# EFFECT OF NITROGEN FERTILIZATION ON P, K, Mg, Ca AND S CONTENT IN SOIL AND EDIBLE PARTS OF WHITE CABBAGE

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### Abstract

The results of three-year investigations on cv. Galaxy $F_1$ of cabbage grown commercially in the south Poland, an important agricultural region, are presented. In 2005-2007, a field experiment was carried out on silty clay soil containing 0.91-1.02% organic carbon and of the soil acidity $pH_{H2O}$ 7.18-8.21.

Effects of the N form (ammonium sulfate and UAN: a solution of ammonium nitrate + urea) and the method of application (placement and broadcast techniques and complementary foliar fertilization with urea and Supervit K) on the P, K, Mg, Ca and S concentrations in edible parts of cabbage were surveyed. Nitrogen fertilizer was applied at the rate of 120 kg N ha$^{-1}$. In the placement treatment, fertilizer was applied on each plant while transplanting seedlings in rows 10 cm deep and spaced 10 cm from one another. Foliar nutrition with 2% urea was carried out 3 times and once 1% Supervit K was applied. The content of nutrients in cabbage leaves changed over the years. On average, the highest K and Mg content was in 2006 and the lowest P, K, Mg and Ca content appeared in 2007, with the harvest of 2005 being intermediate. The sulfur leaf content was the highest in 2007 and the lowest in 2006. The concentrations of P, K, and Mg in edible parts of cabbage were less than sufficient. The source of N affected P concentrations in cabbage leaves in 2005-2006. Slightly higher P amounts were detected in cabbage fed UAN than ammonium sulfate. None of the examined factors influenced K and Mg concentration in cabbage. In 2005-2006, slightly lower concentrations of Ca in cabbage fed UAN than ammonium sulfate were noticed. In every year, higher S concentrations in plants fed ammonium sulfate were detected. In 2005-2006, cabbage fertilized with the broadcast technique had slightly higher amount of S than the one given the placement treatment. Foliar fertilization did not affected the content of the examined nutrients in cabbage in any year of the trials.

Key words: ammonium sulphate, UAN, broadcast and placement fertilization.

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## WPŁYW NAWOŻENIA AZOTEM NA ZAWARTOŚĆ P, K, Mg, Ca I S W GLEBIE I CZĘŚCIACH JADALNYCH KAPUSTY GŁOWIASTEJ BIAŁEJ

### Abstrakt

Badano wpływ nawożenia azotowego siarczanem amonu i roztworem saletrzano-mocznikowym (RSM) na zawartość P, K, Mg, Ca i S w glebie i kapuście głowiastej białej. Badania z kapustą głowiastą białą odmiany Galaxy $F_1$ prowadzono w latach 2005-2007 w Zagorzycach k. Miechowa. Nawozy azotowe stosowano wg schematu: 1) kontrola – 100% N (120 kg ha$^{-1}$) rzutowo w czasie sadzenia rozsady; 2) 75% N rzutowo w czasie sadzenia rozsady + 25% N w trakcie wegetacji; 3) 75% N rzutowo w czasie sadzenia rozsady + nawożenie pozakorzeniowe; 4) 75% N w sposób zlokalizowany w czasie sadzenia rozsady, 5) 75% N w sposób zlokalizowany w czasie sadzenia rozsady + 25% N rzutowo w czasie wegetacji; 6) 75% N w sposób zlokalizowany w czasie sadzenia rozsady + nawożenie pozakorzeniowe. Dokarmianie pozakorzeniowe wykonywano 2% mocznikiem (3-krotnie) i 1% roztworem Supervitu K (1 raz).

Warunki pogodowe w kolejnych latach doświadczenia znacznie modyfikowały wpływ czynników badań na zawartość oznaczanych składników mineralnych w kapuście. Najwięcej K i Mg w roślinach oznaczono w 2006 r., najmniej P, K, Mg i Ca w 2007 r., natomiast 2005 r. był rokiem średnim, jeśli chodzi o stężenia badanych pierwiastków. Zawartość siarki w liściach kapusty była najwyższa w 2007 r., a najniższa w 2006 r. Oznaczone zawartości P, K i Mg były poniżej zakresu przyjętego za wystarczający dla części jadalnych kapusty. Rodzaj nawozu azotowego wpływał istotnie na zawartość P i Ca w roślinach. W 2005 i 2006 r. wyższe stężenia P wykazano w roślinach nawożonych RSM w porównaniu z nawożonymi siarczanem amonu. Więcej Ca oznaczano w kapuście nawożonej siarczanem amonu w porównaniu z kapustą nawożoną roztworem saletrzano-mocznikowym. Żaden z badanych czynników nie różnicował istotnie zawartości K i Mg w kapuście. W każdym roku badań rośliny nawożone siarczanem amonu zawierały więcej siarki. W 2005 i 2006 r. rzutowy sposób nawożenia siarczanem amonu wpływał istotnie na zwiększenie stężenia S w roślinach w stosunku do nawożenia zlokalizowanego. Nawożenie pozakorzeniowe nie wpływało istotnie na zawartość oznaczanych pierwiastków w roślinach.

Słowa kluczowe: siarczan amonu, RSM, nawożenie rzutowe i zlokalizowane.

# INTRODUCTION

Agricultural production and productivity are directly related to nutrient availability and uptake. Relationships between the uptake of macro- and micronutrients by crops and their yield are significant (JANSSEN 1998, FRAGARIA 2009). Soils differ widely in their ability to supply the nutrients necessary to sustain plant productivity. Nutrient availability to plants is a very dynamic and complex process, consisting of the physical, chemical and biological changes that occur in the rhizosphere (MARCHNER 1995). Nutrients are added to soil through weathering, atmospheric deposition, fertilization, fixation and mineralization and lost or made unavailable through harvesting, leaching, biological immobilization, sorption and precipitation chemistry (MENGEL et al. 2001).

Nutrient interactions in crop plants, which may be positive, negative or neutral (no interaction), are probably one of the most important factors affecting yields of annual crops. This is a very complex issue in mineral nutrition and has not been fully clarified yet (FRAGERIA, BALIGAR 2005). Nutrient interactions may be a result of precipitation reactions occurring in the soil solution, which reduce availability for plant uptake, or a consequence of competition during nutrient uptake, translocation or metabolic functions in the plant. Some important nutrient interactions include ammonium-calcium and potassium-magnesium-calcium relations (GOULDING 1983). Farmers often use $NH_4$ and K salts as fertilizer sources. Even though $N-NH_4$ applied as a fertilizer has a short life in agricultural soils (1-3 weeks or more depending on rates of nitrification), the $K-NH_4-Ca$ exchange interaction controls the distribution of these cations between the exchange and solution phases during that period (EVANGELOU et al. 1994). Thus, the availability of $K^+$ and $NH_4^+$ in the solution phase would be affected by all ions present.

For sustainable agriculture, it is important to know how nitrogen interacts with other nutrients in order to improve efficient utilization of this element and, consequently, to enhance yields. Positive interactions between N and other nutrients have been reported by HOLFORD et al. (1992), ZHAO et al. (1997), SADY and SMOLEŃ (2007), SMOLEŃ and SADY (2009). Positive interactions of N with P, K, Ca and other nutrients may be associated with improved yield when N is added. Potassium application may increase plant yields although an optimal supply of N and P leads to a better response of yield to K fertilizer (FRAGARIA 2009).

Nitrogen also enters into positive interactions with S in crop plants It is generally considered that S availability may influence the N utilization by plants and vice versa, indicating that mineral S and N availabilities interact to affect the S and N management by plants (ZHAO et al. 1997, JACKSON 2000, ABDALLAH et al. 2010).

The main objective of the present study was to examine the influence of ammonium sulfate and UAN (solution of ammonium nitrate + urea) applied by the placement and broadcast techniques and additional foliar fertilization (urea and Supervit K) on the mineral concentration of P, K, Mg, Ca and S in cv. Galaxy $F_1$ white cabbage.

## MATERIAL AND METHODS

In 2005-2007, a field experiment was carried out on cv. Galaxy $F_1$ white cabbage grown on silty clay soil containing 0.91-1.02% organic carbon and of the soil acidity $pH_{H_2O}$ 7.18-8.21 (Table 1). The plots were located on a private farm in Zagorzýce (50º23' and 20º04'). Farms in this area specialize in cabbage production in continuous or highly frequent cropping. In short-term

pH values, EC (electrical conductivity) and content of macronutrients content
in soil before cabbage planting in 2005-2007

| Year | Soil layer (cm) | $pH_{KCl}$ | $pH_{H_2O}$ | EC (mS cm$^{-1}$) | C (%) | Nutrient (mg dm$^{-3}$ of soil) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | P | K | Mg | Ca |
| 2005 | 0-30 | 7.70 | 8.21 | 0.24 | 0.91 | 70.6 | 207 | 110 | 3218 |
| | 30-60 | 7.60 | 8.14 | 0.15 | 0.38 | 39.6 | 133 | 124 | 5159 |
| | 60-90 | 7.57 | 8.01 | 0.14 | 0.20 | 35.4 | 56.6 | 129 | 5965 |
| 2006 | 0-30 | 6.17 | 7.18 | 0.19 | 1.02 | 63.7 | 88.3 | 50.3 | 1572 |
| | 30-60 | 6.57 | 7.40 | 0.11 | 0.47 | 56.4 | 17.3 | 99.9 | 2826 |
| | 60-90 | 6.59 | 7.44 | 0.10 | 0.41 | 48.2 | 8.7 | 61.4 | 1462 |
| 2007 | 0-30 | 7.09 | 7.90 | 0.06 | 0.98 | 119.6 | 73.1 | 54.3 | 2301 |
| | 30-60 | 7.05 | 7.99 | 0.07 | 0.49 | 67.2 | 19.4 | 38.3 | 1270 |
| | 60-90 | 7.70 | 7.85 | 0.07 | 0.37 | 60.8 | 8.35 | 40.8 | 944 |

crop rotation systems, liming is commonly used as a control measure against club root. Calcium oxide application one month prior to planting is a practical means to control this fungal disease.

The mineral fertilization of cabbage in our experiment was designed according to the results of chemical analysis of soil samples collected in the previous autumn. The content of soil nutrients such as P, K and Mg were supplemented to the level of 50, 200 and 60 mg dm$^{-3}$, respectively.

Two factors were examined: the type of N fertilizer ammonium sulfate and UAN (1:1 solution of ammonium nitrate and urea), and the method of N application. The treatments 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 growth,
3. 75% N rate broadcasted at planting of seedlings + foliar fertilization,
4. 75% N placement at planting of seedlings,
5. 75% N placement at planting of seedlings + 25% N during plant growth,
6. 75% N placement at planting of seedlings + foliar fertilization.

The treatments were designed in completely randomized split-plot blocks with four replications. Nitrogen fertilizer was applied at rates of 120 kg N ha$^{-1}$ (100% N) or 75 kg N ha$^{-1}$ (75%). With the placement method, fertilizer was applied on each plant (plant were spaced 67.5 x 67.5 cm) in rows 10 cm deep and spaced at 10 cm distance while transplanting the seedlings. Cabbage seedlings were planted in the first decade of June. Foliar sprayings started at the beginning of intensive leaf growth and continued during the growing season in two-week interval. Foliar nutrition with 2% urea was carried out 3 times and once 1% Supervit K was applied (% 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). The total amount of N reached 27.6 kg N ha$^{-1}$ following the foliar urea application and 0.6 kg N ha$^{-1}$ when Supervit was used.

Harvest took place in the last decade of October. Edible parts were analyzed after washing with distilled water and drying at 70°C for 48 h. The K, Mg and Ca content in the samples was determined by atomic absorption spectroscopy (AAS) after digestion with $HNO_3$ : $HClO_4$ : $H_2SO_4$ (6 : 2 : 0.25). Phosphorus in the mineralized samples was analyzed with vanadium-molybdenum method described by OSTROWSKA et al. (1991) whereas $S-SO_4$ was assayed by BARDSLEY-LANCASTER'S method (1960).

Soils samples from three layers: 0-30 cm, 30-60 cm and 60-90 were taken in the spring before the experiment started as well as after the harvest. Organic carbon was assessed by Tiurin's method (OSTROWSKA et al. 1991), and the sorption complex capacity (CEC) was determined in ammonium chloride extract (KOCIAŁKOWSKI, RATAJCZAK 1984). N (N-$NH_4$ and N-$NO_3$), P, K and Mg were measured in 0.03 M $CH_3COOH$ extract according to the universal method (OSTROWSKA et al. 1991). The results of determinations of the physical and chemical properties carried out in 2005-2007 are presented in Tables 1, 2 (before cabbage planting) and 3, 4 (after harvest).

The results were subjected to a two-factor analysis of variance. The means were separated by Fisher LSD test ($p$=0.05). Statistical calculations were performed with the Statistica 7.0 software application.

Table 2

Soil exchangeable complex characteristics in 2005-2007

| Year | Soil layer (cm) | Cation (cmol kg$^{-1}$) | | | | | CEC (cmol kg$^{-1}$) |
|------|------|------|------|------|------|------|------|
| | | Ca$^{2+}$ | Mg$^{2+}$ | K$^+$ | Na$^+$ | H$^+$ | |
| 2005 | 0-30 | 11.00 | 0.17 | 0.67 | 0.00 | 0.52 | 12.38 |
| | 30-60 | 12.94 | 0.24 | 0.20 | 0.00 | 0.60 | 13.98 |
| | 60-90 | 16.44 | 0.20 | 0.14 | 0.00 | 0.49 | 17.27 |
| 2006 | 0-30 | 6.84 | 0.38 | 0.43 | 0.07 | 0.80 | 8.52 |
| | 30-60 | 4.80 | 0.19 | 0.16 | 0.09 | 0.63 | 5.86 |
| | 60-90 | 4.87 | 0.20 | 0.15 | 0.08 | 0.56 | 5.86 |
| 2007 | 0-30 | 9.73 | 0.33 | 0.43 | 0.04 | 0.87 | 11.36 |
| | 30-60 | 8.77 | 0.25 | 0.19 | 0.04 | 0.84 | 10.09 |
| | 60-90 | 6.75 | 0.24 | 0.26 | 0.04 | 0.84 | 8.23 |

# RESULT AND DISCUSSION

The content of nutrients in cabbage leaves changed in the years. On average, the highest K and Mg content was noted in 2006 and the lowest P, K, Mg and Ca in 2007, with the results obtained in 2005 being intermediate.

The sulfur leaf content was the highest in 2007 and the lowest in 2006. Fluctuations in the environmental factors such as the temperature and soil moisture can affect the mineral composition of leaves considerably. In our study, the rainfalls were 326 and 419 mm in 2005 and 2007, respectively (data not shown), but in 2005 they were distributed regularly. In 2007, a relatively low temperature and high rainfalls were observed in September (134 mm). The growing season of 2006 was the warmest and the driest (253 mm of rainfall). In that year, extremely dry weather appeared in July (8 mm) and October (4 mm of precipitation).

In the present experiment, the concentrations of P, K, and Mg in edible parts of cabbage were below the sufficient range of content reported for cabbage by BARKER and PILBEAM (2006).

### Phosphorus

Most soils readily buffer P-additions and P hardly ever appears at high levels in the soil solution. Soil concentrations of P, K, Mg and Ca are generally interpreted using the sufficiency level of available nutrients (SLAN).

Table 3

Phosphorus and potassium content (mg $dm^{-3}$ of soil) in the 0-30 cm soil layer after cabbage harvest

| Fertilizer | Method of N application | | P | | | | K | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2005 | 2006 | 2007 | mean | 2005 | 2006 | 2007 | mean |
| Mean for years | | | 63.0 | 61.6 | 103.3 | | 86.6 | 84.5 | 55.3 | |
| Fertilizer | $(NH_4)_2SO_4$ | | 61.0 | 65.0 | 108.7 | 78.2 | 103.2 | 76.4 | 49.6 | 76.4 |
| | UAN | | 64.9 | 58.2 | 97.9 | 73.7 | 70.0 | 92.6 | 60.9 | 74.5 |
| Metod of N application | broadcast | 1* | 60.4 | 59.9 | 104.3 | 74.9 | 66.3 | 31.3 | 43.9 | 47.2 |
| | | 2 | 60.4 | 56.1 | 113.1 | 76.5 | 51.7 | 68.0 | 50.8 | 56.8 |
| | | 3 | 64.4 | 65.2 | 97.6 | 75.7 | 88.6 | 86.3 | 61.7 | 78.9 |
| | placement | 4 | 66.0 | 61.4 | 95.9 | 74.4 | 133.3 | 106.6 | 47.9 | 95.9 |
| | | 5 | 60.3 | 61.2 | 102.2 | 74.6 | 84.2 | 116.0 | 53.5 | 84.6 |
| | | 6 | 66.3 | 65.8 | 106.8 | 79.6 | 95.6 | 98.5 | 73.8 | 89.3 |
| LSD$_{0.05}$ for: | fertilizer | | n.i. | 6,17 | n.i. | | n.i. | n.i. | n.i. | |
| | method | | n.i. | n.i. | n.i. | | n.i. | n.i. | n.i. | |
| | fertilizer × method | | n.i. | n.i. | n.i. | | n.i. | n.i. | n.i. | |

* 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 growth, 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.

Table 4

Magnesium and calcium content (mg dm$^{-3}$ of soil) in the 0-30 cm soil layer
after cabbage harvest

| Fertilizer | Method of N application | | Mg | | | | Ca | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2005 | 2006 | 2007 | mean | 2005 | 2006 | 2007 | mean |
| Mean for years | | | 54.7 | 54.4 | 69.8 | | 1587 | 1361 | 2972 | |
| Fertilizer | $(NH_4)_2SO_4$ | | 56.4 | 52.7 | 73.1 | 60.7 | 1712 | 1405 | 3087 | 2068 |
| | UAN | | 52.9 | 56.2 | 66.5 | 58.5 | 1462 | 1318 | 2856 | 1879 |
| Metod of N application | broadcast | 1* | 50.9 | 51.7 | 73.1 | 58.6 | 1414 | 1350 | 3527 | 2097 |
| | | 2 | 63.1 | 56.5 | 72.2 | 63.9 | 1569 | 1454 | 3105 | 2043 |
| | | 3 | 57.3 | 53.3 | 71.6 | 60.7 | 1576 | 1411 | 2803 | 1930 |
| | placement | 4 | 55.6 | 58.8 | 73.2 | 62.5 | 2087 | 1320 | 2881 | 2096 |
| | | 5 | 48.1 | 50.6 | 63.3 | 54.0 | 1310 | 1299 | 2857 | 1822 |
| | | 6 | 53.1 | 55.6 | 65.7 | 58.1 | 1563 | 1335 | 2656 | 1851 |
| LSD$_{0.05}$ for: | fertilizer | | ns | ns | ns | | 233.0 | ns | ns | |
| | method | | ns | ns | ns | | 403.5 | ns | ns | |
| | fertilizer × method | | ns | ns | ns | | 570.7 | ns | ns | |

* see Table 3

According to the sufficiency level concept, there are definable levels of nutrient in soil below which crops will respond to added fertilizers and above which they will probably not respond (KOPITTKE, MENZIES 2007). The optimal P-concentration in soil determined by the universal method (OSTROWSKA et al. 1991) for cabbage plants is 50-70 mg P dm$^{-3}$ of soil. In the present study, the concentrations of available phosphorus found in the soil before planting were within or above this range (Tables 1 and 3). However, the content of phosphorus in cabbage (Table 5) was low and tended to be below the sufficient range (0.38%) reported by BARKER and PILBEAM (2006). The soil test recommendation for P should be customized by a crop. However, at present, soil-test-based recommendations are generally not sufficiently sensitive to allow recommendations to accommodate the more subtle genetic variation among cultivars within crop species.

The lowest P concentrations in plants were noted in the wet year 2007 (0.25% d.m.), in comparison to 2005-2006 (0.30% d.m.). P availability is affected by soil water condition. It is generally understood that excessive water causing poor aeration would actually restrict the P uptake by crops. Usually, soil water affects soil reaction, governing the release and diffusion of P in the soil solution and ultimately the positional availability of P relative to roots (MENGEL et al. 2001). In our research, the highest yield was obtained in 2007 (88.4 t ha$^{-1}$) compared to 2005 r (83.8 t ha$^{-1}$) and 2006

Table 5

Phosphorus and potassium content (% d.m.) in cabbage after harvest in 2005-2007

| Fertilizer | Method of N application | | P (%) | | | | K (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2005 | 2006 | 2007 | mean | 2005 | 2006 | 2007 | mean |
| $(NH_4)_2SO_4$ | broadcast | 1* | 0.26 | 0.31 | 0.26 | 0.28 | 2.57 | 2.70 | 2.26 | 2.51 |
| | | 2 | 0.29 | 0.27 | 0.26 | 0.28 | 2.36 | 2.68 | 2.20 | 2.41 |
| | | 3 | 0.26 | 0.26 | 0.27 | 0.26 | 2.26 | 2.81 | 2.38 | 2.48 |
| | placement | 4 | 0.27 | 0.22 | 0.27 | 0.26 | 2.36 | 2.60 | 2.03 | 2.33 |
| | | 5 | 0.30 | 0.30 | 0.26 | 0.29 | 2.21 | 2.72 | 2.09 | 2.34 |
| | | 6 | 0.29 | 0.31 | 0.26 | 0.29 | 2.34 | 2.76 | 2.10 | 2.40 |
| UAN | broadcast | 1 | 0.32 | 0.34 | 0.24 | 0.30 | 2.37 | 2.71 | 2.21 | 2.32 |
| | | 2 | 0.31 | 0.34 | 0.20 | 0.29 | 2.23 | 2.38 | 2.29 | 2.39 |
| | | 3 | 0.29 | 0.30 | 0.23 | 0.27 | 2.30 | 2.66 | 2.15 | 2.36 |
| | placement | 4 | 0.32 | 0.33 | 0.25 | 0.30 | 2.18 | 2.64 | 2.27 | 2.40 |
| | | 5 | 0.30 | 0.34 | 0.24 | 0.29 | 1.99 | 2.75 | 2.23 | 2.36 |
| | | 6 | 0.32 | 0.32 | 0.25 | 0.29 | 2.25 | 2.84 | 2.07 | 2.36 |
| Mean for years | | | 0.30 | 0.30 | 0.25 | | 2.28 | 2.69 | 2.19 | |
| Fertilizer | $(NH_4)_2SO_4$ | | 0.29 | 0.28 | 0.27 | 0.27 | 2.35 | 2.71 | 2.18 | 2.41 |
| | UAN | | 0.30 | 0.33 | 0.23 | 0.29 | 2.22 | 2.67 | 2.20 | 2.37 |
| Metod of N application | broadcast | 1 | 0.29 | 0.32 | 0.25 | 0.29 | 2.47 | 2.54 | 2.23 | 2.41 |
| | | 2 | 0.30 | 0.31 | 0.23 | 0.28 | 2.29 | 2.67 | 2.25 | 2.40 |
| | | 3 | 0.28 | 0.28 | 0.25 | 0.27 | 2.28 | 2.72 | 2.27 | 2.42 |
| | placement | 4 | 0.30 | 0.28 | 0.26 | 0.28 | 2.27 | 2.68 | 2.15 | 2.37 |
| | | 5 | 0.30 | 0.32 | 0.25 | 0.29 | 2.1 | 2.78 | 2.16 | 2.35 |
| | | 6 | 0.30 | 0.31 | 0.26 | 0.29 | 2.29 | 2.77 | 2.08 | 2.38 |
| $LSD_{0.05}$ for: | fertilizer | | 0.017 | 0.041 | ns | | ns | ns | ns | |
| | method | | ns | ns | ns | | ns | ns | ns | |
| | fertilizer × method | | ns | ns | ns | | ns | ns | ns | |

* see Table 3

(64.3 t ha$^{-1}$) (data not shown), which may be attributed to the effect of phosphorus 'dilution' in plant biomass (a decrease in its content in the dry matter). Under favorable soil moisture, the enhanced plant growth after nitrogen application caused 'dilution' of phosphorus without any competition occurring in its uptake.

In our investigations, the form of nitrogen fertilizers affected P concentrations in cabbage leaves in 2005-2006. Slightly higher amounts of phosphorus were detected in cabbage fed UAN than ammonium sulfate. These results are difficult to interpret conclusively. The form in which nitrogen is taken up by plants will induce the change of rhizospheric pH value. The uptake of $NH_4^+$ results in a decrease of the pH value. Contrary, the uptake of $NO_3^-$ will cause an increase of the rhizospheric pH value (MARCHNER 1995). A change in the rhizospheric pH value will affect nutrient availability and thus influence the nutrient uptake and utilization by plants (TYLER and OLSSON 2001). In alkaline or neutral soils, acidification of rhizosphere by $(NH_4)_2SO_4$ should increase P-availability and amount of phosphorus taken up by plants. However, the reverse was observed.

### Potassium, magnesium and calcium

The major soil cations are present partly in the structure of primary and secondary minerals, partly in an exchangeable form on cation exchange sites and partly as soluble ions in the soil solutions. Assessment of the plant-available fraction of any of three types of cations is often based on measurement of the exchangeable fraction (KOPITTKE, MENZIES 2007). Among the exchangeable cations, $Ca^{2+}$ is usually dominant, often amounting to between 60-85% of the total in non-acid soil. In soils in humid regions, Mg normally makes up 5-30% of the total exchangeable cations and K between 2-6% (MENGEL et al. 2001). In our study, 80% (2006) to 89% (2005) of the total exchangeable cations in top soils consisted of $Ca^{2+}$ (Table 2). Magnesium accounted for 1.4% in 2005 to 4.5% in 2006 and potassium reached from 5% in 2006 to 5.4% in 2005. According to BEAR et al. (1945), the soil cation exchange complex is satisfactory for plant growth when comprising 65% Ca, 10% Mg, 5% K and 20% H.

Each of these cations is absorbed by roots as free ions, and the relative amounts taken up are influenced by the absolute and relative concentrations of the ions in the soil solution. Potassium, magnesium and calcium appear to compete with each other in the uptake by plants (EVANGELOU et al. 1994). Nitrogen fertilizer has inconsistent effects on plant concentrations of K and Ca, but generally increases concentrations of Mg and Na (BARKER, PILBEAM 2006). When a supply of cations, especially K, is limited, any increase in the plant growth caused by N fertilizer tends to reduce their concentrations in plant tissues. However, when supplies of cations are plentiful and N is taken up mainly as nitrate, plant concentrations may increase owing to the synergistic effect between nitrate and cation uptake (WHITEHEAD 2000). In our study, N fertilizer had little or no effect on K, Ca and Mg plant concentrations (Tables 5 and 6). The tendency of ammonium N to depress plant K after the application of ammonium sulfate applied was not identified.

Table 6

Magnesium and calcium content (% d.m.) in cabbage after harvest in 2005-2007

| Fertilizer | Method of N application | | Mg (% d.m.) | | | | Ca (% d.m.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2005 | 2006 | 2007 | mean | 2005 | 2006 | 2007 | mean |
| $(NH_4)_2SO_4$ | broadcast | 1* | 0.13 | 0.14 | 0.11 | 0.13 | 0.60 | 0.67 | 0.50 | 0.59 |
| | | 2 | 0.13 | 0.14 | 0.11 | 0.13 | 0.56 | 0.62 | 0.51 | 0.56 |
| | | 3 | 0.14 | 0.14 | 0.12 | 0.14 | 0.60 | 0.58 | 0.55 | 0.57 |
| | placement | 4 | 0.13 | 0.15 | 0.12 | 0.13 | 0.61 | 0.61 | 0.54 | 0.59 |
| | | 5 | 0.13 | 0.15 | 0.11 | 0.13 | 0.56 | 0.56 | 0.47 | 0.53 |
| | | 6 | 0.13 | 0.14 | 0.12 | 0.13 | 0.59 | 0.53 | 0.52 | 0.54 |
| UAN | broadcast | 1 | 0.13 | 0.12 | 0.11 | 0.12 | 0.53 | 0.39 | 0.51 | 0.48 |
| | | 2 | 0.13 | 0.14 | 0.11 | 0.13 | 0.51 | 0.48 | 0.51 | 0.50 |
| | | 3 | 0.13 | 0.14 | 0.11 | 0.13 | 0.56 | 0.52 | 0.51 | 0.52 |
| | placement | 4 | 0.12 | 0.15 | 0.12 | 0.13 | 0.53 | 0.49 | 0.50 | 0.51 |
| | | 5 | 0.12 | 0.15 | 0.11 | 0.13 | 0.52 | 0.51 | 0.44 | 0.49 |
| | | 6 | 0.13 | 0.14 | 0.11 | 0.12 | 0.51 | 0.45 | 0.46 | 0.48 |
| Mean for years | | | 0.13 | 0.14 | 0.11 | | 0.56 | 0.53 | 0.50 | |
| Fertilizer | $(NH_4)_2SO_4$ | | 0.13 | 0.14 | 0.11 | 0.13 | 0.59 | 0.59 | 0.51 | 0.56 |
| | UAN | | 0.13 | 0.14 | 0.11 | 0.13 | 0.53 | 0.47 | 0.49 | 0.50 |
| Metod of N application | broadcast | 1 | 0.13 | 0.13 | 0.11 | 0.12 | 0.57 | 0.53 | 0.51 | 0.54 |
| | | 2 | 0.13 | 0.14 | 0.11 | 0.13 | 0.53 | 0.55 | 0.51 | 0.53 |
| | | 3 | 0.13 | 0.14 | 0.12 | 0.13 | 0.58 | 0.54 | 0.52 | 0.55 |
| | placement | 4 | 0.13 | 0.15 | 0.12 | 0.13 | 0.57 | 0.55 | 0.52 | 0.55 |
| | | 5 | 0.13 | 0.15 | 0.11 | 0.13 | 0.54 | 0.54 | 0.45 | 0.51 |
| | | 6 | 0.13 | 0.14 | 0.11 | 0.13 | 0.55 | 0.49 | 0.49 | 0.51 |
| $LSD_{0.05}$ for: | fertilizer | | ns | ns | ns | | 0.055 | 0.048 | ns | |
| | method | | ns | ns | ns | | ns | ns | ns | |
| | fertilizer × method | | ns | ns | ns | | ns | ns | ns | |

* see Table 3

Potassium uptake during plant growth is a dynamic process, causing K depletion in the root zone through removal of exchangeable K. Our understanding of the nature and rate of release of soil K from different pools of adsorbed and structural K is important in terms of soil fertility (SHARPLEY 1990).

The optimal K-concentration availability determined by the universal method for cabbage ranges between 175-225 mg K dm$^{-3}$ of soil. In this study, the concentrations of available K in the top soil before planting were in this

range only in 2005 (Table 2). In 2006-2007, the soil K content was supplemented using KCl to the level of 200 mg dm$^{-3}$ before cabbage planting. The potassium amount determined in soil at harvest varied from 55.3 to 86.6 mg K dm$^{-3}$ (Table 3). This indicates that both the top soils and subsoil from the cropping sites were highly K-deficient in 2006-2007 and will eventually become depleted unless K fertilizers are provided.

Water soluble K$^+$ depends on the clay concentration in soil and on the type of clay minerals. Some soil minerals may act as a sink for removing K from solution. When K is absorbed in the interlayer sites of illite, vermiculite and other smectit clays, the clay layers collapse and trap the K within the mineral lattice. This fixation process is relatively fast, while the release of this interlayer K is very slow (BOUABID et al. 1991, EVANGELOU et al. 1994, BOLAN et al. 1999). Fixed K$^+$ is higher in high- than in low-pH soil (GOULDING 1983). The most common test for plant available K is the exchangeable K$^+$ with ammonium acetate as an extractant. This fraction contains mainly soil solution K$^+$ plus potassium of the hydrated K$^+$ fractions and only a small part of the interlayer K. For K$^+$ exchange in particular, 5-10% K$^+$ saturation of the total exchangeable cations is most important to crops because the K$^+$ saturation of soil seldom exceeds 10%, even after many years of treatment with K fertilizers (GOULDING 1983). In our research, the soil was characterized by about 5% K$^+$ saturation in the 0-30 cm topsoil layers.

The present results demonstrated that the potassium content in cabbage plants (Table 5) was below the sufficient range (3-4%) reported for *Brassica* species by BARKER and PILBEAM (2006). The highest content of K in plant tissues was detected in the dry 2006, and the lowest – in the wet 2007. Monovalent cations are leached more readily than divalent ones, but when Ca$^{2+}$ is the dominant cation in the soil, it may be leached in the highest amount (WHITEHEAD 2000). Another possible reason, analogously to phosphorus, is the effect of K 'dilution' in plant biomass.

In our research, the examined factors did not influence the K concentration in cabbage. However, plants fed ammonium sulfate with the broadcast technique had a slightly higher level of potassium than fed UAN and with the placement method (Table 5). This is in contrast to the well-known phenomena of competition between NH$_4$$^+$ and K$^+$. Possible explanations for this is that ammonium ions have a relatively small unhydrated radius and low negative hydrogen energy, and they can displace the K$^+$ from interlayer clay sites (GOULDING 1983). However, the chances of NH$_4$$^+$ competing with K$^+$ for plant uptake are more likely to occur in cool rather than warm soils because most ammonium in warmer soils is converted into nitrate by nitrification process.

Plant magnesium is most likely to be low in soils that are either sandy or acid or that have high contents of Ca or K. Calcareous or freshly limed soils often induce low plant concentrations of Mg. Calcium is strongly competitive with Mg$^{2+}$ and the binding sites on the root plasma membrane appear to have less affinity for the highly hydrated Mg$^{2+}$ than for Ca$^{2+}$

(MARCHNER 1995). Thus, high concentrations of substrate $Ca^{2+}$ often result in increased leaf-Ca along with a marked reduction in leaf-Mg. It is well know that in some plants $Mg^{2+}$ uptake is highly controlled by $K^+$ levels, but the reverse is not always true (STOUT, BAKER 1981).

The optimal Mg concentrations in *Brassica* species range between 0.17--1.08% in dry matter (BARKER, PILBEAM 2006). In the present research, the amount of Mg in cabbage was low and ranged between 0.11 (2007) to 0.14 (2006) – Table 6. The highest Mg content in cabbage was determined in 2006. The soil in that year was characterized the highest $Mg^{2+}$ saturation in total exchangeable cations (4.5% Mg) in the 0-30 cm topsoil and high saturation in the 30-90 cm subsoil layer (3.2-3.4%) (Table 2). In 2006, the soil pH values and concentration of calcium extracted by the universal method were relatively low compared to 2005-2007 (Tables 1, 4).

Nitrogen may either inhibit or promote Mg accumulation in plants, depending on the form of N. With ammonium, the Mg uptake is suppressed but with nitrate it is increased (BARKER, PILBEAM 2006). In the present study, none of the examined factors influenced the Mg content in cabbage plants.

The concentration of calcium in cabbage plants tended to increase with increasing soil pH and with an increasing proportion of $Ca^{2+}$ in the total exchangeable cations of the soil (Tables 1, 6). Soil liming generally increases plant Ca. Our research was carried out in an area specialized in cabbage production, with lime used as a control measure for club root. Every year, the amount of Ca in cabbage plants was with the sufficient range 0.1-5% d.m reported by Barker and Pilbeam (2006) for *Brassica* species. The highest concentration of Ca in cabbage was detected in 2005 (0.56%), and the lowest – in 2007 (0.50%).

Nitrogen fertilizer has an inconsistent effect on the plant Ca, partly due to the fact that some N fertilizers contain Ca and partly because of the form in which the N is taken up. Fertilizers that do not contain Ca often depress the plant Ca although, in some cases, the effect is very weak. When N fertilizer is supplied in the form of ammonium or urea, the plant Ca is lower than when N is supplied as nitrate. In this study, lower concentrations of Ca in cabbage fed UAN (solution ammonium nitrate and urea 1:1) than ammonium sulfate were noticed in 2005-2006 (Table 6). However, these differences were relatively small. K-Ca exchange behavior in soils would be influenced by addition of $NH_4^+$. Thus, the relative chemical potential of adsorbed monovalent cations would depend on the number and type of cations present in the soil system (LUMBANRAJA, EVANGELOU 1990).

Optimum leaf Ca/Mg ratios are considered to be approximately 2 : 1, although a Ca/Mg ratio >1 : 1 and < 5 : 1 can produce adequate growth without any expression of Mg deficiency (BARKER, PILBEAM 2006). In our experiment, the Ca/Mg ratios were 4 : 1, 3.8 : 1 and 4.5 : 1 in 2005-2007 respectively.

**Sulfur**

Most *Brassicaceae* plants have greater S requirements than other large crop species. Sulfur availability has been decreasing in many areas of Europe during the last two decades (McGRATH et al. 2002, ZHAO et al. 1997).

Interactions between S and other minerals may significantly influence crop quality parameters. Sulfur and nitrogen show strong interactions in their nutritional effects on crop growth and quality (JACKSON 2000). Under of S deficiency, the utilization of N will be reduced and consequently nonprotein N compounds, including $NO_3^-$, accumulate in the part tissue (KOPRIVA, RENNENBERG 2004, ABDALLAH et al. 2010).

Our research indicated that the environmental conditions, fertilizer type, method of N application and interaction of these factors significantly affected the sulfate content in cabbage plants. The highest amount of S in the wet 2007 was noticed and the lowest one – in 2005 (Table 7). Every year, higher S concentrations in plants fed ammonium sulfate were detected. In 2005-2006, the cabbage fertilized with the broadcast technique had a slightly higher amount of S than with the placement treatment. In 2005, plants fed ammonium sulfate with the broadcast treatment had a higher S concentration than with the placement treatment. HU et al. (2005) tested the bioavailability of water-insoluble sulfate, a sulfate-$CaCO_3$ co-precipitate labelled with $^{35}S$ added to calcareous soil in a pot experiment with either $NH_4^+$ or $NO_3^-$ as the N source. In 29 days, wheat plants took up 10.6% and 3.0% of the $^{35}S$ added to the soil in the $NH_4^+$ and $NO_3^-$ treatments, respectively. The results indicate that sulfate co-precipitated with $CaCO_3$ in calcareous soils may become partly available for plant uptake, depending on the rhizosphere's pH influenced by $N-NH_4$ treatment.

The soil sulfur cycle is driven by biological and physicochemical processes, which affect flora and fauna (McGILL, COLE 1981). Seasonal variations in mineralization leaching, capillary rise and plant uptake cause temporal variations in the sulfate content in soil. Especially under humid growth conditions, plant-available soil water is the largest contributor to the S balance (MENGEL et al. 2001). In the present study, high amounts of sulfates in cabbage plants in the wet 2007 were associated with a high level of nitrates (data not published). A possible explanation includes increasing microbial activity in soil in autumn. In Europe, organic matter mineralization in autumn is relatively high (WIESLER 1998). The flux of inorganic nitrogen and sulfur to soil at harvest might be regulated by the wetting up, breakdown and release of soil organic matter.

Table 7

Sulfur content (% S-SO$_4$ d.m.) in cabbage after harvest in 2005-2007

| Fertilizer | Method of N application | | S-SO$_4$ (% d.m.) | | | |
|---|---|---|---|---|---|---|
| | | | 2005 | 2006 | 2007 | mean |
| (NH$_4$)$_2$SO$_4$ | broadcast | 1* | 0.24 | 0.35 | 0.46 | 0.35 |
| | | 2 | 0.23 | 0.28 | 0.47 | 0.32 |
| | | 3 | 0.23 | 0.30 | 0.45 | 0.33 |
| | placement | 4 | 0.16 | 0.28 | 0.48 | 0.31 |
| | | 5 | 0.21 | 0.24 | 0.47 | 0.31 |
| | | 6 | 0.25 | 0.24 | 0.41 | 0.30 |
| UAN | broadcast | 1 | 0.15 | 0.17 | 0.41 | 0.24 |
| | | 2 | 0.17 | 0.18 | 0.44 | 0.26 |
| | | 3 | 0.11 | 0.12 | 0.40 | 0.21 |
| | placement | 4 | 0.20 | 0.16 | 0.40 | 0.25 |
| | | 5 | 0.20 | 0.12 | 0.40 | 0.24 |
| | | 6 | 0.25 | 0.13 | 0.37 | 0.25 |
| Mean for years | | | 0,20 | 0,21 | 0.43 | |
| Fertilizer | (NH$_4$)$_2$SO$_4$ | | 0,22 | 0.28 | 0.46 | 0.32 |
| | UAN | | 0,18 | 0.15 | 0.40 | 0.24 |
| Metod of N application | broadcast | 1 | 0.19 | 0.26 | 0.43 | 0.30 |
| | | 2 | 0.20 | 0.23 | 0.46 | 0.29 |
| | | 3 | 0.17 | 0.21 | 0.43 | 0.27 |
| | placement | 4 | 0.18 | 0.22 | 0.44 | 0.28 |
| | | 5 | 0.20 | 0.18 | 0.43 | 0.27 |
| | | 6 | 0.25 | 0.18 | 0.39 | 0.27 |
| LSD$_{0.05}$ for: | fertilizer | | 0.022 | 0.026 | 0.033 | |
| | method | | 0.038 | 0.045 | ns | |
| | fertilizer × method | | 0.054 | ns | ns | |

* see Table 3

# CONCLUSIONS

Efficient nutrient management is essential in modern crop production systems by providing a balance between nutrient inputs and outputs over the long term (BINDRABAN et al. 2000, BASSANINO et al. 2010). The present

research has clearly showed that plant tissue tests versus specific standard concentrations that separate deficient, sufficient or toxic levels are an important diagnostic method of the plant nutrient status. Our better understanding of N interactions with other nutrients may be useful in comprehending the importance of balanced supplies of nutrients, and consequently, in obtaining improved plant growth or yields.

At present, nutrient interactions and environmental yield potential as a driving force for establishing optimal nutrient requirements are not taken advantage of in practice. Although experimental research supplies valuable information for a given site, the results can only partly be extrapolated to estimate nutrient requirements on a micro-scale in farmers' fields. It is so because of a much broader range of soil, weather, and agronomic conditions at a farm level.

The observations made in this study appear to confirm than single levels in fertilizer recommendations should be based on standard conditions that take into account the major factors governing crop response to a given nutrient. Quantitative approaches that simultaneously account for yield potential and interactions between N, P and K in estimating the crop requirement for each of the elements are likely to be more precise, particularly at high yield levels.

Sulfur availability has been decreasing in many areas of Europe. S-containing fertilizers such as ammonium sulfate or superphosphate have been replaced by fertilizers containing little or no S. Moreover, sulfur requirements of many crops, especially *Brassicaceae* plants, have increased as a result of intensive agriculture and optimization during plant breeding programmes. The present research results have demonstrated a positive effect of S applied as ammonium sulfate on the concentration of sulfur in cabbage plants.

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