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EFFECT OF NITROGEN FERTILIZATION ON Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr AND Zn AVAILABILITY FOR COMMERCIALLY GROWN WHITE CABBAGE (*Brassica oleracea* var. *capitata alba*)

WPŁYW NAWOŻENIA AZOTEM NA PRZYSWAJALNOŚĆ Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr i Zn PRZEZ KAPUSTĘ GŁOWIASTĄ BIAŁĄ (*Brassica oleracea* var. *capitata alba*) UPRAWIANĄ W WARUNKACH PRODUKCYJNYCH

Abstract: The results of three year investigations with 'Galaxy' F_1 cabbage grown commercially in important agricultural region of the southern Poland are presented. The effect of ammonium sulphate and RSM (solution of ammonium nitrate + urea), the method of application (placement and broadcast technique and foliar fertilization) on Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr and Zn concentrations in edible parts of cabbage were surveyed. In present work all metals concentration in cabbage were below the lower range of content reported for cabbage grown in non-contaminated areas. The low concentration of micro/trace elements were related to soil parent material, with generally low total and extractable levels of metals. Consistently greater concentrations of Cd, Cu, Fe, Mn and Ni were measured in cabbage grown on the site with lower pH compared with concentrations in plants sampled at other soil sites with higher pH. Ammonium sulphate significantly increased Mn and Fe concentrations in cabbage heads. However environmental factors considerably influenced this tendency. The similar trend for Zn was observed. The method of application affected Mn content in 2007 and Ni in 2007 in cabbage. Slightly higher manganese and nickel concentration for placement fertilization was noted. The results obtained would suggest that in commercial cabbage production on over-limed soils using nitrogen ammonium fertilizers may improve Mn, Fe and Zn uptake by plants.

Keywords: white cabbage, micro/trace elements, nitrogen fertilization, bioavailability

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Plant uptake of metals from soil is an important pathway for their entry to the human food chain. Although some elements are essential to plant life, many are toxic in high concentrations [1]. Naturally occurring metals in soils (the pedogeochemical background level) is a direct function of its original natural composition. Over time, the concentration of naturally occurring metals in soil will be influenced by geomorphologic processes such as erosion, weathering, and dissolution of mineral deposit [2]. Background concentrations can be also "anthropogenic" when the concentration of chemical in the environmental is due to human activities, but is not the result of use or release of waste or products, or industrial activity. Anthropogenic inputs from agricultural practices increase metals concentrations in soils as a result of using pesticides/herbicides, lime and fertilizers.

The bioavailability and the potential toxicity of metals in the environmental depend on their speciation in the soil and the soil solution [3]. The pH of the soils is often the most important chemical property governing metals sorption, precipitation, solubility, and availability [4, 5]. Cationic trace element adsorption by oxide surfaces increases to almost 100 % with increasing pH [4]. Sorption by metal oxides is major mechanism for removal of trace element cations: Pb, Cu, Zn, Cd, Cr, and Ni and trace element oxyanions ie CrO_4^{2-} [6]. Liming has often been shown to increase the negative surface charge thereby increase the retention of nutrient ions and toxic heavy metals. It has been widely investigated as a mean of controlling the reaction with nutrients [7–9].

In intensive agricultural systems overapplication of lime may have detrimental effects on factors affecting crop yield, particularly nutrient availability. Alkalinity as result of overlime treatment can subject planting to nutritional deficiencies. But another hand high pH may decrease heavy metals uptake by plants. In a cabbage production liming has been used as a control means for club root (*Plasmodiophora brassiceae*) since the early 19th century. There is a close relationship between soil pH and club root, with acidic soils generally favoring development of the disease.

Application of fertilizers, lime and other materials to soils can affect bioavailability by introducing trace elements into the soil and/or adsorptive phases causing redistribution of trace elements into different chemical pools or chemical "species" [4]. Nitrogen fertilizers induce some direct and/or indirect changes impacting the dynamics availability of metals in soils [7]. Mineral N fertilizers contain ammonium can acidify the soil solution and decrease rhizosphere pH [10]. In neutral or alkaline soils rhizosphere acidification in plants fed with ammonium can enhance the uptake of micronutrients such as iron, manganese, copper and zinc [11–13].

The aim of the present research was to assess the effect of ammonium sulphate and RSM (solution of the ammonium nitrate + urea) applied by placement and broadcast technique on the micro/trace elements accumulation in 'Galaxy' F_1 white cabbage grown commercially under field conditions.

Material and methods

The field experiment was carried out in 2005–2007 with 'Galaxy' F_1 white cabbage on a silty clay soil containing 0.91–1.02 % organic carbon and soil acidity pH_{H_2O}

7.18–8.21 (Table 1). The plots were located at a farm in Zagorzyce (50^{o}23′ and 20^{o}04′) near Miechow. Farms of this area specialize in cabbage production in continuous or highly frequent cropping. In short-term crop rotation systems liming is commonly used as a control measure for club root (*Plasmodiophora brassicae*) potential damage. The calcium oxide application of one month prior to planting is a practical mean of controlling the fungal disease. This land area has an ideal climate for growing a wide range vegetable crop, but there is very little information on the metals content of vegetables produced in the important agriculture region.

Table 1

Organic carbon content [%], soil pH and soil texture in 2005–2007

Year	Sand 0–0.1 mm	Silt 0.1–0.02 mm	Clay < 0.02 mm	% C	CEC cmol kg^{-1}	pH_{KCl}	pH_{H_2O}	Ca mg dm^{-3}
2005	15	47	38	0.91	11.85	7.70	8.21	3000
2006	8	50	41	1.02	7.72	6.17	7.18	1465
2007	9	55	36	0.98	10.49	7.09	7.90	2972

Two factors were examined: the type of N fertilizer ammonium sulphate and RSM (solution ammonium nitrate and urea 1:1), and method of N application. The treatments with both fertilizers were as follows:

1) Control – 100 % N rate (120 kg ha^{-1}) broadcasted at planting of seedlings,
2) 75 % N rate broadcasted at planting of seedlings + 25 % N during plant grow,
3) 75 % N rate broadcasted at planting of seedlings + foliar fertilization,
4) 75 % N placement at seedlings planting,
5) 75 % N placement at seedlings planting + 25 % N during plant growth,
6) 75 % N placement at seedlings planting + foliar fertilization.

Treatments were assigned following the randomized complete block in split-plot arrangement with four replications. Seedlings were transplanted at the beginning of June. Nitrogen fertilizer was applied at the rate of 120 kg N ha^{-1} (100 % N). With the placement fertilization method, fertilizer was located 10 cm depth and 10 cm distance on each plant (plant were spaced 67.5 × 67.5 cm) at transplanting seedlings times. Foliar sprayings started at the beginning of intensive leaves growth and were conducted at growing season in two weeks interval. The foliar nutrition of 2 % urea was carried out 3 times and one time with 1 % Supervit K (% w/v: N-NH_2 – 4.4, N-NO_3 – 0.8, K – 3.1, Mg – 0.6, Mn – 0.05, Ti – 0.05, B – 0.03, Fe – 0.025, Mo – 0.005). Mineral fertilization of phosphorus, potassium and magnesium was based on the results of chemical analysis of the soil samples. The content of soil P, K and Mg was supplemented to level of 50, 200 and 60 mg dm^{-3}, respectively before seedlings planting.

Plant procedures

The harvest was conducted in the last decade of October. Edible parts (disintegrated cabbage head) were dried at 70 ^{o}C for 48 h. The Cd, Cr, Cu, Fe, Mn, Ni, Sr and Zn contents in the samples were determined by inductively coupled argon plasma optical emission spectroscopy (ICP-OES) after microwave digestion with HNO_3.

Soil procedures

Soil samples were collected from a 0–30 cm surface layer. Granulometric analysis was made by the aerometric method of Proszynski and the organic carbon by Tiurin's method [14]. Soil pH was determined by adding deionized water and 1 M KCl at a ratio 1:2 (soil:water/1 M KCl by volume). The total soil metal content was determined with ICP-OES after microwave digestion with *Aqua Regia* [15]. The extractable forms of metals were measured in 1 M HCl extractant [14] by ICP-OES. This soil extractant and procedure is currently used to estimate availability and critical levels for micronutrient cations in Poland.

Statistical procedures

Results were subjected to two or three way factors analysis of MANOWA. Means were separated by the Fisher LSD test ($p = 0.05$). Statistical analysis was performed using the Statsoft Statistica 8.0 software.

Results and discussion

Soil analyses

The content of total metals in soil (Table 2) was low and tended to be below or the lower range reported by Kabata-Pendias and Pendias [2] in non-contaminated soils in Poland. Only cadmium concentration was slightly greater than the average of Cd content in Polish non-polluted soil (0.2–1.05 mg kg dry weight) reported by Trelak [16]. A little elevated Cd concentrations (1.13–1.34 ppm) in tilled horizon of arable land with intensive agricultural system may be due to anthropogenic sources such as lime or phosphates.

Table 2

Total metals content [mg kg^{-1} dry mass] in soil in 2005–2007

Year	Cd	Cr	Cu	Fe	Mn	Ni	Sr	Zn	Pb
2005	1.34	12.6	4.67	8184	152.0	7.77	12.5	24.3	13.6
2006	1.13	9.62	4.74	6176	186.8	5.98	12.0	25.8	14.1
2007	1.23	9.70	4.75	6606	156.3	6.40	14.8	32.9	14.5

Total levels are rarely indicative of plant availability because availability depends of physical, chemical, and biological conditions in the rhisosphere [17]. In our study soil samples are extracted with 1 M HCl commonly using in Poland for estimation plant micronutrients availability and fertilization. According to criteria developed for micronutrients detected by Rinkis method in Poland [18], low content of available Cu and the average of Zn and Mn were measured (Table 3). Any examined factors (fertilizer form and method of application) did not affect extractable forms of metals in soil. This technique with relatively "aggressive extractant" removes more than the soluble, exchangeable and weakly adsorbed fractions. Kashem et al [19] recommend using this procedure for first-level screening of soil contamination. Korzeniowska and Stanislawska-Glubiak [20] showed good correlation between concentration of Cu, Zn and Ni extracted from contaminated soil by 1 M HCl and the white mustard uptake of these elements. In our study plant response was not correlated with metals extracted by the 1 M HCl soil test except Cd and Sr (coefficient of correlation were r = 0.42 and r = 0.64, respectively for p = 0.05, data non published).

Table 3

Extractable fractions (1 M HCl) of metals [mg kg^{-1} dry mass] in soil after cabbage harvest in 2005–2007

Factor	Factor level	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Sr	Zn
Year 2005		0.400	0.983	2.85	982	135	2.09	10.1	9.14	11.8
Year 2006		0.534	0.891	2.39	993	166	2.04	13.4	10.6	15.9
Year 2007		0.027	0.526	3.24	1120	158	3.10	12.4	14.6	20.6
Fertilizer	$(NH_4)_2SO_4$	0.331	0.806	2.70	1044	155	2.42	12.2	11.4	16.2
	RSM	0.310	0.793	2.96	1020	151	2.40	11.7	11.4	16.0
Method of application	1	0.309	0.783	2.74	1023	150	2.46	11.6	11.6	15.8
	2	0.310	0.805	3.04	1030	149	2.38	11.8	12.0	15.7
	3	0.313	0.775	2.70	1010	151	2.44	11.8	11.7	15.6
	4	0.312	0.813	2.81	1039	152	2.33	11.8	11.1	16.8
	5	0.337	0.812	2.69	1059	157	2.46	12.4	11.1	16.4
	6	0.343	0.810	2.98	1031	157	2.38	12.4	11.2	16.2
$LSD_{0.05}$	year	0.0425	0.0439	0.426	46.8	9.6	0.07	0.26	0.55	2.33
	fertilizer	ns	ns	ns	ns	ns	ns	ns	ns	ns
	method	ns	ns	ns	ns	ns	0.09	ns	ns	ns

Presented data shows that 1 M HCl extractant removed to solution about 5–9 % of Cr total content, 12–17 % of Fe, 27–48 % of Ni, similar amounts of Zn and Cu (about 50–60 %), comparable amounts of Sr, Mn and Pb (about 70–99 %). In case of Cd obtained results did were uniform. In 2006 1 M HCl removed 47 % of total Cd content but, in 2007 only 2 %.

Plant analysis

In present work all metals concentration in the edible parts of cabbage were below the lower range of content reported for cabbage grown in non-contaminated areas. The low concentration of micronutrients such as Cu, Mn, Zn, and Fe may indicate deficiencies that would affect crop yield. In case of heavy metals, low concentration in cabbage head improves safety of plant food.

The concentration of cadmium in cabbage ranged between 0.048–0.061 mg kg^{-1} dry matter (Table 4). Cadmium content in plant varies widely and ranged between 0.05–0.20 ppm [2]. Soil pH is often inversely related to Cd uptake by plant [9]. Bolan et al [6] observed that the absorption of Cd^{2+} increases with an raise pH causes an increase in surface negative charge resulting in an increase in cations adsorption. An increase in soil pH is likely to result in the formation of hydroxy species of metal cations which are adsorbed preferently over the metal cation. In present study the significantly higher Cd concentration determined in cabbage growing in 2006 on a field characterized relatively lower pH_{H_2O} 7.18 in comparison with 2005 and 2007 (pH 8.21 and 7.90, respectively). However, total Cd concentration in soil in 2006 was at the lower level (1.13 mg kg^{-1} d.m.). The form of nitrogen fertilizers and method of fertilizers application did not affect Cd concentrations in cabbage leaves. Moreover, the small range of rhizosphere pH change (below 0.1 pH units, data non published) due to the buffering capacity of the soil was not sufficient to influence Cd bioavailability.

Table 4

Effect of nitrogen fertilization on Cd and Cr content in 'Galaxy' F_1 cabbage grown in 2005–2007

Fertilizer	Application method*		Cd [mg kg^{-1} d.m.]				Cr [mg kg^{-1} d.m.]			
			2005	2006	2007	mean	2005	2006	2007	mean
Mean for year			0.050	0.061	0.048		0.183	0.135	0.163	
Factor	$(NH_4)_2SO_4$		0.049	0.060	0.049	0.053	0.168	0.130	0.170	0.156
Fertilizer	RSM		0.050	0.061	0.046	0.052	0.199	0.141	0.155	0.165
Application method	broadcast	1	0.048	0.062	0.041	0.050	0.265	0.156	0.179	0.200
		2	0.049	0.056	0.044	0.050	0.187	0.128	0.130	0.148
		3	0.048	0.065	0.050	0.054	0.136	0.124	0.191	0.150
	placement	4	0.047	0.061	0.049	0.052	0.170	0.133	0.164	0.156
		5	0.061	0.059	0.054	0.058	0.211	0.126	0.171	0.169
		6	0.046	0.060	0.047	0.051	0.131	0.146	0.141	0.139
$LSD_{0.05}$ for	year			0.0051				0.0332		
	fertilizer		ns	ns	ns		ns	ns	ns	
	application method		ns	ns	ns		ns	ns	ns	

* 1–120 kg · ha^{-1} N broadcasted at planting of seedlings; 2–90 kg · ha^{-1} N broadcasted at planting of seedlings + 30 kg · ha^{-1} N during plant grow; 3–90 · ha^{-1} N broadcasted at planting of seedlings + foliar fertilization; 4–90 kg · ha^{-1} N placement at seedlings planting; 5–90 kg · ha^{-1} N placement at seedlings planting + 30 kg · ha^{-1} N during plant growth; 6–90 kg · ha^{-1} N placement at seedlings planting + foliar fertilization; n.s. – no significant.

Chromium is essential nutrient for human and animals. Chromium contents of grain products, fruits, and vegetables vary widely, even well-balanced diets may contain suboptimal levels of dietary chromium (50–200 μg/day). Kabata-Pendias and Pendias [2] reported that in plant tissues chromium concentrations ranged between 0.02–1 mg kg^{-1} d.m. and in cabbage heads intermediate range of Cr was 0.05 mg kg^{-1} d.m. In our study 0.135–0.183 mg Cr kg^{-1} d.m. was detected (Table 4). The highest Cr concentrations were measured in 2005 for the highest levels of pH and higher content of chromium in soil (in total and extractable forms), and the lowest in 2006 for the smallest pH values and smaller Cr content in soil. Taylor and Olsen [5] showed that mechanism of the Cr^{3+} releases was the oxidation of some Cr^{3+} at increasing pH, producting CrO_4^{2-} which was much less sorbed at neutral to slightly alkaline condition. A probable the increasing pH escalating concentrations of soluble organic C in the soil solution and more total Cr would be solubilized.

It is well know that copper bioavailability and hence Cu toxicity is increased in acidic relative to calcareous soils [10, 21]. Increasing the pH involves an increase in the binding of Cu to soil constituents, and decrease in the mobility of copper in soil. The critical deficiency level of copper in vegetative plant parts is generally in the range of 1–5 mg Cu kg^{-1} dry matter [1, 22]. In our study copper contents in plants tended to be less than the ranges reported by Kabata-Pendias and Pendias [2] in non-contaminated sites for the cabbage heads (3–4 mg Cu kg^{-1} d.m.). The smallest value of plant Cu (1.58 mg kg^{-1}) was observed when pH of soils was highest (in 2005) while the largest (2.14 ppm) was measured for the smallest pH in 2006 (Table 5). The form of nitrogen fertilizers did not affect Cu concentrations in cabbage leaves. Similar results were presented by Smolen and Sady [23] who proved that copper content of carrot roots was not influenced by nitrogen fertilizers. The same results with tomato and rape obtained Chaignon et al [10] who concluded that Cu bioavailability was independent of N supply in the calcareous soil. Any year of presented studies the method of nitrogen application did not influence Cu concentration in cabbage (Table 5).

Table 5

Effect of nitrogen fertilization on Cu and Fe content in 'Galaxy' F_1 cabbage grown in 2005–2007

Fertilizer	Application method*		Cu [mg kg^{-1} d.m.]				Fe [mg kg^{-1} d.m.]			
			2005	2006	2007	mean	2005	2006	2007	mean
Mean for year			1.58	2.14	1.97		26.9	28.0	24.0	
Factor	$(NH_4)_2SO_4$		1.53	2.03	1.99	1.85	27.0	28.1	25.5	26.9
Fertilizer	RSM		1.63	2.24	1.95	1.94	26.8	27.8	22.6	25.7
Application method	broadcast	1	1.60	2.28	1.88	1.92	26.4	27.1	23.0	25.5
		2	1.67	2.17	1.73	1.86	27.1	28.1	22.2	25.8
		3	1.59	2.47	2.03	2.03	26.7	28.2	24.4	26.4
	placement	4	1.48	1.91	2.22	1.87	28.0	29.3	25.0	27.4
		5	1.66	2.01	1.94	1.87	28.7	27.9	25.2	27.3
		6	1.49	1.98	2.01	1.83	24.6	27.2	24.3	25.4
$LSD_{0.05}$ for:	year			0.151				1.72		
	fertilizer		ns	ns	ns		ns	ns	1.99	
	application method		ns	ns	ns		ns	ns	ns	

* See Table 3.

The iron is the fourth most abundant element in the earth's crust, yet Fe deficiency is common in crop plant. This anomaly is due to the extremely low concentration of Fe^{2+} and Fe^{3+} in soil solution especially in well aerated soil with a high pH [22]. The critical deficiency content of iron in plant leaves is in the range of 50–150 mg Fe kg^{-1} d.m. [1]. Kabata-Pendias and Pendias [2] report that on average concentration of Fe in edible parts of cabbage there is 42 mg Fe kg^{-1} d.m. In our study iron concentrations in cabbage were low and ranged between 24.0–28.0 mg Fe kg^{-1} d.m. (Table 5). In 2007 $(NH_4)_2SO_4$ fertilization significantly increased iron concentration in cabbage heads in a comparison with RSM. Similarly tendency was also observed in case of Mn and Zn however, these differences were not always significant. Smolen and Sady [23], Gebski and Mercik [24] and Rodriguez-Otriz et al [25] reported that $(NH_4)_2SO_4$ fertilization can strongly affect the heavy metals accumulation in yield. The rhizosphere acidifications from of nitrogen supply as well as of the plant factor (enhanced net excretion of protons or of organic acid) are of particularly importance for acquisition of Fe, Zn and Mn on alkaline soils [8, 26]. The critical deficiency contents of manganese and zinc in plant vary between 10–20 mg Mn kg^{-1} and 15–30 mg Zn, respectively [1]. In our investigations Mn concentrations in cabbage leaves ranged from 13.5 mg to 15.1 mg kg^{-1} d.m. (Table 6).

Table 6

Effect of nitrogen fertilization on Mn and Ni content in 'Galaxy' F_1 cabbage grown in 2005–2007

Fertilizer	Application method*		Mn [mg kg^{-1} d.m.]				Ni [mg kg^{-1} d.m.]			
			2005	2006	2007	mean	2005	2006	2007	mean
Mean for year			14.5	15.1	13.5		0.599	0.637	0.454	0.563
Factor	$(NH_4)_2SO_4$		14.8	15.5	14.2	14.8	0.616	0.629	0.443	0.563
Fertilizer	RSM		14.1	14.7	12.7	13.8	0.582	0.644	0.466	0.564
Application method	broadcast	1	14.2	14.9	12.1	13.7	0.640	0.654	0.416	0.570
		2	15.0	15.9	12.3	14.4	0.541	0.612	0.344	0.499
		3	14.1	14.6	12.9	13.9	0.519	0.650	0.418	0.529
	placement	4	14.1	14.8	14.5	14.5	0.666	0.612	0.507	0.595
		5	15.2	15.4	15.0	15.2	0.739	0.627	0.551	0.639
		6	14.2	15.0	13.9	14.4	0.489	0.675	0.491	0.552
$LSD_{0.05}$ for:	year			0.75				0.0720		
	fertilizer		ns	ns	0.98		ns	ns	ns	
	application method		ns	ns	1.69		ns	ns	0.1369	

* See Table 3.

The Zn concentration in cabbage was below the critical values, and varied from 12.9 mg (2007) to 14.7 mg Zn kg^{-1} d.m. (2006) (Table 7). The method of application and form of nitrogen fertilization did not affect cabbage zinc concentrations any year. In 2007 slightly higher manganese concentrations for placement fertilization was noticed in comparison with N broadcasted. The same reaction was observed in case of nickel (Table 6). Beside the environmentally positive advantages, the subsurface placement of ammonium or ammonium/urea fertilizers has been proposed to supply crops under field conditions (known as the CULTAN cropping system; Controlled Uptake Long Term Ammonium Nutrition) [27]. The ammonium concentration in the deposit is toxic for plant roots and soil microorganisms and pH in this soil area is extremely low. Probably the acidification effect of concentrated ammonium fertilizer locally on the soil improved metals uptake. Roots form a dense root net around the ammonium deposit and can take up the nitrogen as ammonium before it is nitrified and perhaps solubilized metals ions.

Table 7

Effect of nitrogen fertilization on Sr and Zn content in 'Galaxy' F_1 cabbage grown in 2005–2007

Fertilizer	Application method*		Sr [mg kg^{-1} d.m.]				Zn [mg kg^{-1} d.m.]			
			2005	2006	2007	mean	2005	2006	2007	mean
Mean for year			8.16	8.18	12.2		14.4	14.7	12.9	14.0
Factor:	$(NH_4)_2SO_4$		8.34	8.32	12.4	9.69	14.8	14.8	13.2	14.3
Fertilizer	RSM		7.98	8.04	11.9	9.31	14.0	14.5	12.6	13.7
Application method	broadcast	1	7.91	7.89	11.5	9.10	14.4	15.4	12.1	14.0
		2	7.53	7.55	12.5	9.19	15.1	15.7	12.1	14.3
		3	8.41	8.42	12.4	9.74	14.7	15.7	12.5	14.3
	placement	4	8.14	8.23	12.7	9.69	13.0	14.0	13.8	13.6
		5	8.34	8.37	11.7	9.47	15.5	14.5	13.3	14.4
		6	8.64	8.63	12.1	9.79	13.6	12.7	13.5	13.3
$LSD_{0.05}$ for:	year			0.769				0.99		
	fertilizer		ns	ns	ns		ns	ns	ns	
	application method		ns	ns	ns		ns	ns	ns	

* See Table 3.

Nickel is now generally accepted as an essential ultra-micronutrient. The only defined role of Ni is in the metabolism of urea [22]. Nickel has a significant effect on the productivity of field-grown plants, those utilizing urea as a primary nitrogen source. The Ni concentration in leaves of plants grown on uncontaminated soil ranges from 0.05–5 mg Ni kg^{-1} d.m. and is the lowest of any element [1]. In present study in cabbage edible parts nickel concentration ranged from 0.454 to 0.637 mg Ni kg^{-1} d.m. (Table 6). Plant Ni concentration were related to soil pH similar to Cu, Fe, and Mn cabbage content. The form of nitrogen application did not influence Ni concentration in cabbage.

Strontium is chemically similar to calcium, and its biogeochemical cycles are comparable. Best known is the antagonism ions action between calcium and strontium in soil solution [28, 29]. Poor Sr immobilization by soils leads to large availability for plants. Plant foods containing Sr range very low eg in corn (0.4 mg kg^{-1} dry matter) to high, eg in cabbage (45 ppm) or lettuce (74 ppm) [2]. In present study the stable elementary Sr concentration in cabbage was related to total and extractable forms of strontium in soil. We measured 8.16 to 12.2 mg Sr kg^{-1} dry matter (Table 7). Any year of presented studies the form and method of nitrogen application did not influence Sr concentration in cabbage.

Lead concentration in edible parts of cabbage was below the detective limits for using method of detection. Alkalinity as result of overlime treatment might decrease Pb uptake by plants. Lead in totally acido-labile in the soil. The pH and dissolved organic carbon (DOC) are the major factors controlling the speciation and availability of Pb in soil. The Pb^{2+} decrease as pH and DOC increase [3]. The total Pb concentration in soil was low and ranged from 13.6 to 14.5 mg Pg kg^{-1} d.m., while the extractable fraction (1 M HCl) was measured on the range 10.1–13.4 mg Pb (Tables 2, 3).

Conclusions

Field research still required to explain complex interactions of soil chemistry (eg effects of pH, soil response to liming, plant-available nutrients), soil physics, and biology, and the effects of these on crop yield. A better understand of chemistry and availability of micro/trace elements in soil, their distribution and variability in areas of crop production, their absorption by roots and translocation to edible parts of food may lead to control their accumulation by plants and improved human health.

The present study focuses on the effect of nitrogen fertilization on metals concentration in edible parts of commercially grown cabbage. The low concentration of microelements in cabbage may indicate deficiencies that would affect crop yields or human nutrition. We concluded that micronutrient deficiencies were related to soil parent material, with generally low total and extractable levels of metals. The results obtained would suggest that in commercial production on overlimed soils using nitrogen ammonium fertilizers may improve Mn, Fe and Zn uptake by plants. Consistently greater concentrations of Cd, Cu, Fe, Mn and Ni were measured in cabbage grown on the field with lower pH compared with concentrations in plants sampled at other soil sites but relatively near located. This show the importance of sampling many soil and crop combinations in a survey, or having a thorough understanding of soil metals availability. White and Zasoski [30] suggest that rational management of micronutrient fertility and metals toxicity requires understanding of how total and plant-available soil elements vary across the land. According to authors highly detailed maps of soils metals content and availability in individual fields should be developed for site-specific precision agriculture.

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WPŁYW NAWOŻENIA AZOTEM NA PRZYSWAJALNOŚĆ Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr i Zn PRZEZ KAPUSTĘ GŁOWIASTĄ BIAŁĄ (*Brassica oleracea* var. *capitata alba*) UPRAWIANĄ W WARUNKACH PRODUKCYJNYCH

Abstrakt: Doświadczenie z kapustą głowiastą białą odm. Galaxy F_1 prowadzono w latach 2005–2007 w Zagorzycach koło Miechowa. Badano wpływ rodzaju nawozu azotowego (siarczan amonu, RSM – roztwór saletrzano-mocznikowy) oraz sposobu nawożenia (rzutowo, zlokalizowanie) oraz dokarmiania pozakorzeniowego (mocznik i Supervit K) na dostępność dla roślin Cd, Cr, Cu, Fe, Mn, Ni, Sr i Zn.

Zawartość wszystkich badanych metali w główkach kapusty była poniżej poziomu przyjętego za normalny w warunkach gleb nieskażonych. Mała zawartość metali była skorelowana z małą ogólną i przyswajalną zawartością badanych metali w glebach. Rodzaj zastosowanego nawozu azotowego wpływał znacznie na zawartość Fe i Mn w kapuście. Więcej Mn i Fe zawierały rośliny nawożone siarczanem amonu w porównaniu do RSM. Jednak tendencje te były silnie uzależnione od warunków środowiskowych panujących w kolejnych latach prowadzenia badań. Podobne zależności obserwowano także dla Zn, chociaż nie były one statystycznie udowodnione.

Sposób stosowania nawozów azotowych wpływał na zawartość Mn i Ni w kapuście. Lokalizowanie depozytów azotowych w pobliżu roślin podnosiło zawartość Mn i Ni w roślinach w porównaniu do rzutowego stosowania siarczanu amonu i RSM. Zależność ta nie była jednak obserwowana we wszystkich latach.

Otrzymane wyniki mogą wskazywać, że w warunkach gleb nadmiernie wapnowanych wykorzystanie do nawożenia azotem siarczanu amonowego może poprawić zaopatrzenie roślin w Mn, Zn i Fe.

Słowa kluczowe: kapusta głowiasta biała, pierwiastki śladowe, mikroelementy, nawożenie azotem, bioprzyswajalaność