Małgorzata DUCKA, Jerzy BARSZCZEWSKI
Institute of Technology and Life Sciences, Department of Grassland, Falenty, Poland
e-mail: j.barszczewski@itep.edu.pl

ZINC LEVELS IN PERMANENT DRY MEADOW IN DIFFERENTIAL IRRIGATION AND FERTILIZATION CONDITIONS

Summary

The study took place between years 2009–2011 in Falenty, Mazovian Voivodeship, as a part of a long-term scientific experiment, began in 1987, using the randomised block method. All blocks were irrigated until 2008. In 2009 each block was divided into two areas: irrigated and non–irrigated. The study involved four levels of inorganic nitrogen fertiliser and two levels of mixed organic and inorganic fertiliser in the form of fermented cattle urine. Inadequate levels of zinc were observed in the sward from the majority of plots, totalling less than 30 mg Zn·kg^{-1}. This figure continued to decline in subsequent years, which could be correlated to a decline in soil pH, which contributed to the increased filtration of this element into the soil profile, since increased acidity led not only to the greater absorption of zinc by plants but also an increased propensity for leaching. The zinc content of sward differed across consecutive harvests, but no clear tendencies were observed. A significantly lower quantity of the element was observed in sward from the first harvest in all plots only in the first year of the experiment. A tendency was observed for the quantity of the zinc content of sward to decline as the level of fertilisation increased, which may have been caused by the greater crops obtained through the use of greater quantities of inorganic fertiliser and the effect of dilution.
***Key words**: permanent grassland, zinc, soil, sward*

GOSPODARKA CYNKIEM NA ŁĄCE TRWAŁEJ GRĄDOWEJ NAWADNIANEJ ORAZ BEZ NAWODNIEŃ W WARUNKACH ZRÓŻNICOWANEGO NAWOŻENIA

Streszczenie

Badania prowadzono w latach 2009-2011 w Falentach, na wieloletnim doświadczeniu ścisłym, założonym w 1997 r., metodą losowanych bloków. Do 2008 r. wszystkie obiekty były nawadniane, a od 2009 r. każdy obiekt został podzielone na dwie części - nawadnianą i bez nawodnień. Na obiektach stosowano zróżnicowane nawożenie mineralne oraz organiczno-mineralne w formie gnojówki bydlęcej. Na większości obiektów odnotowano niedoborową zawartość cynku w runi łąkowej, wynoszącą poniżej 30 mg Zn·kg-1. W kolejnych latach notowano spadek zawartości cynku w runi, co mogło wiązać się ze spadkiem pH gleby, co mogło przyczynić się do większego przemieszczania się tego składnika w głąb profilu glebowego i w efekcie do jego wymywania. Istotnie mniejszą zawartość tego składnika notowano w runi z pierwszego pokosu na wszystkich obiektach jedynie w pierwszym roku badań. Zawartość cynku w runi łąkowej różnicowała się w kolejnych pokosach w poszczególnych latach, jednak bez wyraźnych tendencji. Na większości obiektów nawadnianych odnotowano większą zawartość cynku w runi, niż na obiektach bez nawodnień. Tendencja zmniejszania się zawartości cynku w runi wraz ze wzrastającym poziomem nawożenia mogła być spowodowana wysokimi plonami uzyskanymi pod wpływem większych dawek nawozów mineralnych i w wyniku rozcieńczenia.
***Słowa kluczowe**: trwałe użytki zielone, cynk, gleba, ruń łąkowa*

1. Introduction

In agricultural production a large yield of high quality crops is dependent not only on providing arable crops with macroelements but also on supplying their need for microelements. One such crucial element is zinc, a key component of numerous plant enzymes and a key component in the metabolisation of carbohydrates, proteins and phosphorus compounds. [1] Zinc deficiency can disrupt nitrogen transformation and cause the accumulation of undesirable amides and free amino acids. Appropriate levels of zinc in sward, a key fodder for farm animals, provide animals with essential levels of this chemical element. The needs of animals are met by plants that contain about 30 mg Zn kg^{-1}.

According to Maciejewska and Kotowska [2] increasing the acidity of soil has significant impact on the solubility of zinc and thus its activity and bioavailability. The absorption of zinc by plants, especially in slightly acidic and acidic soils is high due to the solubility of the majority of its compounds [3, 4, 5, 6]. The availability of this element for plants also depends on its overall content in soil, soil moisture level, organic compound levels and levels of other elements and macro-elements, principally phosphorus, nitrogen and copper [1, 7, 8]. Tiller [9] claims that soil properties are the main factor in the absorption of zinc by plants.

The aim of the study was to examine the correlations between the zinc content of different crops of sward, its presence in soil and yields of sward in different inorganic and mixed organic and inorganic (fermented urine) fertiliser with and without irrigation.

2. Materials and methods

The study took place between 2009-2011 in Falenty, Mazovian Voivodeship, as part of a long-term scientific experiment, began in 1987, using the randomised block method, repeated four times in proper dry meadow conditions on degraded black soil with a granulometric composition consistent with loamy soil. All blocks were irrigated until 2008. In 2009 each block was divided into two areas: irrigated and non-irrigated, resulting in plots of 27 m^2. The sward on the non-irrigated plots received its water from the soil profile supplemented with atmospheric precipitation. On the irrigated plots water deficiencies were supplemented, according to need, between May and September to maintain a water content of 60-100% of field capacity (FC) in the upper strata of the soil. The water requirements of the soil were supplied in single doses of about 25 mm. The soil water content was monitored using readings from sensors (Em 50) at depths of 10-15, 25-30 and 40-45 cm.

The study involved four levels of inorganic nitrogen fertiliser (at the N-180bis level phosphorus had not been applied since 1997) and two levels of mixed organic and inorganic fertiliser (table 1). The inorganic fertilisation comprised nitrogen in the form of ammonium nitrate (34.5% N), phosphorus in the form of triple superphosphate (46% P_2O_5) and potassium in the form of potassium oxide (57% K_2O). The mixed organic and inorganic fertiliser was applied in the form of fermented cattle urine, which supplied adequate levels of potassium while nitrogen and phosphorus levels were topped up to standard dosages with superphosphate and ammonium nitrate. Before each application the dry weight and nitrogen, phosphorus and potassium levels of the fermented urine were established. Fertilisation with a mixture of fermented urine, nitrogen and potassium was carried out three times a year, once for every harvest while the phosphorus was applied once, in spring.

Soil at depths of 0-10 and 10-20 cm was tested for pH in 1M KCl (pH_{KCl}) and for zinc content in autumn 2008 and 2011.

Each year the sward was harvested three times and the dry weight of the crop was determined. The sward samples from each harvest were tested for zinc content, after appropriate treatment, with an atomic absorption spectrometer and ITP methodology, [10] using a mix of concentrated acids: nitric, perchloric and sulphuric.

Table 1. The scheme of meadow sward fertilization
Tab. 1. Schemat nawożenia na poszczególnych obiektach

Fertilization objects		Fertilization dose (kg·ha^{-1})		
		N	P	K
N-60	mineral	60	10.9	33.2
N-120		120	21.8	66.4
N-180		180	31.7	99.6
N-180bis		180	0	99.6
N-240		240	43.6	132.8
G1	organic- mineral	180	31.7	99.6
G2		240	43.6	132.8

Source: Own work / Źródło: opracowanie własne

The crop yield figures obtained were subjected to statistical analysis using analysis of variance. The calculations were made using Statistica software using the Anova/ Manova module.

3. Results and discussion

Significant differences in crop yield were observed in the majority of plots in line with the different levels of fertilisation (table 2). The smallest yields were obtained from plots with the lowest level of inorganic fertilisation (N-60). Compared to this level a significant increase in crop yield was observed in subsequent years in all plots, irrigated and non-irrigated, with higher levels of organic and mixed organic and inorganic fertiliser. No significant difference in crop yield was observed in the plot deprived of phosphorus fertiliser (N-180bis) compared to plots where this component was used alongside an identical dose of nitrogen in the mineral form (N-180) and mixed organic and inorganic fertiliser(G1).

The only significant increase in crop yield from an irrigated plot was observed in plot G2 compared to its first level of fertilisation (G1). The largest dry weight crop in 2009, significantly greater compared to all plots with lower levels of fertiliser, were obtained with the highest levels of inorganic fertiliser (N-240) and mixed organic and inorganic fertiliser (G2). The largest crops of all the plots, showing an upward tendency linked to the level of fertilisation, were obtained in 2010 as a result of well distributed and significant rainfall in that year. Such a link between crop yields and levels of precipitation was found by Sapek et al. [11]. Crops obtained from plots fertilised with ammonium nitrate and fermented urine indicate that these fertilisers similarly improved yields in 2009 and 2010, confirmed in the findings of Wesołowski [12].

The cause of the significant decline in crop yields in 2011, irrespective of irrigation and fertilisation, has been identified as the significant increase in dicotyledonous weeds present in the sward, especially common dandelion (*Taraxacum officinale* F.H. Wigg.), sheep's sorrel (*Rumex acetosa* L.) and broad-leaved dock (*R. obtusifolius* L.). Głowacki's research links declining crop yields with growth in the population of these weeds [13].

At the start of the study significant variance in soil pH was observed at depths of 0-10 cm, oscillating between 4.10-5.65, as well as 10-20cm, where pH ranged from 5.2-5.86. After the initial three years of the experiment a clear downward trend was observed in soil pH in all fertilised plots, both at the 0-10 cm level and at 10-20 cm (table 3). The lowest pH values were observed in plots with the highest levels of inorganic fertiliser (N-240) while the highest occurred at the lowest levels (N-60). A significantly higher soil pH was observed in irrigated plots compared to non-irrigated plots which may be the result, as suggested by Sapek et al, [14] of significant levels of calcium introduced along with the water used to irrigate the sward.

Table 2. Dry matter yields [t·ha^{-1}] from irrigated and non irrigated objects
Tab. 2. Plony absolutnie suchej masy [t·ha^{-1}] z obiektów nawadnianych i nie nawadnianych

Year	Irrigation	**Objects**						
		N-60	**N-120**	**N-180**	**N-180bis**	**N-240**	**G1(180)**	**G2(240)**
2009	non-irrigated	5.70a	8.01bc	9.38bc	9.49bc	9.55bc	7.84b	9.98c
	irrigated	6.41a	8.70b	9.34b	9.81bc	10.99c	9.33b	11.25c
2010	non-irrigated	7.84a	10.03ab	11.52b	10.72b	11.45b	10.30ab	11.38b
	irrigated	7.49a	9.80b	10.01b	10.06b	11.32b	10.18b	11.39b
2011	non-irrigated	5.33a	7.80ab	8.35b	8.00ab	8.41b	9.05b	8.73b
	irrigated	5.43a	8.12b	9.04b	8.10b	8.65b	8.25b	9.41b

Source: Own work / Źródło: opracowanie własne

Table 3. Upper soil layers pH (KCl) depending on the form and level of nitrogen fertilization on irrigated and non-irrigated objects

Tab. 3. Wartości pH (KCl) wierzchnich warstw gleby, w zależności od formy oraz poziomu nawożenia azotem, na obiektach nawadnianych oraz bez nawodnień

Objects		pH KCl			
		Soil layer, cm			
		0-10	10-20	0-10	10-20
		2008		2011	
N-60	irrigated	5.65	5.86	5.43	5.56
	non-irrigated	-	-	5.25	5.60
N-120	irrigated	5.55	5.68	5.16	5.47
	non-irrigated	-	-	5.00	5.30
N-180	irrigated	5.01	5.69	4.77	5.36
	non-irrigated	-	-	4.33	5.14
N-180bis	irrigated	4.81	5.29	4.55	5.22
	non-irrigated	-	-	4.21	5.22
N-240	irrigated	4.10	5.20	3.96	4.72
	non-irrigated	-	-	3.25	4.15
G1	irrigated	5.35	5.79	5.24	5.51
	non-irrigated	-	-	4.89	5.37
G2	irrigated	4.95	5.57	4.68	5.17
	non-irrigated	-	-	4.51	5.32

Source:Own work / Źródło: opracowanie własne

Soil in all the experimental plots was characterised by low levels of zinc, ranging from 12.9 to 25.3 mg Zn·kg^{-1} DMB at a depth of 0-10 cm and from 11,0 do 26,0 mg Zn·kg^{-1} DMB at a depth of 10-20 cm. The zinc levels observed were much lower than the average levels for loamy soil in Poland, which amounts to 52 mg Zn·kg^{-1} DMB [15]. At the start of the experiment the greatest zinc levels found at both the depths tested were observed in the plot with the highest level of mixed organic and inorganic fertiliser (G2). Zinc levels observed in 2008 in plots that were not fertilised with phosphorus were lower compared to other plots at both of the tested soil depths. A possible cause is the absence of zinc supplementation from phosphorus fertilisers, which can supply up to 1450 mg Zn·kg^{-1}.

During the experimental period the zinc content of the soil declined both in irrigated and non-irrigated plots. After three years the lowest zinc levels were observed in non-irrigated plots that were not fertilised with phosphorus. The highest zinc levels were observed in the non-irrigated plots fertilised with mixed organic and inorganic fertiliser (G2), which may be the result of zinc contained in fertilised urine, which amounts to about 220 mg·kg^{-1} DMB. [16] The greatest decline in zinc levels during the experimental period was also observed at this level of fertilisation in irrigated plots.

Table 4. Changes in the zinc content (mg Zn · kg^{-1} DM) in soil layers depending on the form and level of fertilization on irrigated and non-irrigated objects

Tab. 4. Zasobność gleby w cynk (mg Zn·kg^{-1} s.m.) na obiektach bez nawodnień i nawadnianych, w zależności od formy i dawki nawożenia

Objects	Mineral fertilization										Natural-mineral fertilization			
	N-60		N-120		N-180		N-180bis		N-240		G1		G2	
Layer [cm]	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
Irrigated 2008	24.9 bc	20.4 ab	24.1 bc	21.3 ab	21.8 ab	24.3 bc	20.8 a	18.9 a	21.3 ab	21.0 ab	23.2 bc	21.1 ab	25.3 c	26.0 c
Irrigated 2011	16.3 b	15.4 ab	13.6 ab	12.1 ab	15.5 ab	16.1 b	13.8 ab	11.7 a	11.9 a	12.0 ab	16.4 b	14.6 ab	14.4 ab	13.5 ab
Non irrigated 2011	13.8 a	12.9 ab	14.4 ab	11.2 a	14.6 ab	11.9 a	12.9 a	11.0 a	14.4 ab	12.3 ab	16.1 bc	14.5 ab	16.6 c	14.4 ab

Source: Own work / Źródło: opracowanie własne

Table 5. Average zinc content in the sward in the years 2009-2011 in mg·kg^{-1}DM

Tab. 5. Średnie zawartości cynku w runi łąkowej w latach 2009-2011 w mg·kg^{-1}s.m

Objects	Mineral fertilization										Natural-mineral fertilization			
	N-60		N-120		N-180		N-180bis		N-240		G1		G2	
Swath \ Irrigation	NI	I	NI	I	NI	I	NI	I	NI	I	NI	I	NI	I
I	24.1 a	25.0 a	25.0 a	25.3 a	25.3 a	26.8 ab	26.9 ab	26.8 ab	24.7 a	26.2 ab	29.3 b	29.0 b	24.5 a	26.7 ab
II	34.6 c	42.3 cd	29.9 b	36.1 c	28.0 b	30.9 bc	30.1 b	38.6 cd	27.4 ab	34.7 c	31.2 bc	33.4 c	27.1 ab	30.9 bc
III	29.6 b	34.1 c	27.4 ab	30.9 bc	33.2 c	32.6 c	28.8 b	29.3 b	27.4 ab	31.1 bc	33.1 c	35.7 c	30.6 bc	36.2 c
Average 2009	**29.4 b**	**33.8 c**	**27.4 ab**	**30.8 bc**	**28.6 b**	**30.1 bc**	**28.8 b**	**31.6 bc**	**26.5 a**	**30.7 bc**	**31.2 bc**	**32.7 c**	**27.4 ab**	**31.3 bc**
I	26.0 b	26.0 b	25.4 b	24.5 b	23.6 b	25.7 b	23.3 b	29.2 bc	24.7 b	27.5 b	26.8 b	25.6 b	27.0 b	30.1 bc
II	22.0 ab	24.3 b	17.9 a	18.7 a	14.5 a	18.7 a	18.3 a	21.7 a	16.6 a	20.9 ab	19.4 a	24.9 b	20.2 a	19.5 a
III	23.3 b	23.2 b	21.7 ab	25.9 b	20.7 ab	20.9 ab	21.5 ab	25.1 b	20.4 ab	22.9 b	24.9 b	24.4 b	23.6 b	19.2 a
Average 2010	**23.7 b**	**24.5 b**	**21.7 ab**	**23.0 ab**	**19.6 a**	**21.7 ab**	**21.0 ab**	**25.3 b**	**20.5 a**	**23.8 b**	**23.7 b**	**25.0 b**	**23.6 b**	**22.9 ab**
I	24.2 b	23.4 ab	23.8 ab	23.6 ab	21.9 a	22.0 a	20.8 a	28.0 b	21.9 a	20.6 a	21.0 a	22.3 a	20.1 a	21.5 a
II	25.0 b	24.5 b	23.9 b	23.3 b	23.4 b	25.2 b	21.8 a	29.3 bc	31.8 c	25.2 b	25.9 b	26.5 b	29.0 bc	26.9 b
III	23.9 b	20.6 a	21.6 a	21.4 a	20.0 a	19.8 a	19.9 a	22.4	18.2 a	20.7 a	21.5 a	22.6 a	20.8 a	20.2 a
Average 2011	**24.4 b**	**22.8 a**	**23.1 a**	**22.8 a**	**20.8 a**	**22.3 b**	**21.8 a**	**26.6 b**	**24.0 b**	**22.2 a**	**22.3 a**	**23.8 ab**	**23.8 ab**	**22.9 a**

I – irrigated; NI – non-irrigated

Source: Own work / Źródło: opracowanie własne

The availability of mobile zinc in soil, according to Rogóż and Kabaty-Pendias and Pendias, [5, 15] increases in inverse proportion to soil pH. The present study showed that the reduction in soil pH caused by fertilisation improved the availability of zinc. Within the pH range observed in the experiment, as confirmed by Sapek [16], no correlation was observed between the pH of soil and its zinc content.

Inadequate levels of zinc were observed in the sward from the majority of plots [17, 18], totalling less than 30 mg $Zn \cdot kg^{-1}$ [16] (table 5). This figure continued to decline in subsequent years, which could be correlated to a decline in soil pH, which contributed to the increased filtration of this element into the soil profile, since increased soil acidity leads not only to the greater absorption of zinc by plants but also an increased propensity for leaching [19].

The zinc content of sward differed across consecutive harvests, but no clear tendencies were observed. A significantly lower quantity of the element was observed in sward from the first harvest in all plots only in the first year of the experiment.

A tendency was observed for the quantity of the zinc content of sward to decline as the level of fertilisation increased, which may have been caused by the greater crops obtained through the use of greater quantities of inorganic fertiliser (table 2) and the effect of dilution. When plants are fertilised with inorganic fertiliser there is a strict correlation between the metabolisation of zinc and phosphorus. As the level of assimilable phosphorus in soil increases the amount of zinc available to the plant decreases [20, 21] which is why high levels of phosphorus fertiliser can be a factor in inhibiting the absorption of zinc by plants. [22] This is confirmed by the greater quantity of zinc found in sward from plot N-180bis, which was deprived of phosphorous fertiliser, compared to an analogous plot where phosphorus was applied.

The zinc content in plots fertilised with fermented urine (G1 and G2) was greater than in analogous plots fertilised with the same amount of nitrogen in inorganic form. This may have been the result of the increased supply of zinc provided by fermented urine which is better absorbed by plants in acidic soil conditions. In most irrigated plots a greater quantity of zinc was observed in the sward compared to non-irrigated plots.

4. Conclusions

1. The application of fertiliser, both inorganic and fermented urine, resulted in a significant decline in the pH and zinc content of the soil, irrespective of soil pH, their initial levels and irrigation.

2. A significantly higher level of zinc in sward harvested from the plot which was not fertilised with phosphorus in the following years may have resulted in the reduced its abundance and low soil pH increasing availability of zinc to plants.

3. The apparently greater zinc content observed in sward from plots fertilised with fermented manure may be attributed to the introduction of the element in fertiliser and its ready absorption by plants in soils with a low pH.

5. References

[1] Alloway B. J.: Zinc in soils and crop nutrition. International Zinc Association, Brussels, Belgium. 2004, ss. 129.

[2] Maciejewska M., Kotowska J.: Wpływ wapnowania na zawartość cynku w życicy trwałej przy zróżnicowanym nawożeniu fosforem. Mat. VII Symp. „Mikroelementy w rolnictwie". AR, Wrocław, 1992, 389-393.

[3] Terelak H., Piotrowska M., Motowicka-Terelak T., Stuczyński T., Budzyńska K.: Zawartość metali ciężkich i siarki w glebach użytków rolnych Polski oraz ich zanieczyszczenie tymi składnikami. Zesz. Probl. Post. Nauk Roln. 1995, 418, 45-60.

[4] Gemabarzewski H., Stanisławska-Glubiak E., Korzeniowska J.: Wpływ zakwaszenia gleby na toksyczność cynku dla roślin. Zesz. Probl. Post. Nauk Roln., 1998, 456, 415-419.

[5] Rogóż A.: Zawartość i pobranie pierwiastków śladowych przez rośliny przy zmiennym odczynie gleby. Cz. I. Zawartość i pobranie miedzi, cynku oraz manganu przez rośliny. Zesz. Probl. Post. Nauk Roln., 2002 482, 439-451.

[6] Domańska J.: Soluble forms of zinc in profiles of selected types of arable soils. J. Elementol., 2009, 14(1), 55-62.

[7] Loneragan J. F. Webb M. J.: Interactions between Zn and other nutrients affecting the growth of plants. Zinc in soils and plants. A. D. Robson (red.), Kluwer Academie Publisher, Dordecht. 1993, 119-151.

[8] Patorczyk-Pytlik B., Spiak Z., Rubikowska B., Karoń B., 1992. Wpływ wieloletniego nawożenia fosforowego na zawartość cynku i manganu w glebach i roślinach. Mat. VII Symp. „Mikroelementy w rolnictwie". AR, Wrocław, 206-210.

[9] Tiller K. G.: Heavy metals in soils and their environmental significance. Adv. In Soil. Sci. 1989, 9, 113-142.

[10] Sapek A.: Metody analizy chemicznej roślinności łąkowej, gleby i wody. [Methods of chemical analysis of meadow plants, soil and water] Część 1, IMUZ, Falenty. 1979, ss. 55.

[11] Sapek B., Kalińska D., Barszczewski J., 2002. Wpływ węglanu wapnia i saletry wapniowej na Dynamikę wynoszenia składników mineralnych z plonem roślinności łąkowej. Zesz. Probl. Post. Nauk Rol., Z. 484, cz. 2 s. 549-561.

[12] Wesołowski P.: Wyniki nawożenia gnojówką bydlęcą i nawozami mineralnymi łąki na glebie torfowo-murszowej. Woda Środ. Obsz. Wiej. Falenty: Wyd. IMUZ, 2003, t. 3 z. 1 (7), 39-51.

[13] Głowacki J.: Regeneracja użytków zielonych. Lubuskie Aktualności Rolnicze, 2007, Nr 8, s. 13-14.

[14] Sapek A., Nawalany P., Barszczewski J. 2003b. Stężenie składników nawozowych w wodzie do nawodnień i do picia w Falentach w latach 1995-2001. Woda Środowisko Obszary Wiejskie, T. 3 z. specj., (6), 79-84.

[15] Kabata-Pendias A., Pendias H.: Biogeochemia pierwiastków śladowych. Wyd. Nauk. PWN Warszawa. 1999, 144-156.

[16] Sapek B.: Mikroelementy w roślinności łąkowej nawożonej azotem w wieloleciu przed i po jednorazowym zastosowaniu mikronawozów na tle następczego wpływu wapnowania. Cz. 1.Zmiany zawartości manganu, cynku i miedzi oraz ich wpływ na plony. Woda Środowisko Obszary Wiejskie, 2010, t.10, z. 4(32), s. 179-203.

[17] Preś J.: Nowoczesny system żywienia wysoko wydajnych krów. Top. Agrar. Polska, 1997, 1, 56-57.

[18] Presja J., Mordak R., praca zbiorowa. Wybrane elementy żywienia a problemy zdrowotne krów mlecznych. Wrocław 2010, 37-38.

[19] Kucharzewski A., Dębowski M.: Odczyn i zawartość mikroelementów w glebach Polski. Zesz. Probl. Post. Nauk Roln. 2000, 471, 627-635.

[20] Spiak Z., Radoła J., Romanowska M.: Wpływ nawożenia fosforowego i azotowego na pobranie cynku przez rośliny. Zesz. Probl. Post. Nauk Roln., 2000, 471, 521-528.

[21] Zhu Y.G., Smith S.E., Smith F.A.: Zinc (Zn) - phosphorus (P) interaction in two cultivars of spring wheat *(Triticum aestivum L.)* differing in P uptake efficiency. Ann. Bot., 2001, 88, 941-945.

[22] Marschner H.: Mineral nutrition of higher plants. 1998, Academic Press, London, II ed., 889.