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MICROELEMENT CONCENTRATIONS IN SWARD AND SOIL OF LONG-TERM FERTILIZER EXPERIMENT (CZARNY POTOK)

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A b s t r a c t. The goal of the work was to assess the extent of soil depletion of microelements (Cu, Zn, Mn), observed in the long-term fertilizer experiment carried out on a mountain meadow at Czarny Potok near Krynica. The experiment was set up in 1968 on an acid brown soil and the results presented refer to the year 2003. It comprised eight fertilizer combinations in two series (limed and unlimed). Modifications introduced during the experiment (two-year breaks in fertilization or treatment with copper and magnesium) provided a background for analysis concerning the conservative system of grassland management. The contents of copper, zinc, manganese were assessed in the meadow sward and soil. Liming conducted twice did not cause any increase in the meadow sward yield, but through a change of reaction led to a blocked uptake of a majority of heavy metals. At a higher soil reaction, diversified meadow sward removed smaller amounts of microelements with yield allowing a longer time of utilization. The results of selected heavy metal concentrations in the meadow sward and soil of individual fertilizer combinations allow a conclusion that conservative management of nutrients on grasslands should be systematic. Liming and supplement of microelements for an even expenditure-gain balance are the basic elements of such management.

K e y w o r d s: microelements, meadow sward, long-term fertilizing experiment

INTRODUCTION

It is extremely important for any crop production to learn microelement concentrations in the soil-plant system. A perfunctory treatment of this issue is a mistake often made by farmers. There are many reasons for that, including absence of any specific response in a majority of plants to low soil abundance in microelements. Such symptoms are particularly difficult to register in grasses. It seems that cereal monocultures are in a privileged position because natural fertilizers often applied in crop rotation always improve microelement balance. Grasslands are treated as a cheap forage reservoir, so small outlays are made on fertilization to supplement microelements. Grasslands on heavier soils are in a better position [3,7]. These soils are richer in microelements, so they may be utilised for a longer period of time without the nutrient supplement. For such specifically complex biotopes as permanent grasslands, the fact that roots of species penetrate various soil horizons variously is also very important. These elements cause the effect of buffering of microelement deficiency, which becomes noticeable for a considerable decline in dry matter yields. Correlation relationships between microelement concentrations are often not registered in the soil-plant system [6]. Rational agrotechnical measures on grasslands should consider also physico-chemical properties of soil, which involves microelement management in the environment and allows reaching yields satisfactory to farmers and meeting forage criteria. Ranges of optimal sward microelement concentrations are wide, from the plant physiology perspective. Lower and upper limits for different elements differ even fivefold. Therefore, using agrotechnical measures, it is possible to lower the microelement content and prolong the period of time when outlays on microelement application prove unnecessary. Particularly for zinc and manganese it is possible to limit the quantity of microelements removed with the yield by regulating soil reaction [1,2].

The work aimed to assess the effect of liming of mountain meadow objects receiving diversified mineral treatment on diminishing soil microelement depletion.

MATERIALS AND METHODS

The experimental field was localised at Czarny Potok near Krynica (250^{o}54’ E; 49^{o}24’ N) about 720 m above sea level, at the foot of Jaworzyna Krynicka Mt. on a slope with 7^o inclination and NNE exposition. The experiment was set up in 1968 on a natural mountain meadow of moor mat grass (*Nardus stricta* L.) and red fescue (*Festuca rubra* L.) type with a considerable share of the dicotyledonous.

The experimental soil belonged to brown acid soils developed from Magura sandstone with the granulometric composition of light silty loam (% of 1-0.1 mm fractions: 40; 0.1-0.02 – 37 and <0.02 mm – 23) and three characteristic genetic horizons: turf – AhA (0-20 cm), browning – ABbr (21-46 cm) and matrix BbrC (47-75 cm). The experiment was set up with the randomized block method in 5 replications (6 x 7 m) comprising 8 treatments (Tab. 1). In the 7th and 8th year and in the 26th and 27th year of the experiment the consecutive effect of mineral fertilizers was studied. During the first interval in fertilization, cultivation measures on the experimental field were limited to cutting and harvesting sward yields. In the second break in the mineral treatment and after assessing the quantity of yield, the sward was grazed with sheep. Detailed meteorological data are presented in Table 2, the methods were described in an earlier publication [4].

Table 1. Schematic of fertilizer application in the static experiment at Czarny Potok

Fertilizing objects	Nutrient rate in kg ha^{-1} $year^{-1}$			Nitrogen form
	P	K	N	
PK	39.24	124.5	–	
$PK+N_{1an}$	39.24	124.5	90	ammonium nitrate
$PK+N_{2an}$	39.24	124.5	180	ammonium nitrate
$PK+N_{1u}$	39.24	124.5	90	urea
$PK+N_{2u}$	39.24	124.5	180	urea
N	–	–	90	ammonium nitrate
P	39.24	–	–	
0	–	–	–	

an – ammonium nitrate, u – urea.

Table 2. Statistic parameters of the distribution of precipitation and temperature for the period 1968-2001

Parameter	Precipitation (mm)		Temperature (^{o}C)	
	I-XII	IV-IX	I-XII	IV-IX
arithmetic mean	856.5	567.9	5.78	11.96
Standard deviation	184.1	132.5	0.90	0.86
range 25-75% of cases	728.5-909.0	466.1-649.7	5.30-6.30	11.3-12.5

Since the autumn of 1985, the experiment, at the same fertilization level, has been conducted in two series: unlimed and limed (1985, 1995). Since 2000, the foliar fertilization has been used (twice 2 dm^3 ha^{-1}) with the microelement fertilizer Mikrovit-1 which contained: 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 per 1 kg.

Results presented in this paper refer to the research carried out in 2003. Yields of sward green mass were assessed twice a year: 1^{st} cut was harvested on 28th June, 2^{nd} cut on 10th September. After the harvest of the second cut, soil was sampled for analyses from two layers: 0-10 cm and 10-20 cm. Copper, manganese and zinc in plants and soil were assessed with ICP-AES method following dry mineralization (450^{o}C) and solution in nitric acid(V) (1:2). The analysis was conducted on material sampled from each plot (5 replications per treatment), which made analysis of variance possible.

Long-term fertilizer experiments aim at determining conditions for maintaining yields and the sward quality at an optimal level over a long period of time. The interpretation of results presented in this work refers to the selected microelements from a static fertilizer experiment which since 1968 has been used for studies of long-term effect of diversified levels of NPK fertilization against the background of the same cultivation measures.

RESULTS AND DISCUSSION

Yields in this experiment were shaped by the fertilization level, but after 20 years of significantly higher yields on the objects fertilized with 180 kg N +PK than on the object fertilized with 90 kg N + PK, a gradual equalization of yields on these objects was observed [4]. In the period between 25th and 35th year of the experiment, meadow sward on the object fertilized with nitrogen yielded 5-7 Mg dry matter per hectare (irrespective of this component dose). The yields produced in 2003 (Tab. 3) confirm this rule and, as a result of microelement treatment, a tendency for diversification of yields according to doses has been noticeable, especially in the second cut. Liming has not, to any statistically significant degree, affected the differences among the objects in the two series.

Table 3. Dry matter yields of meadow sward in 2003

Fertilizing objects	Mg (d.m. ha^{-1})		
	1st cut	2nd cut	Sum
		0 Ca	
PK	2.64ab*	1.27cd	3.91bc
$PK+N_{1an}$	3.80bc	1.54de	5.34d
$PK+N_{2an}$	4.00c	2.10g	6.10d
$PK+N_{1u}$	3.99c	1.78efg	5.77d
$PK+N_{2u}$	3.63bc	2.11g	5.74d
N	1.96a	0.87abc	2.83ab
P	2.36a	0.84ab	3.20ab
0	1.83a	0.81ab	2.63ab
		+Ca	
PK	3.75bc	1.27cd	5.02cd
$PK+N_{1an}$	4.15c	1.64def	5.79d
$PK+N_{2an}$	4.37c	1.99fg	6.36d
$PK+N_{1u}$	4.20c	1.61def	5.81d
$PK+N_{2u}$	4.09c	2.00fg	6.09d
N	2.07a	1.01bc	3.08ab
P	2.18a	0.68ab	2.86ab
0	1.86a	0.59a	2.45a

an – ammonium nitrate; u – urea, * homogeneous groups according to the LSD Fisher test in the system of two factors (objects, series)

Microelements are subject to a law of minimum, and their deficiency would limit yields, similarly as in the case of each nutrient. The demand for microelements according to the forage criterion is much higher than the demand resulting from the physiological requirements of plants. Determined critical concentrations showing a microelement deficiency in forage do not necessarily mean a decline in yields. Such a response occurs at much lower values. This has been proved by yields (Tab. 3) obtained at Czarny Potok and their microelement concentrations (Tab. 4).

Table 4. Contents of microelements in the meadow sward in 2003

Fertilizing	Zn		Mn		Cu	
objects	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
			mg kg^{-1}			
			0 Ca			
PK	30.2de*	35.4fgh	138.0f	202.2cde	4.21defg	4.75cde
PK+N_{1an}	26.3d	28.6cdef	132.9f	249.3ef	4.39efgh	4.00abcd
PK+N_{2an}	29.9de	30.5defg	126.9f	253.4ef	6.12i	5.19e
PK+N_{1u}	24.4bcd	25.5bcde	95.4bcdef	222.6def	4.80gh	3.87abc
PK+N_{2u}	24.1bcd	33.2efgh	103.6ef	300.5f	5.30hi	5.18e
N	26.1cd	38.4gh	100.4def	206.2de	4.63fgh	4.87de
P	28.9de	40.1h	96.6cdef	169.6bcde	3.51bcde	3.79abc
0	34.1e	39.9h	89.5abcdef	137.0abcd	3.67cdef	4.16abcd
			+Ca			
PK	17.1a	25.2bcde	57.9abcde	90.2ab	2.61ab	4.03abcd
PK+N_{1an}	14.2a	23.4abcd	64.2abcde	107.9ab	3.31abcd	4.00abcd
PK+N_{2an}	15.3a	16.0a	45.9a	76.6a	3.91defg	3.72ab
PK+N_{1u}	19.9abc	21.4abc	46.7ab	85.7ab	3.50abcde	3.51a
PK+N_{2u}	15.0a	19.1ab	54.4abcd	84.3ab	3.77cdef	4.02abcd
N	19.6abc	28.9cdef	45.7a	115.4abc	3.58cde	4.48bcde
P	19.3ab	28.6cdef	58.0abcde	86.5ab	2.92abc	3.79abc
0	16.6a	26.5bcde	48.2abc	66.5a	2.54a	3.30a

an – ammonium nitrate; u – urea.

* homogeneous groups according to the LSD Fisher test in the system of two factors (objects, series).

The content of microelements in sward was affected by fertilization, duration of the experiment, and quantity of yields [5]. In the 36th year of the experiment, sward microelement concentrations from individual objects were significantly diversified. Microelement concentrations in variously fertilized sward were not unanimous and resulted from the amount of microelements removed with diversified yield, influence of fertilizers on the environment, and microelement availability from soil resources. In comparison with twice lower nitrogen dose, acidifying effect of fertilization with 180 kg N ha^{-1} + PK, irrespective of form, is connected with significantly bigger copper content in the sward of unlimed series, however in limed series and for other microelements no such dependency was found. A systematic removal of microelements with yield and their depletion from soil resources caused, at small contents, a levelling out of the differences in microelement contents and a diminishing of the range within which they fluctuate in sward. In the case of copper, the overlapping effect of regenerative soil application of this element in 1992 is to be considered.

On the basis of 16-year research, Gorlach and Curyło [2] found that the biggest changes in sward due to liming occurred for the manganese content and further for zinc and copper. Also other authors corroborate this finding [1,6,7]. Similar tendencies were noticed in sward from the Czarny Potok experiment. In 2003 the average manganese concentrations in sward of limed series for all objects were 47% in 1st cut and 41% in 2nd cut in comparison with the unlimed series. Analogous zinc contents were 60% and 70%, and copper 71% and 85%. In each case concerning the cuts, the differences in individual element concentrations between two series have been statistically significant.

In the 0-10 cm soil layer a diversification of the total content of selected microelements was registered (Tab. 5). The lowest content was found in soil from objects fertilized with ammonium nitrate in the unlimed series. A significant difference in zinc and manganese content was detected in soil fertilized with 90 kg N ha^{-1} for different forms of nitrogen. Ammonium nitrate caused a bigger soil exhaustion, which may be connected with a strong acidifying effect of this fertilizer. Microelements mobilised in more acid environment were more readily taken up by sward and removed with yield in bigger quantities. In the case of copper, no such significant diversification was found as for zinc and manganese, but its concentrations on objects fertilized with urea in unlimed series were bigger than on objects fertilized with ammonium nitrate.

Zinc and copper contents in limed series were significantly bigger than the contents in unlimed series, except for the untreated object. For manganese no such obvious diversification was noticed, despite its bigger content in limed soil. From among all the microelements, the biggest quantities of manganese were removed with yield.

Table 5. Content of total form of zinc, manganese and copper in soil (0-10 cm)

Fertilizing objects	Zn	Mn	Cu
	mg kg^{-1}		
	0 Ca		
PK	35.66bcd*	270.8ab	4.98ab
PK+N_{1an}	30.15a	239.3a	4.45a
PK+N_{2an}	32.2ab	268.4ab	4.48ab
PK+N_{1u}	36.50bcdef	297.1bc	5.42abcd
PK+N_{2u}	34.95abc	270.2ab	5.09abc
N	36.25bcde	284.5b	4.93ab
P	34.40ab	274.5ab	4.75ab
0	45.12g	337.5c	5.57abcde
	+Ca		
PK	41.15efg	302.9bc	11.84f
PK+N_{1an}	40.30defg	280.6ab	9.34ef
PK+N_{2an}	40.20defg	277.5ab	7.22bcde
PK+N_{1u}	41.00efg	292.6bc	8.08de
PK+N_{2u}	40.45defg	284.1b	7.78cde
N	41.55fg	303.5bc	8.80e
P	43.90g	297.5bc	8.21e
0	47.00g	310.0bc	8.87ef

an – ammonium nitrate; u – urea.
* homogeneous groups according to the LSD Fisher test in the system of two factors (objects, series).

CONCLUSIONS

1. Microelement (Cu, Zn, Mn) concentrations in sward fertilized for many years without microelement supplement were lower than values recognized as forage criteria.
2. Application of microelement dose stimulating yields led to the effect of their dilution in yield and did not increase microelement concentrations in forage.
3. A negative microelement balance based exclusively on soil abundance leads to diminishing their contents in soil proportionately to the quantities removed with yield.
4. Liming is a factor which noticeably affects sward concentrations of zinc and manganese even at their lesser availability from soil. An increase in soil reaction favours rational management of microelement resources in soil.

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ZAWARTOŚĆ MIKROELEMENTÓW W RUNI I GLEBIE DŁUGOTRWAŁEGO DOŚWIADCZENIA NAWOZOWEGO (CZARNY POTOK)

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Streszczenie. Przedmiotem pracy jest ocena stopnia wyczerpywania metali ciężkich z gleby, w tym mikroelementów (Cu, Zn, Mn), w długotrwałym doświadczeniu nawozowym prowadzonym na łące górskiej w Czarnym Potoku koło Krynicy (20^o54’ E; 49^o24’ N). Doświadczenie założono w 1968 roku na glebie brunatnej kwaśnej, a wyniki przedstawione w pracy dotyczą 2003 roku. Obejmuje ono osiem kombinacji nawozowych w dwóch seriach. W runi łąkowej i glebie oznaczono zawartość miedzi, cynku, manganu. Przeprowadzane dwukrotnie wapnowanie nie spowodowało zwiększenia plonów runi łąkowej, ale poprzez zmianę odczynu zmniejszało ilości pobranego manganu i cynku. Urozmaicona ruń łąkowa w warunkach wyższego odczynu odprowadza z plonem mniejsze ilości mikroelementów pozwalając na dłuższy okres użytkowania. Wyniki analizy zawartości wybranych metali ciężkich runi łąkowej i glebie poszczególnych kombinacji nawozowych pozwalają na stwierdzenie, że zachowawcze gospodarowanie składnikami pokarmowymi na użytkach zielonych powinno być prowadzone systematycznie. Podstawowymi elementami takiego gospodarowania są wapnowanie, natomiast dolistne stosowanie mikroelementów stymulując plon przy zmniejszonej zasobności nie poprawiło zawartości metali w paszy.

Słowa kluczowe: mikroelementy, ruń łąkowa, długotrwałe doświadczenie nawozowe