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EFFECT OF NITROGEN FERTILIZATION ON YIELD, NH_4^+ AND NO_3^- CONTENT OF WHITE CABBAGE

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Abstract. The results of three year investigations with 'Galaxy' F_1 cabbage grown under field conditions are presented. The effect of the rate of ammonium sulphate and RSM (solution of ammonium nitrate + urea), the method of application (placement and broadcast technique) and foliar fertilization (urea and Supervit K) on the yield and nitrate accumulation was studied. The form of N fertilizer significantly increased the cabbage yield only in 2007. In this year the better nitrogen source was ammonium sulphate in comparison with RSM. In the other years no differences between the kind of N fertilizer were observed. The method of application did not affect cabbage yield any year. However, slightly better cropping was noted for following treatments 75% N broadcasted at planting + 25% N during growth season, 75% N broadcasted at planting + foliar fertilization, and after placement fertilization with reduced rate (75% N) as compared to control (100% N broadcasted at planting), in every year of the experiment. In 2006 and 2007 fertilization at the rate of 75% N and supplemented with addition 25% N during the growth or foliar sprays significantly increased nitrate content in cabbage as compared to control treatment.

Key words: white cabbage, foliar, placement fertilization, nitrate and ammonium content

INTRODUCTION

Modern agriculture production requires efficient, sustainable, and environmentally sound management practices. The adequate rates, appropriate sources, efficient methods of application, and application timing are important strategies [Fageria and Baligar 2005]. Nitrogen sources and methods of application significantly influence N uptake efficiency in crop plants. In a system of field vegetable production nitrate based fertiliz-

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ers often include excessive nitrate content in the edible part of vegetables, in the soil, leachate and drinking water [Nielsen and Jensen 1990, Lægreid et al. 1999, Neeteson and Carton 2001, Rahn 2002]. Sommer [1991] developed the CULTAN fertilization system. This is based on ammonium fertilizers applied at planting and provides a continuous source of nitrogen for the entire growth period of the crops. According to Sommer [1994] CULTAN improved product quality by reducing nitrate content of vegetables. As studied Sommer [1997] the better N use efficiency and continuous N uptake for this system allows to reduce the rate of applied N by 20% in years with beneficial weather condition.

Foliar application is commonly recommended for of remedying the visual deficiency of nutrients in vegetable crops. It is also recognized that supplementary fertilization during crop growth can improve the mineral status of plants, increase the crop yield [Czuba 1996, Rożek 2000, Rożek et al. 2000, Mareczek et al. 2000]. As an supplementary foliar fertilization it can reduce soil rate of fertilizers and may appear attractive as a more environmentally friendly practice [Kołota and Osińska 2001, Rydz 2001].

The objective of the present project was to study the effect of ammonium sulphate and RSM (solution of the ammonium nitrate + urea) applied in full or reduced rate by placement and broadcast technique and additionally foliar fertilization (urea and Supervit K) on the yield and ammonium and nitrate accumulation in 'Galaxy' F_1 cabbage grown under field conditions.

MATERIAL AND METHODS

The three year field experiment was carried out with white 'Galaxy' F_1 cabbage on a loamy soil containing 0,91–1.02% organic carbon and soil acidity pH_{KCl} 6.17–7.10 (tab. 1). The plots were located at a private farm at Zagorzyce in Poland (50°23' and 20°04'). Mineral fertilization was based on the results of chemical analysis of the soil samples. The content of soil nutrients: P, K and Mg was supplemented to level of 50, 200 and 60 mg dm^{-3}, respectively.

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 were as follows:

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

Treatments were assigned following the randomized complete block in split-plot arrangement with four replication. Nitrogen fertilizer was applied at the rate of 120 kg N ha^{-1} (100% N). With the placement fertilization method fertilizer was applied on the rows in 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 conducted at growing season in two weeks interval.

The foliar nutrition with 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). For foliar urea application the total amount of N reached 27.6 kg N ha^{-1}, whereas for Supervit – 0.6 kg N ha^{-1}.

Table 1. Organic carbon content (%), soil pH and soil texture before cabbage planting in 2005–2007
Tabela 1. Zawartość węgla organicznego (%), pH i rodzaju gleby przed sadzeniem kapusty w latach 2005–2007

Year Rok	Soil layer Warstwa gleby (cm)	% C	Sand Piasek 0–0.1 mm	Silt Pył 0.1–0.02 mm	Clay Glina <0.02 mm	pH_{KCl}	pH_{H2O}
2005	0–30	0.91	15	47	38	7.70	8.21
2006	0–30	1.02	8	50	41	6.17	7.18
2007	0–30	0.98	9	55	36	7.09	7.90

The harvest was conducted in the last decade of October. To estimate the marketable yield, fresh weight head cabbage, and soil samples were collected from the layer 0–30, 30–60 and 60–90 cm. Nitrate and ammonium level was determined using an ionselective electrode, in cooperation with a Unicam-9460 ionometr. Granulometric analysis was made by the aerometric method of Prószyński, the organic carbon by Tiurin's method was determined. N (N-NH_4 and N-NO_3), P, K and Mg was measured in 0.03 M CH_3COOH extract according universal method [Ostrowska et al. 1991]. A bulk density of 1.5 kg per dm^{-3} was used for the conversion of mineral nitrogen in mg per kg soil to kg per ha.

Results were subjected to two or three factors of variance. Means were separated by the Fisher LSD test ($p = 0.05$). Statistical analysis was done with the Statistica 7.0 program.

RESULTS AND DISCUSSION

Plant analysis. Environmental factors significantly influenced the cabbage yield and its quality. The heighest yield was obtained in 2007 (88.4 t ha^{-1}), slightly less in 2005 (83.8 t), and lowest in 2006 (64.3 t). The efficiency and utilization of N by crops was limited by the water availability. In 2005 and 2007 rainfalls were 327 and 420 mm (data no published), respectively, but distributed regularly only in 2005 (fig. 1). In 2007 low temperature and high rainfalls were observed in September (134 mm). Growing season of 2006 was the warmest and the driest (253 mm). This year extremely dry month were recorded July with 7.9 mm and October with 4.5 mm of precipitation.

The form of N fertilizer used significantly increased the cabbage yield only in 2007. This year the better nitrogen source was ammonium sulphate (92,7 t ha^{-1}) as compared to RSM (84.1 t). Other years no differences between the kind of N fertilizer (tab. 2) were noted. The NH_4^+ and NO_3^- forms appear to be equally effective for plants, but the relative advantage of both forms of nitrogen on plant growth also strongly depends on the external conditions [Marchner 1995, Neeteson and Carton 2001]. Ammonium is less mobile in the soil than nitrate and offers the possibility to cover the nitrogen demand in one application. On the other hand ammonia volatilization may contribute to poor N use efficiency. Emission of NH_3 from NH_4^+ fertilizers is decreased by rainfall events following application, but the reverse effect is observed with increasing soil temperature [Fageria and Baligar 2005]. The highest yields for ammonium sulphate treated in 2007 may have been associated with better N use efficiency in intensive growth period of head cabbage (September, October). It could be a result of reduced N losses from volatilization in wet months with low temperature.

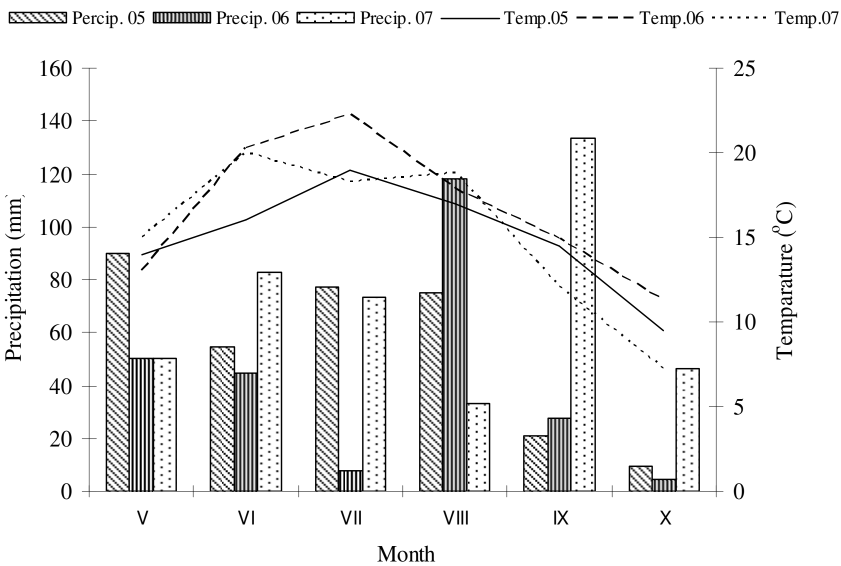

Fig. 1. Mean temperature and precipitation for 2005–2007
Rys. 1. Wartości średnie temperatur i opadów w latach 2005–2007

The method of application did not significantly have an effect on the cabbage yield in any year. Nevertheless, slightly better cropping for placement fertilization with reduced rate (75% N) applied at planting was observed in comparison to control (100% N broadcasted at planting). Sommer [1991] indicated that even the lowest fertilizer levels of placement method would be so effective as inefficient broadcast method. Murakami et al. [2006] reported that stripe (fertilizers were incorporated under the seedling placement lines) is more effective for improving growth at low fertility. In Western Europe current recommended rate of N fertilizer for white cabbage are 200–300 kg N ha^{-1} [Neeteson et al. 1999]. The optimum rate of N fertilizer is defined as the minimum amount needed to achieve the required response. In our research only 120 kg N ha^{-1} (100% N) was applied.

Table 2. Effect of nitrogen fertilization on 'Galaxy' F_1 cabbage marketable yield (t ha^{-1}) in 2005–2007

Tabela 2. Wpływ nawożenia azotowego na plon handlowy (t ha^{-1}) kapusty 'Galaxy' F_1 uprawianej w latach 2005–2007

Factor Czynnik	Factor level Poziom czynnika	Yield – Plon			Mean Średnio
		2005	2006	2007	
	Mean of Year – Średnia roczna	83.8	64.3	88.4	
Fertilizer Nawóz	Ammonium sulphate – Siarczan amonu	82.5	63.9	92.7	79.7
	RSM – Roztwór saletrzano-mocznikowy	85.1	64.6	84.1	77.9
Application method Metoda aplikacji	1. 100% N broadcast 1. 100% N rzutowo	74.0	60.8	87.8	74.2
	2. 75% N broadcast + 25% N 2. 75% N rzutowo + 25% N	83.9	68.0	94.4	82.1
	3. 75% N broadcast + foliar spray 3. 75% N rzutowo + pozakorzeniowo	88.5	68.6	89.4	82.2
	4. 75% N placement 4. 75% N miejscowo	82.5	64.2	91.4	79.4
	5. 75% N placement + 25% N 5. 75% N miejscowo + 25% N	86.5	58.4	83.6	76.2
	6. 75% N placement + foliar spray 6. 75% N miejscowo + pozakorzeniowo	87.4	65.6	83.7	78.9
$LSD_{(0.05)}$ $NIR_{(0,5)}$					
Fertilizer – Nawóz		ns – ni	ns – ni	7.30	
Application method – Metoda aplikacji		ns – ni	ns – ni	ns – ni	
Fertilizer × Application method – Nawóz × Metoda aplikacji		ns – ni	ns – ni	ns – ni	

ns – no significant for p = 0.05
ni – nieistotne dla p = 0,05

The split N rates (75% N + 25% N) and foliar fertilization with reduced rate (75% N) increased yield in 2005, irrespectively of the application method. In 2006 and 2007 only with broadcast method this tendency was observed. Many workers reported [Domagała and Sady 1998, Laegreid et al. 1999, Rahn 2002, Fageria and Baligar 2005] the splitting N fertilizer applications during crop growth can reduce N-NO_3 leaching and improve N use efficiency compared with preplant. No plant reaction to splitting N application for placement method was associated with limited root exploration between the rows. In N placement method the roots grow around the N deposit. With a broadcast application of N, the uptake pattern of nitrogen from the soil by the crop was evenly distributed horizontally, indicating a well rooted soil profile [Throup-Kristensen and Sørensen 1999]. Solo [1999] found more fibrous roots between rows with broadcast application of N, as compared with band placed fertilization.

The average head weight was the highest in 2007 (3.45 kg), lower in 2005 (3.02 kg), and the lowest in 2006 (2.65 kg). The effect of N treatments was similar in respect to the marketable yield. The N form increased the cabbage head weigh in 2006 and 2007. For 2007 the better fertilizer was ammonium sulphate, whereas in dry year 2006 the bigger heads for RSM were obtained. In 2006 the significantly interaction between N form (ammonium sulphate and RSM) and method (broadcast, placement) was proved (fig. 2). For placement fertilization the best form was ammonium sulphate, while for RSM broadcast method of application.

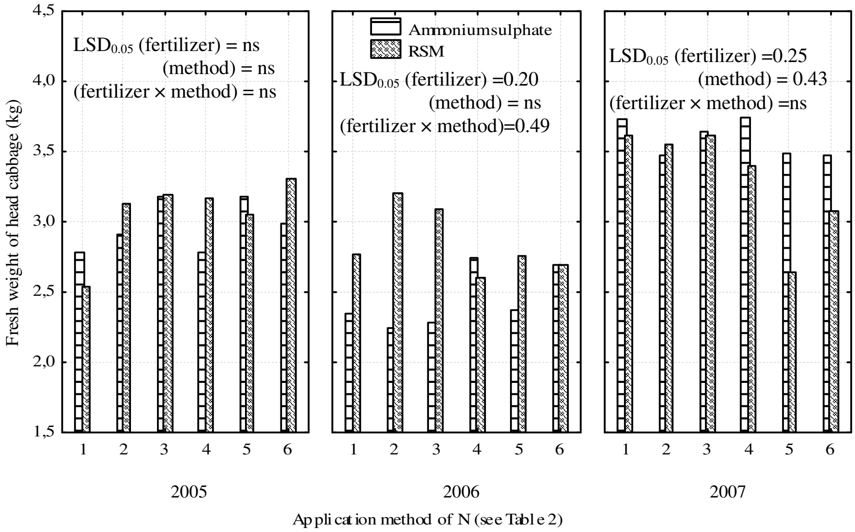

Fig. 2. Effect of form and method of N application on weight (kg) of fresh 'Galaxy' F_1 cabbage head in 2005–2007

Rys. 2. Wpływ formy i metody aplikacji azotu na masę (kg) świeżych główek kapusty 'Galaxy' F_1 uprawianej w latach 2005–2007

The highest nitrate level was ascertained for 2007 (1355 mg NO_3^- kg^{-1} f.m.), while in 2006 and 2005 on average 1091 mg NO_3^- and 1038 mg, respectively was detected (tab. 3). In 2006 and 2007 cabbage fertilized with ammonium sulphate accumulated higher nitrate amount as compared to RSM. This tendency was not confirmed in 2005. In 2006 and 2007 fertilization with 75% N at planting supplemented of 25% N during the growing season or foliar fertilization increased NO_3^- amount in cabbage heads as compared to control ones (100% N broadcasted at planting). This trend was found regardless of the method of N application (broadcast or placement). This is not in agreement with Rożek [2000], Rydz [2001] and Wojciechowska et al. [2005]. They indicated that the foliar fertilization decreased the NO_3^- content in plants, especially with reduced N soil rate. In 2005, method of N application had no impact on NO_3^- level in cabbage. Generally, lower nitrate level was recorded for placement fertilization, particularly with ammonium sulphate (fig. 3). The reduction of NO_3^- content in kohlrabi, lettuce, radish, carrot and white cabbage growing in plastic tunnel/field condition, caused by placement ammonium-based fertilization was reported by Panak et al. [1996], Sady et al. [1996a, b, c], Domagała and Sady [1998]. In Sady et al. [2001] and Wojciechowska [2002] studied N placement fertilization significantly decreased nitrate level in cabbage heads, however, crop was decreased as compared to broadcast method. These results were obtained only in years with beneficial weather condition. In wet years with high rainfalls in the beginning of growing period no differences between N application methods were observed, probably caused by rinsing away N deposits from the soil.

Table 3. Effect of nitrogen fertilization on nitrate (mg NO_3^- kg^{-1} f.w.) and ammonium (mg NH_4^+ kg^{-1} f.w.) content in 'Galaxy' F_1 cabbage grown in 2005-2007

Tabela 3. Wpływ nawożenia azotowego na zawartość azotanów (mg NO_3^- kg^{-1} św.m.) i amonu (mg NH_4^+ kg^{-1} św.m.) w główkach kapusty 'Galaxy' F_1 uprawianej w latach 2005–2007

Factor Czynnik	Factor level Poziom czynnika	NO_3^- 2005	NH_4^+ 2005	NO_3^- 2006	NH_4^+ 2006	NO_3^- 2007	NH_4^+ 2007
	Mean of Year – Średnia roczna	1038	361	1091	297	1355	588
Fertilizer Nawóz	Ammonium sulphate – Siarczan amonu	970	365	1283	305	1447	532
	RSM – Roztwór saletrzano-mocznikowy	1107	357	899	288	1263	644
Application method Metoda aplikacji	1. 100% N broadcast 1. 100% N rzutowo	956	383	691	315	1142	615
	2. 75% N broadcast + 25% N 2. 75% N rzutowo + 25% N	1096	365	951	291	1202	576
	3. 75% N broadcast + foliar spray 3. 75% N rzutowo + pozakorzeniowo	1236	346	1138	306	1299	582
	4. 75% N placement 4. 75% N miejscowo	976	352	1204	286	1586	576
	5. 75% N placement + 25% N 5. 75% N miejscowo + 25% N	993	355	1240	285	1393	601
	6. 75% N placement + foliar spray 6. 75% N miejscowo + pozakorzeniowo	972	365	1322	297	1507	577
$LSD_{(0.05)}$ $NIR_{(0,5)}$							
Fertilizer – Nawóz		ns – ni	ns – ni	119.1	12.01	112.2	18.0
Application method – Metoda aplikacji		ns – ni	18.8	206.3	20.9	194.4	ns – ni
Fertilizer × Application method – Nawóz × Metoda aplikacji		ns – ni	ns – ni	ns – ni	29.6	ns – ni	ns – ni

ns – no significant for p = 0.05
ni – nieistotne dla p = 0,05

In three year studies the highest ammonium content in cabbage was detected in 2007 (588 mg N-NH_4 kg^{-1} f.w.), while in 2005 and 2006 it was 361 mg and 297 mg N-NH_4 kg^{-1} f.w, respectively.

The sources of ammonium ions (NH_4^+) concentration in plant tissues are different, e.g. they can appear as a result of reduction of nitrates, amino acids and amides catabolic reactions, or taken up from soil solution. Ammonium accumulation may also occur when plants are under abiotic and biotic stress [Marchner 1995]. The lowest NH_4^+ level in cabbage leaves in 2006 was caused by the weather condition, when after very dry July with elevated temperature, high rainfalls were observed in September. Probably, excessive soil moisture forced nitrate leaching what might have limit N uptake by plant. The yield obtained this year was low and was characterized by a low ammonium concentration, in addition nitrate level in cabbage was very differentiated and difficult to conclusively interpretation (tab. 3).

No definitive influence of supplied N form on NH_4^+ level in cabbage was found. In 2005 and 2006 significantly influence of N application on ammonium content was detected. Nevertheless, mean differences of ammonium concentration were rather low. It confirms that NH_4^+ ions concentration in cabbage photosynthetic tissues is not strongly related with fertilization treatments [Wojciechowska et al. 2000].

In our studies foliar fertilization did no affect the ammonium content in cabbage leaves. These results suggest rapid absorption and hydrolysis of applied urea, and direct assimilation of NH_4^+ ions [Witte et al. 2002].

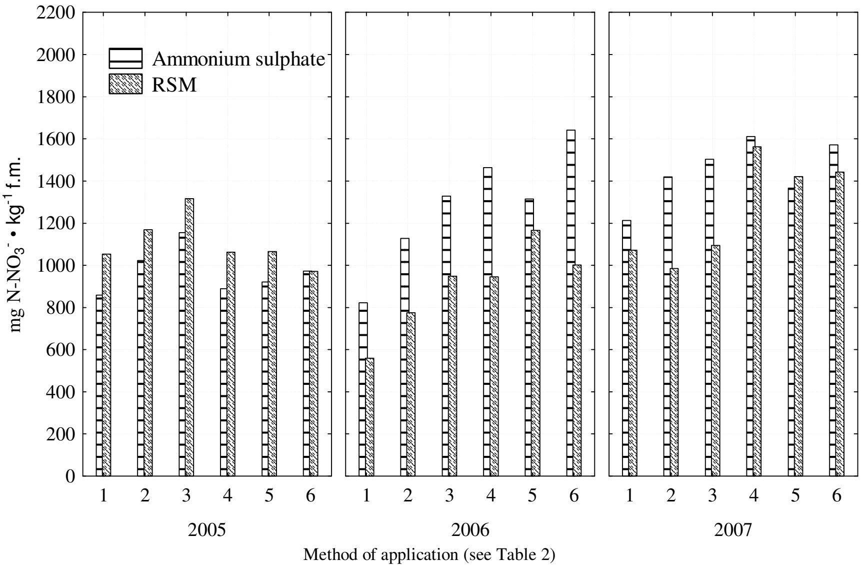

Fig. 3. Effect of nitrogen fertilization on nitrate (mg NO_3^- kg^{-1} f.w.) content in 'Galaxy' F_1 cabbage grown in 2005–2007. LSD results are the same like in Table 3

Rys. 3. Wpływ nawożenia azotowego na zawartość azotanów (mg NO_3^- kg^{-1} św.m.) w kapuście 'Galaxy' F_1 uprawianej w latach 2005–2007. Wyniki NIR są zamieszczone w tabeli 3

Soil analyses. The amount of nitrogen in the soil at harvest was highest in 2007 (15.7 mg N-NO_3 and 14.9 mg N-NH_4 dm^{-3}), while the lowest in 2006 (8.39 mg N-NO_3 .and 6.4 mg N-NH_4) (tab. 4). High soil nitrogen level in 2007 was associated with highest level of ammonium and nitrate in plant tissues. The form and method of N supplied had no significant influence on soil nitrogen amount at harvest. However, in 2006 and 2007 slightly increasing content of nitrogen in soil treated with 75% N + 25% N during plant growth was noted. This tendency was found both for broadcast and placement fertilization. In 2006 the deeper samples of soil were taken, the lower nitrogen amount was found. In the other years the relative nitrogen distribution over the different soil layers was similar. This indicated that leaching was limited during the growth.

At harvest the total content of nitrogen in the soil layer 0–90 cm at harvest was in 2005 – 66.5 kg N-NO_3 ha^{-1}, in 2006 – 50.4 kg and in 2007 – 94.3 kg. In the experiments of Everaarts and Booij [2000] with white cabbage the nitrogen amount left in the soil at harvest was low and reached to maximum of 40 kg ha^{-1} (maximum applied nitrogen was about 400 kg ha^{-1}) for the soil layer 0–90 cm. Sørensen [1993], Throup-Kristensen and Sørensen [1999] and Salo [1999] reported the similar observations.

Table 4. Nitrate (mg N-NO_3^- dm^{-3}) and ammonium content (N-NH_4^+ dm^{-3}) in the soil at harvest in 2005–2007
Tabela 4. Zawartość azotanów (mg N-NO_3^- dm^{-3}) i amonu (N-NH_4^+ dm^{-3}) w glebie w okresie zbioru w latach 2005–2007

Factor Czynnik	Factor level Poziom czynnika	N-NO_3^- 2005	N-NH_4^+ 2005	N-NO_3^- 2006	N-NH_4^+ 2006	N-NO_3^- 2007	N-NH_4^+ 2007
	Mean of Year – Średnia roczna	11.8	8.4	8.4	6.6	15.7	14.9
Fertilizer Nawóz	Ammonium sulphate – Siarczan amonu	11.0	8.9	6.8	5.8	15.4	15.2
	RSM – Roztwór saletrzano-mocznikowy	11.1	7.9	9.9	7.5	16.0	14.7
Application method Metoda aplikacji	1. 100% N broadcast 1. 100% N rzutowo	12.0	8.7	7.8	6.4	13.4	12.2
	2. 75% N broadcast + 25% N 2. 75% N rzutowo + 25% N	11.3	6.6	10.9	10.3	15.0	14.8
	3. 75% N broadcast + foliar spray 3. 75% N rzutowo + pozakorzeniowo	10.3	8.9	6.6	5.0	17.9	15.0
	4. 75% N placement 4. 75% N miejscowo	12.2	8.9	6.0	3.1	15.5	16.7
	5. 75% N placement + 25% N 5. 75% N miejscowo + 25% N	10.3	9.3	13.4	9.1	18.1	16.1
	6. 75% N placement + foliar spray 6. 75% N miejscowo + pozakorzeniowo	10.3	7.9	5.6	5.8	14.4	14.8
Soil layer Warstwa gleby (cm)	0–30	11.3	7.7	9.1	7.4	16.2	15.6
	30–60	10.6	9.0	8.5	7.1	15.3	15.0
	60–90	11.4	8.5	7.6	5.4	15.6	14.2
$LSD_{(0.05)}$ $NIR_{(0,5)}$							
Fertilizer – Nawóz		ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni
Application method – Metoda aplikacji		ns – ni	ns – ni	ns – ni	ns – ni	3.04	ns – ni
Soil layer – Warstwa gleby		ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni
Fertilizer × Application method – Nawóz × Metoda aplikacji		ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni
Fertilizer × Soil layer – Nawóz × Warstwa gleby		ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni
Application method × Soil layer – Metoda aplikacji × Warstwa gleby		5.67	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni

ns – no significant for p = 0.05
ni – nieistotne dla p = 0,05

CONCLUSION

In experiment with white cabbage 120 kg N ha^{-1} (100% N) was applied. Every year of the study placement fertilization with reduced N rate (75% N) increased cabbage yield as compared to control (100% N broadcasted at planting). Split N application (75% N + 25% N during plant growth) and foliar fertilization with reduced N soil rate (75% N) increased yield of 'Galaxy' F_1 only when nitrogen fertilizers were broadcasted. Splitting nitrogen fertilization or foliar N sprays can increase nitrate content in cabbage leaves.

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WPŁYW NAWOŻENIA AZOTEM NA PLONOWANIE ORAZ ZAWARTOŚĆ NH_4^+ I NO_3^- W KAPUŚCIE GŁOWIASTEJ BIAŁEJ

Streszczenie. Przedstawiono wyniki trzyletniego doświadczenia z kapustą głowiastą białą 'Galaxy" F_1 uprawianą w warunkach polowych. Celem badań było określenie wpływu różnych sposobów nawożenia mineralnego azotem (siarczan amonu, RSM – roztwór saletrzano-mocznikowy) oraz uzupełniającego nawożenia pozakorzeniowego (mocznik i Supervit K) na wielkość plonu handlowego oraz zawartość azotanów i amonowej formy azotu w kapuście. Nawozy azotowe stosowano w pełnej dawce (120 kg N ha^{-1}) lub w zredukowanej (75% N), metodą rzutową lub zlokalizowaną. Obserwowano lepsze plonowanie roślin w obiektach, w których nawozy były stosowane rzutowo z doglebowym nawożeniem pogłównym (75% N + 25% N pogłównie) oraz przy ograniczonej dawce N (75% N) uzupełnionej dolistnym dokarmianiem. Nawożenie zlokalizowane w dawce 75% N podnosiło plony kapusty w każdym roku badań w stosunku do rzutowego dostarczania roślinom azotu w pełnej dawce (100% N). W roku 2006 i 2007 przedsiewne doglebowe nawożenie azotem w dawce 75% N uzupełnione w okresie wegetacji nawożeniem pogłównym w dawce 25% N lub dokarmianiem pozakorzeniowym istotnie podnosiło średnią zawartość azotanów w kapuście w stosunku do kontroli (100% N w nawożeniu doglebowym przedsiewnym).

Słowa kluczowe: kapusta głowiasta biała, dokarmienie pozakorzeniowe, nawożenie zlokalizowane, zawartość azotanów i amonu

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