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EFFECT OF LONG-TERM VARIOUS MINERAL FERTILIZATION AND LIMING ON THE CONTENT OF MANGANESE, NICKEL AND IRON IN SOIL AND MEADOW SWARD

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Abstract

Research on grasslands is conducted to assess the yielding potential and determine changes of sward quality depending on applied fertilization. Therefore, the present study was undertaken to assess the contents of manganese, nickel and iron in soil and meadow sward shaped under the influence of diversified mineral fertilization and liming. The experiment is established in the village Czarny Potok near Krynica, about 720 m above sea level., at the foot of Mount Jaworzyna Krynicka. The experiment was set up in 1968 on a natural mountain meadow of mat-grass (*Nardus stricta* L.) and red fescue (*Festuca rubra* L.) type with a large share of dicotyledonous plants. Total content of manganese, nickel and iron was determined in the plant and soil material after sample mineralization in a muffle furnace. The studied were extracted with 0.025 $mol \cdot dm^{-3}$ NH_4EDTA solution and the content of Mn, Ni and Fe in the solutions was assessed with the ICP-AES method. The content of total forms of manganese was higher in the soil of the limed series. The soil reaction significantly affected amounts of this element extracted with NH_4EDTA solution. Soil liming limited manganese bioavailability and improved the forage value of the analyzed biomass. Small quantities of nickel bound to the soil organic substance were found in the analyzed soil, which suggested considerable mobility of this elements and its translocation into deeper levels of the soil profile, beyond the reach of the plant root system. Liming increased the content of iron forms in combinations with the soil organic substance. Iron deficiency in the meadow sward may have a physiological basis such as difficult iron transport from the root system to aerial plant parts, but it was not caused by limited iron uptake from soil.

Key words: manganese, nickel, iron, soil, meadow sward, long term experiment.

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WPŁYW DŁUGOTRWAŁEGO ZRÓŻNICOWANEGO NAWOŻENIA MINERALNEGO I WAPNOWANIA NA ZAWARTOŚĆ MANGANU, NIKLU I ŻELAZA W GLEBIE I RUNI ŁĄKOWEJ

Abstrakt

Badania na użytkach zielonych są prowadzone m.in. w celu wyznaczenia potencjału plonowania oraz określenia zmian jakości runi w zależności od zastosowanego nawożenia. Dlatego celem podjętych badań było określenie zawartości manganu, niklu i żelaza w glebie oraz runi łąkowej ukształtowanej pod wpływem zróżnicowanego nawożenia mineralnego i wapnowania. Doświadczenie jest zlokalizowane w Czarnym Potoku k. Krynicy, na wysokości ok. 720 m n.p.m., u podnóża Jaworzyny Krynickiej. Doświadczenie założono w 1968 r. na naturalnej łące górskiej typu bliźniczki – psiej trawki (*Nardus stricta* L.) i kostrzewy czerwonej (*Festuca rubra* L.) ze znacznym udziałem roślin dwuliściennych. Zawartość ogólną manganu, niklu i żelaza w materiale roślinnym i glebowym oznaczono po mineralizacji próbek w piecu muflowym, ponadto wykonano ekstrakcję badanych pierwiastków roztworem NH_4EDTA o stężeniu 0,025 mol·dm^{-3}. W uzyskanych roztworach zawartość Mn, Ni i Fe wykonano metodą ICP-AES. Zawartość ogólnych form manganu była większa w glebie wapnowanej, a istotny wpływ na ilość tego pierwiastka wyekstrahowanego roztworem NH_4EDTA oraz jego zawartość w runi miał odczyn gleby. Wapnowanie gleby ograniczając dostępność manganu dla roślin poprawiło wartość paszową analizowanej biomasy. W badanej glebie oznaczono niewiele niklu związanego z substancją organiczną gleby. Świadczy to pośrednio o dużej mobilności tego pierwiastka i jego przemieszczaniu do głębszych poziomów profilu glebowego, poza zasięg systemu korzeniowego roślin. Wapnowanie zwiększyło zawartość form żelaza w połączeniach z substancją organiczną gleby. Niedoborowa zawartość żelaza w runi łąkowej może mieć podłoże fizjologiczne związane z trudnościami w transporcie żelaza z systemu korzeniowego do organów nadziemnych roślin, a nie wynikać z możliwości jego pobierania z gleby.

Słowa kluczowe: mangan, nikiel, żelazo, gleba, ruń łąkowa, doświadczenie długotrwałe.

INTRODUCTION

Progressing industrialization and urbanization as well as changes in fertilization systems can be responsible for potential excess of trace elements in soil and plants. Fertilization is an important factor which modifies soil abundance in trace elements. With fertilizers we introduce some trace elements to the soil and modify their availability through changes of soil properties, mainly soil reaction, as well as changes in the content and composition of soil humus.

Trace elements can be beneficial to living organisms, including plants, but they may also be a cause of disturbances in physiological processes and metabolism in plants (Ruszkowska, Wojcieszka-Wyskupajtys 1996). As a result of the unfavourable influence of trace elements on plants, disorder in the uptake, transport and assimilation of some macroelements may occur (Burzyński 1987, Burzyński, Buczek 1989).

The evidence presented in literature (Andrzejewski 1993) shows that soil humus, next to soil reaction, determines availability of some trace elements. Maintaining an adequate level of soil humus requires fertilization with materials abundant in organic matter, liming and supply of appropriate amounts of basic nutrients, such as nitrogen, phosphorus or potassium, which are taken up with plant yields. Among many positive features of soil humus which affect soil fertility there is sorption capacity. Sorption capacity makes soil humus vital for plant nutrition and ecologically important. Soil humus is a kind of nutrient store for plants which also acts as a neutralizer of trace elements, whose concentration is often too high in the soil solution.

Formation and durability of humus compounds in soil, including organic-mineral combinations with trace elements, depends on many factors. The important ones comprise are the amount and structure of humic compounds, soil reaction as well as the kind and concentration of a given element in soil (DZIADOWIEC 1993, MERCIK, KUBIK 1995).

This study has been conducted on grasslands to assess potential crop yield and determine changes of the sward quality depending on the fertilization used. Therefore, analyses were made to asses the content of manganese, nickel and iron in the soil and meadow sward grown under diversified mineral fertilization and liming.

MATERIAL AND METHODS

The experiment is set up in the village Czarny Potok near Krynica (20^{o}54”E; 49^{o}24”N), on the altitude of about 720 m above sea level, at the foot of Mount Jaworzyna Krynicka, in the south-eastern Beskid Sądecki massif on a 7^{o} inclination slope and NNE aspect. The experiment was established in 1968 on a natural mountain meadow of mat-grass (*Nardus stricta* L.) and red fescue (*Festuca rubra* L.) type with a large share of dicotyledonous plants. The soil was classified as acid brown soil developed from the Magura sandstone with a texture of light silt loam (% of fractions: 1 – 0.1 mm: 40; 0.1 – 0.02 mm: 37; > 0.02 mm: 23) and three characteristic genetic horizons: turf – AhA (0 – 20 cm), browning – ABbr (21 – 46 cm) and parent rock BbrC (47 – 75 cm). Detailed data about the experiment were presented in the earlier publications (MAZUR, MAZUR 1972, KOPEĆ 2000).

The experiment has been receiving the same level of fertilization since the autumn 1985, but it is conducted in two series: without liming (0 Ca) and limed (+Ca). Liming was repeated in 1995. The first liming was conducted with a dose calculated on the basis of 0.5 Hh value while the second one was based on the total hydrolytic acidity.

Mineral fertilization was discontinued in the years 1974–1975 and in 1993–1994 when the experiment was restricted to assessment of the sward yield and its chemical composition.

The experiment comprises 8 treatments in five replications (Table 1) receiving unilateral nitrogen or phosphorus fertilization (90 kg N or 39.24 kg $P\cdot ha^{-1}$) and (39.24 kg $P\cdot ha^{-1}$ and 124.5 kg $K_2O\cdot ha^{-1}$) against PK background; nitrogen is applied in two forms (ammonium nitrate and urea) and two doses (90 and 180 $N\cdot ha^{-1}$). In 1968-1980, phosphorous and potassium fertilizers were applied in autumn but since 1981 the fertilization treatments have been performed in spring, although potassium (1/2 of the dose) is supplemented in summer after the first cut. In 1968-1973 thermophosphate was applied; afterwards triple superphosphate has been used. Over the whole period of the experiment nitrogen fertilizers have been applied on two dates: 2/3 of the annual dose in the spring at the start of vegetation and 1/3 of the dose – several days after the first cut harvest. A single regenerative treatment with copper (10 $kg\cdot kg^{-1}$) and magnesium (8 $kg\cdot ha^{-1}$) was applied in 1994. Foliar nutrition (2 $dm^3\cdot ha^{-1}$ applied twice) with microelement Mikrovit -1 fertilizer has been used since 2000. The microelement fertilizer contains (per 1 dm^3): 23.3 g Mg; 2.3 g Fe; 2.5 g Cu; 2.7 g Mn; 1.8 g Zn; 0.15 g B and 0.1 g Mo.

Table 1
Tabela 1

Design of fertilization in the static experiment in Czarny Potok
Schemat nawożenia w statycznym doświadczeniu w Czarnym Potoku

Fertilizer objects Obiekty nawozowe		Annual nutrient rate in Roczna dawka składnika w serii 0 Ca and + Ca (kg · ha^{-1})			Nitrogen form Forma azotu
A	PK	P	K	N	
A	PK	39.24	124.5	-	
B	90 kg N (a) + PK	39.24	124.5	90	ammonium nitrate saletra amonowa
C	180 kg N (a) + PK	39.24	124.5	180	ammonium nitrate saletra amonowa
D	90 kg N (u)+ PK	39.24	124.5	90	urea – mocznik
E	180 kg N (u) + PK	39.24	124.5	180	urea – mocznik
F	90 kg N (a)	-	-	90	ammonium nitrate saletra amonowa
G	90 kg P	39.24	-	-	
H	no fertilization bez nawożenia	-	-	-	

(a) ammonium nitrate – saletra amonowa; (u) urea – mocznik;
0 Ca unlimed series – seria bez wapnowania; + Ca limed series – seria wapnowana

In the investigated area, the growing season lasts from April till September (150 – 190 days). The local weather conditions are characterized by a considerable variability of precipitation (Table 2).

Table 2
Tabela 2

Statistical parameters of the distribution of precipitation and temperatures in 1968–2001
Parametry statystyczne rozkładu opadów i temperatur dla okresu 1968–2001

Parameter Parametr	Precipitation Opady (mm)		Temperature Temperatura (°C)	
	Jan.-Dec.	April-Sept.	Jan.-Dec.	April-Sept.
Arithmetical mean Średnia arytmetyczna	856.5	567.9	5.78	11.96
Standard deviation Odchylenie standardowe	184.1	132.5	0.90	0.86
Range 25-75% of cases Przedział 25-75% przypadków	728.5-909.0	466.1-649.7	5.30-6.30	11.3-12.5

The results of the research presented in this paper were obtained in the 36th year of the experiment. In 2003 two cuts were harvested: on 26 June and 10 September. Manganese, nickel and iron content in the plant material were assessed using the ICP-AES method after drying and dry mineralization (at 450°C for 5 hrs.). A soil sample was collected for analyses from the 0 – 10 cm level of each treatment after II cut harvest. The following assessments were made in the soils: pH in 1 $\mathrm{mol \cdot dm^{-3}}$ KCl and in water solution with a potentiometer, organic carbon content after mineralization in potassium(VI) dichromate using Tiurin method, total content of manganese, nickel and iron after organic substance incineration in a muffle furnace (at 500° C for 8 hrs) and the sample mineralization in concentrated HNO_3 and $HClO_4$ acids (2:1) (v/v) (OSTROWSKA et al. 1991). Manganese, nickel and iron were extracted from the soil using 0.025 $\mathrm{mol \cdot dm^{-3}}$ NH_4EDTA solution with ZEIEN, BRÜMMER method (1989). The results underwent statistical analysis. Two factor analysis of variance was conducted and the significance of differences between the arithmetic means was estimated with Fisher test at the significance level $p < 0.05$. Standard deviation and coefficient of variation were computed for the values obtained within series.

RESULTS AND DISCUSSION

Long-term, systematic mineral fertilization established a stabile level of meadow sward yields (KOPEĆ 2000) on individual treatments (Figure 1). The computed values of a yield variability coefficient within the series were relatively small for both cuts: $V\%_{0Ca} = 32$ and $V\%_{+Ca} = 39$. As the results show, crop yields have been so stable that, despite the cultivation techniques carried out on the whole field, including microelement fertilization, no significant differences were revealed between the ammonium nitrate and urea treatments for both nitrogen doses against the PK background in either series. It is so because of the botanical composition of the sward and the degradation of grassland caused by PK + 180 kg $N \cdot ha^{-1}$, which was discussed in our earlier publication (KOPEĆ, SZEWCZYK 2006). On the basis of the experiments, the first cut yield was larger by an average 122% for the non-limed series and 165% for the limed series. Severe soil

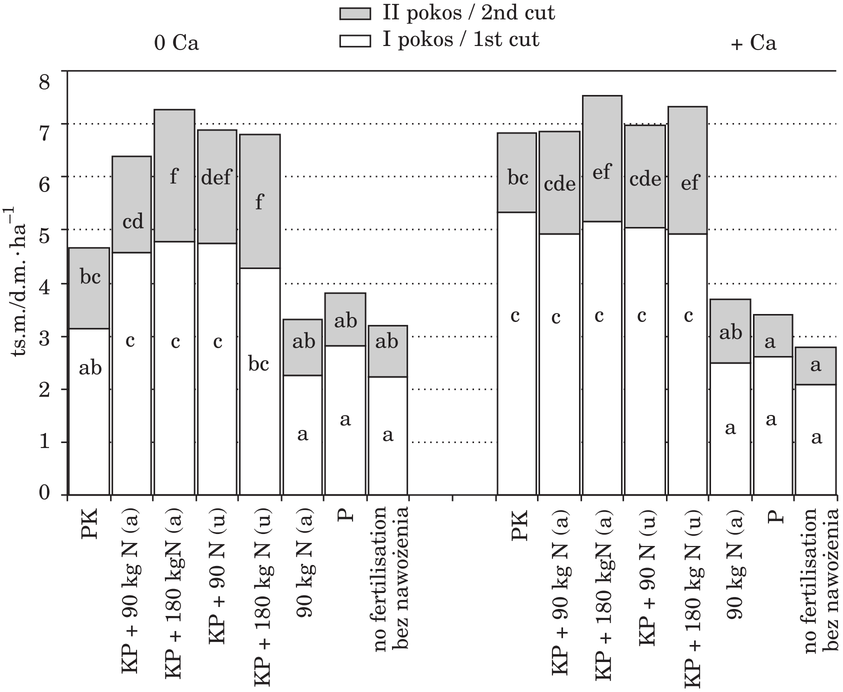

Fig. 1. Yields of meadow sward in 2003: (a) – ammonium nitrate, (u) – urea
Means designated the same letters did not differ significantly at $p < 0.05$ according to the Fisher test

Rys. 1. Plony runi łąkowej w 2003 r.: (a) saletra amonowa, (u) mocznik
Średnie oznaczone tymi samymi literami nie różnią się istotnie dla $p < 0,05$ wg testu Fishera

exhaustion caused by the unilateral nitrogen or phosphorus fertilization led to significantly lower yields of meadow sward biomass in comparison with the PK treatment, particularly in the limed series. Crop yields, including meadow sward, are strictly related to the habitat and agronomic factors. There is no direct dependence between the dose of a fertilizer component and the amount of crop yield. Plant response to fertilization is a resultant of many factors (MALHI et al. 1992). Relatively considerable yield stabilization in individual treatments results mainly from the botanical composition of the plant community, stabilized during the period of over thirty years, which was discussed in detail in an earlier publication (KOPEĆ, SZEWCZYK 2006). The lack of notable differences in biomass yields between 90 kg and 180 kg N treatments (irrespective of the nitrogen form) may have been caused by some disturbance in the ratio between the biomasses of grassland aerial parts versus the roots and runners. Water and nutrients accumulated in the rhizosphere enables plants to survive unfavourable conditions. Intensive fertilization, particularly with nitrogen, means that the soil layer penetrated by roots seeking nutrients and water becomes shallower. This effect may be strengthened by certain physical processes stimulated by increased fertilization (SIEGEL-ISSEM et al. 2005). Obtaining comparable biomass yields on fields fertilized with a single and double dose of nitrogen points indirectly to a positive balance of this component in soil, which, if unused, may migrate into the soil profile and cause groundwater pollution.

The values of soil reaction measured in water suspension, as shown in Table 3, ranged between 5.20 and 5.96 for the non-limed series and between 5.80 and 6.09 for the limed series. Soil pH values measured in the suspension and 1 $mol \cdot dm^{-3}$ KCl fell within the range of 3.36 to 4.21 for the non-limed series and 4.39 to 4.72 for the limed series. The lowest values of soil reaction (in water suspension) were found in the soil (the non-limed series) fertilized with nitrogen used as ammonium nitrate + PK in the dose 180 kg $N \cdot ha^{-1}$. In the limed series, the lowest reaction was measured in the non-fertilized treatment soil. In the soil suspension and KCl, the lowest pH value was determined in the soil treated with urea supplied as 180 kg N + $PK \cdot ha^{-1}$ (the non-limed series) and in the soil unilaterally fertilized with ammonium nitrate dosed 90 kg $N \cdot ha^{-1}$ (the limed series). The investigations conducted by MAZUR and MAZUR (1972) demonstrated similar soil reaction relationships found during the initial years of the experiment, whereas the changes in the soil reaction observed over time suggest increasing soil acidification (MAZUR, KOPEĆ 1993, KOPEĆ, NOWOROLNIK 1999).

Humus concentrations, expressed as a percentage of organic carbon content, observed in soils of individual treatments were lower than determined in non-fertilized soils, irrespective of a series (Table 3). Greater diversification in the content of this component was found in the non-

Table 3
Tabela 3

Soil reaction and organic carbon content in soil
Odczyn i zawartość węgla organicznego w glebie

Fertilizer objects* Obiekty nawozowe*		0 Ca			+ Ca		
		pH		org. C C org. $g \cdot kg^{-1}$	pH		org. C C org. $g \cdot kg^{-1}$
		H_2O	KCl		H_2O	KCl	
A	PK	5.55	3.85	13.34	5.95	4.53	9.40
B	90 kg N (a) + PK	5.61	4.17	10.40	5.99	4.45	8.42
C	180 kg N (a) + PK	5.21	3.73	10.16	6.07	4.44	9.14
D	90 kg N (b) + PK	5.52	4.02	10.28	6.04	4.63	9.44
E	180 kg N (b) + PK	5.20	3.36	13.12	6.07	4.48	8.32
F	90 kg N (a)	5.58	3.83	10.28	5.93	4.39	9.70
G	90 kg P	5.71	4.12	13.02	6.09	4.51	9.28
H	no fertilization bez nawożenia	5.96	4.21	19.30	5.80	4.72	12.00
SD**		-	-	3.10	-	-	1.14
V%***		-	-	24.8	-	-	12.0

* see Table 1 – jak w tabeli 1
** standard deviation – odchylenie standardowe
*** coefficient of variation – współczynnik zmienności

limed series. Less organic carbon occurred in the soil of the limed series (between 5.6% and 37.8% in comparison with the non-limed series). Particularly big differences in the humus content were found in the soil fertilized unilaterally with P, PK,180 kg $N \cdot kg^{-1}$ + PK (as urea) and in unfertilized soil. Niemyska-Łukaszuk et al. (1999) found similar dependencies concerning humus concentrations in the soil of the same experiment assayed in the 30th year, although the differences between the series were not so pronounced, i.e. between 0.5% and 14.8%. An increase in the humus content in soil was registered between the 18th and 30th year of the experiment, irrespective of the treatment (Niemyska-Łukaszuk et al. 1999). However, after 36 years of the experiment, humus concentrations in the analyzed soil samples were found to have declined (Table 3). According to Dechnik (1987) and Myśkow and Stąsiek (1976), long-term application of mineral fertilizers, especially the ones which acidify the environment, leads to a decline in the soil fertility, its biological activity as well as quantitative and qualitative degradation of humus. Changes in the humus content in soil after 36 years of the experiment may have resulted from the increased mineralization of organic matter, which might have been stimulated by the cultivation techniques and weather conditions. A study conducted by Wołoszyk and Nowak (1993), which dealt with changes in the organic carbon content in light soil as a result of mineral fertilization of grasses under field cultivation, revealed that organic carbon concentrations in soil decreased after three years of the treatments, increasing again after the fifth year. The periodic character of changes in soil humus concentrations was also reported by KRAJCOVIC et al. (1993).

The mean total content of manganese in soil (for treatments) of the non-limed series was almost 10% smaller than for the limed series (Table 4). Such a higher content of total manganese forms in the soils of the limed series was most probably due to the poorer bioavailability of this element determined by the soil reaction. Manganese extracted with NH_4EDTA solution ranged between 22.8 – 33.5 mg·kg^{-1} (the non-limed series) and 19.0 and 25.1 mg·kg^{-1}of soil dry mass (the limed series) – Table 4. This fraction, irrespective of the series or treatment, constituted between 6.1% and 11.5% of the total content, although a greater proportion of this manganese form was noticed in the soil of the non-limed series, with small albeit noticeable differences between the treatments. Concentrations of manganese in the sward ranged between 93 and 322 mg·kg^{-1} d.m. for the non-limed series and 48 and 123 mg·kg^{-1} for the limed series (Table 4). Irrespective of the applied fertilization and liming, the sward from the second cut contained more manganese. Statistical analysis of the results also points to a greater variability between the treatments in terms of manganese concentrations in the second cut sward, but higher manganese concentrations were conditioned by significantly smaller biomass yields in comparison with the first cut. Solubility of manganese compounds is a resultant of many factors (Figure 1). Transformations of this element in soil, apart from oxidation-reduction conditions and the soil reaction, depend on the soil concentrations of iron and aluminum hydroxides, clay minerals, carbonates and the content of organic substance (KABATA-PENDIAS, PENDIAS 1999, HALASOVA et al. 2000). However, unlike other metals, manganese is relatively weakly bound by organic matter, as the present study has confirmedwas. Nonetheless, it should be emphasized that the soil reaction significantly influenced the amount of manganese extracted with NH_4EDTA, as demonstrated by the results obtained by VALLMANNOVA et al. (2001). Also, higher levels of the total forms of this element were found in the limed series except for the unfertilized soil. This can be attributed to the poorer manganese bioavailability and formation of hardly soluble combinations with solid soil particles (CZEKAŁA et al. 1996). Despite its higher total content, limited mobility of manganese in the + Ca series soil became reflected in its concentrations in the meadow sward. Similar results, although for a different plant, were cited by BEDNAREK and LIPIŃSKI (1996). Considering the forage value, it was favourably affected by liming, which limited manganese bioavailability (GORLACH 1991).

The total content of nickel in the soil of the non-limed series fell within the range of 7.42 – 10.10 mg·kg^{-1} and 8.42 – 10.55 mg·kg^{-1} of soil

Table 4
Tabela 4

Content of manganese (mg·kg^{-1} d.m.) in soil and meadow sward
Zawartość manganu (mg·kg^{-1} s.m.) w glebie i runi łąkowej

Fertilizer objects* Obiekty nawozowe*	0 Ca				+ Ca			
	soil – gleba		cut – pokos		soil – gleba		cut – pokos	
	total ogólny Mn	Mn-NH$_4$EDTA	I	II	total ogólny Mn	Mn-NH$_4$EDTA	I	II
A	275	28.9 fgh	146 e	215 bcd	303	22.9 a-e	63 a-d	96 a
B	239	27.6 d-g	141 e	268 de	281	24.0 a-f	69 a-d	116 ab
C	268	27.8 efg	135 e	272 de	278	23.2 a-e	50 ab	82 a
D	278	29.1 gh	101 a-e	238 de	293	25.1 c-g	50 ab	92 a
E	270	25.6 c-g	113 de	322 e	284	20.7 abc	57 abc	90 a
F	285	22.8 a-d	109 cde	221 cde	304	19.9 ab	48 a	123 abc
G	275	24.3 b-g	104 b-e	181 a-d	298	24.0 a-f	62 a-d	93 a
H	368	33.5 h	93 a-e	146 a-d	310	19.0 a	55 a-d	71 a
SD**	37.2	3.3	20.1	55.3	11.8	2.2	7.4	16.9
CV****	13	12	17	24	4	10	13	18

* see Table 1 – jak w tabeli 1,
** standard deviation – odchylenie standardowe,
*** coefficient of variation – współczynnik zmienności;
Means designated the same letters in columns did not differ significantly at $p < 0.05$ according to the Fisher test.
Średnie oznaczone tymi samymi literami w kolumnach nie różnią się istotnie dla $p < 0.05$ wg testu Fishera.

dry mass in the limed series (Table 5). Among the applied fertilization patterns, it was only liming which diversified the total content of this element. This may have resulted from a certain load of nickel supplied with the calcium fertilizers used for liming and the reduced uptake of this element under higher soil pH values. The content of nickel extracted from the soil with NH_4EDTA solution was not varied among the experimental series (0 Ca and + Ca) except for the soil from the treatments where PK and 180 kg $N \cdot ha^{-1}$ + PK (ammonium nitrate) were used. In the soil samples from these treatments of the 0 Ca series, the content of Ni-NH_4EDTA form was almost twice as high as in the soil from the + Ca series treatments (Table 5). An opposite relationship was noticed in the soil of unfertilized treatments. The nickel content in the soil organic fraction, which was influenced by the long-term mineral fertilization caused a considerable diversification within the series ($V\%_{0Ca}$ = 43; $V\%_{+Ca}$ = 40). The factors which diversified nickel concentrations in sward more than mineral fertilization were liming and harvest (cut) date. Irrespective of the fertilization applied, more nickel was detected in the sward of the non-limed series. Generally, higher nickel concentrations were characteristic for the sward of the second cut (Table 5). Mobility of nickel, like that of other trace metals, is mainly determined by soil reaction. According to KABATA-PENDIAS, PENDIAS (1999), nickel readily forms combinations with soil organic substance, mostly mobile chelates, as the above authors emphasized. In the present experiments, nickel forms bound to soil humus made up only a slight proportion in comparison with the total content of this element in soil, irrespective of the experimental series. According to KARCZEWSKA et al. (1997) and BRAN et al. (1997), considerable mobility of nickel inhibits accumulation of its bioavailable forms in the surface horizons of soils, which is of crucial importance for plants with shallow roots systems such as grasses. In the mountains, where there is more precipitation than on lowlands, rainfall water seeping through the soil profile may transport this element into deeper layers, beyond the reach of plant root systems (GONDEK, KOPEĆ 2002). This may partially account for the smaller concentration of nickel in the second cut sward despite the lower biomass yield. As there is no evidence to confirm participation of nickel in metabolic processes in plants, this element is not considered to be essential to plants. Therefore, excessively high nickel concentrations in forage are undesirable. The content of nickel in the analyzed biomass, as set against the values suggested by GORLACH (1991), did not restrict the use of the grass for forage, irrespective of the cut.

Soil concentrations of the total iron forms within each series varied only slightly ($V\%_{0Ca}$ = 9%; $V\%_{+Ca}$ = 4%) – Table 6. On average, the content of the total forms of iron in soils was 8314 $mg \cdot kg^{-1}$ dry soil mass in the non-limed series (0 Ca) and 9009 $mg \cdot kg^{-1}$ in the limed series. The determined amount of iron extracted with NH_4EDTA solution was higher in

Table 5
Tabela 5

Content of nickel (mg·kg^{-1} d.m.) in soil and meadow sward
Zawartość niklu (mg·kg^{-1} s.m.) w glebie i runi łąkowej

Fertilizer objects* Obiekty nawozowe*	0 Ca				+ Ca			
	soil – gleba		cut – pokos		soil – gleba		cut – pokos	
	total ogólny Ni	Ni-NH$_4$EDTA	I	II	total ogólny Ni	Ni-NH$_4$EDTA	I	II
A	8.58	0.53 ab	1.81 b	1.60 e	8.90	0.27 a	1.67 b	0.55 a
B	7.42	0.36 a	1.71 b	1.12 cd	9.13	0.36 a	0.98 a	0.50 a
C	8.18	1.01 c	1.91 b	1.08 bcd	8.42	0.52 ab	0.89 a	0.36 a
D	9.05	0.36 a	1.66 b	1.11 cd	8.86	0.38 a	0.90 a	0.32 a
E	8.36	0.34 a	1.41 ab	1.51 de	10.55	0.34 a	0.85 a	0.35 a
F	8.92	0.41 a	1.35 ab	1.72 e	9.10	0.45 a	0.88 a	0.62 ab
G	8.74	0.52 ab	1.32 ab	1.31 de	8.99	0.55 ab	0.88 a	0.39 a
H	10.1	0.49 a	1.42 ab	1.27 cde	9.73	0.86 bc	1.20 ab	0.60 abc
SD**	0.8	0.2	0.2	0.2	0.7	0.2	0.3	0.1
CV****	9	43	14	18	7	40	27	26

* see Table 1 – jak w tabeli 1,
** standard deviation – odchylenie standardowe,
*** coefficient of variation – współczynnik zmienności;
Means designated the same letters in columns did not differ significantly at $p < 0.05$ according to the Fisher test.
Średnie oznaczone tymi samymi literami w kolumnach nie różnią się istotnie dla $p < 0.05$ wg testu Fishera.

Table 6
Tabela 6

Content of iron (mg·kg^{-1} d.m.) in soil and meadow sward
Zawartość żelaza (mg·kg^{-1} s.m.) w glebie i runi łąkowej

Fertilizer objects* Obiekty nawozowe*	0 Ca				+ Ca			
	soil – gleba		cut – pokos		soil – gleba		cut – pokos	
	total ogólny Fe	Fe-NH$_4$EDTA	I	II	total ogólny Fe	Fe-NH$_4$EDTA	I	II
A	8625	192 a	101 a-d	108 a	9215	286 de	114 cd	137 a
B	6855	193 a	73 a-d	112 a	9070	283 de	67 abc	96 a
C	7585	196 a	76 a-d	112 a	9055	346 f	74 a-d	75 a
D	8925	211 a	61 abc	107 a	9155	276 cd	57 ab	89 a
E	8470	204 a	63 abc	201 a	9240	311 e	99 a-d	96 a
F	8335	215 ab	98 a-d	224 b	9435	254 cd	48 a	77 a
G	8345	245 bc	64 abc	131 a	8580	312 e	57 ab	206 a
H	9375	267 cd	127 bcd	121 a	8325	247 bc	141 d	208 ab
SD**	782.1	27.0	23.5	46.1	369.6	32.7	32.7	55.2
CV****	9	13	28	33	4	11	40	45

* see Table 1 – jak w tabeli 1,
** standard deviation – odchylenie standardowe,
*** coefficient of variation – współczynnik zmienności;
Means designated the same letters in columns did not differ significantly at $p < 0.05$ according to the Fisher test.
Średnie oznaczone tymi samymi literami w kolumnach nie różnią się istotnie dla $p < 0.05$ wg testu Fishera.

the soil of the limed series (between 27% and 77%) than in the non-limed treatments except for unfertilized soil, where the absolute content of Fe-NH_4EDTA was lower (Table 6). The amount of iron extracted with the above reagent constituted between 2.2% and 2.9% of the total content of iron in the soil of the non-limed treatments and between 2.7% and 3.8% in the limed treatments. Although the soil reaction was favourable, iron concentrations in the meadow sward were on a similar level, irrespective of the series and applied fertilization (Table 6). The factor which significantly diversified concentrations of this element in sward was the date of harvest (cut). The content of iron bound to organic substance made up a small percentage of the total iron content, which was high. Unlike manganese and nickel, whose soil concentrations extracted with NH_4EDTA were lower in limed soils, iron responded differently to liming. Relatively little iron was determined in forms bound to organic substance, which may suggest a much greater affinity of this element to form stable combinations with other soil constituents (KABATA-PENDIAS, PENDIAS 1999). Iron often seems to be in short supply for plants, but this is most probably due to the fact that plants cannot take it up readily because of some very dynamic changes of its bioavailability rather than because of its low soil concentrations. Relatively small concentrations of iron in the sward may be attributed to the physiological characteristics of plants, which make it difficult to transport this element from the root system to the aerial organs (GONDEK AND FILIPEK-MAZUR 2005). According to MACIEJEWSKA, KOTOWSKA (2001), iron content in hay may also be affected by the harvest date. Analysis of plant material in view of animal nutritional requirements for iron (GORLACH 1991) generally revealed iron deficiency.

CONCLUSIONS

1. The content of total manganese forms was higher in the soil of the limed series and the soil reaction significantly affected amounts of this metal extracted with NH_4EDTA solution and its content in the sward. Soil liming, while limiting manganese bioavailability, improved forage value of the analyzed biomass.

2. The small amount of nickel bound to the soil organic substance indirectly proves considerable mobility of this element and its translocation into deeper levels of the soil profile, beyond the reach of the plant root system.

3. Liming increased the content of iron forms in combinations with the soil organic substance. Iron deficiency in the meadow sward may have a physiological basis such as difficulties in iron transport from the root system to aerial organs, but it does not result from limited possibilities of its uptake from soil.

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