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THE EFFECT OF NITROGEN FERTILIZER FORM ON THE CONTENT OF SIXTEEN ELEMENTS IN RED CABBAGE

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Abstract. Various forms of nitrogen fertilizer were applied in the cultivation of red cabbage (in the years 2003–2005), 'Langendijker' c.v.: control (unfertilized with nitrogen), $Ca(NO_3)_2$, $(NH_4)_2SO_4$, NH_4NO_3, $CO(NH_2)_2$ applied as solid fertilizers. This experiment aimed at determining the influence of various nitrogen forms on the content of Al, B, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sr, Ti, Zn, V in cabbage heads and the changes in the content of the available form of these elements for plants in soil after cabbage cultivation. The heads of plants fertilized with calcium nitrate and urea were characterized by the highest content of Al, Mn, Sr, Zn, Cd and Mo. Urea caused a significant increase in the content of Cu, Li and V, while ammonium nitrate resulted in an elevated level of Fe and Co accumulation in cabbage heads. Fertilization with $(NH_4)_2SO_4$ led to a substantial decrease in the content of Al, Mo and V, and fertilization with NH_4NO_3 caused a decline in Sr concentrations in cabbage in comparison with other objects of the experiment. Each nitrogen fertilizer resulted in the decreased concentrations of Ti in cabbage heads. Applied nitrogen fertilizers significantly influenced the contents of readily soluble forms of B, Fe and Pb in soil after cabbage cultivation.

Key words: nitrogen fertilization, nitrogen, mineral nutrition, heavy metals, red cabbage

INTRODUCTION

The use of mineral fertilizers containing nitrogen in the form of N-NO_3, N-NH_4 or N-NH_2 can cause an increase or decrease of the content of macro- and micro-elements as well as heavy metals in plants [Jurkowska et. al. 1981, Jurkowska and Rogóż 1981, Gębski 1998, Sady and Smoleń 2004]. It results from the fact that the forms of fertilizer nitrogen (N-NO_3, N-NH_4, N-NH_2) after their introduction into soil undergo various processes of transformation and thus they may elevate or decrease soil reaction (pH). In this way they can influence lower or higher concentrations of macro- and micro-

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components and heavy metals available for plants in soil [Gorlach and Mazur 2002, Diatta and Grzebisz 2006]. Increase or decrease in the content of macro- and micro-components and heavy metals in plants result from either antagonistic or synergistic interactions between N-NO_3, N-NH_4, N-NH_2 forms and nutritional elements and heavy metals at the stage of their intake by the plants. [Marschner 1995].

Results of numerous experiments [Jurkowska and Rogóż 1981, Gębski and Mercik 1997, Gębski 1998, Sady and Smoleń 2004] indicate that fertilization with reduced forms of nitrogen N-NH_4 and N-NH_2 (present in physiologically acid nitrogen fertilizers) leads to higher concentrations of heavy metals in the yield. Among nitrogen fertilizers, ammonium sulfate reveals the strongest activity of this type. In turn, plant fertilization with oxygenated form of nitrogen N-NO_3 (present in physiologically alkaline nitrogen fertilizers e.g. calcium nitrate) causes a decrease in heavy metals concentrations in the yield.

However the effect of fertilization (including mineral fertilization with nitrogen) on the content of macro- and micro-components and heavy metals in the yield depends on many factors. Among other things, these factors are connected with physical-chemical properties of soil, and particularly with soil type, granulometric composition, oxidoreductive potential, organic matter content [Gębski 1998, Kabata-Pendias and Pendias 1999, Sady and Smoleń 2004], total cationic soil capacity, sation exchange capacity, saturation of the sorption complex with alkaline elements, content of Ca and Mg in soil as well as general content of heavy metals in soil [Gambuś 1993, Sady and Rożek 2002]. In experiments conducted by Diatta and Grzebisz [2006] the influence of (N) fertilizer form (NH_4NO_3, $CO(NH_2)_2$, $NH_4NO_3 \cdot CaCO_3$) as well as nitrogen dose (100 and 200 kg $N \cdot ha^{-1}$) on the content of Cd, Cu, Pb and Zn in soil was connected with buffer soil properties. Rodríguez-Ortíz et al. [2006] revealed that fertilization with NH_4NO_3 in 50, 100 and 150 mg $N \cdot kg^{-1}$ doses of soil increased the accumulation of Cd and Pb in tobacco to a greater degree than fertilization with $CO(NH_2)_2$ in 50 and 100 mg $N \cdot kg^{-1}$ doses.

However, works quoted above [Gębski and Mercik 1997, Rodríguez-Ortíz et al. 2006] lack a complex evaluation of nitrogen form influence on the content of micro-components and heavy metals in the yield. The aim was to determine the effect of various forms of nitrogen on the content of Al, B, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sr, Ti, Zn, V in cabbage heads and changes in the content of the forms of these elements in soil available for plants after cabbage cultivation.

MATERIAL AND METHODS

An experiment with field cultivation of red cabbage 'Langendijker' was conducted in the years 2003–2005 in Grębałów, a suburbian part of Cracow, near Sędzimir steelworks, on a farm of Polan seed company. The cabbage was grown according to a suitable crop rotation taking into account agricultutal and horticultural plants. In individual years of the experiment, the soil (degraded black-earth) before the outset of the cultivation was characterized by similar physical-chemical properties in reaction (pH_{H_2O} 6.89) and content of (in mg·dm^{-3} soil): N-NH_4 16.3, N-NO_3 84.6, P 135.5, K 214.5, Mg 115.5, Ca 1585.9 – on average in the years 2003–2005 [Sady and Smoleń 2007].

The experiment encompassed plant fertilization with the following forms of fertilizer nitrogen: 1 – control (unfertilized with nitrogen), 2 – $Ca(NO_3)_2$, 3 – $(NH_4)_2SO_4$, 4 – NH_4NO_3, 5 – $CO(NH_2)_2$. Nitrogen fertilization was conducted directly before the seedling planting with the use of 100 kg N·ha^{-1} dose. Nitrogen was supplied to the soil as fertilizer produced by: $Ca(NO_3)_2$ – Yara, NH_4NO_3, $CO(NH_2)_2$ – Zakłady Azotowe in Puławy, $(NH_4)_2SO_4$ – Zakłady Azotowe in Tarnów. Fertilization with P, K, Mg and Ca was not performed – content of those elements in soil was maintained on the level which is considered optimal for cabbage. Cabbage was cultivated in 60×60 cm spacing, with one field being 30 m^2. In every year of the experiment the seedling was planted in the end of June, and the crop together with yield assessment and samples collection was conducted around 20th October.

Every year disintegrated plant material (cabbage heads) was dried in 70°C, and subsequently ground in laboratory grinder and stored in tightly packed plastic bags. After the end of a three-year research cycle the stored plant material (collected in the years 2003–2005) underwent mineralization in a mixture of HNO_3:$HClO_4$:H_2SO_4 in the 6:2:0.25 ratio [Jędrzejczak 1991]. Soil samples collected after the end of the cultivation were dried in the open air, ground, sieved with 1 mm mesh sieve and stored in tightly packed plastic bags. After the end of the experiment cycle, soil samples (only for 2003 and 2005) were extracted with 0.01M $CaCl_2$ [Houba et al. 1997]. The content of sixteen elements (Al, B, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sr, Ti, Zn, V) in mineralized plant material and soil extracts was determined with ICP-OES method with the use of Prodigy Teledyne Leeman Labs USA spectrometer.

Statistical calculations of obtained results were performed with the use of ANOVA module of Statistica 7.1 PL for $P < 0.05$. Significance of variations was assessed with the help of variance analysis. In case of significance of changes homogenous groups were determined on the basis of Duncan test.

RESULTS AND DISCUSSION

A significant influence was revealed in the research on nitrogen fertilizer forms on the content of Al, Cu, Fe, Mn, Sr, Zn, Cd, Co, Li, Mo Ti and V in cabbage heads (tab. 1). The fertilizers investigated did not have a statistically meaningful effect on the concentrations of B, Cr, Ni, Pb and Ti in cabbage. Cabbage heads fertilized with $Ca(NO_3)_2$ and $CO(NH_2)_2$ were characterized by the highest content of Al, Mn, Sr, Zn, Cd and Mo. The concentrations of Mo in the heads of control group were at a similar level as in case of fertilization with $Ca(NO_3)_2$ and $CO(NH_2)_2$. It should also be noted that fertilization with $(NH_4)_2SO_4$ caused a meaningful decrease in the content of Al, Mo and V, and fertilization with NH_4NO_3 resulted in the decrease in the content of Sr when compared with other experiment objects. Fertilization with NH_4NO_3 led to a significant increase in the concentrations of Fe and Co, and fertilization with $CO(NH_2)_2$ resulted in an elevated level of Cu, Li and V concentrations in cabbage in comparison with the control and fertilization with other nitrogen fertilizers. The use of all nitrogen fertilizers

Table 1. The concentrations of sixteen elements in red cabbage depending on nitrogen fertilizer form (mean for years 2003–2005)
Tabela 1. Zawartość szesnastu pierwiastków w główkach kapusty czerwonej w zależności od formy azotu nawozowego (średnie z lat 2003–2005)

N-form for fertilization Forma azotu	$mg \cdot kg^{-1}$ d.w. / $mg \cdot kg^{-1}$ s.m.			
	Al	B	Cu	Fe
Control / Kontrola	5.1 b	80.1 a	9.0 ab	93.4 a
$Ca(NO_3)_2$	6.3 c	87.4 a	7.6 a	112.9 b
$(NH_4)_2SO_4$	3.4 a	55.4 a	8.9 ab	93.7 a
NH_4NO_3	4.6 b	58.2 a	6.4 a	173.8 c
$CO(NH_2)_2$	5.5 bc	88.9 a	11.8 b	105.2 ab
	$mg \cdot kg^{-1}$ d.w. / $mg \cdot kg^{-1}$ s.m.			$\mu g \cdot kg^{-1}$ d.w. $\mu g \cdot kg^{-1}$ s.m.
	Mn	Sr	Zn	Cd
Control / Kontrola	25.0 a	10.4 b	33.2 a	45.7 ab
$Ca(NO_3)_2$	31.4 c	13.3 c	38.7 b	65.3 c
$(NH_4)_2SO_4$	26.9 ab	10.7 b	36.2 ab	43.0 ab
NH_4NO_3	25.7 ab	9.6 a	33.2 a	40.1 a
$CO(NH_2)_2$	29.7 bc	12.8 c	39.5 b	54.0 bc
	$\mu g \cdot kg^{-1}$ d.w. / $\mu g \cdot kg^{-1}$ s.m.			
	Co	Cr	Li	Mo
Control / Kontrola	288.3 a	426.4 a	127.2 abc	1195.5 bc
$Ca(NO_3)_2$	354.4 bc	274.6 a	117.9 ab	1318.9 c
$(NH_4)_2SO_4$	332.2 b	320.8 a	140.5 bc	543.1 a
NH_4NO_3	511.1 d	296.3 a	107.4 a	1036.8 b
$CO(NH_2)_2$	390.8 c	296.2 a	152.9 c	1257.7 c
	$\mu g \cdot kg^{-1}$ d.w. / $\mu g \cdot kg^{-1}$ s.m.			
	Ni	Pb	Ti	V
Control / Kontrola	394.2 a	1775.4 a	1490.8 b	350.1 b
$Ca(NO_3)_2$	445.9 a	161.8 a	742.3 a	341.5 b
$(NH_4)_2SO_4$	435.2 a	1476.3 a	906.1 a	276.2 a
NH_4NO_3	449.7 a	509.5 a	735.8 a	351.1 b
$CO(NH_2)_2$	473.3 a	1515.6 a	935.1 a	542.4 c

Means followed by the same letters are not significantly different for $P < 0.05$.
Średnie oznaczone tą samą litera nie różnią się istotnie dla $P < 0,05$.

Table 2. The concentrations of readily soluble forms of sixteen elements in soil (assessed in 0.01M $CaCl_2$) after cabbage cultivation depending on nitrogen fertilizer form (mean for years 2003 and 2005)

Tabela 2. Zawartość łatwo rozpuszczalnych form szesnastu pierwiastków w glebie (oznaczonych w 0,01M $CaCl_2$) po uprawie kapusty w zależności formy azotu nawozowego (średnie z lat 2003 i 2005)

N-form for fertilization Forma azotu	mg·kg^{-1} soil / mg·kg^{-1} gleby			
	Al	B	Cu	Fe
Control / Kontrola	607.0 a	1.6 b	3.3 a	115.1 a
$Ca(NO_3)_2$	606.4 a	1.2 ab	3.2 a	116.9 a
$(NH_4)_2SO_4$	613.6 a	1.2 ab	3.2 a	126.5 ab
NH_4NO_3	635.9 a	0.8 a	3.1 a	139.0 bc
$CO(NH_2)_2$	652.9 a	0.8 a	3.3 a	144.4 c
	mg·kg^{-1} soil / mg·kg^{-1} gleby			
	Mn	Sr	Zn	Cd
Control / Kontrola	139.8 a	24.1 a	45.0 a	0.62 a
$Ca(NO_3)_2$	143.7 a	25.9 a	43.1 a	0.62 a
$(NH_4)_2SO_4$	142.9 a	24.8 a	41.1 a	0.61 a
NH_4NO_3	147.8 a	24.1 a	41.9 a	0.59 a
$CO(NH_2)_2$	151.4 a	24.8 a	44.3 a	0.59 a
	mg·kg^{-1} soil / mg·kg^{-1} gleby			
	Co	Cr	Li	Mo
Control / Kontrola	1.9 a	0.53 a	0.058 a	1.8 a
$Ca(NO_3)_2$	2.0 a	0.54 a	0.059 a	1.8 a
$(NH_4)_2SO_4$	2.0 a	0.55 a	0.063 a	1.8 a
NH_4NO_3	2.1 a	0.55 a	0.062 a	1.7 a
$CO(NH_2)_2$	2.1 a	0.56 a	0.062 a	1.8 a
	mg·kg^{-1} soil / mg·kg^{-1} gleby			
	Ni	Pb	Ti	V
Control / Kontrola	2.7 a	7.6 bc	0.63 a	2.0 a
$Ca(NO_3)_2$	2.7 a	7.6 bc	0.63 a	2.1 a
$(NH_4)_2SO_4$	2.7 a	7.9 c	0.66 a	2.1 a
NH_4NO_3	2.6 a	7.1 ab	0.66 a	2.1 a
$CO(NH_2)_2$	2.6 a	6.9 a	0.68 a	2.1 a

Means followed by the same letters are not significantly different for $P < 0.05$.

Średnie oznaczone tą samą litera nie różnią się istotnie dla $P < 0,05$.

resulted in a lowered concentrations of Ti when compared to the control. Despite the lack of statistically significant effect it is worth noting that cabbage heads fertilized with $Ca(NO_3)_2$ contained over ten times less Pb, while plants fertilized with NH_4NO_3 contained almost three and a half less Pb than the control plants.

Unlike the results of earlier experiments and other authors' reports [Jurkowska and Rogóż 1981, Gębski and Mercik 1997, Smoleń and Sady 2007, Gębski 1998, Sady and Smoleń 2004] this study revealed that the most physiologically acid nitrogen fertilizer, ammonium sulfate , did not result in an elevated level of micro-elements and heavy metals in cabage crop (tab. 1). It seems that the effect of ammonium sulfate (as well as other nitrogen fertilizers) on the content of micro-elements and heavy metals in crop depends on physical and chemical soil properties, grown plant species, the course of climatic conditions and the mobility of a given element. Research by Smoleń and Sady [2006] revealed a decrease in the content of Cu in storage roots of carrot fertilized with $(NH_4)_2SO_4$ with dose 70 + 70 kg $N \cdot ha^{-1}$ (70 $N \cdot ha^{-1}$ presowing + 70 $N \cdot ha^{-1}$ as top dressing) in comparison to the control (object without nitrogen fertilization) and fertilization with $Ca(NO_3)_2$ with a similar dose. However, research conducted by these authors does not reveal the influence of nitrogen form and dose on the content of Cd and Zn in carrot.

In the presented experiments fertilization with ammonium sulfate led to lowered concentrations of Al, Mo and V in cabbage (tab. 1), which may result from a higher share of sulfur supplied with this fertilizer in the creation of phytochelatins in plant roots. Phytochelatins are proteins which play a significant role in detoxification of heavy metals in plants [Howden et al. 1995, Zenk 1996]. Another reason for the decrease in molybdenum concentrations in cabbage caused by fertilization with ammonium sulfate can be the fact that SO_4^{2-} ion (contained in this fertilizer) antagonistically influences the intake of MoO_4^{2-} ion by the roots. Information presented by Marschner [1995] as well as the results of Jurkowska and Rogóż [1981] suggest that such relations exist. Decrease in soil reaction causes decrease in molybdenum availability for plants in soil [Marschner 1995]. Therefore, despite the lack of ammonium sulfate effect on the content of readily soluble forms of Mo in soil, the decrease in soil reaction, noticed in the experiments, under the influence of ammonium sulfate [Sady and Smoleń 2007], could have been an additional reason for the lowered concentrations of Mo in cabbage.

Tyler and Olsson [2001] revealed two high levels of Cu and Pb concentrations in soil solution. First at pH 5.2–6.5, second at pH 7.5–7.8. Moreover, they showed the growth in Cd, Co, Cr, Hg, Ni and Sr concentrations in soil solution within alkaline reaction. The increased content of calcium in the soil (as well as fertilization with calcium nitrate) can cause to decreased Cd and Zn concentrations in the yield as results of exchange equations between Ca-Cd and Ca-Zn in soil [Voegelin and Kretzschmar 2003]. Our experiments reveal that despite the lack of influence on reaction (pH) [Sady and Smoleń 2007] and the content of readily soluble forms of Al, Mn, Sr, Zn, Cd and Mo in soil, fertilization with calcium nitrate (tab. 2) caused quite surprising effect – it increased concentrations of those elements in cabbage heads (tab. 1).

Results mentioned above are only partly confirmed by the results of Jurkowska and Rogóż [1981]. These authors demonstrated that oats and sorrel fertilization with $Ca(NO_3)_2$ led to an increase of Mo content in roots and overground parts of both investigated species in comparison to the control site (unfertilized with nitrogen) as well as fertilization with NH_4NO_3, $CO(NH_2)_2$ and $(NH_4)_2SO_4$. In case of oats, fertilization with $Ca(NO_3)_2$ resulted in higher concentrations of Mo in roots.

Results of numerous experiments [Czekała and Jakubus 2006, Łukowski 2006, Smoleń and Sady 2006, 2007] reveal that fertilization with various nitrogen forms or multi-component fertilizers influences the content of readily soluble forms of nutritional micro-elements and heavy metals in crop to small degree. Research by Czekała and Jakubus [2006] showed that fertilization with nitrogen in 0, 68.2, 125.7, 188.6 kg $N \cdot ha^{-1}$ doses (used in a set of various crop rotations) has little influence on the content of readily soluble forms of Cu, Mn and Ni except for Zn in soil. The highest content of Zn was noted in the outer layer (0–30 cm) of soil after the use of the above doses of nitrogen. Łukowski [2006] demonstrated that fertilization with mineral fertilizers (urea, multi-element fertilizers, phosphates and phosphate-potassium fertilizers) did not have any influence on the content of mobile forms of Zn in soil in the first and second year after fertilization.

As already mentioned in the introduction, by its chemical properties nitrogen fertilizers can cause the change in soil reaction (pH), and this may, in turn, influence the content of micro-elements and heavy metals forms available for plants. The Results of Zaccheo et al. [2006] showed that ammonium nutrition of higher plants results in rhizosphere acidification due to proton excretion by root cells. These authors also demonstrated that the use of a nitrification inhibitor cause increasing content of heavy metals in plant. However, higher content of heavy metals in soil has the inhibitory influence on the nitrification process [Juliastuti et al. 2003]. As follows from previously published data encompassed by the topic of this work [Sady and Smoleń 2007] fertilization with $(NH_4)_2SO_4$ and $CO(NH_2)_2$ led to the decrease in soil reaction (pH) when compared to the control, while after the use of $Ca(NO_3)_2$ and NH_4NO_3 no change in reaction was noted. Despite recorded changes in soil reaction applied nitrogen fertilizers significantly influenced only the content of readily soluble forms of B, Fe and Pb in soil after cabbage cultivation (tab. 2). The content of the remaining elements (Al, Cd, Co, Cr, Cu, Li, Mn, Mo, Ni, Sr, Ti, Zn, V) in soil from individual objects of the experiment did not differ much from one another. The content of readily soluble forms of boron tended to decrease in soil under the influence of nitrogen fertilization, particularly in the form of NH_4NO_3 and $CO(NH_2)_2$. In case of iron nitrogen fertilization, except for $Ca(NO_3)_2$, resulted in an elevated concentrations of Fe in soil. Soil fertilized with $(NH_4)_2SO_4$ revealed the highest content of lead (similar level in the control as well as in soil fertilized with $Ca(NO_3)_2$), and the lowest lead content after fertilization with $CO(NH_2)_2$ and NH_4NO_3 – homogenous group with the control and fertilization with $Ca(NO_3)_2$. It should be noted that demonstrated changes in the content of readily soluble forms of B, Fe and Pb in soil after cultivation (tab. 2) were not directly reflected in the differences of the content of those elements in cabbage (tab. 1). There was no direct connection between the concentrations of all investigated elements in cabbage and the content of their readily soluble forms in soil after cultivation. Similarly, no direct relation between the content of readily soluble forms of micro-elements and heavy metals (Cd, Cu and Z) extracted with 0.01 M $CaCl_2$ and the concentrations of those elements in carrot was revealed in earlier works [Smoleń and Sady 2006, 2007].

CONCLUSIONS

A significant influence was revealed in the research on nitrogen fertilizer forms on the content of Al, Cu, Fe, Mn, Sr, Zn, Cd, Co, Li, Mo, Ti and V in cabbage heads.

Cabbage heads fertilized with calcium nitrate and urea revealed the highest content of Al, Mn, Sr, Zn, Cd and Mo.

Moreover, urea caused a significant increase in the concentrations of Cu, Li and V, while ammonium sulfate resulted in a higher level of Fe and Co in cabbage heads.

Fertilization with $(NH_4)_2SO_4$ led to a significant drop in the content of Al, Mo and V, while fertilization with NH_4NO_3 resulted in a decrease in Sr concentrations in cabbage when compared with other experiment objects.

Every nitrogen fertilizer used in the experiment caused lowered concentrations of Ti in cabbage heads.

Applied nitrogen fertilizers significantly influenced only readily soluble forms of B, Fe and Pb in soil after cabbage cultivation.

No direct connection between the content of readily soluble forms (assessed in 0.01M $CaCl_2$) of investigated elements (Al, B, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sr, Ti, Zn, V) in soil after cabbage cultivation and their concentrations in cabbage was revealed.

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WPŁYW NAWOŻENIA RÓŻNYMI FORMAMI AZOTU NA ZAWARTOŚĆ SZESNASTU PIERWIASTKÓW W GŁÓWKACH KAPUSTY CZERWONEJ

Streszczenie. Różne formy nawozów azotowych zastosowano w uprawie kapusty czerwonej (w latach 2003–2005), odmiany ‘Langendijker’: kontrola (nienawożona azotem), $Ca(NO_3)_2$, $(NH_4)_2SO_4$, NH_4NO_3, $CO(NH_2)_2$ stosowane jako nawozy stałe. Celem badań było określenie wpływu różnych form azotu na zawartość Al, B, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Sr, Ti, Zn, V w główkach kapusty oraz na zmiany zawartości fitodostępnych form tych pierwiastków w glebie po uprawie kapusty. Najwyższą zawartością Al, Mn, Sr, Zn, Cd i Mo charakteryzowały się główki roślin nawożonych, zarówno saletrą wapniową, jak i mocznikiem. Mocznik powodował także znaczny wzrost zawartości Cu, Li i V, a saletra amonowa podwyższenie poziomu akumulacji Fe i Co w główkach kapusty. Nawożenie $(NH_4)_2SO_4$ powodowało istotne obniżenie zawartości Al, Mo i V, a nawożenie NH_4NO_3 obniżenie zawartości Sr w kapuście stosunku do pozostałych obiektów doświadczenia. Każdy z użytych nawozów azotowych powodował obniżenie zawartości Ti w główkach kapusty. Zastosowane nawozy azotowe w istotny sposób wpłynęły jedynie na zawartość łatwo rozpuszczalnych form B, Fe i Pb w glebie po uprawie kapusty.

Słowa kluczowe: nawożenie azotem, azot, żywienie mineralne, metale ciężkie, kapusta czerwona

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