 280, 282-286, 289, 290, 296, 297, 316, 319, 324, 327, 328, 331, 334, 340, 341; nw = 12: 88, 120, 123, 137, 159, 160, 168, 221, 238, 294, 295, 300.

D i s t r i b u t i o n: Australia (H a l l, A b b o t t, 1984), India (S e l v a r a j, S u b r a m a n i a n, 1987), New Zealand (H a l l, 1977), Poland (B ł a s z k o w s k i, 1989 b), Scotland (N i c o l s o n, G e r d e m a n n, 1968), Taiwan (W u, C h e n, 1986), United States (G e r d e m a n n, T r a p p e, 1974; K o s k e, 1987; M i l l e r, D o m o t o, W a l k e r, 1985; P f l e g e r, S t e w a r d, 1989).

N o t e. This species is one of the most frequently occurring arbuscular fungi in Poland. It abundantly sporulated both in poor and rich soils. This fungus seems to be better adapted to cultivated soils.

19. *Glomus constrictum* Trappe

Nc = 76: 12,, 18, 22-26, 28-30, 35, 38, 40, 52, 58, 92, 102, 112, 116, 145-148, 156, 164, 165, 169, 171, 172, 175, 185, 188, 190-192, 194, 195, 206, 210, 214, 216-219, 222, 225-227, 229, 230, 242, 244, 259, 265, 280-283, 288, 290, 296, 297, 315, 316, 322-325, 327, 329, 330, 332, 334, 336, 338, 341; nw = 59: 19, 88, 98, 99, 113, 114, 118-121, 123, 124, 128, 130, 132, 134, 136-138, 144, 154, 155, 158-160, 163, 174, 176, 178, 179, 181, 184, 186, 187, 189, 199, 200, 221, 231-233, 238, 249, 251, 252, 258, 260, 269, 273, 276, 294, 295, 299, 304, 305, 313.

D i s t r i b u t i o n: Canada (D a l p é et al., 1986), Germany (D e h n e, B a c k h a u s, 1986), India (S e l v a r a j, S u b r a m a n i a n, 1987; S u l o c h a m a, M o n o h a-r a c h a r y, 1989), Mexico (T r a p p e, 1977), Poland (B ł a s z k o w s k i, 1990 b), United States (H e t r i c k, B l o o m, 1983; K o s k e, 1988; M e n g e et al., 1978; M i l l e r, D o m o t o, W a l k e r, 1985; N e m e c et al., 1981; P f l e g e r, S t e w a r d, 1989; T r a p p e, 1977; W a l k e r et al., 1982).

N o t e: *G. constrictum* is the most frequently found species in Poland. It commonly occurred both in cultivated and uncultivated soils. It seems to be well adapted to different ecological conditions: *G. constrictum* abundantly sporuled in industrial heaps, maritime sand dunes, and periodically submerged river sands.

20. *Glomus deserticola* Trappe, Bloss et Menge

Nc = 78: 2, 4, 6-8, 13, 17, 24, 28, 37, 40, 44, 48, 52, 56, 77, 90-92, 104-109, 111, 146, 148, 149, 156, 165, 169, 171, 185, 188, 190-192, 195, 206, 208-210, 212, 213, 215-217, 220, 223-226, 228, 229, 242, 243, 250, 259, 265, 279, 281, 284, 316, 318, 320, 321, 324, 325, 327, 329, 332, 333, 335, 337-339, 342; nw = 25: 1, 5, 32, 64, 83,

87, 89, 93, 97, 100, 101, 113, 114, 134, 155, 160, 168, 176, 179, 186, 187, 189, 221, 294, 295.

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1990 f), United States (B l o s s, W a l k e r, 1987; S y l v i a, 1986; T r a p p e et al., 1984).

N o t e. After *G. constrictum* and *G. mosseae*, *G. deserticola* is the third most frequently occurring arbuscular fungus in Poland. In cultivated soils it was three times was frequent as in uncultivated soils. It abundantly sporulated in maritime dunes, among roots of mountain plants, those colonizing industrial heaps, as well as in the zone of plants cultivated in very rich soils of Żuławy. Hence, *G. deserticola* is probably well adapted to different host plants, soils, and other abiotic and biotic conditions. *Glomus deserticola* has several times mistakenly been reported under the name *G. fasciculatum.*

21. *Glomus dominikii* Błaszk.

Nc = 32: 52, 53, 56, 57, 60-62, 65, 67, 77, 91, 104-108, 111, 165, 192, 216, 217, 241, 244, 245, 280-283, 285-287; nw = 7: 71, 73, 93, 98, 99, 101, 221.

D i s t r i b u t i o n: Poland (B ł a s z k o w s k i, 1988 b).

N o t e. This fungus probably occurs throughout Poland, although not frequently. It seems to prefer cultivated soils.

22. *Glomus etunicatum* Becker et Gerd.

Nc = 31: 74, 91, 92, 149, 164, 170, 190-192, 206-213, 242-245, 279, 281, 284, 287, 288, 297, 335, 337, 339; nw=13: 87, 113, 138, 155, 184, 186, 187, 255, 256, 263, 278, 295, 301.

D i s t r i b u t i o n: Canada (D a l p é et al., 1986), Poland (B ł a s z k o w s k i, 1990 a), Taiwan (W u, C h e n, 1986), United States (B e c k e r, G e r d e m a n n, 1977; D a l p é et al., 1986; H e t r i c k, B l o o m, 1983; K o s k e, H a l v o r s o n, 1981, 1989; K o s k e, T e w s, 1987; M i l l e r, D o m o t o, W a l k e r, 1985; M o r t o n, 1985; N e m e c et al., 1981; P f l e g e r, S t e w a r d, 1989; P o n d, M e n g e, J a r e l, 1984).

23. *Glomus fasciculatum* (Thaxter) Gerd. et Trappe emend. Walker et Koske

Nc = 52: 3, 4, 6-9, 11-13, 16, 17, 21-25, 29, 37, 38, 40, 42, 43, 46, 48, 51, 54, 56-59, 62, 65-67, 69, 72, 74, 77, 90-92, 102, 103, 145, 188, 223, 250, 279, 285, 289; nw = 44: 1, 5, 14, 15, 19, 20, 32, 33, 49, 50, 63, 68, 71, 73, 75, 76, 78, 82, 86, 88, 89, 94-96, 98, 99, 101, 113, 114, 119-121, 128, 132, 138, 140, 144, 162, 200, 202, 256, 271, 276-278, 298.

D i s t r i b u t i o n: Australia (H a l l, A b b o t t, 1984; H a y m a n, S t o v o l d, 1979), Canada (T h a x t e r, 1922), India (S e l v a r a j, S u b r a m a n i a n, 1987), Poland (B ł a s z k o w s k i, 1990 a), Taiwan (W u, C h e n, 1986), United States (A n d e r- s o n, L i b e r t a, D i c k m a n, 1984; B e t h l e n f a l v a y, D a k e s s i a n,

Pacovsky, 1984; Gerdemann, Trappe, 1974; Hetrick, Bloom, 1983; Koske, Halvorson, 1981; Menge, Johnson, 1978; Nemec et al., 1981; Pfleger, Steward, 1989; Schenck, Smith, 1981; Stahl, Christensen, 1982; Walker, Mize, McNabb, 1982).

24. *Glomus fuegianum* (Spegazzini) Trappe et Gerd.

Nc = 4: 12, 25, 26, 29; nw = 3: 14, 15, 101.
Distribution: New Zealand (Hall, 1977), United Kingdom (Godfrey, 1957), South America (Thaxter, 1922).

25. *Glomus geosporum* (Nicol. et Gerd.) Walker

Nc = 55: 6-13, 16, 17, 20-26, 30, 35, 37, 40, 41, 43-46, 51-54, 56, 57, 59, 60, 62, 65, 66, 69, 70, 72, 74, 90, 92, 101-109, 111, 145, 250, 252; nw = 16: 5, 14, 19, 31, 32, 50, 64, 68, 71, 73, 75, 78, 86, 87, 177.
Distribution: Canada (Molina, Trappe, Strickler, 1978), Italy (Puppi, Ries, 1982), New Zealand (Johnson, 1977), Scotland (Nicolson, Gerdemann, 1968), United States (Hetrick, Bloom, 1986; Ho, 1987; Koske, Tews, 1987; Miller, Domoto, Walker, 1985; Molina, Trappe, Strickler, 1978; Pfleger, Steward, 1989; Schenck, Smith, 1981; Walker, Mize, McNabb, 1982).

26. *Glomus globiferum* Koske et Walker

Nw = 2: 131, 134.
Distribution: Poland (Błaszkowski, 1990 f), United States (Bloss, Walker, 1987; Koske, Walker, 1986).

27. *Glomus heterosporum* Smith et Schenck

Nc = 12: 9, 12, 16, 17, 22, 25, 29, 35, 37, 46, 193, 195; nw = 19: 14, 50, 114, 120, 131, 144, 155, 167, 189, 198, 200-202, 239, 268, 275, 294, 295, 305.
Distribution: United States (Bloss, Walker, 1987; Smith, Schenck, 1985).
Note. In Poland *G. heterosporum* is probably widely distributed, but not common. It seems to prefer wild plants, especially those growing in forests.

28. *Glomus hoi* Berch et Trappe

Nc = 1: 156; nw = 6: 168, 249, 267, 270, 272, 277.
Distribution: Canada (Berch, Trappe, 1985) United States (Berch, Trappe, 1985; Bloss, Walker, 1987).

29. *Glomus laccatum* Błaszk.

Nw = 2: 82, 163.
Distribution: Poland (Błaszkowski, 1988 a).

30. *Glomus macrocarpum* Tul. et Tul.

Nc = 43: 2-4, 6-13, 16-18, 20, 21, 23-25, 28, 30, 37, 40, 41, 44, 46, 48, 51, 56, 58-61, 65, 66, 69, 70, 72, 74, 90, 156, 193, 288; nw = 30: 1, 5, 14, 15, 19, 27, 32, 33, 35, 36, 39, 49, 55, 63, 64, 68, 71, 73, 75, 76, 87, 89, 93, 95, 96, 130, 163, 166, 167, 201.

D i s t r i b u t i o n: Australia (H a l l, A b b o t t, 1984), Canada (B e r c h, F o r t i n, 1983, 1984 a; M o l i n a, T r a p p e, S t r i c k l e r, 1978), Denmark (Z y c h a, S i e p m a n, L i n d e r m a n n, 1969), France (B e r c h, F o r t i n, 1983, 1984 a), Italy (P u p p i, R i e s s, 1982), United Kingdom (G o d f r e y, 1957), United States (B e r c h, F o r t i n, 1983, 1984 a; G e d e r m a n n, T r a p p e, 1974; H e t r i c k, B l o o m, 1983; H o, 1987; K o s k e, T e w s, 1987; M i l l e r, D o m o t o, W a l k e r, 1985; M o l i n a, T r a p p e, S t r i c k l e r, 1978; N e m e c et al., 1981; N i c o l s o n, S c h e n c k, 1979; P f l e g e r, S t e w a r d, 1989; S c h e n c k, S m i t h, 1981; T h a x t e r, 1922).

N o t e. In Poland *G. macrocarpum* is probably widely distributed, but does not frequently occur.

31. *Glomus microaggregatum* Koske, Gemma, Olexia

Nw = 1: 291.

D i s t r i b u t i o n: United States (K o s k e, 1988; K o s k e, T e w s, 1987; K o s k e, G e m m a, O l e x i a, 1986).

N o t e. This fungus is mainly present in soils with a large amount of members of the genera *Gigaspora* and *Scutellospora*, e.g., in sand dunes.

32. *Glomus microcarpum* Tul. et Tul.

Nc = 11: 7, 12, 17, 38, 48, 58, 74, 116, 188, 193, 297; nw = 21: 34, 39, 76, 89, 95, 96, 99, 113, 119, 121, 123, 130, 132, 134, 137, 163, 200, 204, 235, 275, 278.

D i s t r i b u t i o n: Australia (H a y m a n, S t o v o l d, 1979), Canada (B e r c h, F o r t i n, 1984 b; M o l i n a, T r a p p e, S t r i c k l e r, 1978), France (T u l a s n e, T u l a s n e, 1845), India (M o h a n k u m a r et al., 1988), Italy (B e r c h, F o r t i n, 1984 b), New Zealand (J o h n s o n, 1977), Switzerland (Z y c h a, S i e p m a n, L i n d e r m a n n, 1969), Tasmania (B e r c h, F o r t i n, 1984 b), United Kingdom (Z y c h a, S i e p m a n, L i n d e r m a n n, 1969), United States (G e r d e m a n n, T r a p p e, 1974; H e t r i c k, B l o o m, 1983; M i l l e r, D o m o t o, W a l k e r, 1985; M o l i n a, T r a p p e, S t r i c k l e r, 1978; N e m e c et al., 1981; P f l e g e r, S t e w a r d, 1989; S t a h l, C h r i s t e n s e n, 1982; W a l k e r, M i z e, M c N a b b, 1982).

N o t e. This fungus occurs throughout Poland, but infrequently. It distinctly preferred wild plants.

33. *Glomus mosseae* (Nicol. et Gerd.) Gerd. et Trappe

Nc = 103: 2-4, 6-11, 13, 16-18, 20-26, 28-30, 35, 37, 38, 40-48, 51-54, 56, 57, 59-62,

65-67, 69, 70, 72, 77, 91, 92, 103-109, 139, 145, 147-150, 169, 171, 172, 208-210, 214, 216, 219, 224, 225, 227, 242, 244-246, 280-283, 287, 288, 290, 296, 297, 317, 319, 321, 323, 326, 329, 330, 333, 340; nw = 30: 1, 5, 14, 15, 19, 31, 34, 49, 64, 68, 71, 75, 76, 88, 93, 94, 101, 113, 124, 131, 132, 138, 154, 161, 173, 182-184, 295.
D i s t r i b u t i o n: Australia (H a y m a n, S t o v o l d, 1979), Canada (Z a k, D a n i e l s o n, P a r k i n s o n, 1982), Germany (N i c o l s o n, G e r d e m a n n, 1968), India (S u l o c h a m a, M o n o h a r a c h a r y, 1989), Italy (G i o v a n n e t t i, N i c o l s o n, 1983), Libya (E l - G i a h m i et al., 1976), Poland (B ł a s z k o w-s k i, 1990 e), Scotland and United Kingdom (N i c o l s o n, G e r d e m a n n, 1968), United States (B e t h l e n f a l v a y, D a k e s s i a n, P a c o v s k y, 1984; H e t r i c k, B l o o m, 1983; H o, 1987; K o s k e, T e w s, 1987; M i l l e r, D o m o t o, W a l k e r, 1985; N e m e c et al., 1981; N i c o l s o n, G e r d e m a n n, 1968; P o n d, M e n g e, J a r e l, 1984; S c h e n c k, S m i t h, 1981; S t a h l, C h r i s-t e n s e n, 1982; W a l k e r, M i z e, M c N a b b, 1982).
N o t e. *Glomus mosseae* is the second most frequently found species in Poland. In cultivated soils it was 3 times as frequent as in cultivated soils.

34. *Glomus occultum* Walker

Nc = 10: 28, 40, 43, 44, 56-58, 77, 215, 228; nw = 7: 75, 89, 93, 114, 117, 138, 274.
D i s t r i b u t i o n: India (M o h a n k u m a r et al., 1988), the Netherlands, United Kingdom, United States (W a l k e r, 1982), Poland (B ł a s z k o w s k i, 1990 a).
N o t e. This fungus probably occurs throughout Poland, but not commonly.

35. *Glomus pansihalos* Berch et Koske

Nc = 5: 112, 188, 190, 259, 265; nw = 12: 130, 132, 134, 138, 140, 141, 179, 186, 189, 266, 267.
D i s t r i b u t i o n: Canada (B e r c h, K o s k e, 1986), Poland (B ł a s z k o w s k i, 1990 e, in press), United States (B e r c h, K o s k e, 1986; H a l v o r s o n, K o s k e, 1987; K o s k e, 1987; K o s k e, H a l v o r s o n, 1989).
N o t e. *Glomus pansihalos* is likely to be widely distributed in Poland, but is not common.

36. *Glomus przelewicensis* Błasz.

Nc = 1: 77.
Distribution: Poland (B ł a s z k o w s k i, 1988 a).

37. *Glomus pustulatum* Koske et al.

Nw = 1: 309.
D i s t r i b u t i o n: Canada and United States (K o s k e et al., 1986), India (M o h a n k u m a r et al., 1988), Poland (B ł a s z k o w s k i, in press).

38. *Glomus tenue* (Greenall) Hall

Nc = 104: 2, 7-11, 13, 17, 20, 21, 23-26, 28, 30, 35, 38, 42, 43, 45, 47, 51-53, 57-59, 61, 62, 65, 70, 91, 103-111, 133, 139, 145-151, 169-172, 188, 191-193, 207-213, 215, 217, 218, 223, 224, 227, 241, 244, 279-290, 296, 316, 318, 319, 321, 324, 327, 328, 330-335, 337, 339-341; nw = 88: 1, 5, 15, 19, 32, 34, 36, 39,, 49, 50, 55, 63, 64, 73, 75, 76, 78, 81-83, 85, 87, 88, 93-101, 113, 114, 117, 119, 120, 121, 123, 124, 126, 128, 130, 131, 132, 134-136, 138, 140, 144, 155, 157, 158-163, 165, 167, 176, 179, 186, 187, 189, 198, 199, 201, 203, 206, 221, 251, 253, 254, 269, 271, 272, 275, 277, 294, 295, 298-300, 303-305.

D i s t r i b u t i o n: Australia (A l i, 1969; H a l l, A b b o t t, 1984), Canada and United States (H e t r i c k, B l o o m, 1983; M o l i n a, T r a p p e, S t r i c k l e r, 1978; M o r t o n, 1985; S c h e n c k, S m i t h, 1981), New Zealand (C r u s h, 1973), United Kingdom (S p a r l i n g, T i n k e r, 1975), United States (M o r t o n, 1989).

39. *Glomus versiforme* (Karsţen) Berch

Nw = 1: 119.

D i s t r i b u t i o n: Canada (D a l p é, G r a n g e r, F u r l a n, 1986), Finland, Italy, Tasmania, United States, U.S.R.R. (B e r c h, F o r t i n, 1983), Poland (B u c h o l t z, 1912), Sweden (K e r s, 1985).

40. *Glomus* 81, Fig. 9

Nw = 7: 154, 173, 174, 181, 182, 256, 258.

N o t e. *Glomus* 81 has deep yellow (4A8) to orange (5B8) spores, 90-140 µm diam. Spore wall structure consists of two walls (1-2) in one group (A). Wall 1 is evanescent, hyaline, 1.5-2.5 µm thick. Wall 2 is laminated, deep yellow (4A8) to orange (5B8), (6.2-)8.5(-11.5) µm thick, with warts projecting inward. Subtending hypha is straight or recurvate, funnel-shaped, 7.5-17.5 µm wide at the spore base, occluted by a septum continuous with the innermost lamina of wall 2. Spores of *Glomus* 81 resemble those of *G. pansihalos* in having an inner wall ornamented with warts (B e r c h, K o s k e, 1986). However, the warts of the former project inward rather than outward as in the latter. In addition, the outermost spore wall of *Glomus* 81 is evanescent, whereas that of *G. pansihalos* is expanding.

41. *Glomus* 86, Fig. 10

Nw = 1: 193.

N o t e. *Glomus* 86 forms yellowish white (1A2-2A2) spores, 120-160 µm diam. Spore wall structure consists of three walls (1-3) in one group (A). Wall 1 is evanescent, hyaline, 1.0-2.5 µm thick. Wall 2 is laminated, yellowish white (1A2-2A2), (5.2-) 7.9 (-10.5) µm thick. Wall 3 is membranous, hyaline, 0.8-1.0 µm thick. Subtending hypha is straight or recurvate, funnel-shaped, 6.8-15.0 µm wide at the spore

base, occluded by a septum and the membranous wall 3.

Other species forming 3-walled spores with an innermost membranous wall are *G. ambisporum* Smith et Schenck, *G. geosporum*, *G. hoi*, and *G. maculosum* Miller et Walker (B e r c h, T r a p p e, 1985; M i l l e r, W a l k e r, 1986; S m i t h, S c h e n c k, 1985; W a l k e r, 1982). However, spores of all the species mentioned above are darker. Additionally, the outermost spore wall of *G. maculosum* is unit and the innermost membranous wall is ornamented with scalloped-shaped ingrowths. *Glomus ambisporum* has an outermost wall with a reticulum consisting of an orderly arranged hexagonal plates.

42. *Glomus* 93, Fig. 11

Nw = 1: 253.

N o t e. This fungus forms hyaline to yellowish white (3A2) spores, 80-140 μm diam. Spore wall structure consists of three walls (1-3) in one group (A). Wall 1 is evanescent, hyaline, 0.8-2.0 μm thick. Wall 2 is laminated, hyaline to yellowish white (2A2), 1.0-7.5 μm thick. Wall 3 is membranous, hyaline, 0.3-0.6 μm thick, tightly adherent to wall 2. Subtending hypha is straight or recurvate, cylindric, 5.0-12.5 μm wide at the spore base, occluded by both the innermost membranous wall 3 and a septum in the subtending hypha.

Species most closely resembling *Glomus* 93 when viewed under a dissecting microscope are *G. diaphanum* Walker et Morton, *G. occultum*, *G. pallidum* Hall, and *G. scintillans* Rose et Trappe (H a l l, 1977; M o r t o n, W a l k e r, 1984; R o s e, T r a p p e, 1980; W a l k e r, 1982). However, only *G. diaphanum* and *G. scintillans* have an innermost membranous wall. Additionally, *G. diaphanum* produces 2-walled spores lacking the outermost evanescent wall of *Glomus* 93, and the outermost wall of *G. scintillans* is ornamented with hyaline knobs.

43. *Sclerocystis rubiformis* Gerd. et Trappe

Nw = 7: 1, 19, 81-83, 251, 278.

D i s t r i b u t i o n: Canada (D a l p é, G r a n g e r, F u r l a n, 1986; M o l i n a, T r a p p e, S t r i c k l e r, 1978), New Zealand (H a l l, 1977), Taiwan (W u, C h e n, 1986), United States (G e d e r m a n n, T r a p p e, 1974; M i l l e r, D o m o t o, W a l k e r, 1985; M o l i n a, T r a p p e, S t r i c h l e r, 1978). *S. rubiformis* is a rare species in Poland. It was mainly found among roots of grasses in forests.

44. *Scutellospora calospora* (Nicol. et Gerd.) Walker et Sanders

Nc = 16: 9, 11, 17, 26, 47, 52, 53, 67, 70, 72, 74, 77, 90, 91, 105, 165; nw = 28: 14, 19, 32, 63, 71, 73, 75, 76, 81, 82, 85, 88, 93, 94, 96, 97, 113, 114, 117, 119, 120, 123, 129, 131, 134, 137, 138, 163.

D i s t r i b u t i o n: Australia and New Zealand (H a l l, A b b o t t, 1984; J o h n-s o n, 1977; M o s s e, B o w e n, 1968 a, b), Canada (D a l p é, G r a n g e r,

Furlan, 1986), Italy (Giovannetti, Nicolson, 1983), Poland (Błaszkowski, 1990 e), Scotland (Nicolson, Gerdemann, 1968), United Kingdom (Mosse, Bowen, 1968 b), United States (Halvorson, Koske, 1987; Hetrick, Bloom, 1983; Koske, 1987; Koske, Tews, 1987; Miller, Domoto, Walker, 1985; Nicolson, Gerdemann, 1968; Pfleger, Steward, 1989; Rose, 1980; Walker, Mize, McNabb, 1982).

45. *Scutellospora dipurpurascens* Morton et Koske

Nc = 15: 112, 175, 190, 195, 206, 210, 217, 223, 246-248, 259, 282, 320, 331; nw = 40: 76, 81, 89, 94, 98-100, 114, 117, 120, 128, 157, 159, 162, 163, 186, 198, 200, 201, 204, 205, 236, 253-255, 261-264, 291, 293, 303, 306-312, 314.

Distribution: Poland (Błaszkowski, in press), United States (Morton, Koske, 1988).

Note. *S. dipurpurascens* is the dominant fungus in sand dunes in Poland.

46. *Scutellospora nodosa* Błaszk.

Nc = 1: 175.

Distribution: Poland (Błaszkowski, 1991 a).

47. *Scutellospora pellucida* (Nicol. et Schenck) Walker et Sanders

Nc = 5: 74, 92, 250, 259, 285; nw = 5: 73, 99, 121, 123, 130.

Distribution: Poland (Błaszkowski, 1989 b), United States (Hetrick, Bloom, 1983; Miller, Domoto, Walker, 1985; Nicolson, Schenck, 1979; Schenck, Smith, 1981).

Note. In Poland this fungus is widely distributed, but occurs sporadically.

Arbuscular mycorrhizae. Mycorrhizal colonization averaged 13.4 % and 27.9 % and ranged from 0 to 81.4 % and 0 to 94.0 % in cultivated and wild plants, respectively.

The most infected roots were those of plant species of the *Cupressaceae* (23.4 %), *Umbelliferae* (23.3 %), *Gramineae* (22.1 %), and *Rosaceae* (22.0 %) (Tab. 8). The values of infection in 5 other families were between 5.1 (*Liliaceae*) and 17.1 % (*Compositae*); among them there were also, e.g., plants of the family *Leguminosae* (13.9 %). The root infections of the other 7 families were within a range of 0.0 (*Buxaceae*)-82.1 % (*Ranunculaceae*). However, these families were represented only by both sibgle plant species and single root samples.

The roots harbouring highest infections of arbuscular fungi were those of *F. arundinacea*, *M. coerulea* (each 94.0 %), *F. verna* (82.1 %), *H. sphondylium* (78.9 %), and *F. rubra* (78.3 %). (Tab. 9). Except for the latter species, all the others were examined only once, however. Six plant species had roots with infections within a range from 50.1 to 75.0 %, including 4 species from the family *Gramineae*.

Table 8

Mycorrhizal colonization of 21 plant families (%)

Family	n	Mean	Range	W
Aceraceae	1	10.0	–	–
Buxaceae	1	0.0	–	–
Caryophyllaceae	4	0.3	0.0-1.0	152.4
Chenopodiaceae	2	0.0	–	–
Compositae	4	17.1	0.2-51.0	135.9
Cruciferae	2	0.1	0.0-0.1	141.4
Crupressaceae	25	23.4	0.1-76.1	110.8
Cyperaceae	1	25.0	–	–
Ericaceae	1	3.1	–	–
Geraniaceae	1	5.8	–	–
Gramineae	194	22.1	0.0-94.0	109.1
Juncaceae	5	0.8	0.0-2.8	149.3
Leguminosae	27	13.9	0.0-56.4	95.9
Liliaceae	4	5.1	1.1-12.1	101.4
Oenotheraceae	1	73.1	–	–
Polypodiaceae	2	0.1	0.0-0.2	141.4
Ranunculaceae	1	82.1	–	–
Rosaceae	37	22.0	0.0-70.0	111.6
Salicaceae	4	10.6	0.1-28.1	116.9
Solanaceae	4	6.6	0.0-24.0	175.7
Umbelliferae	6	23.3	0.4-78.9	133.5

n – number of root samples examined; W – coefficient of variability (%)

However, only *H. pubescens* was investigated more than once. Roots of 9 plant species harboured infections in a range of 25.1-50.0 %, including, e.g., those of *G. aquatica* (35.8 %), *S. cereale* (31.2 %), and *A. arenaria* (30.9 %). In 15 plant species, root infection values were within a range of 15.1-25.0 %. Among them, there were, e.g., *P. arvense* (24.6 %), *P. vulgaris* (20.4 %), *D. glomerata* (19.6 %), *T. aestivum* (18.4 %), *T. pratense* (17.7 %), and *V. faba* (16.9 %). Weak infections (5.1-15.0 %) had roots of 19 plant species, including such plants as *Z. mays* (13.8 %), *N. tabacum* (12.7 %), *A. graveolens* (10.0 %), *H. vulgare* (9.5 %), *T. secalum* (8.4 %), *A. sativa* (7.2 %), *A. porrum* (6.7 %), and *A. schoenoprasum* (6.0 %). Twenty--four plant species were infected below a level of 5 %. These included, e.g., *R. idaeus* (4.8 %), *F. vesca* (4.7 %), *A. cepa* (1.1 %), *S. tuberosum* (0.6 %), *H. annuus* (0.2 %), and *B. napus* (0.1 %). No infections by arbuscular fungi were found in roots of *B. vulgaris*, *B. sempervirens*, *L. luteus*, and *P. chaixi*.

Table 9

Mycorrhizal colonization of 76 plant species (%)

Species	n	Mean	Range	W
Acer palmatum	1	10.0	–	–
Agropyron repens	4	20.4	11.0-39.2	64.6
Agrostis gigantea	3	40.0	0.0-32.0	26.8
Allium cepa	1	1.1	–	–
Allium porrum	2	6.7	1.3-12.1	114.0
Allium schoenoprasum	1	6.0	–	–
Ammophila arenaria	23	30.9	0.1-71.2	76.9
Anthriscus silvestris	2	25.0	8.9-41.0-	90.8
Apium graveolens	1	10.0	–	–
Arrhenatherum elatius	2	10.0	2.0-18.0	113.1
Artemisia campestris	1	13.2	–	–
Avena sativa	3	7.2	2.1-17.4	122.3
Beta vulgaris	2	0.0	0.0-0.1	141.4
Brassica napus	2	0.1	0.0-0.1	141.4
Bulboschoenus maritimus	1	25.0	–	–
Buxus sempervirens	1	0.0	–	–
Calamagrostis arundinacea	3	6.0	0.1-16.1	146.1
Calluna vulgaris	1	3.1	–	–
Chamaecyparis lawsoniana	1	18.1	–	–
Corynephorus canescens	4	39.4	11.1-76.4	83.7
Crataegus monogyna	13	31.5	3.2-70.1	85.0
Dactylis glomerata	2	19.0	0.0-38.0	141.4
Deschampsia caespitosa	1	68.9	–	–
Dianthus carthusianorum	3	0.4	0.1-1.0	123.3
Dryopteris filix-mas	2	0.1	0.0-0.2	141.4
Elymus arenarius	1	1.1	–	–
Epilobium hirsutum	1	73.1	–	–
Eryngium maritimum	2	0.4	–	–
Festuca arundinacea	1	94.0	–	–
Festuca ovina	7	23.9	0.1-64.0	92.5
Festuca polesica	1	54.3	–	–
Festuca rubra	2	78.3	70.1-86.4	14.7
Festuca rubra subsp. *fallax*	1	11.1	–	–
Festuca sp.	1	1.1	–	–
Ficaria verna	1	82.1	–	–
Fragaria vesca	4	4.7	1.2-12.1	111.4
Geranium sp.	1	5.8	–	–
Glyceria aquatica	11	35.8	4.1-89.4	85.3
Glycine hispida	1	27.4	–	–

Species	n	Mean	Range	W
Gypsophila fastigiata	1	0.0	–	–
Helianthus annuus	1	0.2	–	–
Helictotrichon pubescens	2	63.3	48.1-78.4	33.8
Heracleum sphondylium	1	78.9	–	–
Holcus lanatus	1	0.2	–	–
Hordeum vulgare	12	9.5	0.0-38.0	127.7
Juniperus communis	6	60.8	25.0-82.0	36.7
Juncus conglomeratus	5	0.8	0.0-2.8	149.3
Lolium multiflorum	1	66.0	–	–
Lupinus luteus	4	0.0	–	–
Malus domestica	1	0.9	–	–
Malus x purpurea	1	11.1	–	–
Medicago sativa	5	7.2	4.1-10.8	41.8
Molinia coerulea	1	94.0	–	–
Nardus stricta	1	1.1	–	–
Nicotiana tabacum	2	12.7	1.4-24.0	125.8
Petasites officinalis	2	27.6	4.1-51.0	120.2
Phaseolus vulgaris	1	20.4	–	–
Phragmites communis	1	0.1	–	–
Pisum arvense	1	24.6	–	–
Poa chaixi	1	0.0	–	–
Poa pratensis	4	10.1	4.1-21.0	74.8
Populus alba	1	0.1	–	–
Prunus domestica	1	16.4	–	–
Prunus serrulata	1	13.1	–	–
Rosa canina	15	23.9	0.0-64.0	116.3
Rubus idaeus	1	4.8	–	–
Salix arenaria	1	4.0	–	–
Salix triandra	2	19.1	10.0-28.1	67.0
Secale cereale	2	31.2	11.0-51.4	91.6
Setaria italica	1	26.0	–	–
Solanum tuberosum	2	0.6	0.0-1.1	129.6
Sorghum sudanensis	3	42.8	12.1-71.8	69.8
Thuja occidentalis	18	11.4	0.1-51.0	109.4
Trifolium pratense	9	17.7	4.0-56.4	93.4
Triticum aestivum	43	18.4	0.1-81.4	116.9
Triticum secalum	10	8.4	0.2-31.0	108.8
Vicia faba	6	16.9	4.2-27.0	62.2
Zea mays	25	13.8	0.1-61.0	118.3

Explanations as in Table 8

The mycorrhizal colonization of cultivated plants determined in this study (av. 13.4 %; range 0-81.4 %) is very similar to that found in 64 cultivated plant species (av. 15.3 %; range 0-61.3 %) examined by C z a j k o w s k a - S t r z e m s k a (1988). In natural field environments, mycorrhizal colonization frequently achieves 90 % or more of the total root lenght of a plant (S t a h l, C h r i s t e n s e n, 1991). Therefore, the relatively low mean colonization level found in this study suggests that most of the plants examined grew in conditions that were not optimal for arbuscular fungi.

According to M a l l o c h, P i r o z y n s k i, R a v e n (1980), occurrence of arbuscular mycorrhizae is positively correlated with the density of plant species in a site. R e a d et al. (1976) suggested that high infection levels in natural sites are a result of a nutrient stress caused by intensive competition between single plants in close communities; the proximity of roots of different plants additionally facilitates the dissemination of infection. In contrast, in cultivated soils, both the competition for nutrients and the density of roots are lower and therefore the mycorrhizal coloni-zation of cultivated plants is usually less abundant, as was confirmed in this study.

According to S a n d e r s et al. (1977), mycorrhizal colonization at the level of 10 % significantly increases the amount of absorbed P. V o l k m a r and W o o d-b u r y (1989) showed that 2-7 % mycorrhizal infections increased the weight of barley shoots up to 25 %. Thus, most plants examined by the author of this paper probably benefited by the association with mycorrhizal fungi.

Of the 12 plant species examined, about which no literature information on the mycorrhizal status is known, only *P. chaixi* was nonmycotrophic, despite the fact that most members of the *Gramineae* harbour mycorrhizae (B o u l l a r d, 1963). However, the roots of *P. chaixi* came only from a single site that was highly shaded by trees. Light deficiency may reduce the development of arbuscular infections (D a f t, E l - G i a h m i, 1978; H a y m a n, 1974). Hence, the mycorrhizal status of this plant needs to be further studied. *Juncus conglomeratus* grew either without or with very low arbuscular infections. The *Juncaceae* is one of the rare families, whose members are infrequently associated with arbuscular fungi (H a r l e y, S m i t h, 1983). The roots of the other plants species, i.e., *B. maritimus, F. polesica, H. pubescens, Malus* x *purpurea, P. officinalis, P. serrulata, S. arenaria, T. occidenta-lis*, and *T. secalum* always were mycorrhizal, confirming the suggestions of H a r-l e y and H a r l e y (1987) that families of these plants are hosts of arbuscular fungi.

Gypsophila fastigiata was nonmycotrophic, as S t a h l (1900) reported. The roots of *L. luteus* were also free from arbuscular infections, confirming the findings of C z a j k o w s k a - S t r z e m s k a (1988), although *L. luteus* is not comple-tely resistant to mycorrhizal fungi (H a r l e y, S m i t h, 1983). *Buxus sempervirens* was nonmycorrhizal, but H a r l e y and H a r l e y (1987) report this species to harbour arbuscular fungi. In compliance with the literature data (B o u l l a r d, 1963; C z a j k o w s k a - S t r z e m s k a, 1988; D o m i n i k, 1952; H a r l e y, H a r l e y, 1987), *A. gigantea, A. arenaria, B. vulgaris, B. napus*, and *H. vulgare* were either

mycorrhizal or nonmycorrhizal. D o m i n i k (1952) found both nonmycorrhizal and mycorrhizal *A. arenaria* plants, depending on the ege of dunes.

Dryopteris filix-mas, R. canina, and *S. tuberosum* were nonmycotrophic or harboured arbuscular fungi, contradicting other results (C z a j k o w s k a - S t r z e m-s k a, 1988; H a r l e y, H a r l e y, 1987; Ł a n o w s k a, 1955), indicating that these plants have been shown to be only mycorrhizal.

The roots of *A. elatius, A. sativa, C. arundinacea, C. canescens, D. glomerata, E. arenarius, E. maritimum, F. ovina, F. vesca, H. sphondylium, H. lanatus, P. vulgaris, P. communis, P. pratensis, P. domestica, R. idaeus,* and *T. pratense* always had arbuscular infections, whereas B o u l l a r d (1963), C z a j k o w s k a - S t r z e m-s k a (1988), D o m i n i k (1952, 1958), D o m i n i k and W o j c i e c h o w s k a (1963), H a r l e y and H a r l e y (1987, 1990), P a c h l e w s k i (1956, 1958), T r u s z k o w s k a (1953 a), and W o j c i e c h o w s k a (1960) found specimens of these plants that were either nonmycorrhizal or mycorrhizal.

The presence of mycorrhizal fungi in roots of *A. sylvestris, D. carthusianorum,* and *G. aquatica* contradicts the reports of B o u l l a r d (1963), H a r l e y and H a r l e y (1987), and T r u s z k o w s k a (1953 a, b), in which these plants are listed as nonmycortophic.

According to H a r l e y and H a r l e y (1987), *C. monogyna, F. rubra, J. communis,* and *S. triandra* may simultaneously harbour both arbuscular and ectomycorrhizal fungi. In D o m i n i k 's and W o j c i e c h o w s k a 's (1963) studies, *J. communis* was associated only with arbuscular fungi or grew without them (D o m i n i k, 1952). *Populus alba* belongs to the family *Salicaceae,* whose members form endo- and ectomycorrhizae (H a r l e y, S m i t h, 1983), although P a c h l e w s k i (1958) found this plant species with roots infected only by arbuscular fungi. Except for *S. triandra,* which grew with arbuscular fungi one year and was nonmycotrophic the next year, the author of this paper found in the other plants listed above only arbuscular associations.

The roots of *C. vulgaris* contained vesicles (no arbuscules were found), adding evidence to the relatively infrequent reports on the association of this group of fungi with roots of members of *Ericales* (K o s k e, G e m m a, E n g l a n d e r, 1990).

The other plant species listed in Table 9 always harboured arbuscular fungi.

In the conducted studies, the values of the spore and species densities, as well as those characterizing mycorrhizal colonizations of the plants examined highly varied, just as was noted by B e r c h, G a m i e t, D e o m (1988), G i o v a n n e t t i and N i c o l s o n (1983), H a y m a n and S t o v o l d (1979), H e t r i c k and B l o o m (1983), K o s k e and H a l v o r s o n (1981), and W a l k e r, M i z e, M c N a b b (1982). The main source of variability of the occurrence of these fungi is their aggregated pattern of distribution in soil (K o s k e, 1987; S y l v i a, 1986; W a l k e r, M i z e, M c N a b b, 1982). Other reasons may be factors modyfying the germination, infectivity, and sporulation of these fungi (A n d e r s o n, 1984;

D a n i e l s, T r a p p e, 1980; H e t r i c k, B l o o m, 1986; K o o m e n et al., 1987; K o s k e, H a l v o r s o n, 1981; S y l v i a, B u r k s, 1988).

The occurrence of spores of arbuscular fungi versus arbuscular mycorrhizae versus soil chemical properties. The chemical properties of 89 randomly chosen soil samples were highly differentiated and ranged: pH 3.4-7.8; NO_3 10.0-240.0; P 3.0-147.0; K 0.0-351.0; Mg 6.0-362.0; Na 0.0-970.0; Cl 12.0-740.0 (mg/l); humus 0.05-10.0 %.

As the linear correlation analysis showed, the spore density in those soil samples was significantly correlated only with the content of humus ($r = 0.28$; $P = 0.05$), NO_3 ($r = 0.25$), and Mg ($r = 0.28$). The species density significantly depended only on the concentration of P ($r = 0.24$). Mycorrhizal colonization did not significantly correlate with any of the soil chemical property considered. Insignificant were also correlation coefficients determining the relationships between spore and species densities and mycorrhizal colonization.

Of the species most frequently found, i.e., *A. lacunosa, G. caledonium, G. constrictum, G. deserticola, G. macrocarpum, G. mosseae,* and *S. dipurpurascens,* only the spore densities of *G. constrictum* and *G. mosseae* significantly correlated with the soil humus ($r = 0.64$; $P = 0.01$) and NO_3 ($r = 0.28$; $P = 0.05$) contents.

Insignificante correlations between mycorrhizal colonization and the spore and species densities of arbuscular fungi, recovered from a given amount of soil by wet sieving and decanting, may result from the fact that (1) some species do not form spores (B a y l i s, 1969) or they are too small (e.g., *G. tenue*) to be held by soil sieves (H a l l, 1977); (2) sufficiently large spores to extraction may be recovered incompletely (M o s s e, S t r i b l e y, L e T a c o n, 1981); (3) spores are frequently embedded in soil which makes identification difficult (A n et al., 1990); (4) spores usually occur in aggregates (K o s k e, 1987); (5) spores may be dead (M c G r a w, H e t r i x, 1986); (6) sources of infection are also infected roots and extramatrical hyphae (B i e r m a n n, L i n d e r m a n, 1983); and (7) mycorrhizae of some fungal species (e.g., *G. occultum*) do not react with commonly used stains (M o r t o n, 1985).

SUMMARY

In the years 1985-1990, the occurrence of arbuscular fungi and mycorrhizae (*Glomales*) in Poland was examined. A total of 332 soil and root samples were investigated, of which 173 and 159 came from cultivated and natural sites, respectively. The samples were represented by 76 plant species from 21 families. They were collected at 113 localities in 22 voivodships. Spores of arbuscular fungi were found in 330 soil samples. About 87 % of all isolated spores were of the genus *Glomus*. Members of the genera *Acaulospora* and *Scutellospora* also occurred regularly, but in lower amounts. *Entrophospora, Gigaspora,* and *Sclerocystis* sp. were found rarely and in low numbers. Generally, arbuscular fungi were not associated with particular host plants, but some families and species of plants more favoured their development. *Gigaspora* and *Scutellospora* sp. markedly preferred

sandy soils. A total of 40 spore forming species and *G. tenue* were found. Among the species most frequently found, *G. caledonium*, *G. constrictum*, *G. deserticola*, *G. fasciculatum*, *G. geosporum*, and *G. mosseae* occurred more frequently in cultivated soils, whereas *G. macrocarpum* dominated in uncultivated soils. The spore density in 100 g dry soil was higher among roots of wild plants (116.4 vs. 87.9). In contrast, the average species density in 100 g dry soil was higher in cultivated soils (3.9 vs. 3.5). The spore density was significantly correlated with mycorrhizal colonization. In the root zone of cultivated plants, the most abundantly sporulating species were *G. deserticola*, *G. fasciculatum*, and *G. mosseae*, whereas most spores among roots of wild plants were produced by *G. aggregatum*, *G. constrictum*, and *G. heterosporum*. The average mycorrhizal colonization in cultivated plants was ca twice as low as in wild plants (13.4 vs. 27.9 %). Mycorrhizal colonization was not correlated with soil pH and NO_3, P, K, Mg, Na, Cl, and humus contents. The distribution of the species found in Poland is described and their occurrence in the world is presented. Seven species which are probably new to fungal flora were described and illustrated.

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