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ORIGINAL PAPER

# NICKEL CONTENT IN GRAIN OF WINTER WHEAT (*TRITICUM AESTIVUM* L.) AND SPRING BARLEY (*HORDEUM VULGARE* L.) CULTIVATED ON LOESSIAL SOIL, DEPENDING ON LIMING AND MINERAL FERTILIZATION*

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## Abstract

This paper presents results of a study on the nickel content in grain of winter wheat and spring barley grown on a constantly fertilized field lying on loessial soil and situated in Podgórze Rzeszowskie. The experiment was set up in randomized sub-blocks, by growing potato, spring barley, fodder sunflower and winter wheat plants in 4 four-year crop rotation cycles. Fodder cabbage was grown in the second crop rotation instead of sunflower. The first variable factor was liming (A2) or its lack (A1), while the second one consisted of different doses of mineral fertilization. Mineral NPK nutrition was applied against the background of constant Mg as well as Mg and Ca fertilization (liming). The general fertilization level ($N_1P_1K_1$) for spring barley was: 80 kg N ha$^{-1}$, 43.6 kg P ha$^{-1}$ and 99.6 kg K ha$^{-1}$, while for winter wheat it was: 90 kg N ha$^{-1}$, 34.9 kg P ha$^{-1}$ and 83 kg K ha$^{-1}$. Constant magnesium fertilization was applied at a 24.1 kg Mg ha$^{-1}$ dose. Liming at a dose of 4 t CaO ha$^{-1}$ was applied before starting the experiment and each year that completed a subsequent crop rotation. The nickel content in crops was determined with the FAAS technique (Hitachi Z 2000) after digesting samples in a mixture of $HNO_3$:$HClO_4$:$H_2SO_4$, at a 20:5:1 ratio. There was a significant decrease in the nickel concentration in grain of winter wheat and spring barley due to liming. Mineral nutrition had no impact on variation in the amounts of elements in grain of the two cereals. However, some tendency towards a lower metal content in winter wheat grain resulting from increasing NPK doses applied at a constant N:P:K ratio was recorded. Interaction of liming with mineral fertilization (NPK) caused a several-fold

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decrease in the nickel content in grain of winter wheat from the limed treatments, while on the remaining plots it had no statistical influence on the concentration of this element in grain of spring barley.

**Keywords:** liming, mineral fertilization, nickel, cereal grain.

# INTRODUCTION

Among microelements that are the most important for plants, there are boron, molybdenum, manganese, copper and zinc. They play a variety of significant functions in crops, in which their content is an important indicator of yield quality (He et al. 2005, Hänsch, Mendel 2009). Nickel is required by plants in trace amounts, although it does not play any remarkable metabolic functions. It can be counted as a nutrient, although a few plant species present negative symptoms during its deficiency (Singh et al. 2011). Nevertheless, its positive influence on free nitrogen assimilation by microorganisms, which has a positive impact on the growth of papilionaceous plant species, has been reported. Nickel is a component of several enzymes (e.g. ureases and hydrogenases) (Chen et al. 2009). When nickel is absent from soil, there is a decrease in urease activity and disturbances in nitrogen assimilation (Ahmad, Ashraf 2011). According to Brown et al. (1987), nickel is a bio-element necessary for the growth of cereals, especially barley, and for their production of grains. Singh et al. (2011) reported an increased nitrogen uptake by grains and straw of wheat as well as an increase of their yield weight as a consequence of nickel administration with mineral fertilization.

Nickel occurs in different forms in soil, e.g. as exchangeable or non-exchangeable, in minerals and bound to organic matter (Malavolta, Moraes 2007). The prevalent form of nickel in soil is the one bound to organic matter (Khanlari, Jalali 2008), mainly as mobile chelates. Nickel present in soils in mobile forms is readily available to plants and its excessive content in the subsoil can cause the inhibition of the growth and development of plants, as well as chlorosis, a characteristic symptom of this metal's excessive quantity, which is able to induce other injuries and illnesses of leaves and stems (Kumar et al. 2012, Sharma, Dhiman 2013). The reason is the fact that as the nickel concentration in soil increases, its content in crops grows as well. Hamner et al. (2013) reported a positive correlation between the total nickel content in soil and the metal's concentration in cereals.

The amounts of the metal in grain of winter wheat grown on sandy soils of Płaskowyż Kolbuszowski (Kolbuszowa Plateau) and dusty soils of Podgórze Rzeszowskie (Rzeszow Foothills) meet the criteria set to determine the usefulness for consumption (Właśniewski 2003).

The most important soil factors affecting the intensity of nickel uptake by crops are the soil's acidity (Lübben, Sauerbeck 1991, Kaniuczak 1997, Właśniewski 2003, Milivojevič et al. 2008), mineral fertilization (Scott-Fordsmand 1997, Milivojevič et al. 2008, Hamner et al. 2013, Svečnjak et al. 2013), sorption capacity, and organic matter content (Scott-Fordsmand 1997).

Malavolta and Moraes (2007) observed lower nickel availability to plants after liming, especially at pH > 6.5 and due to a fertilization regime with high doses of phosphorus fertilizers. The most intensive uptake of nickel by cereals, including barley straw, was recorded at values of pH about 4.8 (Thevannan et al. 2010). Lillywhite et al. (2009) showed lack of the influence of a compost added to soil on the nickel content in barley, while a soil amendment treatment with municipal sewage sludge contributed to an increase in the bioaccumulation index of this element in wheat grain (Jamali et al. 2009).

Nickel which occurs in soil in a soluble form is toxic to microorganisms if present in larger amounts (and lower pH values) (Scott-Fordsmand 1997).

The current study aimed at evaluating the impact of liming and mineral fertilization on the nickel content in grain of winter wheat and spring barley cultivated in four rotations on loessial soil.

## MATERIAL AND METHODS

The research on the effects of liming (A) and mineral fertilization (B) on the nickel content in grain of winter wheat and spring barley grown in a 4 four-year rotations was carried out on a field submitted to long-term fertilization. The field lies in Krasne (50°02′ N; 22°03′ E, 220 m a.s.l.) near Rzeszów, in Podgórze Rzeszowskie (Rzeszow Foothills) (south-eastern Poland).

The typical lessive soil (FAO-WRB: Haplic luvisol) on which the experiment was carried out was formed from loess and had the textural composition of silt loam (25% sand, 70% silt, 5% clay). Before the experiment (1986), the soil had the bulk density of 1.405 Mg $m^{-3}$, porosity of 45.33 $m^3$ (100 $m^3)^{-1}$ and water content at $pF_{2.0}$ of 24.17 kg (100 $kg)^{-1}$. The soil was highly acidic, i.e. with low pH values: $pH_{KCl}$ = 3.92, $pH_{H2O}$ = 4.93 in the plough humus layer (Ap) and $pH_{KCl}$ = 3.89, $pH_{H2O}$ = 4.90 in the enrichment layer (Bt), and with considerably high hydrolytic acidity: 4.87 cmol (+) $kg^{-1}$ in the Ap layer and 3.6 cmol (+) $kg^{-1}$ in the Bt layer. The content of nickel in the total and soluble forms in 1 M HCl $dm^{-3}$ was 10.40 mg $kg^{-1}$ and 0.71 mg $kg^{-1}$ in the Ap layer and 27.90 mg $kg^{-1}$ and 0.94 mg $kg^{-1}$ in the Bt layer, respectively, which corresponds to its natural content in the soil.

The experiment was set up in a random sub-block design with four replicates. The first variable factor was liming ($A_2$) or its lack ($A_1$), while the second one consisted of different doses of mineral fertilization with constant magnesium nutrition. The following crops were cultivated in the crop rotation system: potato, spring barley, fodder sunflower (fodder cabbage in the 1st crop rotation cycle) and winter wheat. The study covered 4 crop rotation cycles. Winter wheat was grown in 1987, 1991, 1995 and in 1999, whereas spring barley was cultivated in 1989, 1993, 1997 and 2001.

Basic doses of mineral fertilization $N_1P_1K_1$ with constant magnesium nutrition were as follows: $N_1$ = 80 kg N ha$^{-1}$, $P_1$ = 43.6 kg P ha$^{-1}$, $K_1$ = 99.6 kg K ha$^{-1}$ for spring barley, and $N_1$ = 90 kg N ha$^{-1}$, $P_1$ = 34.9 kg P ha$^{-1}$, $K_1$ = 83.0 kg K ha$^{-1}$ for winter wheat. Constant magnesium fertilization was applied before sowing in each experimental sub-block in 1986-1993 at a 24.1 kg Mg ha$^{-1}$ dose for potato, spring barley and winter wheat, and a 72.4 kg Mg ha$^{-1}$ dose for fodder crops. From 1994 on, the magnesium dose was reduced to 24.1 kg Mg ha$^{-1}$, applied to all experimental crops. Liming with a dose of 4 t CaO ha$^{-1}$ was used in 1985, 1989, 1993 and in 1997, prior to the experiment and after the harvest of the crop that was last in a rotation. Mineral fertilizers NPK, Mg and Ca were applied in forms of ammonium nitrate, triple superphosphate, potassium salt KCl (58%), magnesium sulfate and CaO or $CaCO_3$ (dose to according 1 value of the hydrolytic acidity).

The nickel content varied in the applied mineral fertilizers and averaged 0.20 mg kg$^{-1}$ in magnesium sulphate, 0.37 mg kg$^{-1}$ in ammonium nitrate, 0.32 mg kg$^{-1}$ in potassium salt, 1.09 mg kg$^{-1}$ in calcium carbonate, 2.30 mg kg$^{-1}$ in calcium oxide and the most in triple superphosphate – 6.78 mg kg$^{-1}$ dry matter.

Plant material samples were collected after winter wheat and spring barley harvest. Nickel was determined in dry material with the FAAS method and with the atomic spectrophotometric absorbance technique (Hitachi Z 2000), after digesting the samples in a hot mixture of concentrated acids: $HNO_3$ : $HClO_4$ : $H_2SO_4$ (at a 20:5:1 volume ratio) in a Tecator digestion system. Quality assurance of nickel analysis was done by analysing Certified Reference Material (CRM) NCS DC87102, supplied by Analytical Quality Control Services (AQCS), International Atomic Energy Agency (IAEA). The results agree within ± 7.5% of the certified values (certified values 0.69 ± 0.09 mg kg$^{-1}$, observed values 0.64 mg kg$^{-1}$).

The results were statistically processed by two-factor analysis of variance (liming, mineral NPK fertilization) and by calculating the lowest significant difference (LSD) with the Tukey's tests at the significance level of $p$ = 0.05.

## RESULTS AND DISCUSSION

The nickel content in winter wheat grain grown on non-limed soil ranged from 1.19 to 1.75 mg kg$^{-1}$ DM at an average level of 1.51 mg kg$^{-1}$ DM (Table 1). The winter wheat grain harvested from limed soil contained nickel at much lower amounts, i.e. from 0.29 to 0.81 mg kg$^{-1}$ DM at mean value 0.56 mg kg$^{-1}$ DM. Liming repeated regularly every four years had statistically significant

Table 1

Content of nickel in grain (mg kg$^{-1}$ DM) of winter wheat cultivated on loessial soil (means from 4 years)

| Object no. | Treatments of fertilizers (B) | $A_1$ | | $A_2$ | | Mean (B) |
|---|---|---|---|---|---|---|
| | | mean | range | mean | range | |
| (mg kg$^{-1}$ DM) | | | | | | |
| 1 | $N_0P_0K_0$ | 1.60 | 1.05-1.83 | 0.57 | 0.38-0.91 | 1.09 |
| 2 | $N_0P_1K_1$ | 1.61 | 1.45-1.95 | 0.62 | 0.51-0.86 | 1.11 |
| 3 | $N_{0,5}P_1K_1$ | 1.75 | 1.50-2.01 | 0.50 | 0.45-0.75 | 1.12 |
| 4 | $N_1P_1K_1$ | 1.46 | 1.32-1.98 | 0.36 | 0.21-0.47 | 0.91 |
| 5 | $N_{1,5}P_1K_1$ | 1.58 | 1.38-1.84 | 0.34 | 0.26-0.62 | 0.96 |
| 6 | $N_1P_0K_1$ | 1.71 | 1.52-2.11 | 0.40 | 0.24-0.60 | 1.05 |
| 7 | $N_1P_{0,5}K_1$ | 1.19 | 0.98-1.42 | 0.79 | 0.54-0.92 | 0.99 |
| 8 | $N_1P_{1,5}K_1$ | 1.70 | 1.50-2.00 | 0.81 | 0.60-1.05 | 1.25 |
| 9 | $N_1P_1K_0$ | 1.32 | 1.18-1.87 | 0.29 | 0.20-0.48 | 0.80 |
| 10 | $N_1P_1K_{0,5}$ | 1.32 | 1.09-1.97 | 0.64 | 0.53-0.96 | 0.98 |
| 11 | $N_1P_1K_{1,5}$ | 1.50 | 1.25-2.09 | 0.59 | 0.48-0.87 | 1.04 |
| 12 | $N_{0,5}P_{0,5}K_{0,5}$ | 1.50 | 1.36-2.11 | 0.62 | 0.51-1.02 | 1.06 |
| 13 | $N_{1,5}P_{1,5}K_{1,5}$ | 1.41 | 1.28-1.73 | 0.60 | 0.55-0.90 | 1.00 |
| 14 | $N_2P_2K_2$ | 1.54 | 1.42-1.87 | 0.69 | 0.59-0.86 | 1.11 |
| | Mean (A) | 1.51 | - | 0.56 | - | - |
| LSD | | A* = 0.68, B = ns<br>AB* = 0.55 | | | | |

$A_1$ – NPK fertilization + Mg without Ca constans, $A_2$ – NPK fertilization +MgCa constans, LSD – lowest significant difference for: A – liming, B – mineral fertilization (irrespective from liming), AB – interaction between liming and mineral fertilization,
* significant at $p = 0.05$, ns – no significant differences

impact reducing the metal in grain of the test cereal, as the average nickel content in grain of winter wheat grown on unlimed soil was almost three times as high as that in grain of wheat cultivated on limed soil.

Huang et al. (2012) also reported lower nickel content in grain of wheat grown on alkaline soil. Prolonged liming considerably decreased the nickel level in spring wheat grain (Lübben, Sauerbeck 1991). Along with an increase in pH and higher alkaline cation saturation of silty soils in Podgórze Rzeszowskie, the nickel uptake by winter wheat grain decreased (Właśniewski 2003).

The nickel content in grain of spring barley grown on non-limed soil ranged from 0.54 to 0.91 mg kg$^{-1}$ DM at the mean concentration of 0.76 mg kg$^{-1}$ DM (Table 2). Grain of spring barley grown on limed soil con-

Table 2

Content of nickel in grain (mg $kg^{-1}$ DM) of spring barley cultivated on loessial soil (mean from 4 years)

| Object no. | Treatments of fertilizers (B) | $A_1$ | | $A_2$ | | Mean (B) |
|---|---|---|---|---|---|---|
| | | mean | range | mean | range | |
| (mg $kg^{-1}$ DM) | | | | | | |
| 1 | $N_0P_0K_0$ | 0.80 | 0.60-1.00 | 0.72 | 0.66-0.80 | 0.76 |
| 2 | $N_0P_1K_1$ | 0.75 | 0.66-0.85 | 0.69 | 0.47-0.70 | 0.72 |
| 3 | $N_{0,5}P_1K_1$ | 0.54 | 0.33-0.68 | 0.49 | 0.30-0.80 | 0.51 |
| 4 | $N_1P_1K_1$ | 0.88 | 0.68-1.03 | 0.47 | 0.40-0.55 | 0.67 |
| 5 | $N_{1,5}P_1K_1$ | 0.91 | 0.69-1.09 | 0.63 | 0.55-0.75 | 0.77 |
| 6 | $N_1P_0K_1$ | 0.80 | 0.72-0.85 | 0.64 | 0.55-0.78 | 0.72 |
| 7 | $N_1P_{0,5}K_1$ | 0.78 | 0.64-0.88 | 0.70 | 0.50-0.95 | 0.74 |
| 8 | $N_1P_{1,5}K_1$ | 0.65 | 0.46-0.90 | 0.46 | 0.40-0.50 | 0.55 |
| 9 | $N_1P_1K_0$ | 0.72 | 0.55-0.87 | 0.44 | 0.32-0.60 | 0.58 |
| 10 | $N_1P_1K_{0,5}$ | 0.67 | 0.49-0.76 | 0.67 | 0.50-0.91 | 0.67 |
| 11 | $N_1P_1K_{1,5}$ | 0.80 | 0.70-0.88 | 0.66 | 0.36-0.82 | 0.73 |
| 12 | $N_{0,5}P_{0,5}K_{0,5}$ | 0.84 | 0.71-1.02 | 0.69 | 0.60-0.76 | 0.76 |
| 13 | $N_{1,5}P_{1,5}K_{1,5}$ | 0.70 | 0.53-0.88 | 0.54 | 0.40-0.72 | 0.62 |
| 14 | $N_2P_2K_2$ | 0.80 | 0.63-1.14 | 0.55 | 0.40-0.74 | 0.67 |
| Mean (A) | | 0.76 | - | 0.60 | - | - |
| LSD | | A* = 0.170, B = ns<br>AB = ns | | | | |

$A_1$ – NPK fertilization + Mg without Ca constans, $A_2$ – NPK fertilization +MgCa constans, LSD – lowest significant difference for: A – liming, B – mineral fertilization (irrespective from liming), AB – interaction between liming and mineral fertilization,
* significant at $p = 0.05$, ns – no significant differences

tained nickel in the amounts from 0.44 to 0.72 mg $kg^{-1}$ DM and the average content of 0.60 mg $kg^{-1}$ DM. The effect of liming consisting in the decreased nickel quantities was statistically significant.

Liming, while improving the soil reaction, reduces the uptake of some micronutrients, including nickel, by cereal plants (KANIUCZAK 1997, SCOTT-FORDSMAND 1997, MALAVOLTA, MORAES 2007, MILIVOJEVIČ et al. 2008, WŁAŚNIEWSKI et al. 2014). Liming applied to soil with very acidic reaction (in Serbia) significantly decreased the nickel uptake by winter wheat and winter barley grain (MILIVOJEVIČ et al. 2008). Studies performed by HAMNER et al. (2013) showed a negative correlation of nickel content in winter wheat and spring barley grain with pH value.

The average nickel concentration in wheat grain was twice as high as in spring barley, but only in the plants originating from non-limed objects, whilst the Ni content was similar in grain from limed objects. The nickel level determined in grains of the test cereals did not exceed the threshold set for grain suitable for consumption (Kabata-Pendias et al. 1993), same as in grain of winter wheat grown on sandy and silty soils in Podkarpacie (Właśniewski 2003).

Mineral fertilization (B) applied independently of liming had no significant impact on the nickel content in winter wheat grain (Table 1). There was some tendency towards a lower Ni quantity in winter wheat grain due to increasing NPK doses applied at the constant N:P:K ratio, although only for the basic dose (treatments $N_0P_0K_0$, $N_{0,5}P_{0,5}K_{0,5}$, $N_1P_1K_1$) – Table 1. Application of 1.5- and 2-fold higher NPK doses resulted in an increase in the element's content in wheat grain, which was due to the supplying of soil with elevated doses of superphosphate containing the largest amounts of nickel among all fertilizers used. A similar trend was recorded in grain of wheat grown on non-limed soil. Decrease in the nickel concentration in winter wheat grain from acidic soil due to applied mineral NPK fertilization was also observed by Milivojevič et al. (2008). And similarly, Hamner et al. (2013) reported that applying NPK mineral fertilizers decreased nickel content, while prolonged supply of natural fertilizer caused slight increase in the element concentration in wheat grain.

The winter wheat grain originating from limed objects showed a trend to decrease the nickel content due to increasing rates of nitrogen at a constant fertilization using other components (Figure 1). Different dependencies were

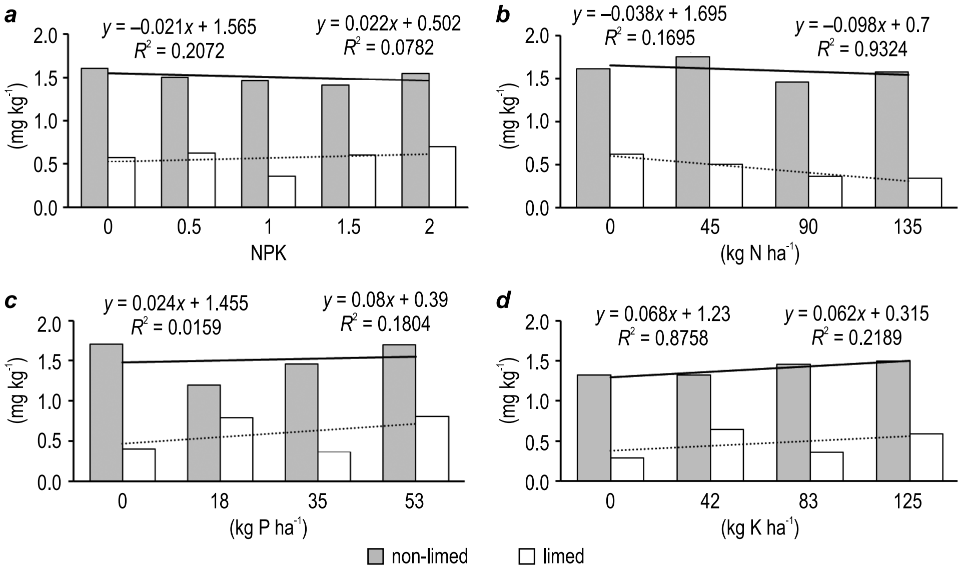


Fig. 1. The influence of liming and mineral fertilization: *a* – NPK (NPK at constant in the range of $N_0P_0K_0$ - $N_2P_2K_2$), *b* – N (at constant $P_1K_1$), *c* – P (at constant $N_1K_1$), *d* – K (at constant $N_1P_1$) on the nickel content in grain of winter wheat (trend line: non-limed —, limed ·····; regression equation, coefficient of determination)

discovered in studies by SVEČNJAK et al. (2013) on loamy soil, in which increasing the nitrogen fertilization resulted in an increasing tendency of nickel amounts in winter wheat grain. The winter wheat grain originating from unlimed objects showed a trend towards an increasing nickel content due to the increasing doses of phosphorus (starting from object $N_1P_{0,5}K_1$) and potassium at constant fertilization with the other components.

Mineral nutrition (B), regardless of liming, did not affect the nickel content in spring barley grain (Table 2). However, there was a trend towards increasing nickel concentrations in barley grain from some treatments where no liming was applied ($A_1$), due to increasing NPK does at a constant N:P:K ratio (objects $N_0P_0K_0$, $N_{0,5}P_{0,5}K_{0,5}$, $N_1P_1K_1$) – Table 2, Figure 2. An experiment

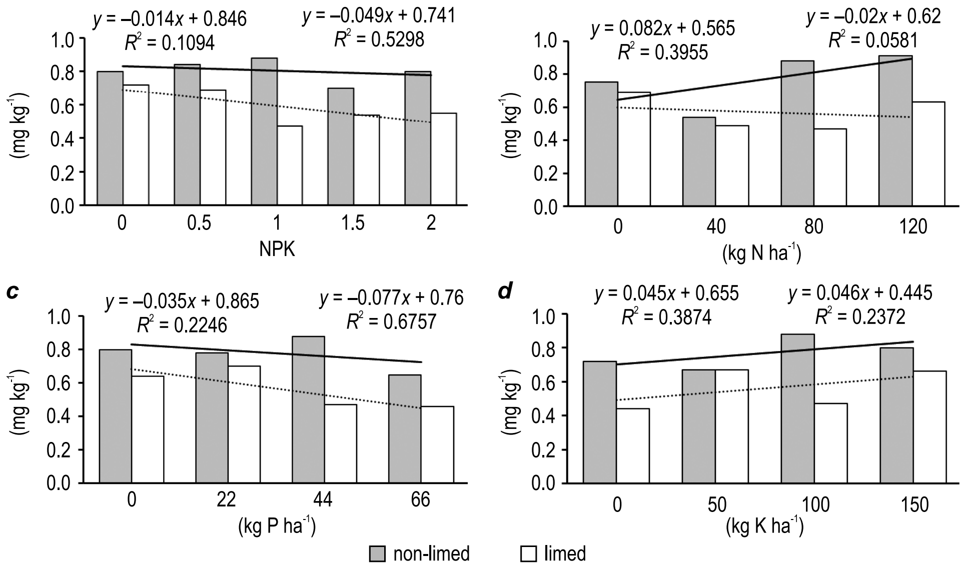


Fig. 2. The influence of limed and mineral fertilization: *a* – NPK (NPK at constant in the range of $N_0P_0K_0$ - $N_2P_2K_2$), *b* – N (at constant $P_1K_1$), *c* – P (at constant $N_1K_1$), *d* – K (at constant $N_1P_1$) on the nickel content in grain of spring barley (trend line: non-limed —, limed ······; regression equation, coefficient of determination)

by HEJCMAN et al. (2013) also revealed a slight increase in the nickel content in spring barley grain grown on loess as a result of prolonged mineral NPK fertilization and a decrease in this element's concentration when mineral and natural fertilization were combined. MILIVOJEVIČ et al. (2008) proved lack of the influence of mineral fertilization on the nickel content in spring barley grain.

There was an interaction between liming and mineral fertilization (AB) in shaping the nickel concentration in wheat grain sometimes consisting in a several-fold lower nickel level in grain from limed objects ($A_2$) compared to non-limed ones ($A_1$) – Table 1. Interaction of these procedures had no statistically significant effect in the case of spring barley, although a trend towards a decreasing nickel content in treatments with liming was recorded (Table 2).

In a study performed by Milivojevič et al. (2008), nitrogen fertilization in combination with liming as well as fertilization using all NPK components also combined with $CaCO_3$ application halved the nickel content in winter barley grain and reduced it to a lesser extent in winter wheat grain. These authors showed a remarkable decrease in the nickel concentration in grains of winter cereals, both wheat and barley, after the application of NPK mineral fertilization along with liming combined with manure.

# CONCLUSIONS

1. Liming had a statistically significant effect on a decrease in the nickel content in grain of both winter wheat and spring barley.

2. Mineral fertilization (regardless of liming) had no statistically significant influence on the nickel concentration in grain of the test cereals. However, there was usually a tendency towards a decreasing content of this metal in winter wheat grain in response to the increasing NPK doses at a constant N:P:K ratio. No univocal trend in the nickel content of spring barley grain shaped under the influence of increasing NPK doses was observed.

3. Interaction of liming with mineral fertilization showed a statistically significant impact on the nickel concentration in winter wheat grain, making its several-fold lower in grain of the cereal plants from limed than from non-limed treatments. No statistically confirmed interaction between these two agrotechnical procedures on the nickel content in the grain of spring barley was recorded; instead, a tendency towards a decreasing nickel content in grain from limed treatments was observed.

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