Karstenia 30:1–13. 1990.

Polish Endogonaceae 2. Acaulospora rugosa, Glomus aggregatum, Glomus etunicatum, Glomus fasciculatum and Glomus occultum

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BŁASZKOWSKI, J. 1990: Polish Endogonaceae 2. Acaulospora rugosa, Glomus aggregatum, Glomus etunicatum, Glomus fasciculatum and Glomus occultum. — Karstenia 30:1–13.

The Polish occurrence and distribution are described and illustrated for five species of the Endogonaceae. *Glomus fasciculatum* (Thaxter) Gerd. & Trappe emend. Walker & Koske has frequent occurrences throughout the country. *Glomus aggregatum* Schenck & Smith emend. Koske, *G. etunicatum* Becker & Gerd. and *G. occultum* Walker probably occur in the whole of Poland as well, although with lower frequencies. All four species were found among both cultivated and natural plants. *Acaulospora rugosa* Morton was isolated from only 1 of the 152 soil samples studied. The species is new to Europe, having earlier been known only from West Virginia.

Key words: Acaulospora, Endogonaceae, Glomus, occurrence in Poland, taxonomy

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Acaulospora rugosa Morton

The spores from Poland (Figs. 1–4) do not differ from those described by Morton (1986). They are pale yellow (2.5Y 8/6, Munsell Color Company, INC., Baltimore, Maryland 1954), globose to subglobose, (70–)80(–120) µm in diam, sometimes ovoid, 70 x 120 µm. The spore wall consists of five walls (walls 1–5) in three groups (groups A, B, C). Group A consists of a hyaline, membranous, (0.7–) 0.9(–1.2) µm thick outermost wall (wall 1) and of a pale yellow (2.5Y 8/6), laminate, (2.4–)3.1 (–3.8) µm thick inner wall (wall 2). Group B consists of a hyaline, unit, (0.5–)0.7(–1.2) µm thick wall (wall 3). Group C consists of a hyaline, membranous, beaded, ± 0.5 µm thick wall (wall 4), adhering to a hyaline, amorphous, (0.9–)1.1(–2.0) µm thick innermost wall (wall 5).

This species has been known only from West Virginia.

In Poland *A. rugosa* was found in only one soil sample, taken from under *Calamagrostis arundinacea* (L.) Roth in a forest (Table 1, Fig. 22). Its spore density and the relative density (the number of spores of *A. rugosa* as a percentage of the total spores in a soil sample) was 39 per 100 g dry soil and 10.9%, respectively.

Material examined

See Table 1; specimens deposited: 720–746, 1049–1053 (DPP).

Table 1. Frequency of occurrence of *Acaulospora rugosa* in Poland and chemical properties of the soil from which this species was isolated.

Plant family	Plant species	No. of soil sample (see Fig. 22)	No. of spores/ 100 g dry soil	Chemical properties pH (in H_2O)	No_3	P_2O_5 (mg kg^{-1})	K_2O
Gramineae	*Calamagrostis arundinacea*	89	39	4.8	21	16	14

Glomus aggregatum Schenck & Smith emend. Koske

G. aggregatum is one of the species of the *G. fasciculatum* complex, from which *G. deserticola* Trappe, Bloss & Menge and *G. hoi* Berch & Trappe have also been separated. It is distinguishable from other species by its small, smooth, thin-walled spores of various shapes, which are pale yellow to yellow–brown, generally have an open pore of a subtending hypha, and possess (mature spores) one or two thin walls. The most characteristic feature, however, is the production of spores by internal proliferation (Koske 1985).

The Polish specimens possess all the features mentioned above (Figs. 5–10). The spores occurred both singly in the soil and in sporocarps. Those isolated singly from the soil most often contain internal proliferations. The spores in sporocarps are usually 1-walled, although spores with 2 walls and with internal proliferations occur as well (Figs. 5–7). The walls of 1- and 2-walled spores are usually coloured and laminate, although their inner wall is sometimes hyaline and very thin, resembling a membranous wall. The hyphae of *G. aggregatum* sporocarps often possess internal hyphae or double walls (Figs. 10) similar to those described and illustrated by Koske (1985).

G. aggregatum was originally described on the basis of spores found in a citrus nursery in Florida (Schenck & Smith 1982). Koske (1985, 1987) and Sylvia (1986) considered it to be common in maritime sand dunes of the U.S. and Canada. Zak et al. (1982) found it to be one of the most common vesicular-arbuscular mycorrhizal fungi associated with *Agropyron trachycaulum* (Link) Malte. on two mine spoils, and Dalpé et al. (1986) often isolated this species from an apple orchard. Bloss and Walker (1987) found *G. aggregatum* spores among roots of *Agave* spp. and *Trifolium repens* L. in the Santa Catalina Mountains in Arizona.

In Poland *G. aggregatum* was found in 25 soil samples (Table 2, Fig. 22). Only three of them (nos. 93, 123, 128) come from maritime dunes, five (nos. 25, 37, 38, 48, 113) from soils adjacent to them, six from forest soils, and the others from other cultivated and natural localities. The spore densities and the relative densities of this species ranged from 1 to 116 per 100 g dry soil and from 0.5 to 42.8% ($\bar{x}$ = 6.3%), respectively. No significant correlation was observed between the spore densities and the chemical properties of the soils examined. The species is new to Poland.

Material examined

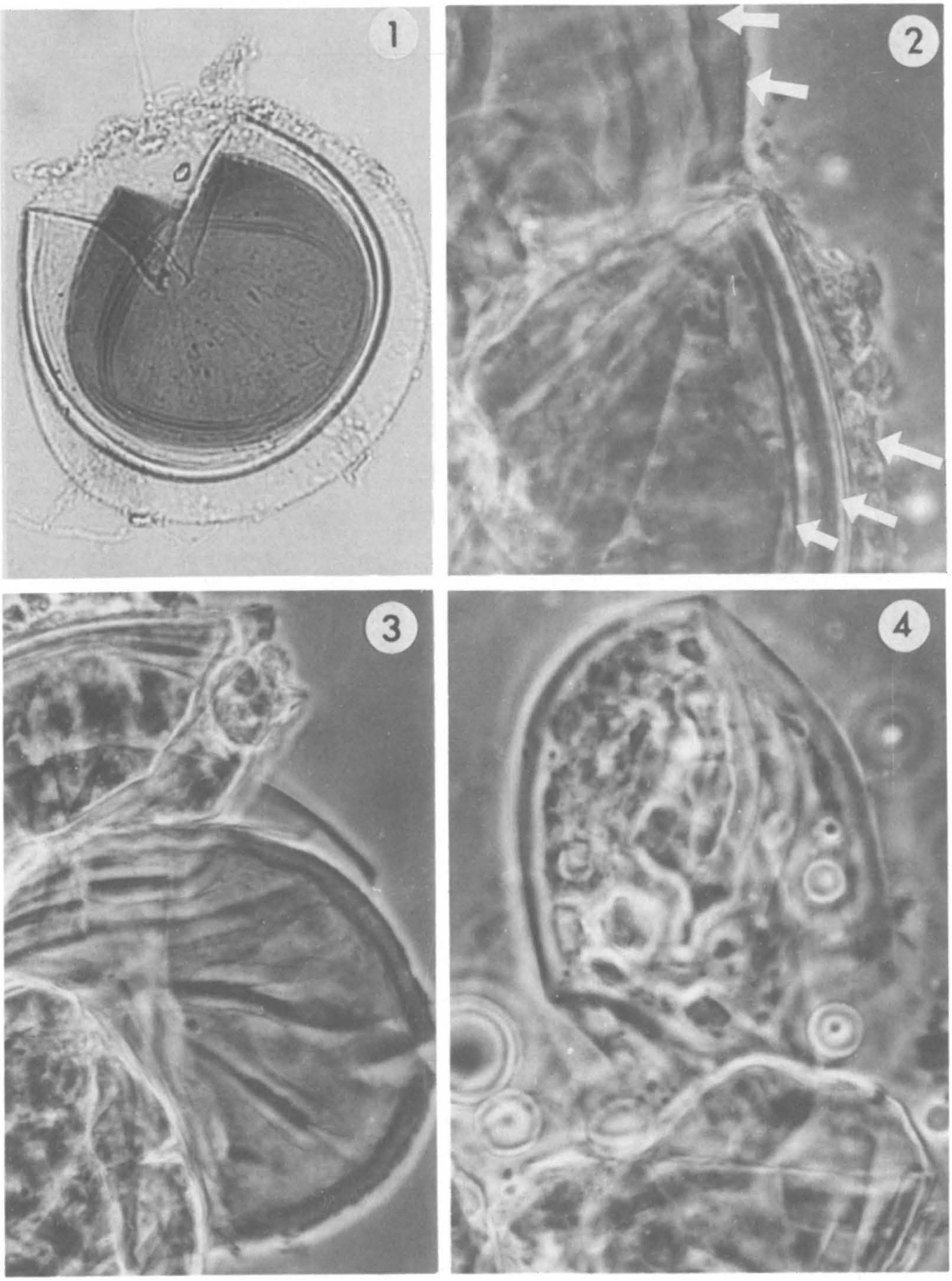
See Table 2; specimens deposited: 292–303 (DPP).

Glomus etunicatum Becker & Gerd.

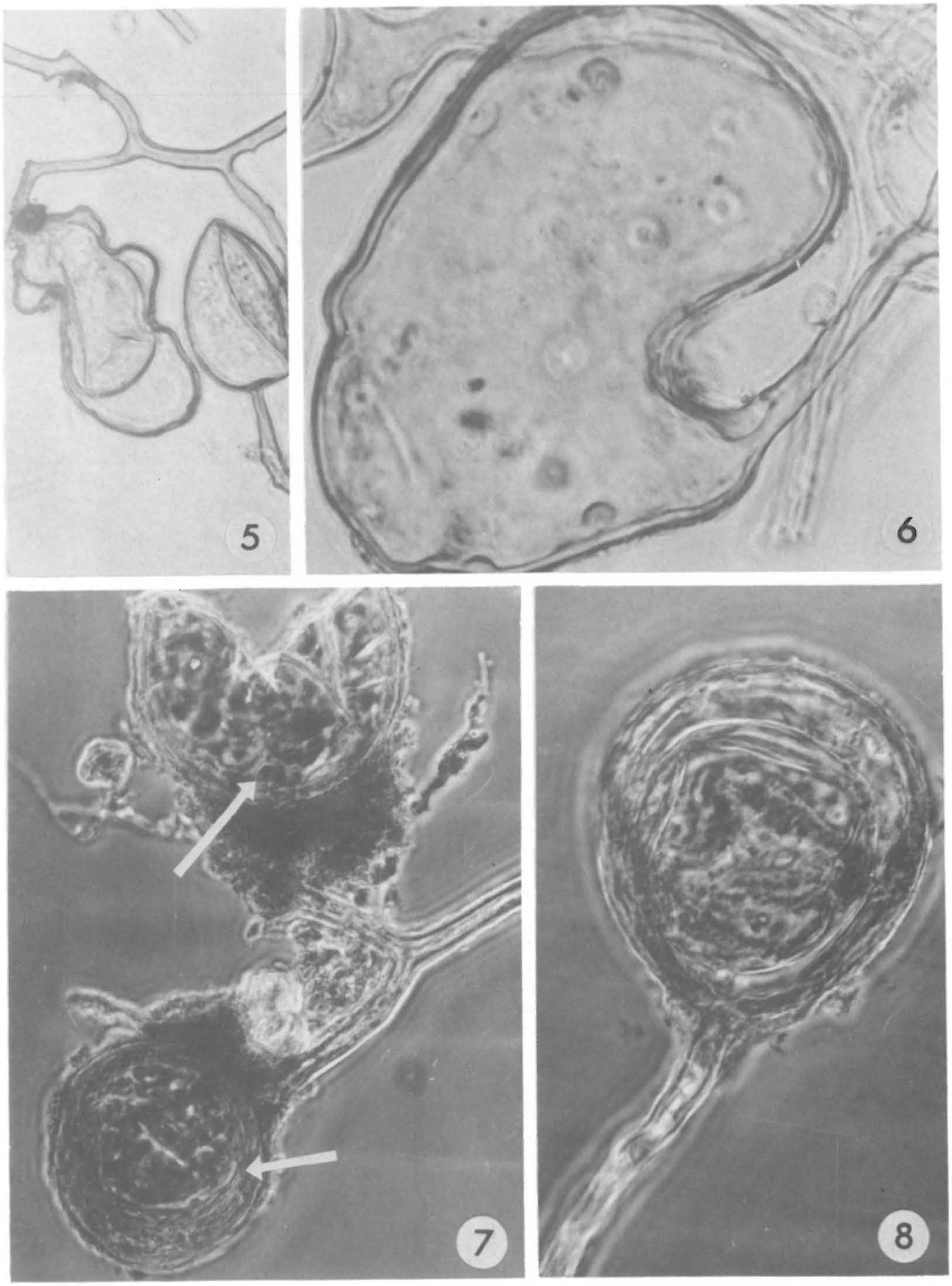
G. etunicatum is a very confusing species because of its inconstant spore wall structure. Among the specimens from Poland are spores with a fully developed wall (2-walled with an outer evanescent wall and an inner laminate wall) as well as spores without the outer wall, which easily sloughs (Figs. 11–14). Other features, such as the presence of a thin-walled and fragile subtending hypha, and the dimensions and colour of the spores, agree with the original description by Becker and Gerdemann (1977).

G. etunicatum is probably globally widespread, although its occurrence has formally been recorded only in the U.S. (e.g. Becker & Gerdemann 1977, Schenck & Smith 1981, Hetrick & Bloom 1983, Miller et al. 1985, Bloss & Walker 1987) and Canada (Dalpé et al. 1986).

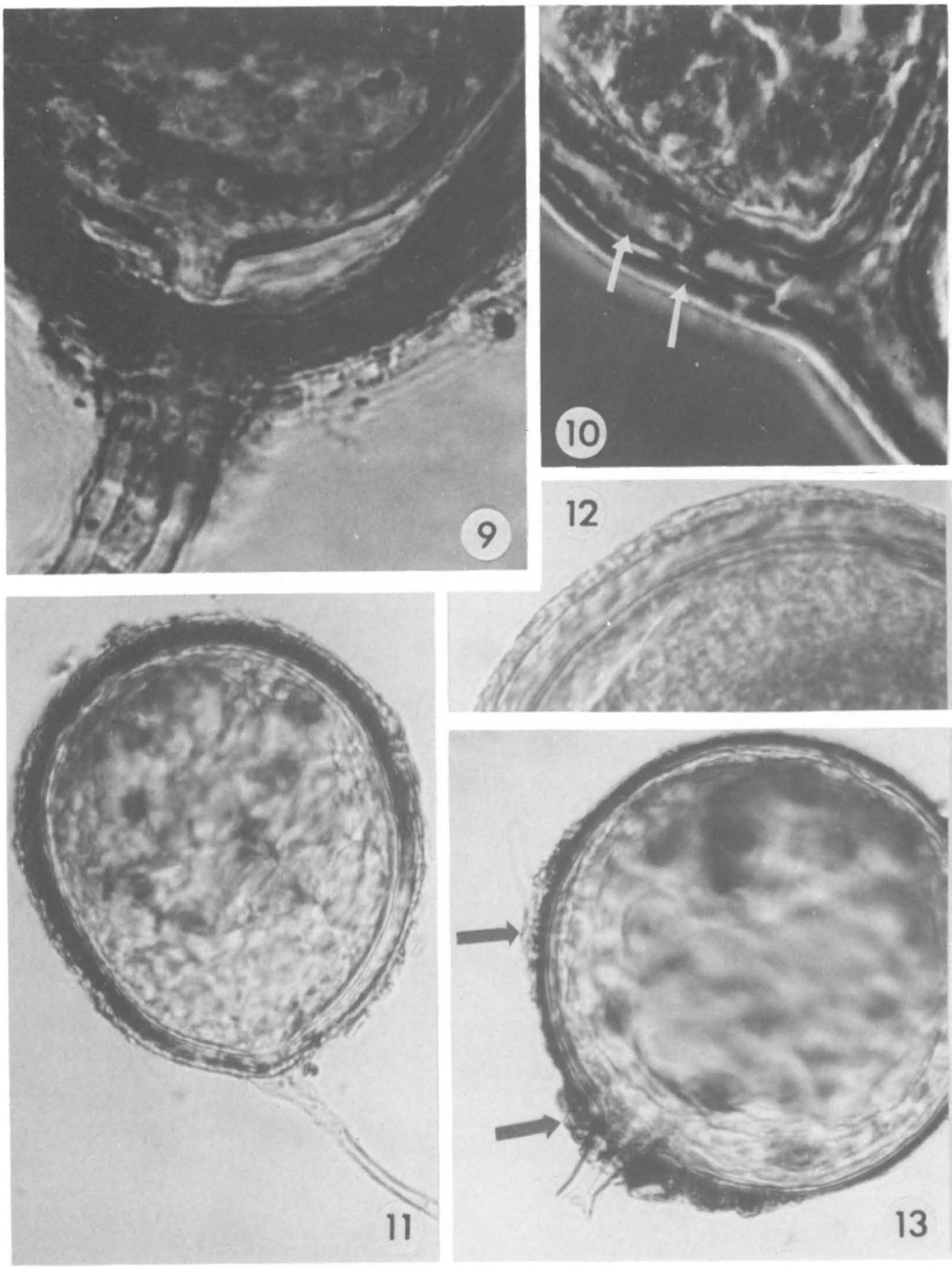
In Poland *G. etunicatum* was found in only 4 soil samples, taken from under cultivated and natural plants (Table 3, Fig. 23). Its spore density was relatively high (30 per 100 g dry soil) only in sample no. 91, ranging from 2 to 6 per 100 g dry soil in the



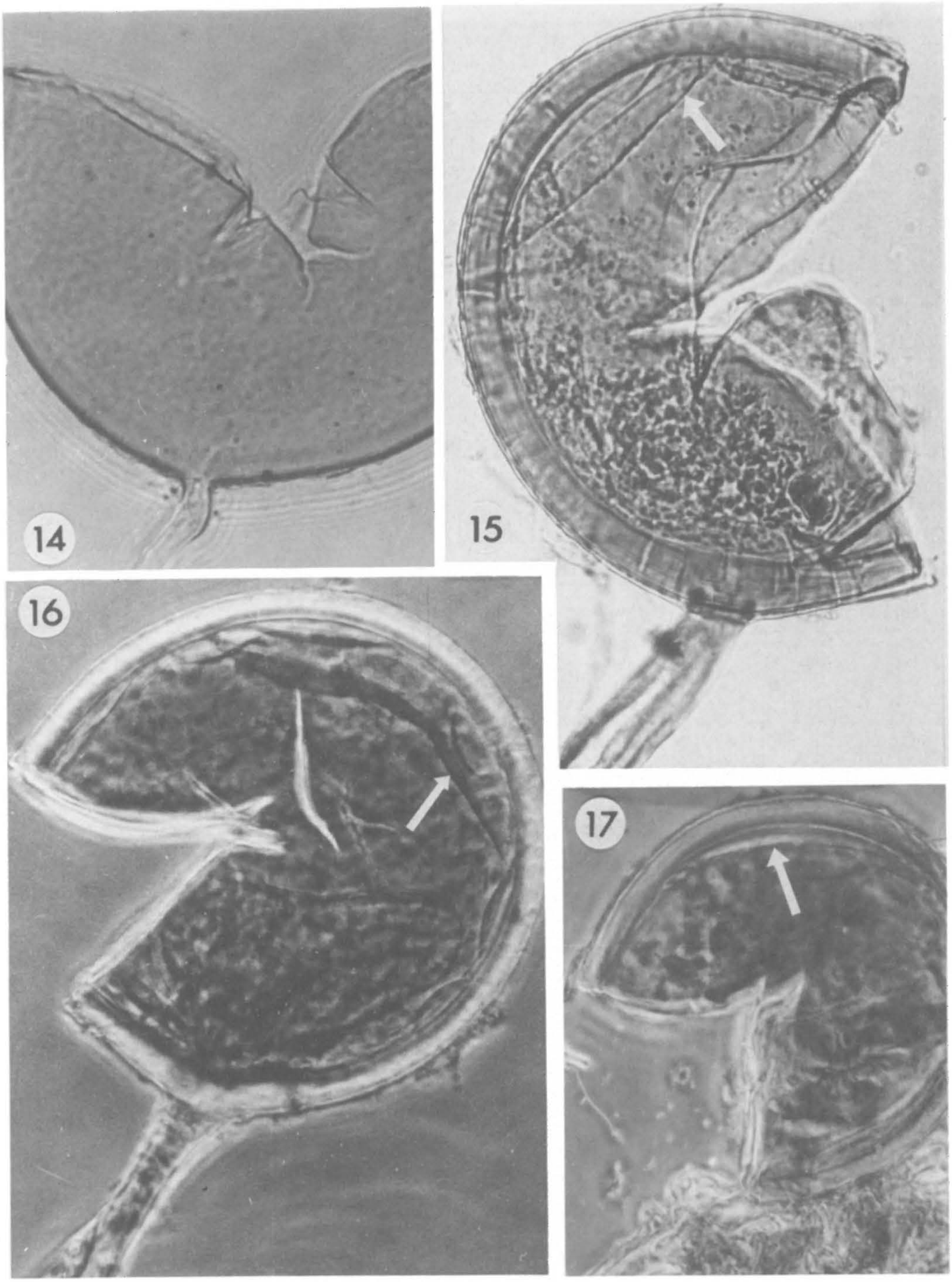
Figs. 1–4. *Acaulospora rugosa*. — 1: A crushed spore in Melzer's reagent with lactic acid, showing the swollen outermost wall and the innermost one stained dark, x 520. — 2: 5 walls of a spore are visible, phase contrast (PC), x 1 200. — 3: Another crushed spore showing the spore wall structure, PC, x 645. — 4: The amorphous nature of the innermost wall is evident, PC, x 900.



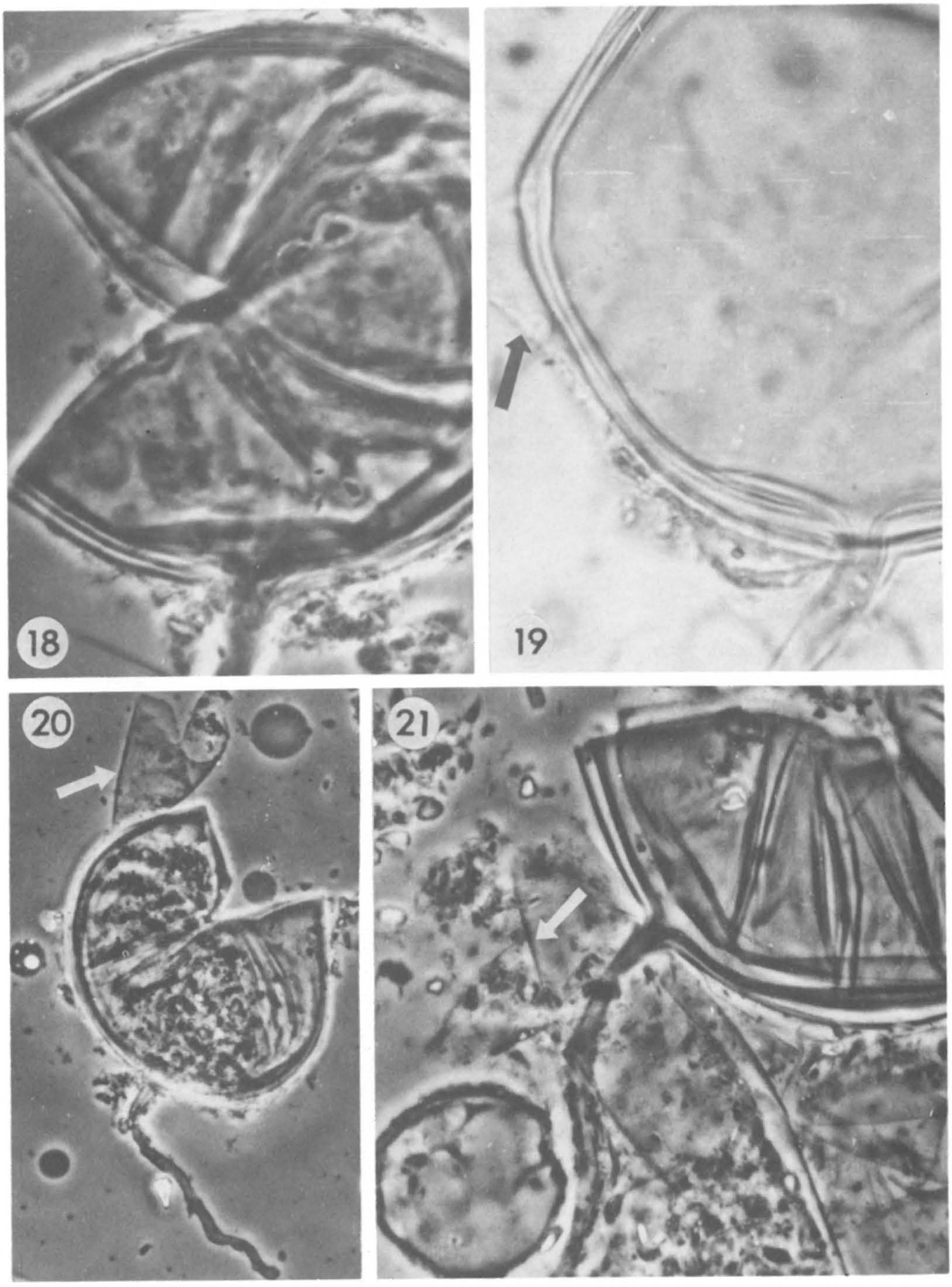
Figs. 5–8. *Glomus aggregatum.* — 5: A fragment of a sporocarp with the 1-walled spore and the inner spore formed by internal proliferation from the subtending hypha, x 347. — 6: A spore from the same sporocarp showing the funnel-shaped subtending hypha, x 1 084. — 7: Two spores with inner proliferations of different developmental degrees (arrows), PC, x 360. — 8: A spore with the fully formed inner spore, PC, x 530.



Figs. 9–13. — 9–10. *Glomus aggregatum*. — 9: The same spore as in Fig. 8 showing the inner spore proliferating from the subtending hypha of the mother spore, x 1 550. — 10: Hyphae with the outer and inner hyphal walls (arrows), PC, x 1 530. — 11–13. *Glomus etunicatum*. — 11: An intact spore with fully developed walls, x 590. — 12: The inconstant nature of the outer wall can be observed, x 638. — 13: Only fragments of the outer wall can be seen (arrows); the hyaline subtending hypha is visible, x 600.



Figs. 14–17. — 14. *Glomus etunicatum*, a crushed spore without its outer wall, which has been completely sloughed, x 533. — 15–17. *Glomus fasciculatum*. — 15: A crushed spore with 3 walls; the innermost wall is marked (arrow), x 680. — 16: The wrinkling innermost wall can be seen (arrow), PC, x 770. — 17: A crushed spore from a sporocarp; the innermost wall (arrow) is separated from the middle wall, PC, x 548.



Figs. 18–21. *Glomus occultum*. — 18: A crushed spore with 3 walls separated near the subtending hypha, PC, x 1 100. — The 3-walled spore wall structure with the additional layer of debris (arrow) can be seen, x 1 030. — 20 and 21: Two spores with the additional unit-like wall (arrows), PC, x 550 and 890, respectively.

Table 2. Frequency of occurrence of *Glomus aggregatum* in Poland and chemical properties of soils from which this species was isolated.

Plant family	Plant species	No. of soil sample (see Fig. 22)	No. of spores/ 100 g dry soil	Chemical properties pH (in H_2O)	No_3	P_2O_5 (mg kg^{-1})	K_2O
Cupressaceae	*Thuja occidentalis*	37, 90, 116	6, 1, 10	4.5–6.6	34–260	6–10	9–209
Gramineae	*Avena sativa*	25	1	6.3	40	31	27
	Festuca polesica	75	1	4.8	20	15	17
	Festuca rubra	73	116	5.6	16	13	13
		88	8	6.1	20	17	16
	Poa pratensis	95	5	5.1	17	16	18
	Triticum vulgare	107	1	5.2	30	14	10
		148	1	6.0	50	114	161
	Zea mays	38	3	5.6	72	19	17
		91	1	6.5	80	23	25
	Unknown grass	99	13	5.1	10	14	9
Leguminosae	*Lupinus luteus*	69	26	6.4	83	64	60
	Phaseolus vulgaris	48	16	6.7	71	57	62
Liliaceae	*Allium porrum*	41	2	5.9	38	24	28
Rosaceae	*Crataegus monogyna*	113, 121, 140	1, 4, 3	5.2–6.2	35–160	22–35	25–30
	Fragaria vesca	42	2	4.3	48	14	21
	Prunus domestica	74	3	5.2	24	18	17
	Rosa canina	93, 123, 128	4, 8, 30	3.8–4.5	20–38	6–18	14–17
Umbelliferae	*Anthriscus sylvestris*	71	3	4.1	51	12	21

other samples. The relative density of this species ranged from 0.4 to 13.9% ($\bar{x}$ = 6.2%). These are the first finds of *G. etunicatum* in Poland.

Material examined

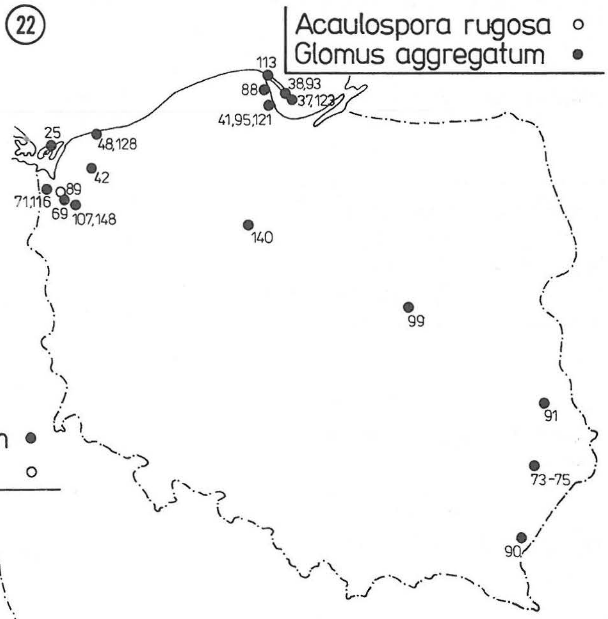
See Table 3; specimens deposited: 539–550 (DPP).

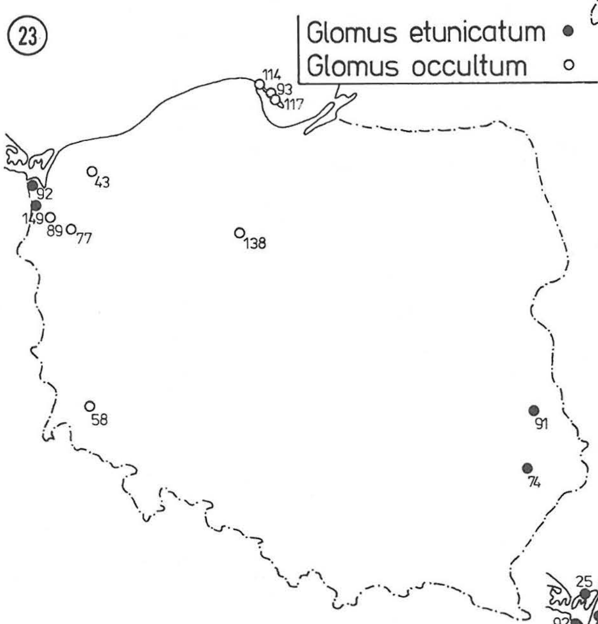
Glomus fasciculatum (Thaxter) Gerd. & Trappe emend. Walker & Koske

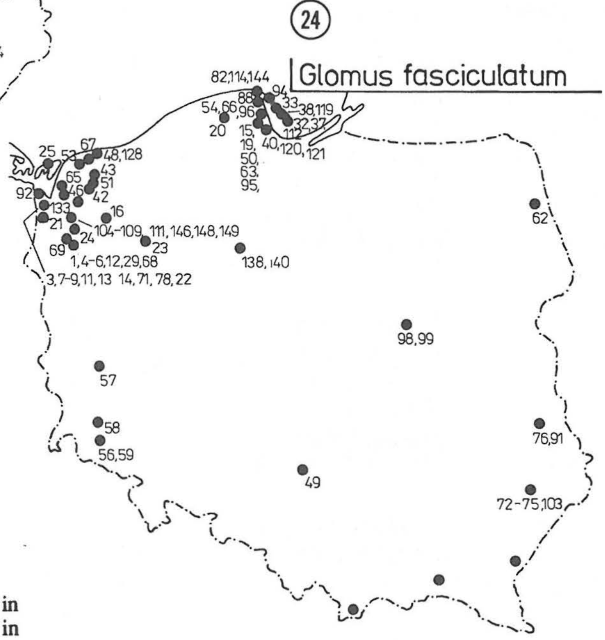
The Polish collections (Figs. 15–17) conform well with the emended description by Walker and Koske (1987), although the innermost wall of the spores from Poland (a membranous wall) rarely stains in Melzer's reagent. Most of the collections studied were preserved in lactophenol, in which spores usually lose their ability to react to this reagent (Morton 1986), which is probably the reason for this divergence.

According to Walker and Koske (1987), *G. fasciculatum* is one of the species of the Endogonaceae most often recorded in soil surveys and most often cited as used in studies of plant growth responses. These authors stated that it is frequently confused with other species, especially *G. aggregatum*, *G. deserticola*, *G. invermaium* Hall, *G. fuegianum* (Speg.) Trappe & Gerd., *G. occultum* Walker and *Sclerocystis rubiformis* Gerd. & Trappe, and that at present it is impossible to determine its real distribution in the world.

Although the occurrence of *G. fasciculatum* had already been treated in Poland (Błaszkowski 1989), I







Figs. 22–24. Maps of the distribution of the Endogonaceae in Poland. — 22: *Acaulospora rugosa* and *Glomus aggregatum* in Poland. — 23: *Glomus etunicatum* and *Glomus occultum* in Poland. — 24: *Glomus fasciculatum* in Poland.

Table 3. Frequency of occurrence of *Glomus etunicatum* in Poland and chemical properties of soils from which this species was isolated.

Plant family	Plant species	No. of soil sample (see Fig. 23)	No. of spores/ 100 g dry soil	Chemical properties pH (in H_2O)	No_3	P_2O_5 (mg kg $^{-1}$)	K_2O
Gramineae	*Triticum vulgare*	149	2	6.2	56	113	160
	Zea mays	91	30	5.6	72	19	17
Rosaceae	*Malus domestica*	92	4	5.7	74	26	12
	Prunus domestica	74	6	5.2	24	18	17

Table 4. Frequency of occurrence of *Glomus fasciculatum* in Poland and chemical properties of soils from which this species was isolated.

Plant family	Plant species	No. of soil sample (see Fig. 24)	No. of spores/ 100 g dry soil	Chemical properties pH (in H_2O)	No_3	P_2O_5 (mg kg $^{-1}$)	K_2O
Aceraceae	*Acer palmatum*	29	110	5.8	34	22	20
Cupressaceae	*Juniperus communis*	98	38	5.1	10	14	9
		144	7	5.2	27	15	24
	Thuja occidentalis	4, 37, 90, 102	21, 155, 12, 12	4.5–	20–	10–	9–
		112	3	6.1	26	30	37
Geraniaceae	*Geranium* sp.	3	7	6.5	40	35	45
Gramineae	*Avena sativa*	25	11	6.3	40	31	27
	Calamagrostis arundinacea	76	20	5.8	28	24	30
		78	10	4.0	68	6	5
	Corynephorus canescens	32	1	6.1	34	30	39
	Festuca ovina	50	52	5.1	31	25	28
	Festuca polesica	75	86	4.8	20	15	17
	Festuca rubra	73	35	5.8	32	21	19
		88	48	5.9	35	25	32
	Festuca sp.	49	6	5.1	35	30	34
	Hordeum vulgare	24	5	6.3	35	32	40
	Lolium multiflorum	82	170	5.7	35	34	30
	Poa pratensis	95	23	5.1	17	16	18
	Secale cereale	65	35	5.8	38	27	30
	Setaria italica	13	17	6.4	40	35	38
	Sorghum sudanense	8	24	7.0	61	24	41
		11	12	6.6	45	29	40
	Triticum aestivum	58	689	6.7	71	24	28
	Triticum vulgare	21, 62, 104–109, 111, 145, 146, 148, 149	2, 6, 190, 352, 20, 45, 78, 27, 13, 2, 1, 1, 1	5.2– 6.6	26– 61	6– 114	4– 161
	Zea mays	38, 40, 46, 56,	78, 1, 3, 1, 8	5.6–	31–	19–	17–

(contnd.)

Table 4. Contnd.

Plant family	Plant species	No. of soil sample (see Fig. 24)	No. of spores/ 100 g dry soil	Chemical properties pH (in H_2O)	No_3	P_2O_5 (mg kg^{-1})	K_2O
		91		6.7	80	75	81
	Unknown grass	1, 5, 15, 19, 63, 94, 96, 99	5, 5, 6, 90, 41, 5, 46, 84	4.7–6.8	10–22	14–39	9–29
Leguminosae	*Glycine hispida*	9	5	4.8	26	14	9
	Lupinus luteus	16	2	5.7	35	28	34
		69	19	6.4	83	64	60
	Medicago sativa	51	21	5.8	29	17	9
	Phaseolus vulgaris	48	25	6.7	71	57	62
	Trifolium repens	7, 43, 57	12, 2, 1	5.1–6.7	29–84	15–21	10–28
	Vicia faba	54	1	5.7	34	19	15
		66	14	5.9	30	21	20
Liliaceae	*Allium porrum*	22	3	6.1	32	27	39
	Allium schoenoprasum	67	1	5.9	24	17	17
Polypodiaceae	*Dryopteris filix-mas*	68	2	4.9	18	15	17
Rosaceae	*Crataegus monogyna*	114, 121, 140	32, 1, 18	5.1–6.2	19–160	20–35	17–30
	Fragaria vesca	20, 42, 53	22, 3, 4	4.3–5.9	31–48	14–25	18–21
	Malus domestica	92	5	5.7	74	26	12
	Malus x *purpurea*	12	38	5.1	14	17	8
	Prunus domestica	74	118	5.2	24	18	17
	Prunus serrulata	6	47	4.9	14	17	12
	Rosa canina	119, 128, 138	20, 3, 4	3.8–6.7	38–66	6–20	14–59
	Rubus idaeus	120	8	6.5	19	12	26
Salicaceae	*Populus alba*	86	28	5.7	22	18	12
Solanaceae	*Nicotiana tabacum*	72	6	4.5	22	11	6
		103	48	5.2	73	13	24
	Solanum tuberosum	59	4	5.1	45	22	19
Umbelliferae	*Anthriscus sylvestris*	14	28	5.2	18	15	12
		71	12	4.1	51	12	21
	Apium graveolens	23	1	5.8	32	18	15
	Eryngium maritimum	33	5	4.8	11	9	12

decided to re-examine all my specimens of this species and other collections of the Endogonaceae consisting of spore populations obtained from single soil samples. Altogether 152 such collections were re-examined and 48 of the earlier determinations were found to be doubtful or incorrect. The spores from these collections mainly belong to *G. deserticola*, and in addition to *G. heterosporum* Smith & Schenck and

Table 5. Frequency of occurrence of *Glomus occultum* in Poland and chemical properties of soils from which this species was isolated.

Plant family	Plant species	No. of soil sample (see Fig. 23)	No. of spores/ 100 g dry soil	Chemical properties			
				pH (in H_2O)	No_3	P_2O_5	K_2O (mg kg^{-1})
Cupressaceae	*Thuja occidentalis*	77	44	5.7	24	17	15
Gramineae	*Calamagrostis arundinacea*	89	2	4.8	21	16	14
	Triticum aestivum	58	1	6.7	71	24	28
Leguminosae	*Trifolium repens*	43	25	6.7	84	21	28
Rosaceae	*Crataegus monogyna*	114	2	6.2	160	22	31
		117	1	5.0	42	15	25
	Rosa canina	93	9	4.5	45	18	17
		138	1	6.7	66	20	59

S. rubiformis, and possibly to some other little known or unknown species. *G. fasciculatum* spores were found in 87 soil samples (Table 4, Fig. 24). They most often occurred singly in the soil, though samples nos. 29, 37, 58, 74, 75, 82 and 104 mainly contained sporocarps. The spore densities ranged from 1 to 689 per 100 g dry soil, and the relative densities from 0.3 to 89.6% ($\bar{x}$ = 19.4%). There was no significant correlation between soil pH and nutrients (N, P, K) and the abundance of spores of this species.

Material examined

See Table 4; specimens deposited: 155 and 1037–1044 (DPP).

Glomus occultum Walker

According to Walker (1982), *G. occultum* spores are hyaline to white, 15–100 x 20–120 µm, with 1–3 walls, of which (when 3-walled) the outermost one sloughs with age, the middle is a very thin (<1 µm) unit wall (Walker 1983), and the innermost wall is usually composed of two laminations. Morton's (1985) collections contained only 3-walled spores with a rarely sloughing outermost wall. Morton stated that the two innermost walls form a wall group rather than a single, laminated wall, since both walls separate near the subtending hypha.

The Polish collections usually have 3-walled spores, sometimes with an additional layer of debris (Figs. 18, 19). The inner two walls are usually separated near the subtending hypha, but they are adherent at some distance from this hypha, forming a wall group. No 1-walled spores were observed. There are also spores with an additional, very thin and rigid wall, which separates from the inner ones and usually fractures under the pressure of a cover glass (Figs. 20, 21). In fact, it is probably an evanescent wall of the kind described by Walker (1982), who (Walker 1983) stressed that evanescent walls can be incorrectly identified as unit walls, especially in youth. The other features correspond with the abovementioned descriptions.

G. occultum is probably globally widespread. The countries in which it has been found include the U.S.A., the Netherlands, England (Walker 1982, Miller et al. 1985, Morton 1985) and Italy (Puppi et al. 1986).

In Poland this species was found in 8 soil samples taken from under cultivated and natural plants (Table 5, Fig. 23). Its spore densities ranged from 1 to 44 per 100 g dry soil, and the relative densities ranged from 0.4 to 13.9% (av. 6.2%). The species is new to Poland.

Material examined

See Table 5; specimens deposited: 156–218 (DPP).

Acknowledgements. I wish to express my sincere thanks to the editor, Dr. M. Härkönen, and the referee, Dr. S.M. Berch (Canada), for their kind reception and careful revision of this article, particularly for constructive criticism and valuable suggestions.

References

Becker, W.N. & Gerdemann, J.W. 1977: Glomus etunicatum sp. nov. — Mycotaxon 6:29–32.

Błaszkowski, J. 1989: Z badań nad występowaniem Endogonaceae w Polsce. — Biul. Lubel. Tow. Nauk (in press).

Bloss, H.E. & Walker, C. 1987: Some endogonaceous mycorrhizal fungi of the Santa Catalina Mountains in Arizona. — Mycologia 79:649–654.

Dalpé, Y., Granger, R.L. & Furlan, V. 1986: Abondance relative et diversité des Endogonacées dans un sol de verger du Québec. — Canadian J. Bot. 64:912–917.

Hetrick, B.A.D. & Bloom, J. 1983: Vesicular-arbuscular mycorrhizal fungi associated with native tall grass prairie and cultivated winter wheat. — Canadian J. Bot. 61:2140–2146.

Koske, R.E. 1985: Glomus aggregatum emended: a distinct taxon in the Glomus fasciculatum complex. — Mycologia 77:619–630.

Koske, R.E. 1987: Distribution of VA mycorrhizal fungi along a latitudinal temperature gradient. — Mycologia 79:55–68.

Miller, D.D., Domoto, P.A. & Walker, C. 1985: Mycorrhizal fungi at eighteen apple rootstock plantings in the United States. — New Phytol. 100:379–391.

Morton, J.B. 1985: Variation in mycorrhizal and spore morphology of Glomus occultum and Glomus diaphanum as influenced by plant host and soil environment. — Mycologia 77:192–204.

Morton, J.B. 1986: Three new species of Acaulospora (Endogonaceae) from high aluminium, low pH soils in West Virginia. — Mycologia 78:641–648.

Morton, J.B. 1986: Effects of mountants and fixatives of wall structure and Melzer's reaction in spores of two Acaulospora species (Endogonaceae). — Mycologia 78:787–794.

Puppi, G., Chiapperi, F., Tabacchini, P., Sanvito, A. & Carpigo, F. 1986: Endogonaceae del litorale tirrenico. — Micol. Italiana 2:7–14.

Schenck, N.C. & Smith, G.S. 1981: Distribution and occurrence of vesicular-arbuscular mycorrhizal fungi on Florida agricultural crops. — Soil Crop Sci. Florida, Proc. 40:171–175.

Schenck, N.C. & Smith, G.S. 1982: Additional new and unreported species of mycorrhizal fungi (Endogonaceae) from Florida. — Mycologia 74:77–92.

Sylvia, D.M. 1986: Spatial and temporal distribution of vesicular-arbuscular mycorrhizal fungi associated with Uniola paniculata in Florida foredunes. — Mycologia 78:728–734.

Walker, C. 1982: Species in the Endogonaceae: a new species (Glomus occultum) and a new combination (Glomus geosporum). — Mycotaxon 15:49–61.

Walker, C. 1983: Taxonomic concepts in the Endogonaceae: spore wall characteristics in species descriptions. — Mycotaxon 18:443–445.

Walker, C. & Koske, R.E. 1987: Taxonomic concepts in the Endogonaceae 4. Glomus fasciculatum redescribed. — Mycotaxon 30:253–262.

Zak, J.C., Danielson, R.M. & Parkinson, D. 1982: Mycorrhizal fungal spore numbers and species occurrence in two amended mine spoils in Alberta, Canada. — Mycologia 74:785–792.

Received on 15 January 1989