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The Ecology of Plant Populations Growing on Serpentine Soils

III. Some Plant Species from North Greece in Relation to the Serpentine Problem.

By

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With 7 Figures

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Summary

BABALONAS D.,KARATAGLIS S. & KABASSAKALIS V. 1984. The ecology of plant populations growing on serpentine soils. III. Some plant species from north Greece in relation to the serpentine problem. — Phyton (Austria) 24 (2): 225—238, 7 figures. — English with German summary.

Plant material from the species *Stachys germanica* L., *Silene fabarioides* HAUSSKN., *Silene* sp., *Verbascum glandulosum* DELILE, *Scropularia canina* L. ssp. *canina*, *Alyssum murale* s. l., *Lactuca viminea* (L.) J. & PRESL. ssp. *ramosissima* BONNIER and *Rumex scutatus* L. as well as soil samples from the serpentine site of the mount Voras were analysed with regard to their content on Ca, Mg, Ni, Cr, Co, Fe, Mn, Cu, Zn and Pb respectively. The quantitative determinations were performed in root, shoots, leaves and seeds separately.

In certain cases, the levels of Ca, Mg and Ni were found to be higher within the plants than in the soil.

As for the rest of the elements appearing in the soil in small quantities, Cr. Cu and Zn occurred in small amounts within the plants, whereas Co and Pb

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were only traceable. In the case of Fe, high quantities of which are typical of a serpentine substrate, all levels within the plants exceed normal limits.

Leaves in comparison to other plant organs were found to generally accumulate to higher levels of Ca, Mg, Ni, Fe and Mn; on the contrary the shoot tends to accmulate the lower ones.

Among the plant species examined, *Alyssum murale* exhibits a strange behaviour against Ca, Mg and Ni, in particular.

Evidently, the Ca/Mg ratio was proved to be typical of serpentine soils in the soil samples (Ca/Mg < 1), but within the plant material it was found to reverse under certain circumstances.

Zusammenfassung

Babalonas D., Karataglis S. & Kabassakalis V. 1984. Die Ökologie von Pflanzenpopulationen auf Serpentinböden. III. Einige nordgriechische Pflanzenarten und das Serpentinproblem. — Phyton (Austria) 24 (2): 225—238, 7 Abbildungen. — Englisch mit deutscher Zusammenfassung.

Pflanzenmaterial von *Stachys germanica* L., *Silene fabarioides* Hausskn., *Silene* sp., *Verbascum glandulosum* Delile, *Scrophularia canina* L. ssp. *canina, Alyssum murale* s. l., *Lactuca viminea* (L.) J. & C. Presl. ssp. *ramosissima* Bonnier und *Rumex scutatus* L. sowie Bodenproben von dem Serpentinstandort auf dem Berg Voras bei Garefi wurden auf ihren Gehalt an Ca, Mg, Ni, Cr, Co, Fe, Mn, Cu, Zn und Pb analysiert, und zwar getrennt nach Wurzel, Sprosse, Blätter und Samen.

In mehreren Fällen wurden die Ca-, Mg- und Ni-Gehalte der Pflanzen höher gefunden als die des Bodes. Die übrigen, im Boden in geringen Mengen vorkommenden Elemente Cr, Cu und Zn fanden sich auch in den Pflanzen nur in geringer Menge, Co und Pb nur in Spuren. Der Gehalt an Eisen, charakteristisch für Serpentinböden, liegt in den darauf wachsenden Pflanzen überdurchschnittlich hoch. Blätter speichern Ca, Mg, Ni, Fe und Mn in höherem Maße, die Wurzeln hingegen nur in geringerem. *Alyssum murale* zeigt gegenüber Ca, Mg und Ni ein abweichendes Verhalten.

Für Serpentinböden ist ein Verhältnis Ca/Ma < 1 charakteristisch, in den darauf wachsenden Pflanzen kann es sich unter Umständen umkehren.

(Editor transl.)

Introduction

Low productiveness, being one of the most characteristic trends of serpentine soils, is due to soil conditions most unfavourable for plant growth (Robinson *et al.* 1935, Shewry & Peterson 1976, Sasse 1979). These condition that several plant species encounter are such that they usually act toxically (Ernst 1965 a, b, Baumeister 1967).

Reasons responsible for this low productivity include insufficient supply with nutrients (P, K, N, Mo, Johnson *et al.* 1952, Duvigneaud 1966, Krapfenbauer 1967), unfavourable Ca/Mg ratio (Kruckeberg 1954, Sasse 1979) and presence of relatively high quantities of certain toxic metals such as Ni, Cr, Co etc. (Robinson et al. 1936, Vergnano & Hunter 1953).

There have been occasional studies with soils and with plants growing on serpentine soils in an effort to locate the above mentioned reasons. Plant species from different parts of the world have been referred to as indices or accumulators of metals such as Mg, Fe, Ni, Co, Cu, etc. (Ernst 1965 b, Ritter-Studnička & Dursun-Grom 1973, Jaffre *et al.* 1976, Brooks & Radford 1978, Brooks *et al.* 1981). Minguzzi & Vergnano (1948) mention as an example an unusual Ni concentration (10%) on dry leaves of *Alyssum bertolonii* Desf. This value is ten thousand times higher than the Ni content of plants not growing on serpentine soils.

This study aims to contribute in the investigation of the serious serpentine problem by presenting facts concerning the behaviour of certain species of the greek flora in relation to Ca/Mg ratio and heavy metals. This is to be attempted by taking into consideration that this behaviour and generally the problem as a whole depend on the peculiarities of the flora and the climatic conditions of each area. In addition heavy metal content is greatly affected by the geological genesis and alteration of the parent rock.

Research area

The material used in this study was collected from a serpentine soil located NE of the village Garefi, at the slopes of mount Voras (Nidie Planina, North of Aridea) and during a research project conducted in the years of 1979—1981 and concerned with the vegetation of the wider serpentine area of this mountain.

According to Mersier (1968) this serpentine site of mount Voras lies in an altitude of 200—1000 m and in the vicinity of limestones and schists. The serpentine part of this area, in particular, is characterized by a strong erodibility while any tree vegetation, that might develop, has *Quercus frainetto* as the dominant species. In open spaces a steppe- and meadow-like vegetation is seen to grow.

The annual rainfall reaches 751 mm, November being the most rainy month (111,5 mm) and July the least (24,7 mm). The rain distribution within the year is the following (mm):

J	F	M	A	M	J	J	A	S	O	N	D
62.6	66.7	82.5	75.7	65.8	35.3	24.7	31.1	32.5	75.5	111.5	87.1

The existing data, as regards the air temperature, show that the isothermals of 3° C in January, 13° C in April, 24° C in Juli and 14° C in October pass over the Voras range (Balafoutis 1977).

According to Walter & Lieth (in Horvat *et al.* 1974) the climate in this area is submediterranean-continental with a moderate summer aridity.

Materials and Methods

From the aforesaid region and particularly from the bushy vegetation of a landslide site looking east the following plant species were selected:

Stachys germanica L.	(*Lamiaceae*)
Silene fabarioides HAUSSKN.	(*Caryophyllaceae*)
Silene sp.	(*Caryophyllaceae*)
Verbascum glandulosum DELILE	(*Scrophulariaceae*)
Scrophularia canina L. subsp. *canina*	(*Scrophulariaceae*)
Alyssum murale s. l.	(*Brassicaceae*)
Lactuca viminea (L.) J. C. PRESL. subsp. *ramosissima* BONNIER	(*Compositae, Cichoriaceae*)
Rumex scutatus L.	(*Polygonaceae*)

During collection of these species, which took place on September 9th 1980, it was pursued that the individuals be in full growth (bearing fruits and flowers), with the exception of *Silene* sp., which was at blossom start. All species belonged to the same vegetation sample which covered an area not greater than 30 m^2. Vegetation coverage did not exceed 20%. Other plant species belonging to the vegetation sample were: *Jasione heldreichi* BOISS. et ORPH., *Cleome ornithopoides* L., *Arabis turrita* L., *Lactuca seriola* L., *Onosma montana* SIBTH & SM., *Nigella arvensis* NYMAR, *Euphorbia taurinensis* ALL. etc.

Four soil samples (0—10 cm depth) were also taken from this area for soil analyses.

All plants material was washed with distilled water, dried at 40° C and ground to a fine powder. A quantity of 0.1 g was treated with 2 ml conc. HNO_3 for 15 min. It was then heated to about 120° C, 1 ml of H_2O_2 added and heat continued up to 160° C. After complete decomposition, the digest was filtered to a 50 ml volumetric flask and brought to volume with distilled water.

Soil samples were air-dried and ground to pass 2 mm sieve. Decomposition of soil samples for elemental analysis was performed by treating 0.8 g of soil with 10 ml conc. HCL for 30 min until only a residue silica persisted. A small amount of water was added and the digest remained on a sandbath for another 20 min. It was then filtered to a 50 ml volumetric flask and brought to volume with distilled water.

Total amounts of Ca, Mg, Fe, Ni, Cr, Cu, Mn, Zn, Co and Pb were determined in plant materials and soils as well using the atomic absorption spectrophotometer (Perkin Elmer 503) after appropriate dilution.

pH measurements were made in soil-paste by means of a glass electrode.

Results and discussion

It must be pointed out that the study of the examined plant species behaviour towards soil chemical conditions does not concern species grown exclusively on serpentine soils (serpentine plants). Plant species collection was a random one and based on the fact that plant species should be at about the same growth stage and end their biological cycle. In this way they could be considered members of the vegetation of this serpentine area.

Soil analyses

Total elemental of soils used, along with their pH values are shown in Table 1. It is evident that the Ca/Mg ratio is lower than unity due to the increased concentration of Mg in the soil.

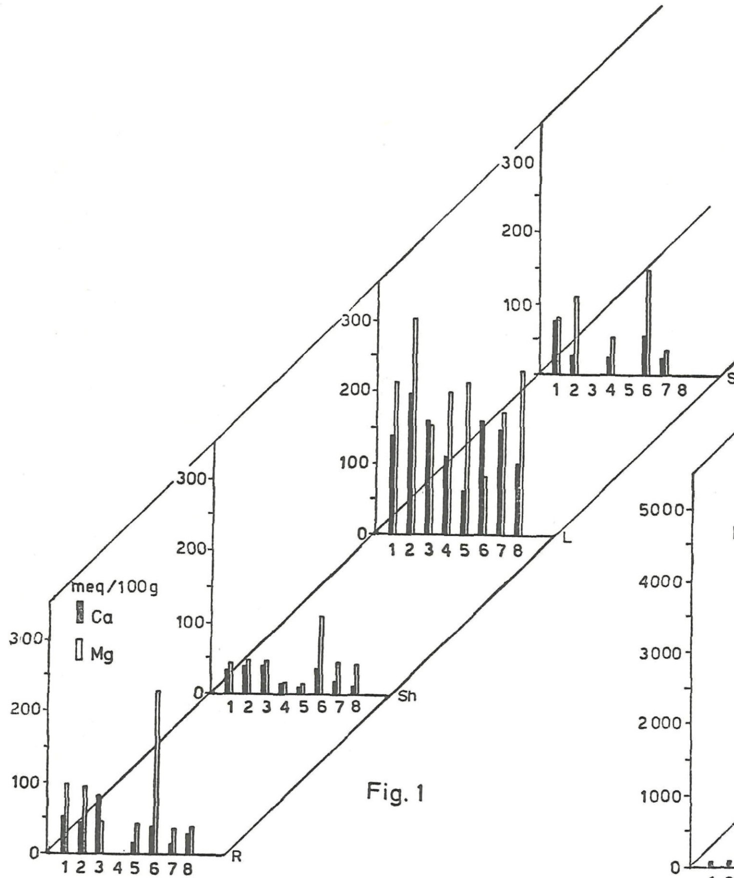
Table 1
Results of chemical analyses in soil samples

Sample No	M 10	M 11	M 12	M 13
Depth (cm)	0–10	0–10	0–10	0–10
pH	7.5	7.3	7.0	6.9
Ca (meq/100 g)	11.18	2.20	6.14	4.79
Mg (meq/100 g)	88.38	84.18	42.44	138.74
Ca : Mg	0.13	0.03	0.04	0.03
Ni (ppm)	1473	728	2093	2039
Cr (ppm)	476	167	92	737
Fe (ppm)	10355	72753	2310	44650
Mn (ppm)	1227	1516	1231	1098
Cu (ppm)	144	77	37	50
Zn (ppm)	52	79	40	30
Co (ppm)	86	85	98	69
Pb (ppm)	18	55	31	25

An increased concentration of Ni, Fe and Mn is observed in comparison with normal soils. Specifically Ni, which is known to be toxic, exists in quantities higher than 500 ppm which is considered the highest level for normal soils (Swaine 1955).

The other elements, though toxic, were found in small quantities (mean values: Cr: 368 ppm, Co: 84 ppm, Cu: 75 ppm, Zn: 52,5 ppm, Pb: 32,3 ppm). These values, however, exceed normal limits in most cases (Brooks 1972).

All properties concerning the studied soil and especially the low Ca status and the high Mg and Ni concentrations, characterize generally all serpentine soils and constitute inhibitory factors to the development of most plant species (Proctor 1970, 1971).



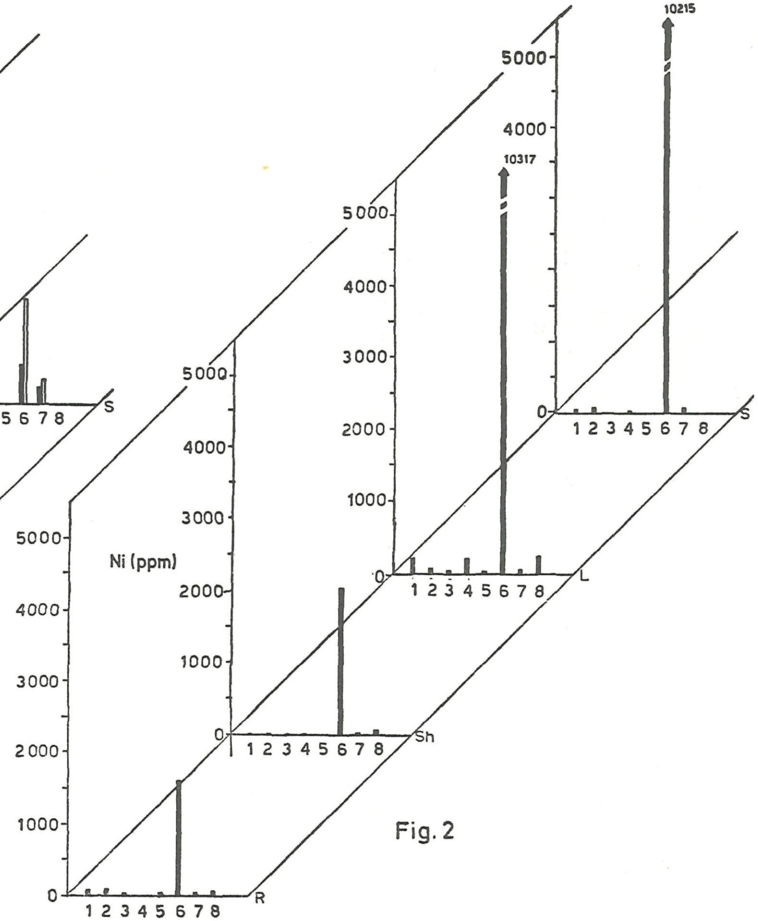


Fig. 1. Ca and Mg concentrations in different parts of the investigated plants. 1 = *Stachys germanica*, 2 = *Silene fabarioides*, 3 = *Silene sp.*, 4 = *Verbascum glandulosum*, 5 = *Scrophularia canina* ssp. *canina*, 6 = *Alyssum murale*, 7 = *Lactuca viminea* ssp. *ramosissima*, 8 = *Rumex scutatus*. R = root, Sh = shoot, L = leaves, S = seeds

Fig. 2. Ni concentrations in different parts of the investigated plant species. Symbols see Fig. 1.

It has not been entirely clarified whether Fe, usually contained in high amounts on serpentine soils, affects plants toxically (RITTER—STUDNIČKA & DURSUN-GROM 1973). SASSE (1979) suggests that Fe as well as Mn, though found in high amounts on these soils, are not available to a great extent because of the high pH (ordinarily > 7) resulting in the formation of sparingly soluble oxides.

Analyses of plant material

All plant parts (root, shoot, leaves, seeds) of the species studied displayed a Ca concentration much larger than that of the soil (Table 1). Mg behaves similarly in most of the cases. The Ca/Mg ratio, which is smaller than unity and characterizes the soil, continues to be so even within the plant parts, the only difference being the somewhat higher absolute values. In 3 cases (roots and leaves of *Silene* sp., leaves of *Alyssum murale*) the values of this ratio appear to be higher than unity (1,80 1,05 and 1,97 respectively). This slight increase in Ca/Mg ra-

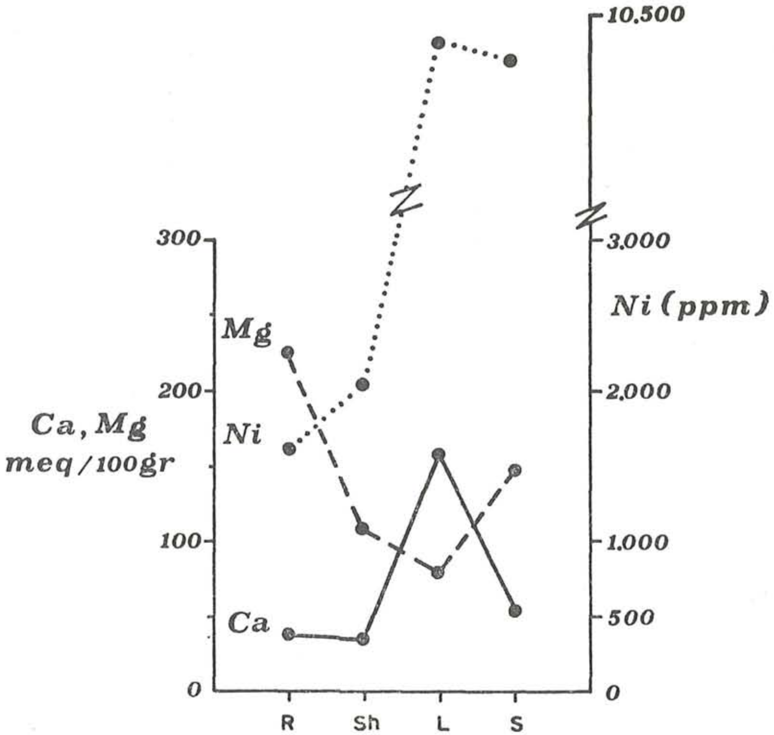


Fig. 3. Ca, Mg and Ni concentrations in different parts of *Alyssum murale*. R = root, Sh = shoot, L = leaves, S = seeds

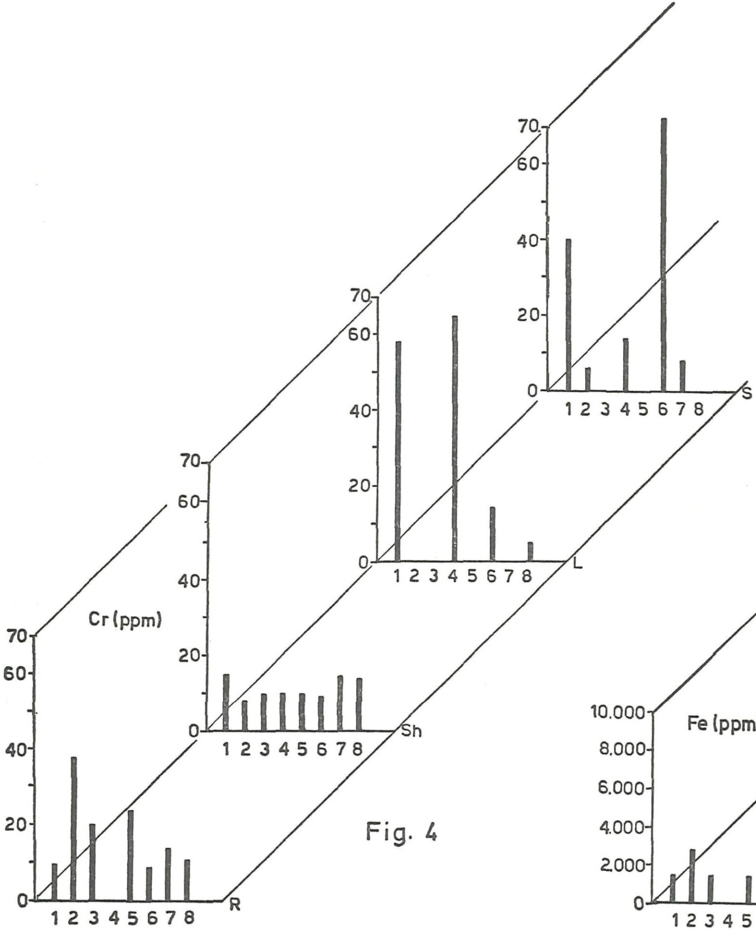


Fig. 4

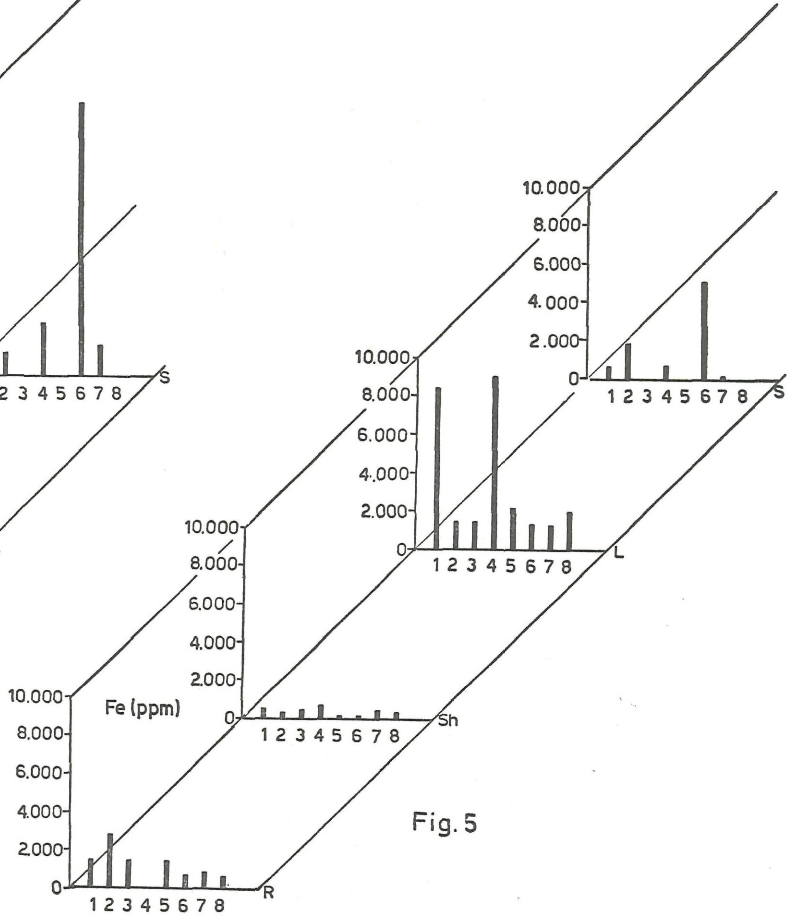


Fig. 5

Fig. 4. Cr concentrations in different parts of the investigated plant species. Symbols see Fig. 1
Fig. 5. Fe concentrations in different parts of the investigated plant species. Symbols see Fig. 1

tio values within plants can be explained by the fact that plants accumulate Ca because it functions antagonistically not only to Ni but also to the other heavy toxic metals (PROCTOR & WOODELL 1975, KARATAGLIS 1981, KARATAGLIS *et al.* 1982).

Judging from analyses specifically concentration do not only exist between various plant species but also between parts of each species (Fig. 1). Leaves show the highest Ca and Mg concentrations while the shoot the lowest. *Alyssum murale,* known as a serpentine plant, exhibits quite a peculiar behaviour as regards Mg. Its leaves present the lowest Mg concentration and its root the highest. Compared to the other plant species investigated, *A. murale* shows the higest Ca/Mg ratio (leaves: 1,97) and the lowest as well (root: 0,17).

The group of the following three elements, namely Ni, Cr and Co, is considered by some investigators to be the main cause of peculiarity characteristic of serpentine flora and vegetation (ROBINSON *et al.* 1935, TAKAGISHI *et al.* 1973, SASSE 1979 etc.).

From all plant species studied, *Alyssum murale* is distinguished for much higher Ni concentrations (Fig. 2). It is known that it belongs to Section Odontarrhena, the species of which are heavy metals and especially Ni accumulators (BROOKS & RADFORD 1978, MORRISON *et al.* 1979).

The mean Ni concentration of this species reaches up to 6048,5 ppm ranging from 1611 (roots) to 10317 ppm (leaves). It should be noted that the Ni concentration in leaves is 6,5 times higher than the mean soil concentration.

Ni concentration in the remaining seven species was much lower ranging from traces to 252 ppm. *Stachys germanica,* Silene sp., *Verbascum glandulosum, Alyssum murale, Rumex scutatus* contained the higher Ni concentration in leaves, *Silene fabarioides, Scrophularia canina* in roots and *Lactuca viminea* in seeds.

An examination of the Ca and Ni content, found in different parts of *A. murale,* revealed a direct relationship between the two elements (Fig. 3), although further experimentation is required to substantiate this relationship. Mg content is related in the opposite way to Ca and Ni content (Fig. 3). This proportional relationship between Ca and Ni can be explained by the antagonistic effect of Ca to Ni toxitity, which constitute one of the main adverse conditions in serpentine soils.

Besides the relationship between Ca and Ni observed in *A. murale* is in agreement with the experimental results of BROOKS *et al.* (1981) that the amounts of Ca taken up by plants are independent of the amounts of the element in the soil and are regulated by the amount Ni taken up. The same investigators also suggest that Mg uptake does not depend on

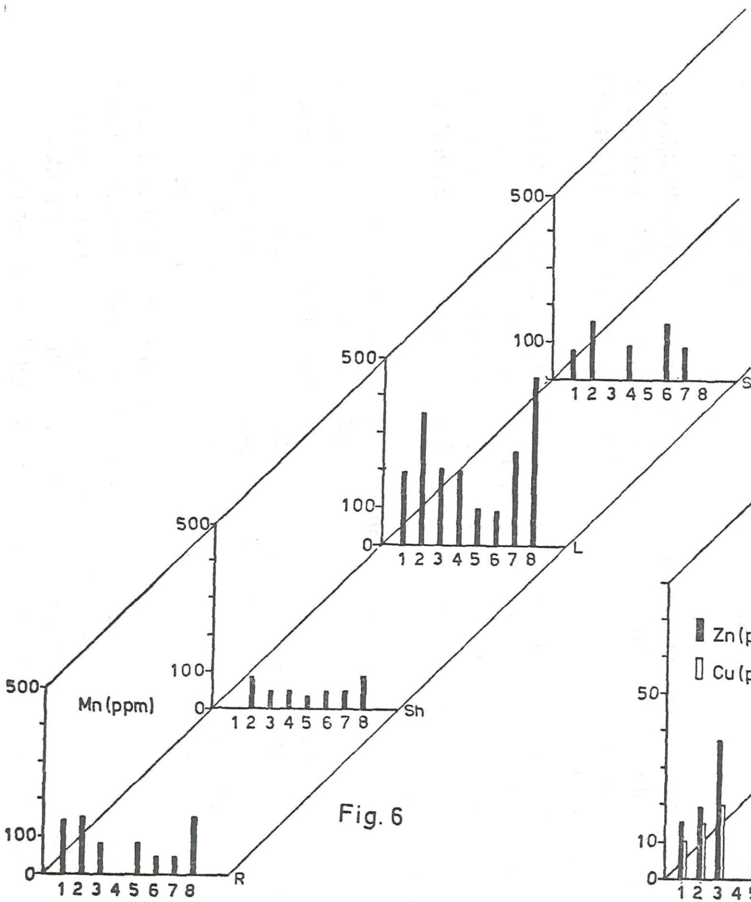


Fig. 6

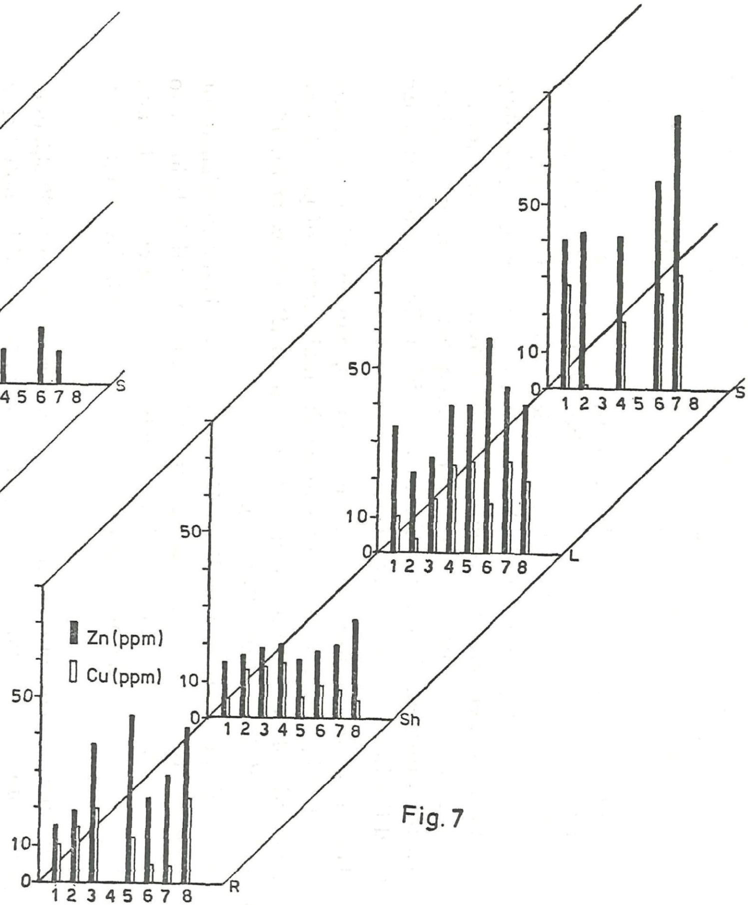


Fig. 7

Fig. 6. Mn concentrations in different parts of the investigated plant species. Symbols see Fig. 1

Fig. 7. Zn and Cu concentrations in different parts of the investigated plants. Symbols see Fig. 1

Ni uptake but is more passively reserved and in proportion to soil Mg concentrations. Such an independence is not evident in our case (Fig. 3).

Cr concentrations in all plant materials ranged from traces to 72 ppm and were smaller than the quantities existing in the soil and much lower than those of Ni. Based on analysed materials the highest values are displayed by the roots in 3 species, the shoot in 2 species, the leaves in 2 species and the seeds in one (Fig. 4).

Comparing Ni to Cr content of the leaves of 8 plant species examined, we observe that Ni shows a higher concentration in leaves (higher amounts in 5 out of the 8 species studied), whereas Cr a lower one (higher quantities in only two species, with 4 species containing only traces). Such a fact is found to be in agreement with LÖTSCHERT (1969) that Ni is likely to be stored in the most active areas around the stomata and Cr in parts away from the leaves.

Finnally, Co, the third element of this toxic group, was found in traces only and not in any sufficient amount in most of the cases.

Excessive and consequently toxic levels of Fe in plants have not clearly been established. RITTER-STUDNIČKA & DURSUN-GROM (1973) have found that Fe content of the same plant species developed on serpentine and limestone soils, very rarely exceed the 1000 ppm when developed on limestone soils.

If we take the 1000 ppm as basis for comparison, the amounts of Fe found in the plant species examined can be characterized as very high. In the leaves, where the six out of the eight species exhibit the higher concentrations, values range between 1360 and 9070 ppm. *Silene fabarioides* and *Alyssum murale* exhibit higher concentrations in the roots (2850 ppm) and the seeds (5107 ppm) respectively (Fig. 5).

Fe and other elements tend to accumulate in higher amounts in the leaves of most plants and in lower amounts in the shoot. Generally it can be said that a great variation of values exist between species and parts of each species as well.

The results of this study and particularly the leaf Fe content, indicate that the high Fe content of plants is not a unique characteristic of the serpentine flora in Bosnia as concluded by RITTER-STUDNIČKA & DURSUN-GROM (1973). High Fe contents reported by the mentioned investigators are almost identical to those found in this study. This characteristic should be given some further attention and it may probably be applicable to all the serpentine flora of the Balkans.

From the rest of the elements Pb was detected in traces in almost all plant materials, while Mn, Cu and Zn in relatively small amounts (Figs. 6 and 7). In the case of Mn, the higher amounts are found in the leaves with the only exception of *A. murale*, where the higher Mn amounts are found in the seeds (Fig. 6). The values in leaves range from 96 to 454 ppm in different species while in other plant parts range from traces to 157 ppm. Mn amounts within plants were found to be much lower than those in the soil (mean soil value 1268 ppm) a fact which can be attributed to the soil pH (mean value 7). At this pH Mn forms insoluble oxides resulting in reduced availability.

Conclusions

From the plant material examined it seems that each plant species behaves in a special way with respect to each chemical factor of the serpentine substrate. Considering also the variation of element content of the studied species no general rule can be deduced. Nevertheless, certain tendencies are distinguished. So in most cases the leaves accumulate the higher amounts of Ca, Mg, Fe, Ni and Mn and the shoot the lower ones.

Ca, Mg and Ni were found in plants (at least in one of the observed plant part) in higher levels than in soil.

Cr, Cu, Co, Zn and Pb, although existing in small amounts in the soil, were found either in small quantities within the plants (Cr, Cu, Zn) or in traces (Co, Pb).

Storage of the much toxic Ni seems to be a characteristic of certain plant species only. *Alyssum murale* behaves differently from the 8 plant species examined in this study. Besides the fact that it accumulates Ni 50 higher levels than those in the soil, this species has also shared a somewhat peculiar behaviour as regards the Ca/Mg ratio. It gave the lowest value of this ratio (roots) as well as the highest (leaves) than all the species, something attributed to interactions occuring among Ni, Ca and Mg.

The Ca/Mg ratio typical of serpentine soils (< 1) is maintained as such even within plants with the axception of certain instances where it is inversed. This is accounted for by the acceptance that plants accumulate more Ca than they need in their antagonistic action against toxic metal.

Finally the Fe quantities within plants, though smaller than the ones in the soil, are considered to be excessive but their toxicity is still open to debate.

References

Balafoutis C. 1977. Beitrag zum Studium des Klimas von Mazedonien und Westthrazien. — Dissertation Thessaloniki (griech.).

Baumeister W. 1967. Schwermetall-Pflanzengesellschaften und Zinkresistenz einiger Schwermetallpflanzen. — Angewandte Botanik 40: 185—204.

Brooks R. 1972. Geobotany and Biogeochemistry in mineral exploration. — Harper and Row, New York.

BROOKS R. & RADFORD C. 1978. Nickel accumulation by European species of the genus *Alyssum*. — Proc. R. Soc. Lond. B. 200: 217—224.

—, SHAW S. & ASENSI-MARFIL A. 1981. Some observations on the ecology, metal uptake and nickel tolerance of *Alyssum serpyllifolium* Subspecies from the Iberian peninsula. — Vegetatio 45: 183—188.

DUVIGNEAUD P. 1966. Note sur la biogéochemie des serpentines du sudouest de la France. — Bull. Soc. Bot. Belg. 99: 271—239.

ERNST W. 1965 a. Ökologisch-soziologische Untersuchungen der Schwermetall-Pflanzengesellschaften Mitteleuropas unter Einschluß der Alpen. — Abh. Landesmus. Naturk. Münster 27: 1—54.

— 1965 b. Über den Einfluß des Zinks auf die Keimung von Schwermetallpflanzen und auf die Entwicklung der Schwermetallpflanzengesellschaft. — Ber. Deutsch. Bot. Ges. 78: 205—212.

HORVAT I., GLAVAČ V. & ELLENBERG H. 1974. Vegetation Südosteuropas. — G. Fischer, Jena.

JAFFRE T., BROOKS R., LEE J. & REEVES R. D. 1976. *Sebertia acuminata*, a Nickel-accumulating plant from New Caledonia. — Science 193: 579—580.

JOHNSON C. M., PEARSON G. A. & STOUT R. R. 1952. Molybdenium nutrition of crop plants. — Soil Sci. 4: 178—196.

KARATAGLIS S. 1981. Influence of the soil Ca on the tolerance of *Festuca rubra* populations against toxic metals. — Phyton 21: 103—113.

—, BABALONAS D. & KABASSAKALIS B. 1982. The ecology of plant populations growing on serpentine soils. II. Ca/Mg ratio and the Cr, Ni, Co, Fe concentrations as development factors of *Buxus sempervirens*. — — Phyton 22: 317—327.

KRAPFENBAUER A. 1967. Eine autökologische Studie eines Serpentinstandortes im Dunkelsteinerwald und ein Gefäßversuch mit *Pinus silvestris* und *Pinus nigra* var. *austriaca* auf Serpentinboden. — CBl. ges. Forstw. 84: 207—230.

KRAUSE W. 1958. Andere Bodenspezialisten. — In: RUHLAND W. (ed.) Handb. Pfl. Physiol. 4: 755—806.

—, LUDWIG W. & SEIDEL F. 1963. Zur Kenntnis der Flora und Vegetation auf Serpentinstandorten des Balkans 6. Vegetationsstudien in der Umgebung von Mantoudi (Euböa). — Bot. Jb. 82: 337—403.

KRUCKEBERG A. R. 1954. Plant species in relation to serpentine soils. — Ecology 35: 267—274.

LÖTSCHERT W. 1969. Pflanzen an Grenzstandorten. — G. Fischer, Stuttgart.

MERCIER J. 1968. Etude géologique des zones internes des Hellenides en Macédoine centrale. Contribution à l'étude du metamorphisme et de l'évolution magmatique des zones internes des Hellenides. — Ann. Geol. Pays Hell. 20: 1—792.

MINGUZZI C. & VERGNANO O. 1948. Il contenuto di nichel nelle ceneri di *Alyssum bertolonii* DESV. — Memorie Soc. tosc. Sci. nat. 55: 49—74.

MORRISON R. S., BROOKS R. R., REEVES R. D., DUDLEY T. R. & AKMAN Y. 1979. Hyperaccumulation of nickel by *Alyssum* Linnaeus (*Cruciferae*). — Proc. z. Soc. Lond. Sec. B. 203: 387—403.

PROCTOR J. 1970. Magnesium as a toxic element. — Nature, Lond. 227: 742—743.

PROCTOR J. 1971. The plant ecology of serpentine III. The influence of a high Mg/Ca ratio and high nickel and chromium levels in some British and Swedish serpentine soils. — J. Ecol. 59: 827—842.

— & WOODELL S. R. J. 1975. The ecology of serpentine soils. — Adv. ecol. Res. 9: 256—365.

RITTER-STUDNIČKA H. & DURSUN-GROM K. 1973. Über den Eisen-, Nickel- und Chromgehalt in einigen Serpentinpflanzen Bosniens. — Österr. Bot. Z. 121: 29—49.

ROBINSON W., EDINGTON G. & BYERS H. 1935. Chemical studies in infertile soils derived from rocks high in magnesium and generally in chromium and nickel. — Tech. Bull. U. S. Dept. Agric. 471: 1—28.

SASSE F. 1979. Untersuchungen an Serpentinstandorten in Frankreich, Italien, Österreich und der Bundesrepublik Deutschland. I. Bodenanalysen. — Flora 168: 379—395.

SHEWRY P. & PETERSON P. 1976. Distribution of chromium and nickel in plants and soil from serpentine and other sites. — J. Ecol. 64: 195—212.

SWAINE D. J. 1955. The trace-element content of soils. — Tech. Commun. Commonw. Bur. Soils No 48.

TAKAGISHI H., HIGASHINO S. & JIZUKA T. 1973. Studies on the abnormal features of mulberry plants growing on the soil derived from serpentine. Part I. — Nippon Sanshigaku zasshi 42: 135—143.

VERGNANO D. & HUNTER J. G. 1953. Nickel and cobalt toxicities in oat plants. — Ann. Bot. 17: 317—328.