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ACCUMULATION OF COPPER, ZINC, MANGANESE AND IRON BY SELECTED SPECIES OF GRASSLAND LEGUMES AND HERBS

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Abstract

The aim of this study was to determine the accumulation of copper, zinc, manganese and iron by selected species of permanent grassland legumes and herbs. The study was conducted in 1998-2000 (June to the first ten days of July) in the Olsztyn Lakeland. A total of 444 plant samples were analyzed, including 123 collected in organic soils. The following legume and herb species were studied: *Trifolium pratense, Trifolium repens, Lotus corniculatus, Lathyrus pratensis, Lotus uliginosus, Vicia cracca, Taraxacum officinale, Achillea millefolium, Plantago lanceolata, Alchemilla vulgaris, Heracleum sibiricum* and *Cirsium oleraceum*.

The analyzed organic soils were characterized by moderate abundance of copper, zinc and manganese and low abundance of iron, whereas mineral soils contained medium levels of zinc, manganese and iron, and had a low copper content. The average copper content of plants ranged from 5.3 to 10.6 mg kg^{-1} d.m. The highest copper levels were noted in *Taraxacum officinale,* and the lowest in *Lotus corniculatus* grown on organic soils. The average zinc content of plants ranged from 31.0 to 71.0 mg kg^{-1} d.m. *Vicia cracca* grown on organic soils had the highest zinc content, while the lowest zinc concentrations were observed in *Trifolium repens*. The average manganese content of plants ranged from 45.0 to 233.0 mg kg^{-1} d.m. *Alchemilla vulgaris* grown on mineral soils accumulated the highest levels of manganese, and *Trifolium repens* had the lowest manganese content. The iron content of plants varied widely, from 116.0 to 223.0 mg kg^{-1} d.m.

Keywords: copper, zinc, manganese, iron, legumes, herbs.

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GROMADZENIE Cu, Zn, Mn I Fe PRZEZ WYBRANE GATUNKI ROŚLIN MOTYLKOWATYCH I ZIÓŁ ŁĄKOWYCH

Abstract

Celem badań było pokazanie zdolności gromadzenia Cu, Zn, Mn i Fe przez pospolite gatunki roślin motylkowatych i ziół łąkowo-pastwiskowych występujących na trwałych użytkach zielonych. Badania prowadzono w latach 1998-2000 (czerwiec – pierwsza dekada lipca) na terenie Pojezierza Olsztyńskiego. Łącznie przebadano 444 próby roślinne, w tym 123 pochodzące z gleb organicznych. Badaniami objęto *Trifolium pratense, Trifolium repens, Lotus corniculatus, Lathyrus pratensis, Lotus uliginosus, Vicia cracca, Taraxacum officinale, Achillea millefolium, Plantago lanceolata, Alchemilla vulgaris, Heracleum sibiricum* i *Cirsium oleraceum*.

Analizowane siedliska gleb organicznych charakteryzowały się średnią zasobnością w miedź, cynk i mangan oraz niską w żelazo, zaś gleby mineralne odznaczały się średnią zasobnością w cynk, mangan i żelazo oraz niską w miedź. Średnia zawartość Cu w roślinach wahała się od 5,3 do 10,6 mg kg^{-1} s.m. Najwięcej Cu gromadził *Taraxacum officinale*, najmniej zaś *Lotus corniculatus* występująca na glebach organicznych. Średnia zawartość Zn mieściła się w granicach 31,0-71,0 mg kg^{-1} s.m. Istotnie najwięcej Zn gromadziła *Vicia cracca* występująca na glebach organicznych, najmniej zaś *Trifolium repens*. Zawartość Mn mieściła się w granicach 45,0-233,0 mg kg^{-1} s.m. Istotnie najwięcej Mn gromadził *Alchemilla vulgaris* występujący na glebach mineralnych, najmniej zaś *Trifolium repens*. Zawartość Fe w roślinach była bardzo zróżnicowana, a średnie wartości wahały się od 116,0 do 223,0 mg kg^{-1} s.m.

Słowa kluczowe: miedź, cynk, mangan, żelazo, rośliny motylkowate, zioła.

INTRODUCTION

The species composition of grasslands is an important consideration since it affects the quality of green forage and animal feedstuffs. Legumes and herbaceous plants are valuable components of grassland communities. The latter are a rich source of essential nutrients with therapeutic and medicinal properties as well as other compounds that affect feed intake and utilization by animals (Trzaskoś, Czyż 2000, Warda, Ćwintal 2000). In Northern Europe, the most common legume species in grasslands are *Trifolium repens, Trifolium pratense, Trifolium hybridum*, *Medicago sativa* and *Lotus corniculatus*. In Western Europe, the most common species is *Trifolium repens,* accompanied by *Lotus corniculatus* and *Lotus uliginosus* which – in contrast to other legumes - can be grown under extreme conditions (Novoselowa, Frame 1992). The most common herb species are, among others, *Taraxacum officinale, Achillea millefolium, Plantago lanceolata* and *Alchemilla vulgaris.*

Mineral nutrients, in right proportions, are necessary for plant growth, development and maximal yield. Essential nutrients comprise macronutrients and micronutrients such as iron, manganese, zinc, copper, molybdenum and boron. Micronutrients regulate biochemical reactions and participate in numerous physiological processes including photosynthesis, respiration, maintaining hormonal balance and water balance, nitrogen metabolism and metabolism of organic compounds. Microelement deficiencies in plants may result not only from low micronutrient concentrations in soils

but also from reduced levels of nutrients available for uptake. Adequate micronutrient concentrations in crop plants are an important criterion while evaluating their quality and suitability as livestock feed (GRZYŚ 2004).

The aim of this study was to determine the accumulation of copper, zinc, manganese and iron by selected species of permanent grassland legumes and herbs.

MATERIAL AND METHODS

The study was conducted in 1998-2000 (June to the first ten days of July) in the Olsztyn Lakeland. The analysis covered permanent grassland communities with at least 5% share of the following legume and herb species: *Trifolium pratense*, *Trifolium repens*, *Lotus corniculatus*, *Lathyrus pratensis*, *Lotus uliginosus*, *Vicia cracca*, *Taraxacum officinale*, *Achillea millefolium*, *Plantago lanceolata*, *Alchemilla vulgaris*, *Heracleum sibiricum* and *Cirsium oleraceum*. A total of 444 plant samples were analyzed, including 123 collected on organic soils. The chemical composition of soil samples was determined in 0.5 mol dm^{-3} HCl extract, by atomic absorption spectrometry (AAS). Plant material, mineralized in a mixture of nitric acid and perchloric acid (4:1 ratio), was assayed for the content of Cu, Fe, Mn and Zn by atomic absorption spectrometry (AAS).

RESULTS AND DISCUSSION

Copper is essential for the growth and development of plants and animals. Adequate quantities of copper in plants are necessary to meet the nutrient requirements of animals (CZEKAŁA 2004). Copper affects the chlorophyll content of plants; it is involved in the synthesis of proteins and carbohydrates and it stimulates the activity of nitrate reductase (FALKOWSKI et al. 2000, BARCZAK et al. 2006). Copper is important for proper photosynthesis and maintaining water balance (Olszewska et al. 2008). The copper content of plants varies widely depending on the part of plant, growth stage, species and variety, as well as on copper concentrations in soil and climate conditions (RUSZKOWSKA et al. 1996). In the present study, copper abundance was affected by soil type. Higher copper concentrations are generally observed in mineral soils than in organic soils, and in more acidic soils (GONDEK 2009, TRĄBA, WYŁUPEK 1996). However, in our experiment lower copper levels were noted in mineral soil habitats (Figure 1), at 3.2-5.7 mg kg^{-1}. Organic soil habitats were richer in copper, where its average content ranged from 5.6 to 9.6 mg kg^{-1}, which is considered moderate abundance. Copper was present in the largest (although highly variable) quantities in the

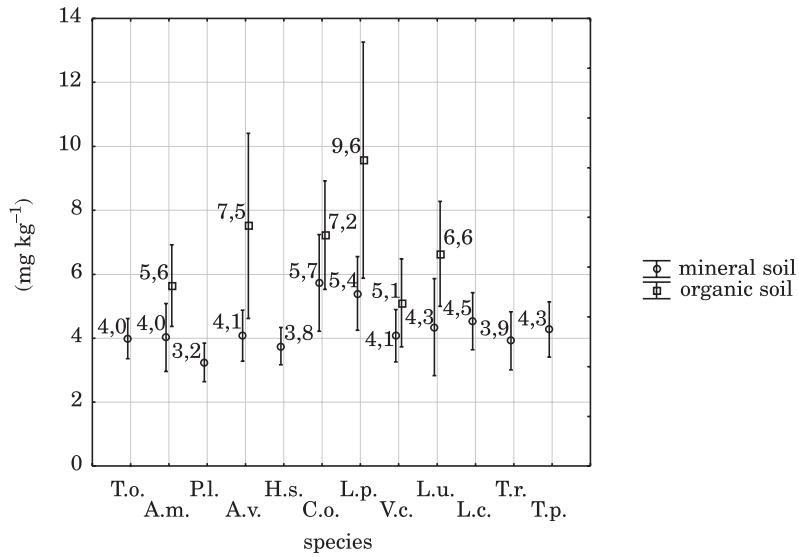

Fig. 1. Copper content of soil (means and 95.00% confidence interval)

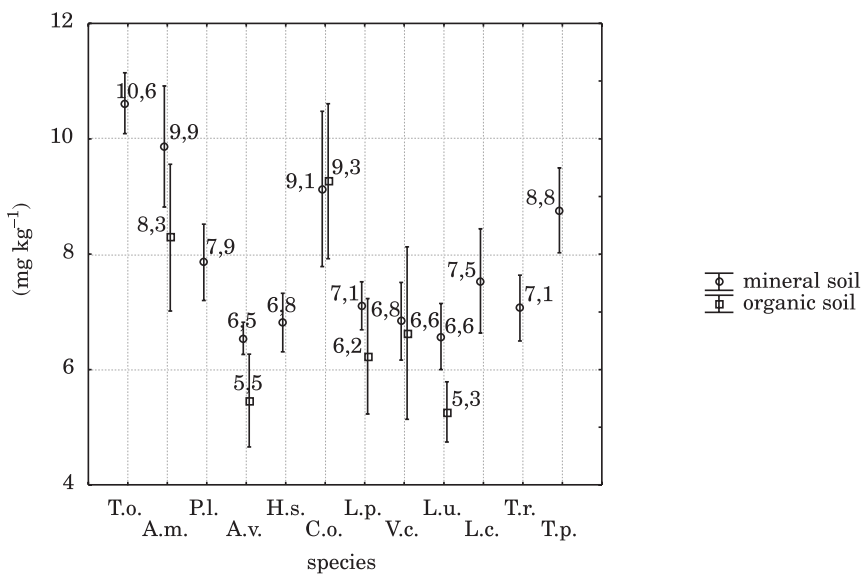

Fig. 2. Copper content of plants (means and 95.00% confidence interval)

habitats of *Lathyrus pratensis* and *Alchemilla vulgaris* on organic soils. The average copper content of plants ranged from 5.3 to 10.6 mg kg^{-1} d.m. (Figure 2). The highest copper levels were noted in *Taraxacum officinale,* and the lowest in *Lotus corniculatus* grown on organic soils. In view of the copper requirements of ruminants, only *Taraxacum officinale* had the opti-

mal copper content. Soil abundance in copper was not directly correlated with the copper content of plants. According to Czekała (2004), copper in soils forms compounds of different solubility and availability to plants. The cited author demonstrated that copper accumulation in plants was significantly affected by water availability and plant species.

Zinc is important for both plants and animals. The zinc content of animal feedstuffs is often insufficient due to its low availability caused by high soil pH, high phosphorus concentrations and the specific biological properties of plant species (Bowszys et al. 2009, Kopeć, Gondek 2004, Trąba et al. 2000). Mineral soil habitats were characterized by moderate zinc abundance (Figure 3). Zinc concentrations remained in the narrow range of 12.0-18.0 mg kg^{-1}. A higher zinc content was noted only in the habitat of *Cirsium oleraceum*. Moderate but varying zinc abundance was observed in organic soil habitats (27.0-40.0 mg kg^{-1}). Zinc content was highest in the habitats of *Achillea millefolium* on organic soils. The average zinc content of plants ranged from 31.0 to 71.0 mg kg^{-1} d.m. (Figure 4). The majority of the examined plant species contained zinc concentrations which were too low, as 50 mg Zn per kg feed d.m. is necessary to meet the nutritional requirements of animals. *Vicia cracca* grown on organic soils had the highest zinc content, while the lowest zinc levels were observed in *Trifolium repens*. Such trends in zinc concentrations were also reported by Trąba and Wolański (2003), and Wyłupek (2003).

Manganese is a growth stimulator and an activator of numerous enzymatic processes. It also participates in nitrogen assimilation, the synthesis of proteins and vitamin C, respiration, as well as in the reactions of water

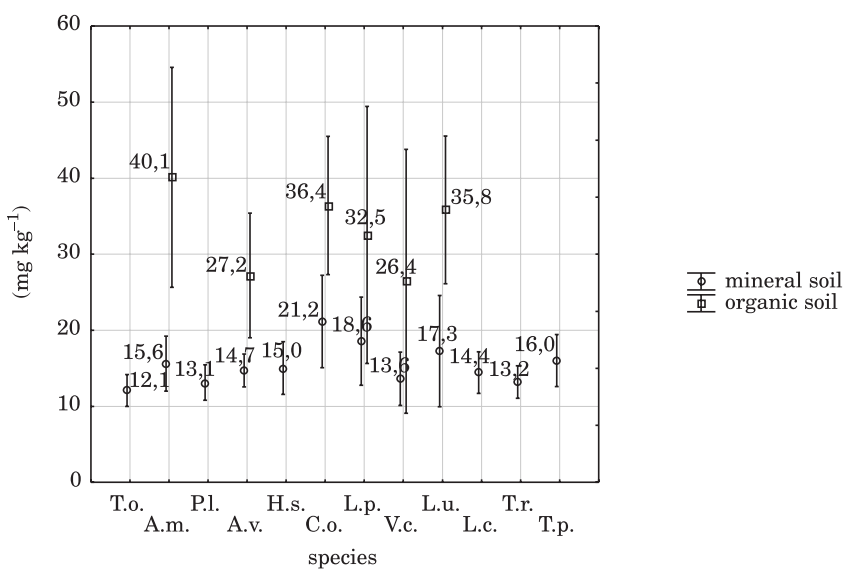

Fig. 3. Zinc content of soil (means and 95.00% confidence interval)

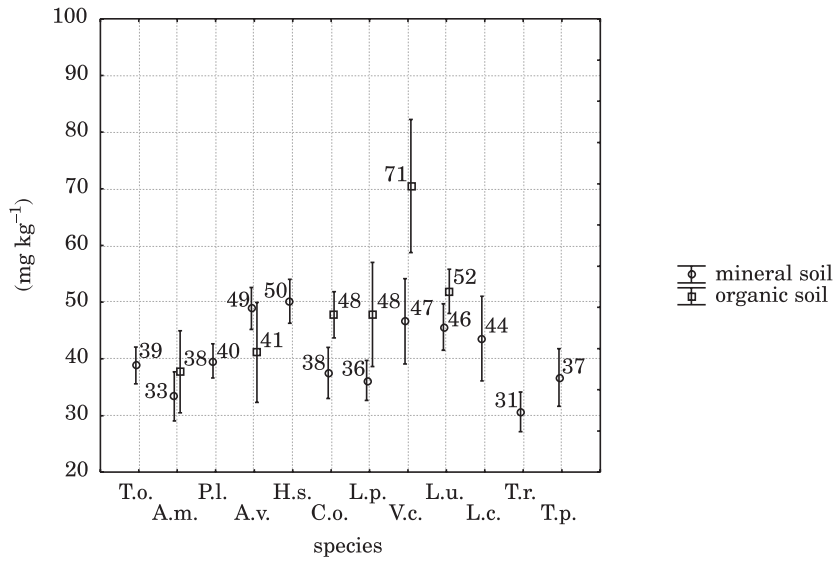

Fig. 4. Zinc content of plants (means and 95.00% confidence interval)

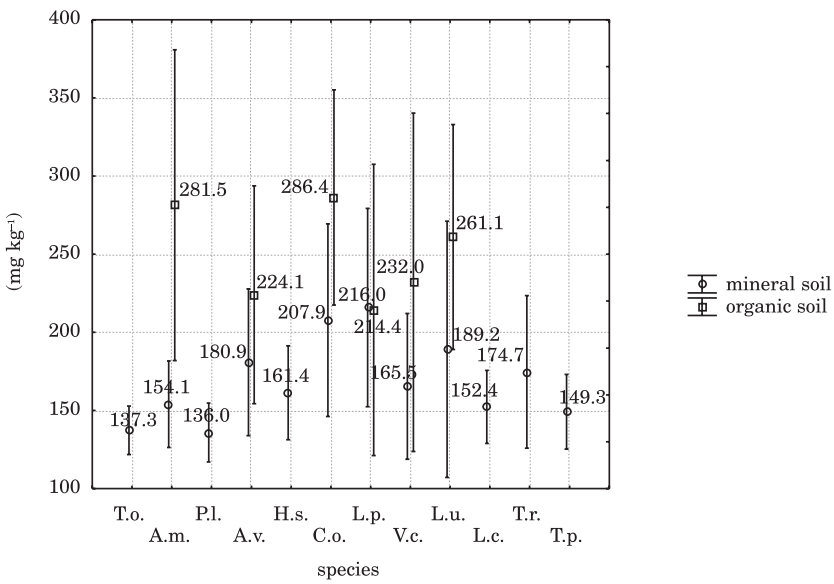

Fig. 5. Manganese content of soil (means and 95.00% confidence interval)

splitting to release oxygen during photosynthesis (Grzyś 2004). Manganese affects chlorophyll persistence, and its deficiency causes chlorophyll breakdown under the influence of intense light (Olszewska, Grzegorczyk 2008). Manganese deficiency occurs most often in crops grown on neutral carbonate soils and on soils with a high humus content (Bowszys et al. 2006, Malhi et

al. 1999, Halasova et al. 2001, Kopittke, Menzies 2004). The analyzed soil habitats were characterized by moderate manganese abundance. Manganese concentrations in mineral and organic soils ranged from 136.0 to 216.0 mg kg^{-1} and from 214.4 to 286.4 mg kg^{-1}, respectively. Manganese levels varied widely across the studied habitats (Figure 5). Communities with *Achillea millefolium, Cirsium oleraceum* and *Lotus uliginosus* were richer in manganese. Chemical analyses of plant material revealed that in the majority of species, the manganese content determined on a dry matter basis exceeded the nutrient requirements of animals. The manganese content of plants ranged from 45.0 to 233.0 mg kg^{-1} d.m. (Figure 6). The biomass of plant species grown on mineral soils contained more manganese in comparison with those

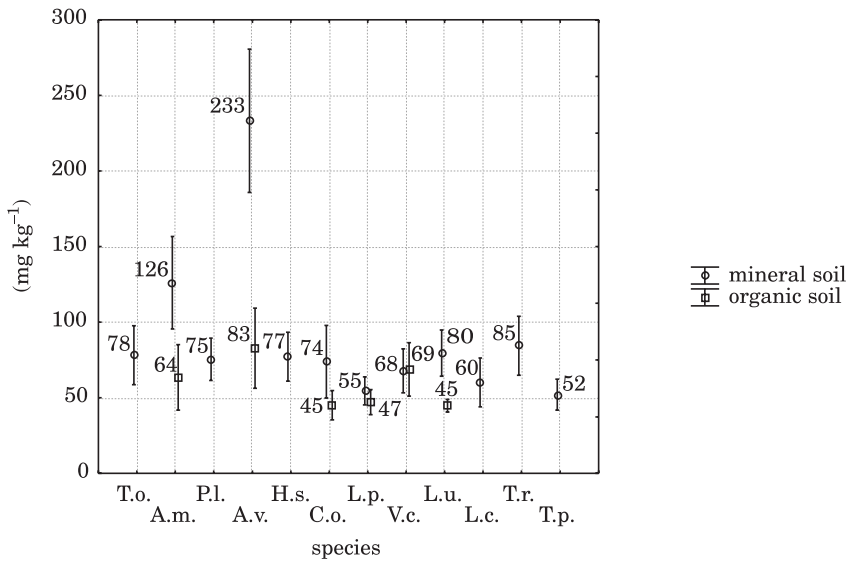

Fig. 6. Manganese content of plants (means and 95.00% confidence interval)

grown on organic soil. *Alchemilla vulgaris* and *Achillea millefolium* grown on mineral soils accumulated high levels of manganese, whereas *Cirsium oleraceum* and *Lotus uliginosus* grown on organic soils had the lowest manganese content. According to Harkot (2000), there is no close correlation between manganese concentrations in soil and hay since the supply of this micronutrient to grassland plants is largely dependent on its uptake (soil organic matter content, soil pH, water relations), a conclusion which is consistent with our findings.

Iron stimulates the biosynthesis of chlorophyll pigments in plants and participates in the light phase of photosynthesis (Grzyś 2004, Zaharieva et al. 2004). Iron deficiency in animals can result in anemia, digestion disorders and impaired immunity (Kinal 2009). In the present study, iron abundance was moderate in mineral soils (1589.7-3178.8 mg kg^{-1}; Figure 7) and

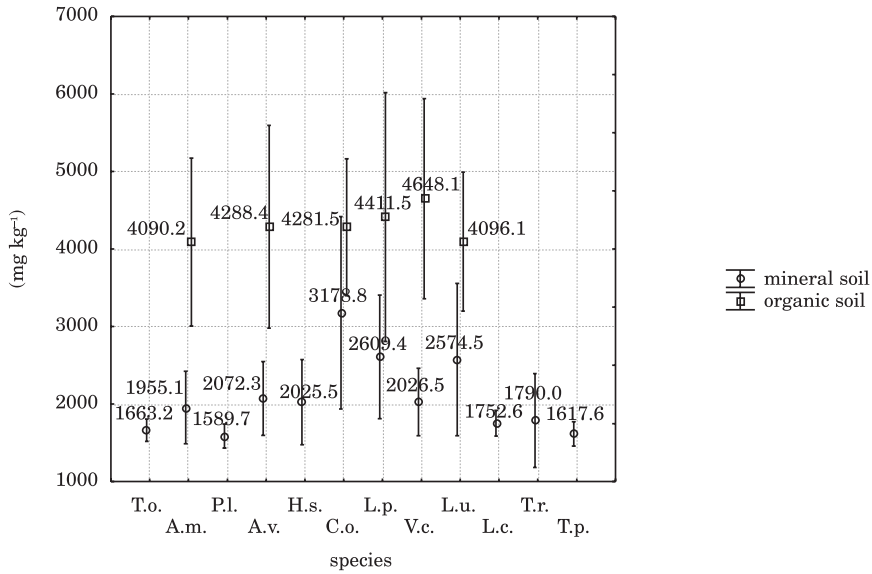

Fig. 7. Iron content of soil (means and 95.00% confidence interval)

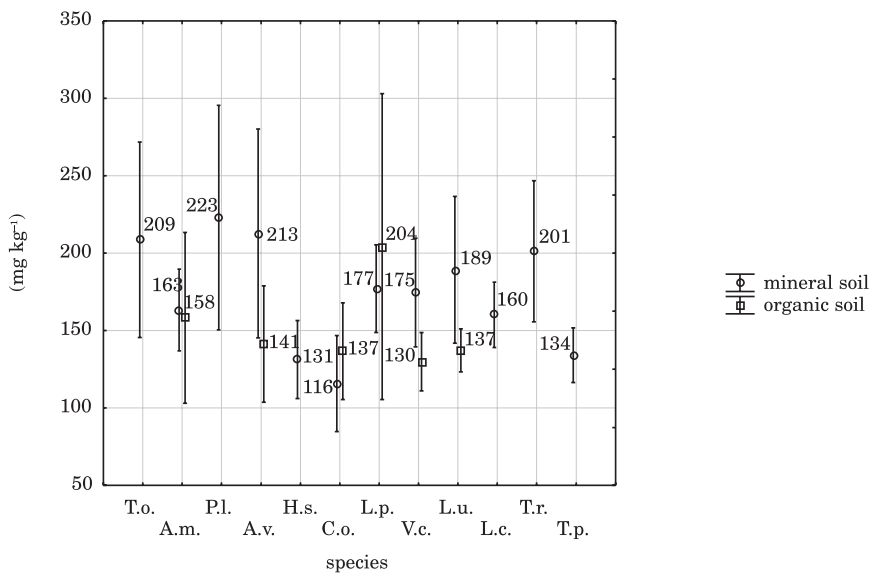

Fig. 8. Iron content of plants (means and 95.00% confidence interval)

low in organic soils (4096.1-4648.1 mg kg^{-1}), and it varied widely across the examined habitats. The highest iron levels were noted in communities with *Vicia cracca* on organic soils, and in communities with *Cirsium oleraceum* on mineral soils. High-quality animal feed should contain 50 to 100 mg

Fe kg^{-1} d.m. The analyzed plant species differed significantly with respect to average iron content, which ranged from 116.0 to 223.0 mg kg^{-1} d.m. (Figure 8). *Plantago lanceolata*, *Taraxacum officinale* and *Alchemilla vulgaris* accumulated the highest quantities of iron in their biomass. *Cirsium oleraceum* (cabbage thistle) grown on mineral soils that were richest in iron had the lowest iron content in dry matter. This indicates that the iron content of plants, similarly as manganese content, is not determined by iron concentrations in soil but by iron mobility and uptake by plants (HARKOT 2000).

CONCLUSIONS

1. The analyzed organic soils were characterized by moderate abundance of copper, zinc and manganese and low abundance of iron, whereas mineral soils contained medium levels of zinc, manganese and iron, and had a low copper content.

2. In most cases, the abundance of micronutrients in soils was not directly related to the microelement content of plants, which confirms that concentrations of microelements in plants are determined primarily by their availability, uptake and plant species.

3. Among the studied plant species, *Vicia cracca* accumulated the highest levels of zinc, *Taraxacum officinale* had the highest copper content, *Alchemilla vulgaris* and *Achillea millefolium* were rich in manganese, while *Plantago lanceolata*, *Taraxacum officinale* and *Alchemilla vulgaris* had the highest iron content.

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