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EFFECT OF NITROGEN FERTILIZATION ON Cu, Mn, Zn, Fe, B AND Mo AVAILABILITY IN COMMERCIALLY GROWN WHITE HEAD CABBAGE

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The results of three-year investigations with cv. Galaxy F_1 cabbage grown commercially in an important agricultural region of South Poland are presented. The effect of the rate of ammonium sulphate and UAN (solution of ammonium nitrate + urea), the method of application (placement and broadcast technique) and foliar fertilization (urea and Supervit K) on Cu, Mn, Zn, Fe, B and Mo concentrations in edible parts of cabbage were surveyed. Nitrogen fertilizer was applied at the rate of 120 kg N ha^{-1}. With the placement fertilization method, fertilizer was applied in rows 10 cm deep and 10 cm away from each plant when seedlings were transplanted. Foliar sprayings started at the beginning of intensive leaf growth and continued during the growing season at two-week interval. The foliar nutrition with 2% urea was carried out 3 times and 1% Supervit K was applied once. The field experiment was carried out in 2005-2007 with cv. Galaxy F_1 white cabbage on silty clay soil containing 0.91-1.02% organic carbon and soil acidity pH_{H_2O} 7.18-8.21 Micronutrient concentrations were below the lower range of the content reported for cabbage grown in non-contaminated areas. Ammonium sulphate significantly increased Mn and Fe concentrations in cabbage heads and decreased B and Mo content. However, the environmental factors considerably modified this tendency. The method of N application affected Mn content in cabbage in 2007 and Mo in 2006 and 2007. Slightly higher manganese and molybdenum concentrations for placement fertilization were noted. In 2005 and 2006, the placement fertilization at the rate of 75% N and supplemented foliar sprays increased Mo content in cabbage.

Key words: white cabbage, nitrogen fertilization, method of N application, micronutrient content.

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WPŁYW NAWOŻENIA AZOTEM NA DOSTĘPNOŚĆ Cu, Mn, Zn, Fe, B I Mo W KAPUŚCIE GŁOWIASTEJ BIAŁEJ ODM. GALAXY F_1 UPRAWIANEJ W WARUNKACH PRODUKCYJNYCH

Abstrakt

Doświadczenie z kapustą głowiastą białą odm. Galaxy F_1 prowadzono w latach 2005--2007, w prywatnym gospodarstwie warzywniczym, w Zagorzycach k. Miechowa. Badano wpływ rodzaju nawozu azotowego (siarczan amonu, RSM – roztwór saletrzano-mocznikowy), sposobu nawożenia (rzutowy, zlokalizowany) oraz dokarmiania pozakorzeniowego (mocznik i Supervit K) na stopień odżywienia roślin mikroelementami (Cu, Mn, Zn, Fe, B i Mo). Azot stosowano w dawce 120 kg N ha^{-1}. Nawożenie zlokalizowane polegało na umieszczaniu depozytów azotowych w rzędach roślin – w odległości 10 cm od rośliny i na głębokości 10 cm – w chwili sadzenia rozsady. W obiektach z dokarmianiem dolistnym opryski wykonywano 4-krotnie, rozpoczynając na początku fazy intensywnego wzrostu wegetatywnego. W pierwszym, drugim i czwartym terminie dokarmianie wykonano z użyciem 2% roztworu mocznika, natomiast w trzecim terminie stosowano 1% roztworu Supervitu K. Kapustę uprawiano na glebie ciężkiej o składzie pyłu ilastego, zawartości węgla organicznego (%C) 0,91-1,02% i odczynie pH_{H_2O} 7,18-8,21.

Rodzaj zastosowanego nawozu azotowego wpływał istotnie na zawartość Mn, Fe, B i Mo w kapuście. Istotnie więcej Mn i Fe zawierały rośliny nawożone siarczanem amonu w porównaniu z roztworem saletrzano-mocznikowym (RSM), natomiast RSM wpływał na wzrost w liściach kapusty zawartości B i Mo. Obserwowany wpływ nawozów na oznaczane w materiale roślinnym składniki zależał od warunków środowiskowych w kolejnych latach badań.

Sposób stosowania nawozów azotowych wpływał na zawartość Mn i Mo w kapuście. Lokalizowanie depozytów azotowych w pobliżu roślin miało wpływ na wzrost zawartości Mn i Mo w roślinach w porównaniu z rzutowym stosowaniem siarczanu amonu i RSM. Pozakorzeniowe dokarmianie roślin z wykorzystaniem mocznika i Supervitu K zawierającego molibden wpływało na wzrost stężenia Mo w kapuście w przypadku zlokalizowanego doglebowego nawożenia azotem.

Słowa kluczowe: kapusta biała, nawożenie azotem, metody aplikacji N, zawartość mikroelementów.

INTRODUCTION

Soils vary widely in their micronutrient content and the ability to supply micronutrients in quantities sufficient for optimal crop growth. Micronutrient availability defined as the quantity of a soil nutrient that is accessible to plant roots, depends on soil pH, organic matter content, adsorptive surfaces and other physical, chemical, and biological conditions in the rhizosphere (De Pieri et al. 1996, Gębski 1998, White, Zasoski 1999).

Nutrient interactions in crop plants are probably one of the most important factors affecting yields of annual crops. They can be measured in terms of crop growth and nutrient concentrations in plant tissues. Interactions on the root surface are usually due to the formation of chemical bonds by ions and precipitation or complexes (Marchner 1995). An example of this type of a nutrient interaction is the liming of acidic soils. Massive or repeated application of lime reduces the availability of micronutrients except molybdenum. In the 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. Due to a more rapid effect of liming, alkalinity may often lead to nutritional deficiencies (Boland et al. 1999).

Nitrogen fertilizers induce some direct and/or indirect changes which influence the dynamics of the availability of metals in soils. Mineral N fertilizers contain ammonium and can acidify the soil solution, thus decreasing the pH of the rhizosphere. In neutral or alkaline soils, acidification of the rhizosphere of plants fed with ammonium can enhance the uptake of micronutrients such as boron, iron, manganese, copper and zinc (Jurkowska et al. 1996, Fageria and Baligar 2005, Diatta and Grzebisz 2006).

The objective of the present project was to assess the effect of ammonium sulphate and UAN (solution of the ammonium nitrate + urea) applied by placement and broadcast technique and additionally foliar fertilization (urea and Supervit K) on the accumulation of micronutrients in cv. Galaxy F_1 cabbage grown commercially under field conditions.

MATERIAL AND METHODS

A field experiment was carried out in 2005-2007 with cv. Galaxy F_1 white cabbage on silty clay soil containing 0.91-1.02% organic carbon and soil acidity pH_{H2O} 7.18-8.21 (Table 1). The plots were located on a private farm in Zagorzyce (50°23' and 20°04'). Farms in this area specialize in cabbage production in continuous or highly frequent cropping. In short-term crop rotation systems liming is commonly used as a measure to prevent potential damage caused by club root. Application of calcium oxide one month prior to planting is a practical means of controlling fungal disease.

Table 1

Organic carbon content (%), soil pH and soil texture before cabbage planting in 2005-2007

Year	C (%)	Sand 0-0.1 mm	Silt 0.1-0.02 mm	Clay <0.02 mm	pH_{KCl}	pH_{H_2O}
2005	0.91	15	47	38	7.70	8.21
2006	1.02	8	50	41	6.17	7.18
2007	0.98	9	55	36	7.09	7.90

Two factors were examined: the type of N fertilizer - ammonium sulphate and UAN-30 (ammonium nitrate – 42.8%, urea 32.2%, water – 25%), and the method of N application. The treatments with both fertilizers were as follows:

1) control – 100% N rate (120 kg ha^{-1}) broadcast during the planting of seedlings;
2) 75% N rate broadcast during the planting of seedlings + 25% N as top dressing;
3) 75% N rate broadcast during the planting of seedlings + foliar fertilization;
4) 75% N placement during the planting of seedlings;
5) 75% N placement during the planting of seedlings + 25% N as top dressing;
6) 75% N placement during the planting of seedlings + foliar fertilization.

Treatments were assigned the following completely randomized blocks in a split-plot arrangement with four replications. Nitrogen fertilizer was applied at the rate of 120 kg N ha^{-1} (100% N). With the placement fertilization method, fertilizer was applied in rows 10 cm deep and 10 cm away from each plant (plants were spaced 67.5 x 67.5 cm) when seedlings were transplanted. Foliar sprayings started at the beginning of intensive leaf growth and continued during the growing season in two-week intervals. The foliar nutrition with 2% urea was carried out 3 times and 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) was applied once. Mineral fertilization with phosphorus, potassium and magnesium was adjusted to the results of chemical analysis of the soil samples. The content of soil P, K and Mg was supplemented to the level of 50, 200 and 60 mg dm^{-3}, respectively before the planting of seedlings.

The harvest was conducted in the last decade of October. Edible parts were analyzed after washing with distilled water and drying at 70°C for 48 h. The Cu, Mn, Zn, Fe, B and Mo content in the samples was determined by inductively coupled argon plasma atomic emission spectroscopy (ICP-OES) after microwave digestion with HNO_3. Soil samples were collected from a 0-30 cm surface layer. Granulometric analysis was made by the aerometric method of Prószyński and the organic carbon by Tiurin's method (Ostrowska et al. 1991). Soil pH was determined by adding deionized water and 1 M KCl at a ratio 1:2 (soil:water by volume). Total micronutrients in soil were determined by inductively coupled argon plasma atomic emission spectroscopy (ICP-OES) after microwave digestion with Aqua Regia (Houba et al.1991).

The results were subjected to a two-way factor analysis of MANOVA. The mean were separated by Fisher's LSD test ($p = 0.05$).

RESULTS AND DISCUSSION

In a current survey, the micronutrient concentration in edible parts of cabbage were below the lower range of the content reported for cabbage grown in non-contaminated areas. Low concentrations of micronutrients may indicate deficiencies that would affect crop yield.

Copper deficiency is often observed in plants growing on soils with a low total Cu and on soils high in organic matter, where Cu is bound to organic substances. Its bioavailability increases under slightly acidic conditions (CHAIGNON et al. 2002, MERCIK et al. 2004). The total Cu concentration in Polish soils range from 0.2 to 725 mg kg^{-1} dry weight (TRELAK 1997). In the present study, the total Cu concentrations in soils were low and ranged between 4.68-4.75 mg Cu kg^{-1} (Table 2). A critical deficiency level of copper in vegetative plant parts is generally in the range of 1-5 mg Cu kg^{-1} dry matter, depending of a plant species, plant organ, development stage and nitrogen supply (MARCHNER 1995, BARKER and PILBEAM 2006). In this experiment, the copper content in plants tended to be less than the ranges reported by KABATA-PENDIAS and PENDIAS (1999) for heads of cabbage grown in non-contaminated sites (3-4 mg Cu kg^{-1} d.m.). The highest Cu concentration was detected in 2006 (2.14 ppm Cu) and the lowest one appeared in 2005 (1.58 ppm) – Table 3. When the lowest pH of soil was noticed in 2006 (pH 7.18) and in 2005 (pH 8.21), the Cu concentration in cabbage was the highest. The form of nitrogen fertilizers did not affect Cu concentrations in cabbage leaves. Similar results were presented by SMOLEŃ and SADY (2007), who proved that copper content in carrot roots was not influenced by nitrogen fertilizers. The same conclusions were drawn by CHAIGNON et al. (2002) who investigated tomato and oilseed rape and reported that the Cu bioavailability was independent of the N supply in calcareous soil The method of nitrogen application did not influence the Cu concentration in cabbage in any year during the presented study (Table 3).

Table 2

Total micronutrients content (mg kg^{-1} dry weight) in soil before cabbage planting in 2005-2007

Year	Cu	Mn	Zn	Fe	B	Mo
2005	4.68	152	24.3	8184	6.02	<0.03
2006	4.74	187	25.8	6176	3.94	0.033
2007	4.75	156	32.9	6606	4.06	0.031

Samples of soil from sites where experimental plots were located had a pH level between 7.18-8.21. Increasing the soil pH by liming usually decreases the plant availability of Mn and Zn much more than of any other

Table 3

Effect of nitrogen fertilization on Cu and Mn content in Galaxy F_1 cabbage grown in 2005-2007

Fertilizer	Application method*		Cu (mg kg^{-1} d.m.)				Mn (mg kg^{-1} d.m.)			
			2005	2006	2007	mean	2005	2006	2007	mean
$(NH_4)_2SO_4$	broadcast	1	1.45	1.90	1.83	1.73	14.2	14.8	12.6	13.9
		2	1.65	1.96	1.76	1.79	15.2	16.4	12.3	14.6
		3	1.63	2.47	2.22	2.11	15.3	15.4	13.2	14.6
	placement	4	1.38	1.94	1.92	1.75	14.3	15.1	15.8	15.1
		5	1.64	2.04	2.04	1.91	15.6	15.9	16.5	16.0
		6	1.44	1.89	2.13	1.82	14.4	15.4	14.8	14.9
UAN	broadcast	1	1.74	2.66	1.92	2.11	14.1	15.1	11.6	13.6
		2	1.69	2.39	1.70	1.93	14.9	15.5	12.2	14.2
		3	1.55	2.48	1.84	1.96	12.9	13.8	12.5	13.1
	placement	4	1.58	1.88	2.54	2.00	13.9	14.5	13.2	13.9
		5	1.67	1.98	1.83	1.83	14.9	15.0	13.5	14.5
		6	1.54	2.07	1.90	1.84	14.0	14.6	13.1	13.9
Mean for year			1.58	2.14	1.97		14.5	15.1	13.5	
Factor Fertilizer	$(NH_4)_2SO_4$		1.53	2.03	1.99	1.85	14.0	15.5	14.2	14.8
	UAN		1.63	2.24	1.95	1.94	14.1	14.7	12.7	13.8
Application method	broadcast	1	1.60	2.28	1.88	1.92	14.2	14.9	13.7	13.7
		2	1.67	2.17	1.73	1.85	15.0	15.9	14.4	14.4
		3	1.59	2.47	2.03	2.03	14.1	14.6	13.9	13.9
	placement	4	1.48	1.91	2.22	1.87	14.1	14.8	14.5	14.5
		5	1.66	2.01	1.94	1.97	15.2	15.4	15.2	15.2
		6	1.49	1.98	2.01	1.83	14.2	15.0	14.4	14.4
$LSD_{0.05}$ for:	fertilizer		ns	ns	ns		ns	ns	0.98	
	application method		ns	ns	ns		ns	ns	1.69	
	fertilizer x application		ns	ns	ns		ns	ns	ns	

*1 – 120 kg ha^{-1} N broadcast at planting of seedlings; 2 – 90 kg ha^{-1} N broadcasted at planting of seedlings + 30 kg ha^{-1} N as top dressing; 3 – 90 ha^{-1} N broadcast at planting of seedlings + + foliar fertilization; 4 – 90 kg ha^{-1} N placement at seedling planting; 5 – 90 kg ha^{-1} N placement at seedling planting + 30 kg ha^{-1} N as top dressing; 6 – 90 kg ha^{-1} N placement at seedling planting + foliar fertilization
n.s. – non – significant

mineral nutrient (Czekała et al. 1996). A critically deficient content of manganese in plants is similar among crop species, varying between 10-20 mg Mn kg^{-1} dry matter (Marchner 1995). In our investigations, the Mn concentration in cabbage leaves ranged from 13.5 mg to 15.1 mg kg^{-1} d.m. (Table 3). The nitrogen form and N application method affected the manganese content in plants only in 2007. A significant increase in the Mn content in cabbage fertilized with $(NH_4)_2SO_4$ was observed. However, the form of mineral nitrogen fertilizers did not affect the pH of soil measured after harvest in any year (data not published). Slightly higher manganese concentrations for placement fertilization were noticed in comparison to the N broadcast method.

The risk of Zn deficiency is high in soil after liming or in calcareous soils. In leaves, the critical deficiency levels are below 15-20 mg Zn kg^{-1} d.m. Barker and Pilbeam (2006) report that in cabbage heads an intermediate range is 34 mg Zn kg^{-1} d.m. In this research, the Zn concentrations in cabbage varied from 12.9 mg (2007) to 14.7 mg Zn kg^{-1} d.m. (2006) – Table 4. The method of application and form of nitrogen fertilization did not affect the zinc concentrations in cabbage in any year. This result does not confirm the conclusions presented by Smoleń and Sady (2007), who reported that $(NH_4)_2SO_4$ fertilization can strongly affect accumulation of heavy metals (including Zn) in yield.

In Poland, clay mineral soils have on average 0.8-2.78% of Fe in total (Kabata-Pendias and Pendias 1999). However, in a well-aerated soil of a high pH, the concentration of Fe^{2+} and Fe^{3+}in soil solution is extremely low. In the present research, samples of soil from the experimental plots contained the total Fe of 6176-8184 mg kg^{-1} dry weight (Table 2). Iron deficiency is a worldwide problem in crop production on calcareous soils. It is the major factor responsible for the so-called lime-induced chlorosis (Barker, Pilbeam 2006). The critical deficiency content of iron in leaves is 50-150 mg Fe kg^{-1} dry matter (Marchner 1995). Kabata-Pendias, Pendias (1999) report that on average the concentration of Fe in edible parts of cabbage 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 4) In 2007, the $(NH_4)_2SO_4$ fertilization treatment significantly increased the iron concentration in cabbage heads compared to the UAN treatment (Table 4).

The total boron content of most agricultural soils ranges from 1-467 mg kg^{-1} dry weigh, with an average content of 9-85 mg (Kabata-Pendias, Pendias 1999). The boron concentration in the experimental soil was low and varied from 3.94 to 6.02 mg B kg^{-1} dry weight. Boron uptake is closely related to the pH. Boron adsorption to clay minerals increases sharply above pH = 6.5. In alkaline soils, low boron solubility is dictated by B adsorption to clay minerals (Tyler, Olsson 2001). The critical deficiency range, expressed as mg B kg^{-1} dry matter, is 20-70 mg in most dicotyledonous species (in cabbage leaves, B concentration is reported above 14 ppm) (Marchner 1995).

Table 4

Effect of nitrogen fertilization on Zn i Fe content in Galaxy F_1 cabbage grown in 2005-2007

Fertilizer	Application method*		Zn (mg kg^{-1} d.m.)				Fe (mg kg^{-1} d.m.)			
			2005	2006	2007	mean	2005	2006	2007	mean
$(NH_4)_2SO_4$	broadcast	1	13.9	13.9	12.7	13.5	25.1	25.5	25.3	25.3
		2	15.5	15.8	12.3	14.5	27.6	27.3	23.7	26.2
		3	15.7	16.8	12.4	15.0	28.7	29.7	27.1	28.5
	placement	4	13.8	14.6	13.4	13.9	27.4	28.0	26.1	27.2
		5	16.1	14.6	13.7	14.8	27.8	28.6	25.9	27.4
		6	14.1	13.3	14.6	14.0	25.4	29.6	24.7	26.6
UAN	broadcast	1	15.0	16.9	11.6	14.5	27.7	28.7	20.7	25.7
		2	14.7	15.6	11.8	14.0	26.6	28.9	20.8	25.4
		3	13.8	14.6	12.6	13.7	24.6	26.6	21.7	24.3
	placement	4	12.3	13.3	14.2	13.3	28.6	30.5	24.0	27.7
		5	14.8	14.4	12.9	14.0	29.6	27.2	24.5	27.1
		6	13.1	12.1	12.4	12.5	23.8	24.8	24.0	24.2
Mean for year			14.4	14.7	12.9		26.9	28.0	24.0	
Factor Fertilizer	$(NH_4)_2SO_4$		14.8	14.8	13.2	14.3	27.0	28.1	25.5	26.9
	UAN		14,0	14.5	12.6	13.7	26.8	27.8	22.6	25.7
Application method	broadcast	1	14.4	15.4	12.1	14.0	26.4	27.1	23.0	25.5
		2	15.1	15.7	12.1	14.3	27.1	28.1	22.2	25.8
		3	14.7	15.7	12.5	14.3	26.7	28.2	24.4	26.4
	placement	4	13.0	14.0	13.8	13.6	28.0	29.3	25.0	27.4
		5	15.5	14.5	13.3	14.4	28.7	27.9	25.2	27.3
		6	13.6	12.7	13.5	13.3	24.6	27.2	24.3	25.4
$LSD_{0.05}$ for:	fertilizer		ns	ns	ns		ns	ns	1.99	
	application method		ns	ns	ns		ns	ns	ns	
	fertilizer x application		ns	ns	ns		ns	ns	ns	

*see Table 3

In cabbage heads 12.6-13.4 mg B kg^{-1} dry matter was detected (Table 5). In 2005 and 2006, plants fertilized with UAN solution contained significantly more B than treated with ammonium sulphate. The form of nitrogen fertilizers can affect boron accumulation in plants. WÓJCIK (2000) reported that in boron deficient soils, nitrogen added as $Ca(NO_3)_2$ and NH_4NO_3 increased

Table 5

Effect of nitrogen fertilization on B i Mo content in Galaxy F_1 cabbage grown in 2005-2007

Fertilizer	Application method *		B (mg kg^{-1} d.m.)				Mo (mg kg^{-1} d.m.)			
			2005	2006	2007	mean	2005	2006	2007	mean
$(NH_4)_2SO_4$	broadcast	1	9.9	10.1	13.7	11.2	0.049	0.042	0.089	0.060
		2	9.5	9.7	12.9	10.7	0.045	0.044	0.107	0.065
		3	9.4	9.9	14.5	11.3	0.052	0.052	0.221	0.108
	placement	4	12.1	12.7	13.5	12.8	0.073	0.073	0.088	0.078
		5	10.5	10.5	14.2	11.7	0.063	0.061	0.066	0.063
		6	11.2	12.0	13.2	12.1	0.068	0.088	0.070	0.075
UAN	broadcast	1	15.3	16.9	12.6	14.9	0.079	0.086	0.265	0.143
		2	14.7	15.8	13.0	14.5	0.073	0.081	0.126	0.093
		3	13.8	15.3	13.4	14.2	0.074	0.088	0.153	0.105
	placement	4	14.2	15.4	13.8	14.5	0.082	0.090	0.093	0.088
		5	15.6	15.5	13.3	14.8	0.094	0.083	0.075	0.084
		6	14.6	15.9	13.0	14.5	0.100	0.111	0.093	0.101
Mean for year			12.6	13.3	13.4		0.070	0.070	0.120	
Factor Fertilizer	$(NH_4)_2SO_4$		10.4	10.8	13.7	11.6	0.058	0.060	0.110	0.076
	UAN		14.7	15.8	13.2	14.6	0.084	0.090	0.130	0.101
Application method	broadcast	1	12.6	13.5	13.2	13.1	0.064	0.064	0.177	0.102
		2	12.1	12.8	13.0	12.6	0.059	0.062	0.116	0.079
		3	11.6	12.6	14.0	13.7	0.063	0.070	0.187	0.107
	placement	4	13.2	14.1	13.6	13.6	0.077	0.082	0.090	0.083
		5	13.0	13.0	13.8	13.3	0.079	0.072	0.071	0.074
		6	12.9	13.9	13.1	13.3	0.084	0.100	0.082	0.089
$LSD_{0.05}$ for:	fertilizer		0.87	1.15	ns		0.0082	0.0074	ns	
	application method		ns	ns	ns		0.0143	0.0129	ns	
	fertilizer x application		ns	ns	ns		ns	ns	ns	

*see Table 3

the availability and uptake of B by roots. This increase was attributed to the fact that nitrate inhibited boron sorption on iron and aluminum oxides and increased B in soil solution.

The molybdenum plant requirement is lower than that of the other mineral nutrients. In an aqueous solution Mo occurs as molybdate oxyanion

MoO_4^{-2}. Depending on a plant species and source of N supply, the critical deficiency levels of Mo may vary between 0.1-1.0 mg kg^{-1} (MARCHNER 1995). The molybdenum content in plant tissues increases when the soil pH rises from 5-7 because of soil liming. On the other hand, excessive Ca concentration in soil solution can reduce the availability of Mo. In the present research, molybdenum concentrations in a cabbage were below the lower range of content and varied between 0.07 to 0.120 mg Mo kg^{-1} dry matter (Table 5). In 2005 and 2006, ammonium sulphate fertilization significantly decreased the molybdenum content in cabbage. Sulphate and molybdate are strongly competing anions during the uptake by roots (BARKER and PILBEAN 2006). In the case of a wide concentration ratio of SO_4^{-2}/MoO_4^{-2} in the soil solution, sulfate containing fertilizers depresses the molybdenum uptake. In 2005 and 2006, placement fertilization at the rate of 75% N and supplemented foliar sprays increased the Mo content in cabbage.

CONCLUSIONS

In the current study, the Cu, Zn, Fe, B and Mo concentration in edible parts of cabbage was below the lower range of the content reported for cabbage grown in non-contaminated areas. The low concentration of micronutrients may indicate deficiencies that would affect cabbage crop yield in commercial production in this area. It was concluded that deficiencies of micronutrients were related to the parent material, with generally low total levels of Cu, Zn, Fe, B, and Mo leading to the deficit of these elements. WHITE, ZASOSKI (1999) report that micronutrient deficiencies in agricultural soils worldwide are disturbingly large. The problem is aggravated by the fact that many modern cultivars of major crops are highly sensitive to low micronutrient levels. The results of this study confirm other reports indicating that deficiency of micronutrients is on an increase in intensive agricultural systems characterized by large nitrogen, phosphorus and potassium fertilization rates and lime applications, inducing nutrient imbalance and increasing micronutrient demand.

The research has demonstrated that in neutral or slightly alkaline soils mineral N fertilizers containing ammonium can enhance the uptake of micronutrients such as iron and manganese. In the case of a wide concentration ratio of SO_4^{-2}/MoO_4^{-2} in the soil solution, sulfate depresses the molybdenum uptake. The UAN solution including $N\text{-}NO_3$ increased the availability and uptake of B by cabbage.

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