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Dedicated to Prof. dr. LJUDEVIT ILIJANIĆ on the occasion of his 70th birthday.

Chemical composition of the plants of loess steppes in Hungary

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The first two stages of the successional series on loess (*Agropyro-Kochietum*, *Salvio-Festucetum rupicolae*) differ from each other in their floristic composition, the total element content of their soils and plant species as well as their water demand. *Chrysopogon gryllus*, a characteristic species of the loess steppe, belongs to the calciotroph physiotype according to the Ca/K ratio in its leaves. The leaves of this species contain relatively high concentrations of Ca and Mg and a low concentration of N. The high C/N ratio in the leaves and roots of *Chrysopogon gryllus* should indicate that the mineralization dynamics is slowed down in the stands dominated by this species. *Barbula cordata*, a moss species of the *Salvio-Festucetum rupicolae* community, accumulates very high amounts of heavy metals from its surroundings. In the *Agropyro-Kochietum* community, *Bromus* species accumulated the highest amounts of heavy metals in their leaves.

Key-words: semidesert, loess, steppe, grassland, plant community, chemical pomposition, *Chrysopogon gryllus*, Hungary

Introduction

Characteristic plant communities of Hungary are the semidesert community on loess walls (*Agropyro-Kochietum*) and the loess steppe grassland (*Salvio-Festucetum rupicolae*) developing on chernozem or calcic chernozem soils. The floristic composition of these communities was described by ZÓLYOMI (1958) and ZÓLYOMI and FEKETE (1994).

On steep loess walls, the post-glacial, xerotherm semidesert community (*Agropyro-Kochietum*) has developed with a relict character. Its field layer has a 60–70% coverage. In addition to annuals it is composed of perennial herbs,

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shrubs and undershrubs in a significant number. Its floristic composition is relatively stable, having *Agropyron pectiniforme* and *Bassia prostrata* as characteristic species. The dynamics of the community is rather slow and on steep loess walls it seems to have been stable for thousands of years (MOLNÁR 1999).

If this community develops on plain loess areas, it can be considered the first stage of a successional series. In this case the second stage of the successional series is loess steppe grassland (*Salvio-Festucetum rupicolae*) with an 80–90% field layer coverage and the frequent presence of the species *Elymus hispidus* and *Festuca rupicola*. Recently, in some places *Chrysopogon gryllus* has been spreading. Nowadays, characteristic loess steppe grasslands can be found already on very limited areas, several of which have become degraded.

Materials and methods

The investigation of the chemical element composition of the plant components of loess steppes in Hungary was carried out under the organization of the International Association for Ecology (INTECOL) and the International Union of Biological Sciences (IUBS) in the context of the international research program «Element Concentration Cadasters in Ecosystems« (ECCE).

The frequent and characteristic species of the two plant communities as well as the soil profiles belonging to them, were sampled at the border of the village Érd, to the south of Budapest. Sampling was carried out according to the prescriptions of the international program (LIETH and MARKERT 1985, 1988; MARKERT 1986). In addition, sampling of soils and plants in grassland areas dominated by *Festuca valesiaca* and *Chrysopogon gryllus* was carried out in 8 patches, each having the same soil type and spread over several square meters in contact with each other.

The following species of the *Agropyro-Kochietum* community were subjected to multielement analysis: *Ephedra distachya*, *Artemisia austriaca*, *Erodium cicutarium*, *Bassia prostrata*, *Linaria genistifolia*, *Sedum telephium* subsp. *maximum*, *Xeranthemum annuum*, *Iris pumila*, *Agropyron pectiniforme*, *Elymus hispidus*, *Bromus squarrosus*, *B. tectorum*, *Festuca valesiaca* and *Stipa capillata*. Characteristic species of the communities are underlined.

The species of the *Salvio-Festucetum rupicolae* community investigated were as follows: *Ephedra distachya*, *Achillea pannonica*, *Artemisia campestris*, *Aster linosyris*, *Brassica elongata*, *Cephalaria transsylvanica*, *Chrysopogon gryllus*, *Chamaecytisus austriacus*, *Nepeta nuda*, *Peucedanum alsaticum*, *Phlomis tuberosa*, *Plantago media*, *Potentilla incana*, *Salvia nemorosa*, *Thymus odoratissimus*, *Allium sphaerocephalon*, *Agropyron pectiniforme*, *Elymus hispidus*, *Festuca rupicola*, *Festuca valesiaca* and *Barbula cordata*.

Following separation of the different organs (roots, stems and leaves) of the plants, they were subjected to a thorough tap-water wash. Samples were dried at 70°C. Ashing was carried out with nitric acid and hydrogen peroxide in teflon-bombs. With an ICP–AES, at the Department of Chemistry of the Horticultural University in Budapest, the amounts of the following elements in the soil and plant samples were established: Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, Ga, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Se, Si, Sr, Ti, V and Zn. Minimal detection limits of the separate elements were in μg g^{-1} as follows: Al: 0.0015; As: 0.0003; B: 0.0003; Ba: 0.0001; Ca: 0.0010; Cd: 0.0003; Co: 0.0006; Cr: 0.0005; Cu: 0.0003; Fe: 0.0003; Ga: 0.0024; K: 0.0050; Li: 0.0020; Mg: 0.0015; Mn: 0.0001; Mo: 0.0002; Na: 0.0500; Ni: 0.0003; P: 0.0750; Pb: 0.0025; Se: 0.0030; Si: 0.0025; Sr: 0.0001; Ti: 0.0002; V: 0.0002; Zn: 0.0001. The overall amount of these elements in the plant samples is mentioned in the present work as «total element content«. The total nitrogen content was measured with the standard Kjehldahl method. The amount of this element was not added to the «total element content«. The present evaluation is based chiefly on the results of the leaf investigations. All data are presented in μg g^{-1} dry weight.

Results and discussion

The *Agropyro-Kochietum* and *Salvio-Festucetum rupicolae* communities are situated on skeleton and chernozem soils, respectively, both formed on loess. The total element contents of the uppermost soil layers of both communities are high. The uppermost 10 cm soil layer is particularly rich in Ca (Tab. 1, 2).

Tab. 1. Chemical composition (in μg g^{-1}) of the soil of the *Agropyro-Kochietum* community

Soil layers in cm	0–10	10–20	20–30	30–40	40–50	50–60
Al	4525	4316	5106	4553	6183	5048
As	<dl*	<dl*	<dl*	<dl*	<dl*	<dl*
B	2.0	<dl*	<dl*	<dl*	<dl*	<dl*
Ba	64.4	53.9	52.7	51.6	56.8	61.7
Ca	68264	8614	8061	9147	9521	10252
Cd	1.3	1.1	1.2	1.1	1.4	1.2
Co	5.1	4.9	5.4	4.9	5.9	5.4
Cr	8.6	7.8	2.3	8.2	11.0	9.3
Cu	17.8	12.8	16.2	11.1	12.4	11.0
Fe	5208	5014	5892	5271	7320	5921
Ga	5.9	5.1	5.6	5.2	6.4	5.5
K	1668	1451	1450	1138	1203	969
Li	9.7	10.9	12.5	11.9	16.4	14.2
Mg	7175	7151	7630	7661	8628	8368
Mn	452	355	372	323	348	355
Mo	0.1	0.02	<dl*	<dl*	<dl*	<dl*
Na	61.2	51.9	53.4	56.6	62.8	66.2
Ni	21.2	17.6	19.6	18.4	22.0	19.5
P	1165	648	561	503	554	497
Pb	25.6	9.1	11.1	7.4	7.3	7.2
Se	<dl*	<dl*	<dl*	<dl*	<dl*	<dl*
Si	1053	822	925	776	918	825
Sr	95.6	112	115	12	128	142
Ti	22.1	13.2	15.7	11.9	13.7	11.7
V	18.9	7.5	7.9	6.9	8.2	7.2
Zn	71.9	33.7	40.4	30.6	38.0	32.6

<dl*: element concentration under the detection limit of the instrument

Tab. 2. Chemical composition (in $\mu g\ g^{-1}$) of the soil of the *Salvio-Festucetum* community

Soil layers in cm	0–10	10–20	20–30	30–40	40–50	50–60
Al	3762	3492	4761	3517	7433	3423
As	<dl*	<dl*	<dl*	<dl*	<dl*	<dl*
B	0.21	0.08	<dl*	<dl*	<dl*	<dl*
Ba	43.4	46.7	44 3	41.9	45.2	48.4
Ca	65343	5832	5894	9847	10371	10593
Cd	0.95	0.96	1.2	0.88	0.93	0.86
Co	5.1	4.9	5.7	5.2	5.4	5.3
Cr	7.0	6.8	9.1	6.9	7.1	6.6
Cu	8.9	9.2	8.2	5.9	5.3	5.1
Fe	4547	4314	5855	4832	4817	4424
Ga	5.1	4.9	5.7	4.6	4.9	4.5
K	606	705	654	497	493	471
Li	7.8	7.6	9.8	8.3	9.3	8.7
Mg	6505	6835	7072	6889	7930	7771
Mn	292	284	307	271	277	276
Mo	<dl*	0.2	<dl*	<dl*	<dl*	<dl*
Na	30.4	35.9	36.3	36.3	39.4	42.8
Ni	16.5	17.6	18.3	16.2	17.2	16.4
P	574	587	591	516	563	634
Pb	11.0	16.9	7.8	5.7	5.0	4.9
Se	<dl*	<dl*	<dl*	<dl*	<dl*	<dl*
Si	962	967	1182	878	862	809
Sr	72.2	79.8	77.5	87.4	99.5	105
Ti	16.5	17.3	18.7	13.7	12.7	11.9
V	10.9	7.6	7.5	5.8	6.0	5.6
Zn	9.5	29.7	28.7	22.6	22.9	22.1

<dl*: element concentration under the detection limit of the instrument

The soil profile of the *Agropyro-Kochietum* community contains more Al, Cu, Fe, K, Li, Mg, Mn, Na and Sr, than the same layer of the *Salvio-Festucetum rupicolae* community. The heavy metals are of geogenic origin, although the elevated Pb and Zn contents of the upper layers suggest that some anthropogenic impacts also contributed to the element composition of these soils. The upper soil layers contain only low amounts (0.2–0.4%) of nitrogen.

The plant species of the two communities can be well separated on the basis of the total element contents of their leaves. The species of the semidesert community on loess walls, which is considered to be the first stadium of the successional series, contain less total amounts of elements (Fig. 1) than those of the loess steppe grassland (Fig. 2). The total element content is lowest in the annual grass species, which are followed, in order of increasing element contents, by the perennial grasses as well as dicotyledons (Figs. 1, 2). The leaves of the gymnosperm dwarf shrub *Ephedra distachya* contain moderate amounts of elements. The chemical constitutions of *Agropyron pectiniforme* and *Bassia prostrata* are significantly different; the leaves of the latter contain much more Ca, K, Mg, Fe and P, than those of the first. The higher Fe content of the skeleton soil is also indicated by the investigated exemplars of *Bassia prostrata* as well as of *Agropyron pectiniforme* occurring in the *Agropyro-Kochietum* community (Tab. 3).

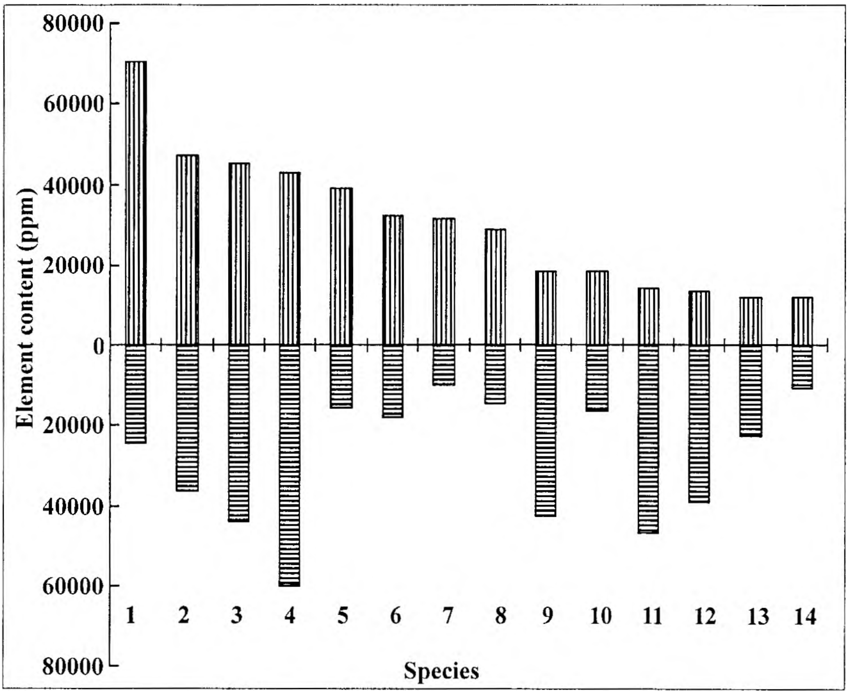

Fig. 1. Total element contents in the leaves (above the abscissa) and roots (under the abscissa) of the species of an *Agropyro-Kochietum* plant community in Hungary

Gymnospermatophyta
5. *Ephedra distachya*

Dicotyledonopsida
1. *Sedum telephium* subsp. *maximum*
2. *Bassia prostrata*
4. *Erodium cicutarium*
6. *Artemisia austriaca*
7. *Xeranthemum annuum*
8. *Linaria genistifolia*

Monocotyledonopsida
3. *Iris pumila*
9. *Elymus hispidus*
10. *Stipa capillata*
11. *Festuca valesiaca*
12. *Agropyron pectiniforme*
13. *Bromus squarrosus*
14. *Bromus tectorum*

Bromus species accumulated in their leaves the highest amounts of heavy metals amongst the investigated species in the *Agropyro-Kochietum* community (Fig. 3), whereas in the *Salvio-Festucetum rupicolae* community, besides *Barbula cordata*, a moss species, *Thymus odoratissimus*, *Potentilla incana* and *Aster linosyris* were the best accumulators of these elements (Fig. 4).

The total element content of the leaves of *Sedum telephium* subsp. *maximum* (70345 $\mu g\ g^{-1}$) is the highest amongst all the investigated species as a consequence of the large amount of Ca (44969 $\mu g\ g^{-1}$) accumulated by this plant. The K/Ca ratios within the leaves of the plants indicate that the wooded steppe plants (e.g. *Nepeta nuda* with a K/Ca ratio of 0.41 and *Phlomis tuberosa* with a K/Ca ratio of 0.74) belong to the calciotroph physiotype (KINZEL 1982).

Tab. 3. Chemical composition (in µg g^{-1}, in the case of N in %) of the leaves of *Agropyron pectiniforme* and *Bassia prostrata*

	Agropyron pectiniforme (*Agropyro-Kochietum*)	*Agropyron pectiniforme* (*Salvio-Festucetum rupicolae*)	*Bassia prostrata*
Al	172	137	241
As	<dl*	<dl*	<dl*
B	40.5	6.7	85.8
Ba	6.2	5.8	15.2
Ca	4816	4584	18851
Cd	0.14	<dl*	0.44
Co	0.17	0.23	0.66
Cr	1.1	1.1	2.3
Cu	3.6	6.3	6.9
Fe	165	107	1141
Ga	1.9	0.16	3.1
K	6443	6707	18288
Li	8.5	4.0	14.3
Mg	718	640	4543
Mn	65.9	31.8	230
Mo	<dl*	0.21	<dl*
Na	53.5	40.8	109
Ni	2.6	1.7	5.8
P	679	549	1004
Pb	3.0	1.7	6.7
Se	0.44	<dl*	<dl*
Si	162	176	139
Sr	22.5	9.9	46.0
Ti	3.9	<dl*	22.8
V	1.5	0.86	4.9
Zn	30.2	55.8	51.2
N%	1.32	1.32	1.65

<dl*: element concentration under the detection limit of the instrument

As a consequence of the relatively low N concentration in the soils the N content of the species is between 0.73% (*Iris pumila*) and 2.18% (*Erodium cicutarium*) in the *Agropyro-Kochietum*, and between 0.79% (*Plantago media*) and 2.57% (*Chamaecytisus austriacus*) in the *Salvio-Festucetum rupicolae* communities, respectively.

The total element contents in the roots of the investigated species of the *Agropyro-Kochietum* community vary within a relatively wide range (9870 µg g^{-1} in the case of *Xeranthemum annuum*, and 60172 µg g^{-1} in the case of *Erodium cicutarium*). This phenomenon is presumably in connection with the openness of the community, its low number of species, as well as the absence of concurrence amongst the roots.

In the loess steppe grassland, where the concurrence amongst the roots is relatively strong, the total element contents of the roots vary within a narrower range (with the extremes of 12895 µg g^{-1} in *Chamaecytisus austriacus* and 41641 µg g^{-1} in *Agropyron pectiniforme*). In both communities there is a con-

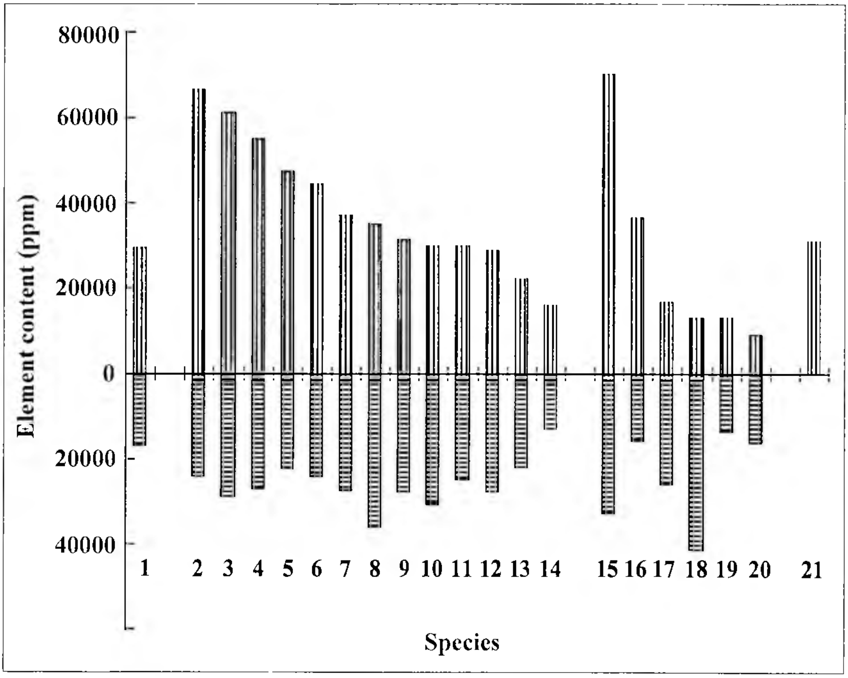

Fig. 2. Total element contents in the leaves (above the abscissa) and roots (under the abscissa) of the species of a *Salvio-Festucetum rupicolae* plant community in Hungary

Gymnospermatophyta
1. *Ephedra distachya*

Dicotyledonopsida
2. *Nepeta nuda*
3. *Plantago media*
4. *Peucedanum alsaticum*
5. *Phlomis tuberosa*
6. *Aster linosyris*
7. *Artemisia campestris*
8. *Cephalaria transsylvanica*
9. *Thymus odoratissimus*
10. *Potentilla incana*
11. *Achillea pannonica*
12. *Salvia nemorosa*
13. *Brassica elongata*
14. *Chamaecytisus austriacus*

Monocotyledonopsida
15. *Festuca rupicola*
16. *Allium sphaerocephalon*
17. *Elymus hispidus*
18. *Agropyron pectiniforme*
19. *Festuca valesiaca*

Briophyta
20. *Barbula cordata*

spicuous accumulation of relatively high amounts of heavy metals by the roots of some grass species (Figs. 3, 4) as compared with their total element contents (Figs. 1, 2).

The characteristic species of the loess steppe grassland contain in their leaves higher amounts of elements (Tab. 4) than those of the semidesert community on loess walls, first of all as a consequence of their higher Ca and Mg contents. The chemical composition of the two woody steppe species (*Nepeta nuda*, *Phlomis tuberosa*) seems to be similar to that of those exemplars investigated previously

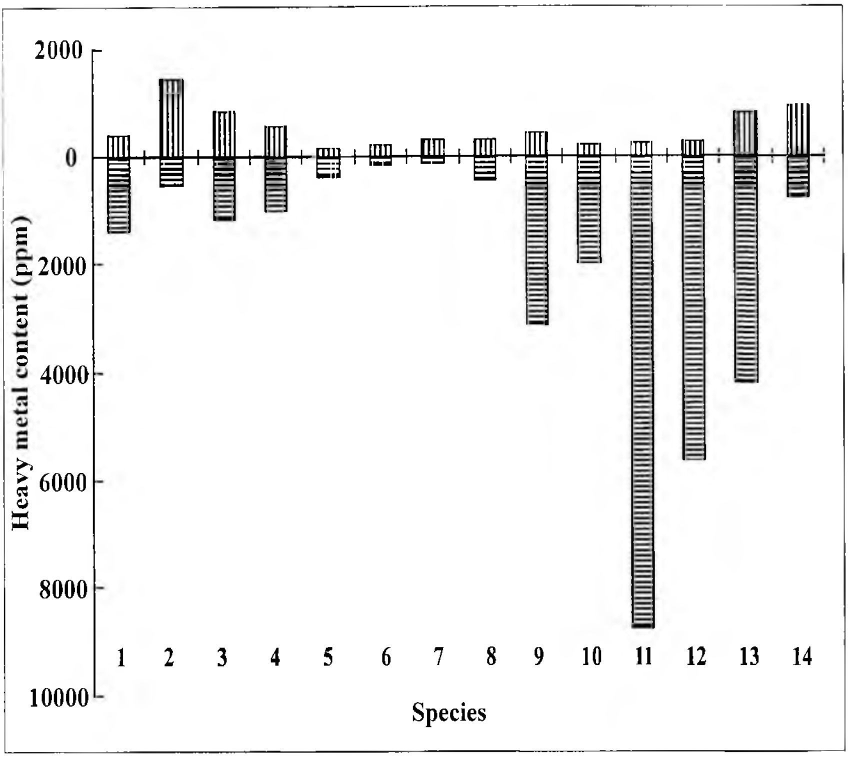

Fig. 3. Heavy metal contents in the leaves (above the abscissa) and roots (under the abscissa) of the species of an *Agropyro-Kochietum* plant community in Hungary

Gymnospermatophyta
5. *Ephedra distachya*

Dicotyledonopsida
1. *Sedum telephium* subsp. *maximum*
2. *Bassia prostrata*
4. *Erodium cicutarium*
6. *Artemisia austriaca*
7. *Xeranthemum annuum*
8. *Linaria genistifolia*

Monocotyledonopsida
3. *Iris pumila*
9. *Elymus hispidus*
10. *Stipa capillata*
11. *Festuca valesiaca*
12. *Agropyron pectiniforme*
13. *Bromus squarrosus*
14. *Bromus tectorum*

in the *Aceri tatarico-Quercetum* community (climax stage of the successional series) on a chernozem brown forest soil (KOVÁCS et al. 1993).

The higher total element content in species of the *Salvio-Festucetum rupicolae* community than in those of the previous successional stage (Figs. 1, 2) can be explained by the findings of ZÓLYOMI and FEKETE (1994), who established that the species of the *Agropyro-Kochietum* and *Salvio-Festucetum rupicolae* communities are different in respect of their W- (water requirement) values. A favourable water supply may contribute to the accumulation of more elements by the plants. Consequently, it seems that plant species constituting the different

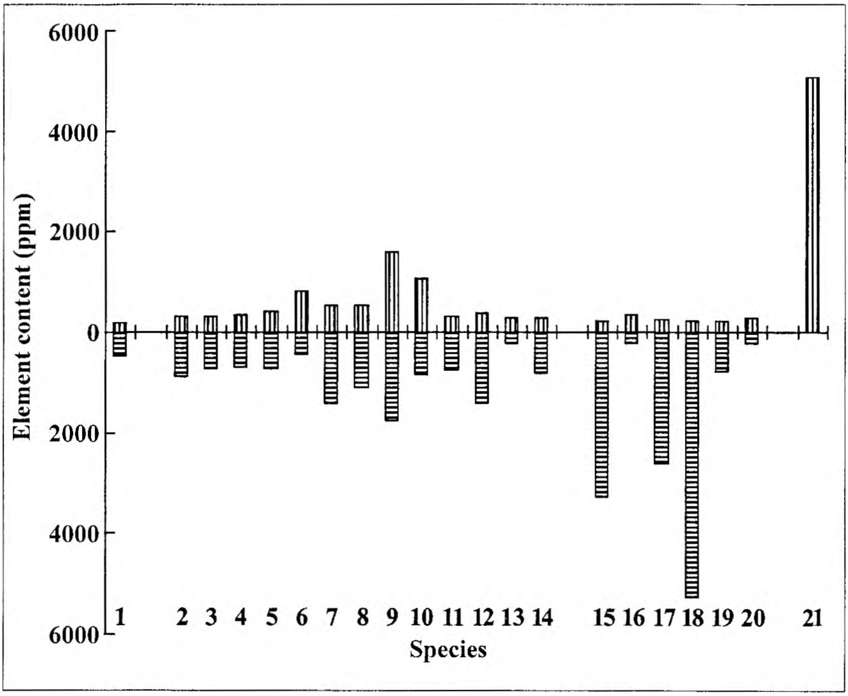

Fig. 4. Heavy metal contents in the leaves (above the abscissa) and roots (under the abscissa) of the species of a *Salvio-Festucetum rupicolae* plant community in Hungary

Gymnospermatophyta
1. *Ephedra distachya*

Dicotyledonopsida
2. *Nepeta nuda*
3. *Plantago media*
4. *Peucedanum alsaticum*
5. *Phlomis tuberosa*
6. *Aster linosyris*
7. *Artemisia campestris*
8. *Cephalaria transsylvanica*
9. *Thymus odoratissimus*
10. *Potentilla incana*
11. *Achillea pannonica*
12. *Salvia nemorosa*
13. *Brassica elongata*
14. *Chamaecytisus austriacus*

Monocotyledonopsida
15. *Festuca rupicola*
16. *Allium sphaerocephalon*
17. *Elymus hispidus*
18. *Agropyron pectiniforme*
19. *Festuca valesiaca*

Briophyta
20. *Barbula cordata*

stages of the successional series are, besides their ecological demands, different in their chemical composition.

Soils in Hungary are very poor in Se. However, this element can be detected in small concentrations (0.008–1.405 $\mu g\ g^{-1}$) in the stems and leaves of the species of some plant communities occurring on sand or loess (KOVÁCS et al. 1998).

Barbula cordata is a moss species growing on the soil surface of loess steppe grasslands. The total element content of the moss is higher than that of the inves-

Tab. 4. Chemical composition (in µg g^{-1}) of the leaves of some characteristic species of the *Salvio-Festucetum rupicolae* community

	Brassica elongata	*Nepeta nuda*	*Phlomis tuberosa*	*Salvia nemorosa*	*Barbula cordata*
Al	157	191	256	294	3380
As	<dl*	<dl*	1.0	<dl*	<dl*
B	29.0	33.1	39.9	65.0	25.8
Ba	11.8	87.7	90.0	31.5	40.8
Ca	26349	41945	23045	18021	15359
Cd	0.11	0.01	0.24	0.07	1.1
Co	0.08	0.02	0.45	<dl*	2.9
Cr	0.47	<dl*	1.5	0.33	7.7
Cu	7.4	5.4	6.1	5.1	14.2
Fe	151	221	308	284	4642
Ga	0.24	1.9	5.4	0.5	7.2
K	38964	17010	17163	20904	2507
Li	4.6	2.6	3.2	1.6	8.3
Mg	2698	5737	4079	5148	2879
Mn	36.9	35.9	54.1	39.0	186
Mo	0.19	<dl*	<dl*	<dl*	<dl*
Na	41.9	47.7	54.9	68.8	60.2
Ni	1.3	0.73	2.1	1.2	21.5
P	1399	1062	2460	1539	1269
Pb	1.5	3.4	3.6	2.3	25.3
Se	0.7	<dl*	<dl*	<dl*	<dl*
Si	154	219	98.6	104	167
Sr	78.1	52.4	62.6	44.4	30.2
Ti	2.5	4.4	0.34	1.6	71.6
V	0.72	1.3	1.6	1.6	49.5
Zn	21.2	50.5	32.8	36.8	113
N%	1.78	0.97	1.32	1.25	1.19

<dl*: element concentration under the detection limit of the instrument

tigated grasses (Tab. 4). 19% of the total element content is made up by heavy metals (Fig. 4). In higher concentrations first of all Fe, Mn and Zn were detected. The chemical composition of the moss, which is capable of accumulating ions through its entire body surface, is very similar to that of the uppermost soil layer.

Chrysopogon gryllus, which is an indigenous steppe species in Hungary with a southern Eurasian area, often occurs not only on loess soils, but also in dry grasslands on sandy soils. Recently this species – similarly to other grass species of the C_4 photosynthetic type – has been spreading in the loess steppe grasslands at the cost of *Festuca valesiaca*. As a consequence of its specific root system the species possesses a capacity for a concurrence as well as a significant drought tolerance.

The chemical compositions of the leaves of *Festuca valesiaca* and *Chrysopogon gryllus* are different (Tab. 5). The leaves of *Chrysopogon gryllus* – like other perennial C_4 type grass species (KOVÁCS et al. 1998) – contain higher amounts of Ca and Mg and a lower concentration of N than the perennial C_3 type grasses. Characteristic of the leaves of *Festuca valesiaca* is a relatively high con-

Tab. 5. Chemical element content of the leaves, roots and soils of *Festuca valesiaca* (C_3) of the ***Salvio-Festucetum rupicolae*** community and *Chrysopogon gryllus* (C_4) of the *Agropyro-Kochietum* community on a loess steppe in Érd, Hungary (n=8)

	Chrysopogon gryllus	*Festuca valesiaca*
Leaf		
Ca ($\mu g\ g^{-1}$)	3230	2674
Mg ($\mu g\ g^{-1}$)	1346	860
K ($\mu g\ g^{-1}$)	3144	5880
C (%)	42 41	41 57
N (%)	0.81	1 10
C/N	52.6	38 3
Root		
Ca ($\mu g\ g^{-1}$)	3638	18488
Mg ($\mu g\ g^{-1}$)	1729	3083
K ($\mu g\ g^{-1}$)	2029	1718
C (%)	42.3	33 3
N (%)	0.91	1 66
C/N	46.5	20 0
Soil		
Ca ($\mu g\ g^{-1}$)	68234	57409
Mg ($\mu g\ g^{-1}$)	8307	8940
K ($\mu g\ g^{-1}$)	1253	1353
C (%)	5.06	5.99
N (%)	0.35	0.37
C/N	17.9	17.0

centration of K and P. In the leaves of the two species the K/Ca ratio is also different (2.19 in the case of *Festuca valesiaca*, and 0.96 in the case of *Chrysopogon gryllus*). This latter ratio is known to be characteristic of the calciotroph physiotype (KINZEL 1982).

Whereas the carbon content of the two species is similar, the lower nitrogen content of the leaves of *Chrysopogon gryllus* results in an increased C/N ratio. The relatively high C/N ratio in both the leaves (52.3) and roots (46.5) of *Chrysopogon gryllus* is presumably the consequence of the slow mineralization dynamics, which may result in a decreased rate of the biogeochemical cycle of the community and also an accumulation of organic matter within it.

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