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EFFECT OF NITROGEN FERTILIZATION ON THE YIELD AND QUALITY OF FIELD-GROWN LEAF LETTUCE FOR SPRING HARVEST

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Summary

Two field experiments with leaf lettuce were carried out in 2006-2008. Each of them was set up in a random sub-block design in 3 replications and a two-factorial system. The first factor represented different nitrogen doses that were used to obtain the required N level in the soil prior to planting the seedlings, the levels being: 50, 100 and 150 mg $N \cdot dm^{-3}$. The second factor incorporated 4 nitrogenous fertilizers which were different in terms of chemical composition, and, more importantly, contained different nitrogen forms for introduction to the soil: ammonium nitrate 34% N-[NH_4NO_3], calcium nitrate 15.5% N-[$Ca(NO_3)_2xH_2O+NH_4NO_3$], ammonium sulphate 20.0% N-[$(NH4)_2SO_4$], and ENTEC 26% N-[$NH_4NO_3+(NH_4)_2SO_4$+0.8% DMPP]. Two varieties of leaf lettuce were used: Casabella (of the type Lollo Bionda) with green leaves, and Klausia (of the type Lollo Rosa) with red leaves. The best sources of nitrogen for the lettuce plants were the fertilizers ENTEC 26 and ammonium nitrate, which in contrast to calcium nitrate and ammonium sulphate made it possible to obtain significantly higher yields of lettuce. Irrespective of the kind of the nitrogenous fertilizer used, increasing the concentration of nitrogen in the soil from 50 mg $N \cdot dm^{-3}$ to 100 mg $N \cdot dm^{-3}$ resulted in a significant increase in the marketable yield of lettuce. At 150 mg $N \cdot dm^{-3}$ this yield remained at a level similar to that at 100 mg $N \cdot dm^{-3}$. The lettuce fertilized with ammonium sulphate was marked by the lowest mean nitrate content in the leaves before harvest. The use of gradually higher doses of nitrogen resulted in a reduced dry weight content and lower levels of total and reducing sugars in lettuce leaves. With respect to yield size and quality, the recommended concentration of nitrogen in the soil for leaf lettuce should not exceed 100 mg $N \cdot dm^{-3}$.

key words: leaf lettuce, nitrogen dose, nitrogen form, yield, quality

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INTRODUCTION

Rosette leaf lettuce (*Lactuca sativa* L. var. *foliosa*) is a species which enjoys great popularity in many countries of Western Europe and Scandinavia. In Poland, it has not as yet been cultivated on a large scale, but its importance is gradually growing (Stępowska & Rogowska 2004).

The leaves of the rosette lettuce, apart from their nutritional value, are characterized by an original growth habit and colour, from greenish-yellow to reddish-brown. The leaf lettuce, like other species in the group of leafy vegetables, has a short growing period and is marked by a fairly high tendency towards the accumulation of nitrates, which in effect can lead to the lowering of its quality (Rożek 2000). This undesirable phenomenon can be controlled by efficient fertilization with nitrogen, taking into account the nutritional requirements of the plants and the mineral nitrogen content in the soil. The important things in the cultivation of lettuce are the size of the nitrogen dose, the type of the nitrogenous fertilizer, and also the time and technique of its application (Kowalska *et al*. 2006). When the ammonium form (ammonium sulphate) or amide form (urea) are used, the level of nitrates in lettuce leaves is usually lower than after fertilization with the nitrate form. However, when fertilizing plants with ammonium sulphate, it should be remembered that it causes strong acidification of the soil, and that this fertilizer has a high salt index, whereas the lettuce belongs to the group of vegetables susceptible to soil salinity.

The aim of the completed experiments was to determine the effect of nitrogen form and dosage on the yield and quality of two varieties of leaf lettuce of a feathery type.

MATERIALS AND METHODS

The field experiments with the leaf lettuce were carried out in the years 2006-2008. They were set up using the method of random sub-blocks, in 3 replications, and in a two-factorial system. The first factor (A) represented different nitrogen levels in the soil before the cultivation of lettuce began, which were: 50, 100, and 150 mg $N \cdot dm^{-3}$. The second factor (B) incorporated 4 nitrogenous fertilizers which differed in terms of chemical composition, and, more importantly, contained different nitrogen forms for introduction to the soil: ammonium nitrate 34% N-[NH_4NO_3], calcium nitrate 15.5% N-[$Ca(NO_3)_2xH_2O+NH_4NO_3$], ammonium sulphate 20.0% N-[$(NH4)_2SO_4$], and ENTEC 26% N-[$NH_4NO_3+(NH_4)_2SO_4$+0.8% DMPP]. The fertilizer ENTEC 26 contains a nitrification inhibitor, 3,4-dimethyl pyrazole phosphate, whose task is to stabilize the ammonium form of nitrogen by blocking the activity of the bacteria of the genus *Nitrosomonas*. The concentration of mineral nitrogen in the control combination, in which there was no fertilization with nitrogen, was in the range of 25-35 mg $N \cdot dm^{-3}$, and that of other constituents was at a level sufficient to satisfy the nutritional requirements of lettuce.

In two independent experiments, two varieties of feathery lettuce were grown: Casabella (of the Lollo Bionda type) with green leaves, and Klausia (of the Lollo Rosa type) with red leaves. Lettuce seedlings produced in a greenhouse were used as the starting material. Towards the end of March, lettuce seeds were sown into multi-pots filled with a peat substrate with a pH of 6.00. Later, towards the end of April, the hardened lettuce seedlings were planted at 35 x 30 cm on 5 m^2 plots. Weeds were controlled by mechanical means; soil moisture content was maintained at a level of 70% FWC. The lettuce was harvested in the first week of June. The marketable yield consisted of healthy plants whose rosette of leaves weighed more than 100 g. The lettuce leaves were analyzed for nitrate content (potentiometric method), the total and reducing sugar content (Lane Eynon method), and dry weight (by weighing).

The experimental data concerning the yielding of lettuce plants were evaluated statistically with an analysis of variance according to Tukey's test at a significance level of P=0.05.

RESULTS AND DISCUSSION

On the basis of the completed experiments it was found that the highest mean marketable yield of lettuce cv. Casabella (27.49 $t \cdot ha^{-1}$) was obtained from the plots fertilized with ENTEC 26 (Table 1). The yield of lettuce fertilized with ammonium nitrate (26.09 $t \cdot ha^{-1}$) was significantly higher than the yield recorded for ammonium sulphate (24.94 $t \cdot ha^{-1}$). A yield similar to that resulting from the use of ammonium sulphate was obtained with calcium nitrate (25.12 $t \cdot ha^{-1}$).

Irrespective of the kind of the nitrogenous fertilizer used, increasing the nitrogen concentration in the soil from 50 mg $N \cdot dm^{-3}$ to 100 mg $N \cdot dm^{-3}$ had resulted in a significant increase in the marketable yield of lettuce cv. Casabella. At the concentration of 150 mg $N \cdot dm^{-3}$ this yield remained at a level similar to that at the concentration of 100 mg $N \cdot dm^{-3}$. The application of ammonium nitrate at 100 mg $N \cdot dm^{-3}$ made it possible to obtain the highest mean marketable yield out of all the experimental combinations.

The marketable yields of the cultivar Klausia fertilized with ENTEC 26 (18.66 $t \cdot ha^{-1}$) and ammonium nitrate (18.64 $t \cdot ha^{-1}$) were similar and significantly higher than those obtained with the other fertilizers tested. The mean values for calcium nitrate and ammonium sulphate were not significantly different, which indicates the possibility of using different forms of nitrogen in lettuce cultivation. This is also a confirmation of the results obtained by Sady *et al*. (1990), who had observed lack of variation in the yields of lettuce fertilized with nitrate nitrogen and reduced forms of nitrogen in a hydroponic culture. Similar results were obtained by Kowalska (1998) for tomato.

Taking into consideration the nitrogen dosage only, it was observed that increasing the concentration of this element from 50 mg $N \cdot dm^{-3}$ to 150 mg $N \cdot dm^{-3}$ caused a significant increase in the total yield of lettuce cv. Klausia. At the same time there were no significant differences between the levels of 100 mg $N \cdot dm^{-3}$ and 150 mg $N \cdot dm^{-3}$. Allowing for interactions, the highest total yield was obtained from the plots fertilized with calcium nitrate to the level of 150

mg N·dm^{-3} (19.81 t·ha^{-1}) and ammonium nitrate at 100 mg N·dm^{-3} (19.51 t·ha^{-1}). The lowest marketable yield for both lettuce cultivars was obtained from the control plots. The yield-enhancing role of nitrogen in lettuce cultivation has been well documented in scientific research (Kozik & Ruprik 2000, Kalisz 2007).

Table 1. Effect of nitrogenous fertilizer dose and form on the marketable yield of feathery lettuce (t·ha^{-1})

Fertilizer	Mineral nitrogen content in soil (mg N·dm^{-3})			
	50	100	150	mean
Casabella				
ENTEC 26	26.91	27.83	27.73	27.49
Calcium nitrate	25.33	24.53	25.50	25.12
Ammonium nitrate	22.10	29.93	26.25	26.09
Ammonium sulphate	23.30	24.00	27.52	24.94
mean	24.41	26.57	26.75	
Non-fertilized control		20.18		
$LSD_{P=0.05}$ for: factor A=1.30, factor B=1.12, interaction AxB=1.98				
Klausia				
ENTEC 26	17.87	19.11	19.00	18.66
Calcium nitrate	16.28	16.50	19.81	17.53
Ammonium nitrate	17.60	19.51	18.81	18.64
Ammonium sulphate	17.22	16.78	16.50	16.83
mean	17.24	17.97	18.53	
Non-fertilized control		14.55		
$LSD_{P=0.05}$ for: factor A =0.98, factor B=0.85, interaction AxB=1.85				

In the light of the results obtained, the highest usefulness for fertilizing both lettuce varieties was shown by the fertilizer ENTEC 26. Comparable results were obtained by Hähndel & Zerulla (2000, 2001), who found that the effects produced by ENTEC 26 and ammonium nitrate in lettuce were similar, but the effect of ENTEC on the yields of cauliflower, radish, Chinese cabbage and corn salad (lamb's lettuce) was more advantageous.

In the authors' own experiments, in both varieties of lettuce, it was observed that the increasing doses of nitrogen generally contributed to a reduction in the dry weight of leaves. In the case of the cultivar Casabella, the plants from the control plot were marked by the highest dry weight content (Table 2), whereas in the cultivar Klausia in the plants grown at the lowest fertilization level of 50 mg N·dm^{-3}. Similar relationships were found by Kowalska (1998), who reported that lettuce grown under the conditions of insufficient supply in nitrogen had hard leaves with an increased dry weight content. The accumulation of dry weight was also aided by the use of the fertilizer ENTEC 26 as a source of nitrogen, the lowest levels of it were found in the plants fertilized with ammonium sulphate, especially when the N content in the soil was in the range of 100-150 mg N·dm^{-3}.

The use of increasingly higher doses of nitrogen was observed to have a significant effect on the accumulation of nitrates in the leaves of the lettuce varieties tested. The lowest amounts of these compounds were contained in the control plants that had not been fertilized with nitrogen (Table 3), with the amounts of nitrates in cv. Klausia being almost twice as high as those in cv. Casabella.

Table 2. Effect of nitrogenous fertilizer dose and form on dry weight content in feathery lettuce leaves (% DW)

Fertilizer	Mineral nitrogen content in soil (mg N·dm^{-3})			
	50	100	150	mean
Casabella				
ENTEC 26	8.01	7.45	7.71	7.72
Calcium nitrate	7.12	7.17	6.99	7.09
Ammonium nitrate	7.35	8.00	7.11	7.49
Ammonium sulphate	7.44	6.89	6.86	7.06
mean	7.48	7.38	7.17	
Non-fertilized control		8.76		
Klausia				
ENTEC 26	8.11	7.70	7.50	7.77
Calcium nitrate	8.68	7.34	7.14	7.72
Ammonium nitrate	8.21	7.75	7.00	7.65
Ammonium sulphate	7.46	7.22	7.02	7.23
mean	8.12	7.50	7.17	
Non-fertilized control		7.69		

Table 3. Effect of nitrogenous fertilizer dose and form on the nitrates content in the leaves of feathery lettuce (mg NO_3·kg^{-1} FW)

Fertilizer	Mineral nitrogen content in soil (mg N·dm^{-3})			
	50	100	150	mean
Casabella				
ENTEC 26	1036	1828	1706	1523
Calcium nitrate	1172	1793	2023	1663
Ammonium nitrate	938	1949	1882	1590
Ammonium sulphate	805	841	1950	1199
mean	988	1603	1890	
Non-fertilized control		426		
Klausia				
ENTEC 26	1706	2438	2316	2153
Calcium nitrate	1523	1950	2742	2072
Ammonium nitrate	1406	1731	2534	1890
Ammonium sulphate	1055	2243	2072	1790
mean	1423	2091	2416	
Non-fertilized control		840		

The increase in mineral nitrogen in the soil from 50 mg $N \cdot dm^{-3}$ to 150 mg $N \cdot dm^{-3}$ had contributed to the increase in the levels of nitrates from 998 mg $NO_3 \cdot kg^{-1}$ to 1890 mg $NO_3 \cdot kg^{-1}$ fresh weight (FW) of the lettuce leaves cv. Casabella, and respectively from 1423 mg $NO_3 \cdot kg^{-1}$ to 2416 mg $NO_3 \cdot kg^{-1}$ FW in cv. Klausia. It should be emphasized that at the highest experimental level of nitrogen in the soil, fertilization with calcium nitrate and ammonium nitrate had resulted in an accumulation of nitrates in lettuce leaves in the amounts that exceeded the permissible limit of 2500 mg $NO_3 \cdot kg^{-1}$ FW.

Analysing the effects of the individual fertilizers, it can be stated that the use of ammonium sulphate played a contributing role in limiting the average nitrate content in the leaves of both lettuce varieties in comparison with the other fertilizers, whose use modified the nitrate content only to a relatively small degree. These results agree with the data presented in the literature, namely, that fertilization with the reduced forms of nitrogen markedly reduce the concentration of nitrates (Kowalska 1997, Wojciechowska 2004, Biesiada 2005, Jarosz & Dzida 2006, Kozik 2006).

The experimental results concerning the total and reducing sugars content (Table 4 & 5) provide proof of the effect of nitrogen fertilization on their amounts. It can be seen that increasing the concentration of mineral nitrogen in the soil resulted in a drop in the mean sugar content in lettuce leaves. This fact was particularly obvious in cv. Klausia. In the studies by Kozik (1998), concerning, among other things, the effect of nitrogen fertilization on sugar content in seven varieties of lettuce, it was also observed that an increased amount of nitrogen in the substrate, irrespective of the cultivar, had an effect on the lowering of the levels of water-soluble sugars. On the basis of the authors' own experiments it can also be seen that the concentration of the sugars in lettuce leaves was favourably affected by the use of ammonium sulphate as a source of nitrogen. This confirms the experimental results of other authors. In the experiment conducted by Sady *et al*. (1990), involving the cultivation of lettuce in a plastic tunnel covered with two types of foil, it was observed that the accumulation of sugars in lettuce leaves was affected by such factors as foliar fertilization and the form of the nitrogenous fertilizer. Similar observations were made by Kalisz (2007) in an experiment with Chinese cabbage.

In summary, it can be stated that the best production results were obtained by growing lettuce at the initial nitrogen concentration in the soil of 100 mg $N \cdot dm^{-3}$. Increasing the nitrogen content to 150 mg $N \cdot dm^{-3}$ resulted in only a small, not statistically proven, increase in the marketable yield of the lettuce varieties studied. It did, however, contribute to an increased accumulation of nitrates in lettuce leaves.

Table 4. Effect of nitrogenous fertilizer dose and form on the total sugar content in the leaves of feathery lettuce (% FW)

Fertilizer	Mineral nitrogen content in soil (mg N·dm^{-3})			
	50	100	150	mean
Casabella				
ENTEC 26	1.95	1.85	2.10	1.97
Calcium nitrate	1.95	1.90	2.00	1.95
Ammonium nitrate	2.15	2.15	1.65	1.98
Ammonium sulphate	2.45	2.25	2.35	2.35
mean	2.12	2.04	2.02	
Non-fertilized control		1.98		
Klausia				
ENTEC 26	2.00	1.90	1.55	1.82
Calcium nitrate	1.85	1.85	1.98	1.89
Ammonium nitrate	1.98	1.55	1.45	1.66
Ammonium sulphate	2.15	2.45	2.15	2.25
mean	2.00	1.94	1.78	
Non-fertilized control		2.05		

Table 5. Effect of nitrogenous fertilizer dose and form on the reducing sugars content in the leaves of feathery lettuce (% FW)

Fertilizer	Mineral nitrogen content in soil (mg N·dm^{-3})			
	50	100	150	mean
Casabella				
ENTEC 26	1.76	1.78	1.82	1.79
Calcium nitrate	1.45	1.55	1.75	1.58
Ammonium nitrate	1.88	1.95	1.36	1.73
Ammonium sulphate	2.25	2.05	2.28	2.19
mean	1.83	1.83	1.80	
Non-fertilized control		1.82		
Klausia				
ENTEC 26	1.82	1.55	1.35	1.57
Calcium nitrate	1.55	1.44	1.80	1.59
Ammonium nitrate	1.76	1.27	1.15	1.39
Ammonium sulphate	2.00	2.15	1.95	2.03
mean	1.78	1.60	1.53	
Non-fertilized control		1.90		

CONCLUSIONS

1. The best sources of nitrogen for leaf lettuce of the type Lollo were the fertilizers ENTEC 26 and ammonium nitrate, which in contrast to calcium nitrate and ammonium sulphate made it possible to obtain significantly higher yields.

2. Irrespective of the kind of the nitrogenous fertilizer used, increasing the concentration of nitrogen in the soil from 50 mg $N \cdot dm^{-3}$ to 100 mg $N \cdot dm^{-3}$ caused a significant increase in the marketable yield of lettuce. At 150 mg $N \cdot dm^{-3}$ this yield remained at a level similar to that at 100 mg $N \cdot dm^{-3}$.
3. The lettuce fertilized with ammonium sulphate was marked by the lowest mean nitrate content in the leaves before harvest.
4. The use of gradually higher doses of nitrogen resulted in a reduced dry weight content and lower levels of total and reducing sugars in lettuce leaves.
5. With respect to yield size and quality, the recommended concentration of nitrogen in the soil for leaf lettuce of the type Lollo should not exceed 100 mg $N \cdot dm^{-3}$.

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WPŁYW NAWOŻENIA AZOTEM NA PLONOWANIE I JAKOŚĆ SAŁATY LIŚCIOWEJ W UPRAWIE POLOWEJ NA ZBIÓR WIOSENNY

Streszczenie

Dwa doświadczenia polowe z sałatą liściową przeprowadzono w latach 2006-2008. Każde z nich zostało założone metodą losowanych podbloków w 3 powtórzeniach w układzie dwuczynnikowym. Pierwszy czynnik stanowiły zróżnicowane dawki azotu zapewniające uzyskanie poziomu zasobność gleby przed sadzeniem rozsady, na poziomie: 50, 100 i 150 mg $N \cdot dm^{-3}$. Czynnik drugi obejmował 4 następujące nawozy azotowe różniące się składem chemicznym, a przede wszystkim formą azotu, wprowadzaną do gleby: saletra amonowa 34% N-[NH_4NO_3], saletra wapniowa 15,5% N-[$Ca(NO_3)_2xH_2O+NH_4NO_3$], siarczan amonu 20,0% N-[$(NH4)_2SO_4$], ENTEC 26% N-[$NH_4NO_3+(NH_4)_2SO_4$+0,8% DNPP]. W badaniach wykorzystano dwie odmiany sałaty liściowej: o zielonych liściach – Casabella (typ Lollo Bionda), oraz o czerwonych liściach – Klausia (typ Lollo Rosa). Najlepszymi źródłami azotu dla sałaty były nawozy ENTEC 26 i saletra amonowa, które w porównaniu z saletrą wapniową i siarczanem amonu zapewniły uzyskanie istotnie wyższych plonów tej rośliny. Niezależnie od rodzaju zastosowanego nawozu azotowego zwiększenie koncentracji tego składnika w glebie z 50 mg $N \cdot dm^{-3}$ do 100 mg $N \cdot dm^{-3}$ spowodowało istotny wzrostu plonu handlowego sałaty. Przy zawartości 150 mg $N \cdot dm^{-3}$ plon ten utrzymywał się na podobnym poziomie jak przy 100 mg $N \cdot dm^{-3}$. Sałata nawożona siarczanem amonu odznaczała się najniższą średnią zawartością azotanów w liściach przed zbiorem. Stosowanie wzrastających dawek azotu powodowało obniżenie zawartości suchej masy oraz cukrów ogółem i redukujących w liściach sałaty. Mając na uwadze wysokość i jakość plonu zalecana koncentracja azotu w glebie dla sałaty liściowej nie powinna przekraczać 100 mg $N \cdot dm^{-3}$.