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The spore densities of Arbuscular mycorrhizal fungi related to the Soils collected from Polluted and Unpolluted areas

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오염지역과 비오염지역의 토양에 관한 Arbuscular mycorrhizal fungi의 포자밀도

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ABSTRACT: Ecological variations of Arbuscular mycorrhizal (AM) fungi were determined from the soils collected from different sites of the polluted and unpolluted areas related to the soil pollutions. Average 24.5 spores (per 20 g)$^{-1}$ soil of AM fungal spore were counted from the 32 sites of soils collected from On-san (polluted), whereas average 4.1 spores (per 20 g)$^{-1}$ soil from the 18 sites of those from Mt. Kwanak (polluted); Average 23.6 spores (per 20 g)$^{-1}$ soil of AM fungal spore were also counted from the 30 sites of soils collected from Chung-mu (unpolluted), whereas average 15.8 spores (per 20 g)$^{-1}$ soil from the 14 sites of those from Mt. Chungwang (unpolluted). The spores of AM fungi were the species of *Glomus, Gigaspora, Acaulospora* and *Scutellospora.* Among the above four genera, the species of Glomus were observed to be more abundant than the other genera in the soils collected from On-san, Chung-mu and Mt. Chungwang whereas the species of *Gigaspora* in those from Mt. Kwan-ak. The parameters of soils measured showed some variations between the polluted and unpolluted areas; 12.9 to 16.4% in the soil moisture, 5.6 to 8.3% in the organic matter and 4.3 to 5.7 at soil pH (polluted to unpolluted areas, respectively). The soils collected, thereby, appeared to be more strongly acidic and also lower in the contents of soil moisture or organic matter at the polluted area than unpolluted area. Based on the ecological criteria, the species richness or species diversity had significant differences ($p<0.05$) between polluted and unpolluted area. The spore density of genus *Glomus* or *Gigaspora* was significantly different ($p<0.05$) among the soils of three different plant vegetations (conifer plants, broad leaf plants, and grass plants). Also, there were significant differences ($p<0.05$) in the species evenness or species diversity among the soils referring to three different plant vegetations. There was a direct relationship ($r^2=0.38$) between soil moisture and organic matter measured from 94 soil samples. Since there was a direct relationship ($r^2=0.22$) between organic matter and total spores, it seems to be likely to presume that mycorrhizal spores can be increased in proportion to enhanced organic matters in soils. The species richness or species diversity was inclined to increase in proportion to enhanced soil pH and total spores in soils.

KEYWORDS: Ecology, AM, AMF, Pollution, *Glomus, Gigaspora, Acaulospora, Scutellospora,* Species richness, Species diversity

Arbuscular mycorrhizal (AM) fungi were reported to form symbiotic associations with the roots of most agricultural and horticultural plants, enhancing uptakes of P, Zn,

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and Cu under conditions of nutrient deficiency (Weissenhorn *et al.*, 1995). The microminerals of Cu and Zn were observed to be retained in the roots of *Calluna vulgaris* infected by ericoid mycorrhizas, thus protecting the plants from the harmful metals (Bradley *et al.*, 1981). The increases of soybean yields were reported to be often directly correlated with increased phosphorus uptake, since AM fungi increased phosphorus uptake (Mosse, 1973). Until nowadays, little was known about their function of AM fungi in the environments containing potentially toxic concentrations of metallic elements, although many studies of AM fungi have repeatedly demonstrated their capacity to enhance nutrient capture in the rhizospheres of growths limiting quantities for the elements essential for the plants.

Apart from enhancing uptake of heavy metals (Zn, Cu, Ni, Cd and Pb), AM fungi were found to have an adverse effect on plant growth due to enhanced uptake of toxic metals when these essential metals were deficient (Killharm and Firestone, 1983). Toxic metals or substances were reported to decrease the microbial biomass, ATP concentrations and N_2-fixation in the soils of the legume-growing areas (MacGrath *et al.*, 1988). One of the main factors affecting the degree of toxicity was known to the acidic rain caused by the air pollution (Killharm and Firestone, 1983; Angle and Heckman, 1986). Low pH was reported to increase the solubility of metals available to the soils and promote their adverse effects for the plants. The marked reductions of the plant growths exposed to the acidic and metal depositions might be suggested to be resulted from either toxicity of the heavy metal to the plant or nutrient-deficiency of the plants caused by the poor development of the mycobiont under the acidic conditions (Killharm and Firestone, 1983). In this moment, the acidic conditions of soils or the depositions of heavy metals toxic to the plants were probably considered to show the adverse effects to the plants in the industrial and urban areas. Therefore, some studies have been carried out to investigate the changes of environment and vegetation by industrial urbanization in the main polluted areas in Korea (Kang, 1986 ; Annual reports published by Institute of Forestry Research, 1993, 1994). Kang (1986) investigated if vegetative changes resulted from the contaminations of atmosphere, water quality and soil condition in Ulsan-Onsan area, an industrial area. Another studies were carried out to develop techniques for monitoring the states of air pollution in the forest using lichens, a kind of fungi and to investigate their ecology in the forest of polluted or unpolluted areas (Annual reports published by Institute of Forestry Research, 1993, 1994).

Recently, the mean contents of toxic heavy metals such as Cd, Cu and As were measured in the range of 0.194~9.654 mg/kg at the soils of urban or the industrial areas, as compared with that of 0.135~3.995 mg/kg at the natural soils in Korea (Reports from Dept. of Environ., 1994). Therefore, the mean contents of the metals are determined to be remarkably higher at the soils of the industrial area (polluted) than the natural areas (unpolluted). The soil acidification has been reported to be continuously progressed in the soils of the industrial or the urban areas, and to be seriously reached to the range of pH 4. 25~4.44 in the main industrial or the urban areas in Korea (Annual Reports published by Institute of Forestry Research, 1994). Also, the acidifications of the soils were predicted to be increased with the scale of 0.2 to 0.3 every year, as compared with the statistics of pH's shown from the year of 1986.

Roughly, most plant species were reported

to be associated with some types of mycorrhiza at the 90% of the plants grown under the nature (Amaranthus *et al*, 1989). Of them, the types of mycorrhiza have been known to be mostly involved in AM fungi in Korea (Lee, 1992). Here, It was, before this work, assumed that AM fungi were involved to the plant growths related to the soil pollutions. Also, the spore densities (spore populations) of AM fungi were predicted to be sensitive to the plant growths in the soil environments of the metal-contaminated areas. Thus, our aims were to examine the populational fluctuation of AM fungal spores related to the soils of polluted and unpolluted area in Korea and to investigate whether their populational fluctuation was correlated with abiotic or biotic factors of the soils. The spore density of AM fungi was measured to be related to the soil factors, as compared with the determinants in the soils of both areas. After then, the AM fungal spores were identified on the basis of the morphological characteristics under microscopes.

Materials and Methods

Soil collection

A total of soil samples used were collected from the forests or the pastures on four localities from June to September, 1994 in Korea, after the surface litter was cleared. Of four localities, various sites of two areas were defined as "polluted areas" (On-san and Mt. Kwan-ak) whereas the rest as "unpolluted areas" (Chung-mu and Mt. Chung-wang). Unless stated, each sample was collected from the rhizospheres ranging from the depths of 0 to 30 cm under soil surface, which represented the different vegetation, soil type, or elevation. After then, the soils were sieved by the small particles (less than 2 mm) and stored at 5°C in the growth chamber (Kim and Kim, 1992).

Soil analysis of collected soils

The soil was analysed by the routine soil-analyzing method (Dept. of Environ., 1988, 1993, 1994) modified by National Institute of Environmental Research, Department of Environment, Korea. Five soil samples (collected from the soil areas surrounding the individual plant within each site) were throughly mixed to form a composite soil, and used for the collections of AM fungal spore, moisture content (dried 12 hr at 105°C), organic matters (burnt 4 hr at 600°C) or soil pH. Soil pH was determined by the pH meter after mixing soil with distilled water (1 : 5, w/v).

The identification of spores

The wet sieving or decenting method was used for the isolation of spores (Gerdemann and Nicolson, 1963). The soils collected were mixed with a 50% sucrose solution (w/v) and then adjusted to a total of 50 ml into the tube, centrifuged at 705 g for 10 minutes at 20°C. These mixtures were sieved by the mess of 300 to 38 μm and filled in the plate marking with the degrees (5×5 mm). After then, the number of spores was counted under a dissecting microscopes. The identification of AM fungal spores was made with the morphological characteristics of spores and sporocarps (Trappe, 1982; Hall and Abbott, 1981; Schenck and Perez, 1987; Morton and Benny, 1990). The spores of AM fungi mentioned above were collected again, to be identified by microscope (40X), and stored for the further works.

Results

All the spores were counted under stereoscopic microscopes (10 to 40 time magnifications), and identified to four genera such as

Table 1. Average moisture content (%), organic matter (%), pH, and spores of arbuscular mycorrhizal fungi collected from three different plant vegetations

Sites (Numbers of samples)	Moisture content	Organic matter	pH	Spores of genus counted per 20 g of soils collected				
				Glomus	*Gigaspora*	*Acaulo-spora*	*Scutel-lospora*	Total average*
Polluted area; Onsan (32)	12.91^{a}	6.21^{ab}	4.4^{a}	10.1^{a}	9.1^{a}	3.4^{a}	1.9^{abc}	24.5
Mt. Kwanak (18)	12.89^{a}	5.03^{a}	4.3^{a}	1.2^{b}	2.3^{b}	0.5^{ab}	0.1^{b}	4.1
Unpolluted area; Chungmu (30)	13.65^{a}	7.55^{bc}	5.1^{b}	11.4^{a}	8.9^{b}	2.2^{ab}	1.1^{bc}	23.6
Mt. Chungwang (14)	19.23^{b}	8.95^{c}	6.1^{c}	7.1^{ab}	6.5^{ab}	1.4^{ab}	0.8^{bc}	15.8

Each small letter at the numerical values indicated the same values analysed from the ANOVA by the programming of SPSS plus. Different letters indicated the different values of LSD at 95 % confidence level ($p<0.05$).

*These were indicated as a result of aggregating the average spore numbers of 4 genera collected from each area.

Table 2. Average moisture content (%), organic matter (%), pH, and spores of arbuscular mycorrhizal fungi collected from three different plant vegetations.

Plant vegetations (Numbers of samples)	Moisture content	Organic matter	pH	Spores of genus counted per 20 g of soils collected			
				Glomus	*Gigaspora*	*Acaulospora*	*Scutellospora*
Conifer plant (30)	13.96^{a}	7.46^{a}	4.6^{a}	12.2^{a}	12.2^{a}	2.5^{a}	1.5^{a}
Broad leaf plants (33)	15.19^{a}	6.68^{a}	4.8^{a}	6.4^{b}	5.3^{b}	1.3^{a}	0.8^{a}
Grass plants (31)	13.03^{a}	6.34^{a}	5.0^{a}	6.8^{b}	4.7^{b}	2.7^{a}	1.1^{a}

Each small letter at the numerical values indicated the same values analysed from the ANOVA by the programming of SPSS plus. Different letters indicated the different values of LSD at 95% confidence level ($p<0.05$).

Glomus, Gigaspora, Acaulospora and *Scutellospora*. As a result of spore density related with polluted areas, the spores of AM fungi averaged 24.5 spores (per 20 g)$^{-1}$ soil collected from 32 sites of Onsan area, whereas those 4. 1 (per 20 g)$^{-1}$ soil from 18 sites of Mt. Kwanak (Table 1). the spores recognized or identified as a species of *Glomus* were composed of 41% at the total of 770 spores collected from all the soils of Onsan area, whereas those as a species of *Gigaspora* of 56% among a total of 73 spores from all the soils of Mt. Kwanak. As a result of spore density related to unpolluted area, the average 23.6 spores (per 20 g)$^{-1}$ soil of AM fungi were collected from 30 sites of Chungmu area, whereas 15.8 spores (per 20 g)$^{-1}$ soil from 14 sites of Mt. Chungwang (Table 1). The spores recognized or identified as a species of *Glomus* were composed of 48% at the total of 723 spores collected from all the soils of Chungmu area, whereas those of 45% among a total of 218

Table 3. Average moisture content (%), organic matter (%), pH, and spores of arbuscular mycorrhizal fungi collected from three different plant vegetations

Sites and plant vegetation (Numbers of samples)	Moisture content	Organic matter	pH	Spores of genus counted per 20 g of soils collected			
				Glomus	*Gigaspora*	*Acaulospora*	*Scutellospora*
Vegetations in Onsan							
Conifer plants (11)	13.25	7.24	4.2	12.5	14.3	3.6	2.4
Broad leaf plants (11)	13.46	6.00	4.2	7.7	7.6	0.8	1.4
Grass plants (10)	11.95	5.31	4.8	10.2	5.2	6.1	2.0
Vegetations in Mt. Kwanak							
Conifer plants (6)	10.62	4.37	4.3	2.7	2.8	1.0	0.0
Broad leaf plants (6)	12.95	4.69	4.3	0.8	1.3	0.3	0.0
Grass plants (6)	15.13	6.02	4.2	0.2	2.7	0.2	0.2
Vegetations in Chungmu							
Conifer plants (10)	15.08	8.67	5.1	19.6	16.6	2.7	1.8
Broad leaf plants (10)	15.32	6.86	5.2	7.6	6.0	1.8	0.4
Grass plants (10)	10.57	7.12	5.2	7.1	4.0	2.0	1.1
Vegetations in Mt. Chungwang							
Conifer plants (3)	19.55	10.41	5.8	6.0	8.7	1.3	0.7
Broad leaf plants (6)	20.40	9.63	6.3	7.3	4.5	2.2	1.0
Grass plants (5)	17.62	7.26	6.2	7.4	7.6	0.6	0.6
Statistic analyses	a	a	a	ab	ab	a	a

Statistic analyses indicated that a was the different values of numericals among those collected from the areas, that b was the different values of numericals among those collected from the plant vegetations. The statistic analyses were done with ANOVA by the programming of SPSS plus by LSD at 95% confidence level ($p<0.05$).

spores from all the soils of Mt. Chungwang. The spore density was significantly different ($p<0.05$) among four locations (Table 1 and 3).

The soil acidity averaged pH 4.4 in Onsan area and pH 4.3 in Mt. Kwanak, whereas that pH 5.1 in Chungmu area and pH 6.1 in Mt. Chungwang. Therefore, both polluted areas mentioned were strongly acidic in their soil conditions referring to soil acidity (Table 1 and 3). Definitely, the soil acidity was far higher in the soils of unpolluted area than polluted area. The mean contents of soil moistures and organic matters were significantly different from each other ($p<0.05$), and more higher in the soils of unpolluted area than polluted area (Table 1 and 3). Several parameters measured here were observed to be changed between two typical areas, polluted or unpolluted. Among AM fungi collected from the soils, the spore densities of Genus *Glomus* or *Gigaspora* were significantly different ($p<0.05$) at the polluted or unpolluted areas into three different plant vegetations (Table 2 and 3). Based on three different plant vegetations, the numbers of AM fungal spores were ranged from 0.8 to 12.2 spores per 20 g of soil (Table 2).

Various spores were collected from four locations, and examined under three ecological criteria(species richness, species diversity and species evenness). Based on the species richness and species diversity of AM fungi in

Table 4. Average values of richness of species, species diversity, and evenness of species of spores of arbuscular mycorrhizal fungi collected from the four different locations[w]

Locations (Numbers of samples)	Richness of species[x]	Species diversity[y]	Evenness of species[z]
Onsan (31)	3.39[a]	1.023[a]	0.974[a]
Mt. Kwanak (18)	1.39[b]	0.23[b]	1.141[a]
Chungmu (30)	2.93[a]	0.95[a]	0.986[a]
Mt. Chungwang (14)	2.93[a]	0.86[a]	0.807[a]

Each small letter at the numerical values indicated the same values analysed from the ANOVA by the programming of SPSS plus. Different letters indicated the different values of LSD at 95 % confidence level ($p<0.05$).

[w]The data having no spores of arbuscular mycorrhizal fungi were excluded from the above.

[x]Numbers of the genera of arbuscular mycorrhizal fungi found in each soil.

[y]Shannon's index(H), see Ludwig and Reynolds(1988).

[z]Evenness index(El), see Ludwig and Reynolds(1988).

Table 5. Average values of richness of species, species diversity, and evenness of species of spores of arbuscular mycorrhizal fungi collected from three different plant vegetations[w]

Plant vegetation (Numbers of samples)	Richness of species[x]	Species diversity[y]	Evenness of species[z]
Conifer plants (30)	2.97[a]	0.86[a]	1.24[a]
Broad leaf plants (33)	2.67[a]	0.73[b]	1.00[ab]
Grass plants (27)	3.04[a]	0.87[a]	0.69[b]

Each small letter at the numerical values indicated the same values analysed from the ANOVA by the programming of SPSS plus. Different letters indicated the different values of LSD at 95 % confidence level ($p<0.05$).

[w]The data having no spores of arbuscular mycorrhizal fungi were excluded from the above.

[x]Numbers of the genera of arbuscular mycorrhizal fungi found in each soil.

[y]Shannon's index(H), see Ludwig and Reynolds(1988).

[z]Evenness index(El), see Ludwig and Reynolds(1988).

Table 6. Correlations between the two parameters measured from the 94 different soils

Parameters	OM	pH	GM	GG	AC	SC	TS
Moisture content	.3884[a]	.0926	.1472	-.0479	-.1579	-.0512	.0308
Organic matter (OM)		.1374	.2464[b]	.1200	.0378	.1327	.2275[b]
pH			.0190	-.0253	.1203	-.0708	.0266
Glomus (GM)[c]				.6281[a]	.2899[b]	.4810[a]	.9151[a]
Gigaspora (GG)[c]					.2468[b]	.4565[a]	.8075[a]
Acaulospora (AC)[c]						.2323[b]	.4872[a]
Scutellospora (SC)[c]							.5937[a]
Total spores (TS)[c]							

[a]Indicated the significant correlationships between the two parameters at 99.9 % confident levels.

[b]Indicated the significant correlationships between the two parameters at 99 % confident levels.

[c]The numerical values of spores collected.

Onsan area, the indice of AM fungal genus recorded 3.39 in the species richness and 1.02 in species diversity, and were calculated to be higher in Onsan area than other three lo-

Table 7. Correlations between the two parameters measured from the 90 different soils

Parameters	OM	pH	TS	R	DS	EV
Moisture content	.3850[a]	.0984	.0187	-.0021	-.0662	-.0430
Organic matter (OM)		.1406	.2276[b]	.1681	.1435	-.0270
pH			.0550	.1943[b]	.2007[b]	-.0383
Total spores (TS)				.4925[a]	.3868[a]	-.1390
Richness (R)					.8940[a]	-.2940[a]
Species diversity (DS)						-.2764[a]
Eveness(EV)						

[a]Indicated the significant correlationships between the two parameters at 99.9% confident levels.
[b]Indicated the significant correlationships between the two parameters at 99% confident levels.
[c]The numerical values of spores collected.

cations (Table 4). Significant differences ($p<0.05$) were observed for AM fungal spores in the species richness and species diversity, whereas any significant difference was not in the species evenness (Table 4). The species richness and species diversity calculated, as based on the genara of AM fungal spores, were extremely high at the area of glass plants, whereas the species evenness was high at the area of conifer plants (Table 5). There was a significant difference ($p<0.05$) in the species diversity and species evenness, respectively (Table 5).

The direct relationship ($r^2=0.38$) was calculated between the moisture content and the organic matter measuerd from each soil (Table 6 and 7). Also, the direct relationship ($r^2=0.22$) was observed between the organic matters and total spores of AM fungi (Table 6 and 7). Therefore, it seemed to be likely to presume that the AM fungal spores could be increased in proportion to enhanced organic matters at the soils. All the direct relationships were observed between total spores of a genus and those of the other genus. The species richness or species diversity was inclined to increase in proportion to enhanced soil acidities (pH) and total spores in the soil (Table 7). The more species diversity increased, the more species evenness decreased (Table 7).

Discussions

Killharm and Firestone (1983) insisted that heavy metals have been accumulated in the soil from the atmosphere by the acid rain caused by air pollution. Also, they determined that the results mentioned above resulted in the soil acidification. The mean soil pHs of the polluted area were observed to be less than pH 4.5 in the soils of Onsan area or Mt. Kwanak, whereas those of unpolluted area averaged pH 5.1 in Chungmu area and pH 6.1 in Mt. Chungwang, respectively. The above results seemed to suggest that the deposition degrees of heavy metals were far higher in the soils of polluted area than unpolluted area due to soil acidifications caused by an acidic rain.

Mycorrhizal spore populations were reported to be positively correlated with the amount of organic matters in soil (Sheikh, *et al.*, 1975 ; Hepper and Warner, 1983). These works were also consistent with our results. Perhaps spore production was related to the conditions of higher soil organic matter. Also, perhaps higher spore numbers in the poorly drained soils were correlated to stress response by the fungus, whereby stressed fun-

gi channeled a higher percentage of their available energy into spores (Khalil and Loynachan, 1994).

Though there was an exception in case of Mt. Chungwang, ecological variations in the characteristics of soil such as texture, structure, pH, drainage or moisture and management factors were considered to be coupled with variations in mycorrhizal spore density (spore population). Though Mt. Chungwang known as the unpolluted area was the highest of four locations including both polluted areas in the case of comparing soil moistures or organic matters with those of other three locations, the spore populations of Mt. Chungwang were far less than those of Onsan, polluted area. However, the moisture contents have been reported to be positively correlated with the amount of organic matters. Also, total mycorrhizal spores were increased in proportion to enhanced organic matters in the soils. The numerical values of soil moisture or organic matter from four locations were far higher in the soils of unpolluted area than in those of polluted area. Probably, higher spore numbers were speculated to be stimulated under the conditions of higher soil organic matters and soil moistures with the relation of plant vegetations. Ahn *et al* (1992) reported that the numbers of isolated AM fungal spores were ranged from 0.3 to 10.0 spores per 10g of soil at the natural or forest areas in Korea. Based upon three different plant vegetations, the numbers of mycorrhizal spores were counted to be ranged from 0.8 to 12.2 spores per 20 g of soil, resulting to be quite similar to those made by Ahn,s work.

Based on the soils collected from three different plant vegetations, the physical property was not significantly different. However, the species diversity and species evenness were reported to have a significant gap among the soils of three different plant vegetations. Miller (1979) suggested that the species diversity of AM fungi was far higher in the undisturbed area than in the disturbed area. Since four locations tested are all based upon the disturbed areas, it may be meaningless to determine whether the species diversity is far higher in the undisturbed area than in the disturbed area.

As previously mentioned, the direct relationships were calculated between total spores of a genus and the other genus of AM fungi. The results obtained seem to presume that a genus of AM fungi is symbiotic with any other genera for maintaining their life cycle in the soils. Angle and Heckman (1986) concluded that the increased heavy metal associated with the low soil pH inhibited either the soil mycorrhizal population or infection process itself, and had an adverse effect on plant growth. Undoubtly, the soil pH was far higher in the soils of the unpolluted area than polluted area. Though the soil mycorrhizal populations were irregular in four locations, the correlationships indicated that the species richness and species diversity of mycorrhizal spores were inclined to increase in proportion to enhanced soil pH.

Killharm and Firestone (1983) pointed out that the high population of AM fungi had an adverse effect on plant growth due to enhanced uptake of toxic metals caused by AM fungi in a study of the deposition of metals from the atmosphere. Though Onsan known as polluted area had the highest mycorrhizal population among four locations, Mt. Kwanak considered as another polluted area was on the contrary. Therefore, it is disputable to determine that high mycorrhizal populations are adversely effective to promoting plant growth in the soils. The adverse effect appears to take place by the complex causes of some factors in the soil. To determine if the

high population of AM fungi is adversely effective to plant growth in soils, it may be desirable to focus our attention on soil factors rather than on spore numbers. The heavy metals entering the soil from the atmosphere are generally complexed with the clay and organic fractions, and accumulated in the soil (Killharm and Firestone,1983). Especially, sandy soils are more less in the amounts of clay and organic constituents than any other sorts of soils, and may buffer increased metal availability of AM fungi caused by soil acidification. Also, it is likely to suggest that the significant relationships between mycorrhizal populations and soil factors can not be established if soil factors such as soil moisture, soil pH, soil structure or soil organic matter can not be attained up to exatly correspondent degree capable of increasing or decreasing spore production by their systematic cooperation under the soil conditions.

Leyval *et al* (1991) detected a lower sensitivity to heavy metals in indigenous AM fungi from a sludge-polluted site as compared to a reference isolate from an unpolluted soil. Gildon and Tinker (1983) found *Glomus mosseae* was resistant to high concentration of Zn and Cd in heavily polluted soils, effective in enhancing the growth of clover, and more predominant than any other species in the polluted soils. Also, Willkins (1991) suggested that heavy metal tolerance of host plant was increased by preferential binding of these metals in fungal structures for controlling an excessive uptake of Cu and Zn. Koomen and MacGrath (1990) mentioned that a number of *Glomus* species were tolerant to the high concentrations of metals in the soils. According to the distribution of mycorrhizal spores collected from polluted areas, Genus *Glomus* was superior to any other genera from the soils of Onsan, whereas Genus *Gigaspora* was more predominant than any other genera from the soils of Mt. Kwanak. Therefore, it is necessary to investigate if Genus *Glomus* or *Gigaspora* is resistant to the high concentrations of heavy metals in the soils of Onsan or Mt. Kwanak, and more predominant than any other genera in mycorrhizal abundance due to their metal-tolerance in soils. If the indigenous AM fungi are resistant to high concentrations of heavy metals in heavily polluted soils and then identified under taxonomic criteria, it is inevitable to clarify whether they have any other mechanisms for protecting the plants from harmful effects of these metals except previously mentioned mechanisms.

적 요

균근균(Arbuscular Mycorrhizal fungi)의 생태조사가 토양오염과 관련하여 오염 지역과 비오염 지역의 토양으로 부터 실시 되었다. 오염 지역인 온산의 총 32개 지역으로 부터 채집된 포자의 평균 분포수는 토양 20 g당 24.5의 수치였고, 관악산의 총 18개 지역으로 부터 채집된 토양의 포자의 평균 분포수는 토양 20 g당 4.1의 수치를 나타내었다. 비오염 지역인 충무의 총 30개 지역에서 채집된 토양의 포자의 평균 분포수는 토양 20 g당 24.5의 수치였고, 중왕산의 14개 지역의 토양에서 포자의 평균 분포수는 토양 20 g당 15.8의 수치를 나타내었다. 채집된 포자는 *Glomus, Gigaspora, Acaulospora* 그리고 *Scutellospora* 속으로 분류 되었고, 그 중에서 *Glomus*는 온산, 충무 및 중왕산 지역의 토양에서 가장 높은 분포수를 나타낸 반면 *Gigaspora*는 관악산 지역의 토양에서 가장 높았다. 토양수분 함량은 오염 지역의 토양에서 평균 12.9 %인 반면, 비오염 지역에서는 평균 16.4 %였고, 토양 유기물의 함량은 오염 지역의 토양에서 평균 5.6 %였던 반면, 비오염 지역에서는 평균 8.3 %였으며, 토양의 산도는 오염 지역과 비오염 지역에서 각각 pH 4.3과 pH 5.7을 나타내어 오염 지역의 토양은 비오염 지역의 토양보다 토양산도에 있어서 강산성의 특징을 나타낼 뿐 아니라 토양수분과 유기물의 함량에서도 비오염 지역의 토양보다 낮았

다. 생태학적 기준에 의한 종의 풍부도 및 종의 다양도의 결과는 오염 지역과 비오염 지역 사이에서 유의성($p<0.05$)을 나타냈다. *Glomus* 및 *Gigaspora*속의 포자밀도는 3부류의 식생지역으로 나누어진 토양에서 유의성($p<0.05$)을 갖고 있었으며, 종의 균등도 및 종의 다양도의 결과도 역시 유의성($p<0.05$)을 나타내었다. 전체 94개 토양으로부터 조사된 토양수분과 유기물의 함량 사이에 正의 相關($r^2=0.38$)을 나타내었다. 토양의 유기물 함량과 전체 포자수의 사이에 正의 相關($r^2=0.22$)을 나타냄에 따라 균근균의 포자는 토양의 유기물이 높아짐에 비례하여 증가하는 경향이었으며, 종의 풍부도 및 종의 다양도는 토양의 산도와 전체 포자수가 토양속에서 증가 함에 비례하여 높아지는 경향이었다.

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