The role of titanium in biomass production and its influence on essential elements' contents in field growing crops

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ABSTRACT

The role of titanium (Ti) in plant metabolism is not so far fully clear. Many positive beneficial effects as well as a few adverse effects of Ti application are described in literature. The objective of our study was to investigate the effects of Ti foliar applications alone or in combination with Mg on the yield and accumulation of essential cations in consumable portions of frequently grown agricultural crops (potatoes, winter wheat and spring barley) grown under reduced and optimum nitrogen availability in field conditions. Nitrogen side dress fertilization significantly affected the investigated parameters, especially yield and N content. The effect of foliar Ti applications was substantially influenced by the nutrient N status of the individual plants. The plant response to Ti applications was almost negligible under N deficiency. At N treated plots the responses were much clearer but not many significant differences were found confirming high soil buffering capacity and many counteracting effects under field conditions.

Keywords: titanium; potatoes; winter wheat; summer barley; yield; content of nutrients; foliar application

The biological role of titanium in plant development and metabolism has been studied for more than ninety years. Traetta-Mosca (1913) observed that Ti enhanced the growth of tobacco leaves and noticed that Ti is an inherent constituent of the ash from all plants. They proposed that Ti might participate in plant metabolism as a redox catalyst. It was assayed that Ti mainly accumulates in assimilation organs (Geilmann 1920). A systematic study of Ti dose-response relationship was done on several crops by Němec and Káš (1923). They firstly reported optimal Ti content causing intensified plant growth and development, increased intensity of green colour (higher chlorophyll content). The detailed history of Ti research was reviewed by Kužel et al. (2003b).

Titanium is present in soil in a relatively high concentration within the range from several tenths of percent up to several percentage points. The overwhelming majority of Ti is poorly available for plants, because it is present mostly in the form of minerals that are insoluble in water (as TiO_2 or $FeTiO_3$) (Dumon and Ernst 1988). Ti is generally present in most plants in relatively low concentrations (0.1–10 ppm) (Wait 1896), but there is no evidence about the essential participation of naturally occurred Ti in plant metabolism (Carvajal and Alcaraz 1998). We have recently proposed a hypothesis (Hrubý et al. 2002) considering the "positive" beneficial effects of Ti as a result of the effect called "hormesis". This effect is based on the fact that a harmful substance (poison) at low doses can cause stimulation, because it induces counter effects against its influence that are at low doses higher than proper doses to eliminate the toxic effects. Since Ti is considered to be non-toxic for animals, the effects on herbivores should be negligible in this particular case.

Several authors presented that the application of Ti increases the yield of about 5–50% for various crops (Pais 1983, Balík et al. 1989, Carvajal and Alcaraz 1998). The positive effect of Ti applications on the contents of some essential elements in young or mature plant tissues is frequently documented (Giménez et al. 1990, Carvajal and Alcaraz 1998). The increased activity of certain enzymes as peroxidase, catalase and nitrate reductase in plant tissues (Pais 1983), and the increased lipoxygenase (Daood et al. 1988) and phosphofructokinase (Simon et al. 1990) activities in tomatoes

Table 1. The contents of available nutrients and exchangeable pH values in Suchdol soil during the 3 years of the experiment

Year	P (mg/kg)	K (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	pH/KCl
2001	115 ± 24	174 ± 32	181 ± 19	7793 ± 522	7.2 ± 0.1
2002	132 ± 10	219 ± 22	202 ± 22	6717 ± 490	7.0 ± 0.2
2003	117 ± 15	225 ± 26	214 ± 9	7409 ± 620	7.0 ± 0.2

were also observed. Martinéz-Sanchéz et al. (1993) found the increased ascorbate content and Simon et al. (1990) found the increased content of citrate and malate in plant tissues as a result of the application of Ti compounds. Pais et al. (1969a, b) discovered the strong effect of Ti rate either on stimulation or reduction of pepper and tomatoes biomass development. Concentration of 1 ppm Ti in nutrient solution was groundbreaking for plant response. Lower limited concentration 0.4 ppm Ti found for cabbage development Hara et al. (1976), but Hrubý et al. (2002) observed some phytotoxic effect to oat biomass at concentration of 18 ppm Ti in nutrient solution.

Although the effects of the applications of Ti alone under field conditions were already studied, the effects of Ti in combination with other mineral nutrients are according to our knowledge mostly uncharted. There is evidence (Hrubý et al. 2002) that Ti should interact with the metabolism of magnesium (Mg). The objective of our study was to investigate the effect Ti foliar application alone or combined with Mg on the yield of consumable portions of frequently grown agricultural crops (potatoes, winter wheat and spring barley) grown under reduced and optimum nitrogen availability and the accumulation of essential cations in investigated parts of the plants.

MATERIAL AND METHODS

Experimental field. The experiment was set up at the Experimental University Station at Suchdol following a three-year crop rotation (2001–2003). The soil of this location is loamy Chernozem containing a sufficient amount of available nutrients; see Table 1 for analytical data. Experimental design was identical for all crops and the individual treatments kept the same area for all three experimental years. There were four individual treatments set up without and with nitrogen side dress application in a total of eight treatments, each in four replications. The size of the individual plots was 5.0 × 4.0 m. Experimental design including applied concentrations and total annual rates of individually applied elements as described in Table 2. Foliar application was done exactly the same for all crops and the control treatment was sprayed by tap water (2000 ml per plot) at each application. Titanium applied was as a solution of Ti citrate and magnesium as a solution of $MgSO_4.7\ H_2O$ in the same amount of water per plot. Treatment Mg + Ti was sprayed individually by both solutions totally receiving 2000 ml of water. Each crop was sprayed three times during vegetation. All plants were harvested at full maturity. In the case of potatoes all tubers were checked for fresh and dry matter yield at

Table 2. Experimental design expressing rates of foliarly applied elements

Treatment No.	Soil application	Foliar application	Concentration of substances (mg/kg)	Total amount** (g/ha)
1	0	0	water	0
2	0	Ti	18 – Ti solution	30 – Ti
3	0	Mg	200 – Mg solution	6000 – Mg
4	0	Mg + Ti	18 – Ti solution + 2000 – Mg solution	30 – Ti + 6000 – Mg
5	+ N*	0	water	0
6	+ N*	Ti	18 – Ti solution	30 – Ti
7	+ N*	Mg	2000 – Mg solution	6000 – Mg
8	+ N*	Ti + Mg	18 – Ti solution + 2000 – Mg solution	30 – Ti + 6000 – Mg

*N rates differ among individually growing crops

**total amount of elements delivered by three sprays for each crop each replication, the biomass of both grains were checked for yield of grain as well as straw on fresh and dry basis. Dried biomass (65°C) was grounded and analysed.

Potatoes. Potatoes (variety Cordoba) were planted on the 30th of April and harvested on the 22nd of August. There was a first crop for the experiment at the site, before the oat was planted at the whole location receiving an identical amount of NPK fertilizers. Potatoes were not fertilized by organic fertilizers; treatment with N application received 120 kg N/ha in the form of ammonium nitrate-limestone (27.5% N). Nitrogen was applied 16 days after seeding just before the first leaves appeared and cultivated into the top layer of the soil. Foliar application started at the beginning of June with a plant height of 30 cm. The second and third sprays were done in two-week intervals.

Winter wheat. The year after the harvest of the potatoes, winter wheat (variety Alana) was sown on October 15th and harvested on August 16th. The wheat has received a total of 140 kg N/ha applied also as ammonium nitrate. The total rate was split in half and applied in early spring and before stem elongation. Foliar application was started just after second side dressing at stem elongation, the second one was done shortly before ear emergence and the last foliar application was done at the beginning of the flowering stage.

Summer barley. The third crop was summer barley (variety Akcent) sown on the 14th of March and harvested on 22nd of August. The barley received 70 kg N/ha side dress applied five weeks after sowing. Foliar application was started at the beginning of stem elongation; the second one was done shortly before the beginning of ear emergence and last one at the beginning of flowering.

Soil and plant analysis. The soil was analysed for the content of available nutrients using Mehlich III extraction procedure (Mehlich 1984); K, Mg and Ca were determined by atomic absorption spectrometry (Varian SpectrAA-300) and P by spectrophotometry (Specol 210). Exchangeable pH in the soil was determined in 0.2 mol/l KCl suspension by glass electrode (Zbíral 2001). Organic C was determined spectrophotometrically after the oxidation of organic matter by $K_2Cr_2O_7$ (Sims and Haby 1971). The total N content in plants was determined after wet digestion by concentrated sulphuric acid with the addition of selenium calalyst using Tecator digestion system (Tecator 20) and following distillation by Kjeltec 1030 (Horwitz 1980). Other elements in plant biomass were determined after dry combustion and solubilization of ash with nitric acid by flame atomic absorption spectrometry (Varian SpectrAA-300) (Miholová et al. 2003). The quality of the analyses was controlled by reference materials.

Statistical analysis. Analyses of variance were conducted and significant differences among treatments were determined at a level of 95% using Statgraphic version 5.0 software.

RESULTS AND DISCUSSION

Results of foliar Ti and Mg applications under two different nitrogen statuses showed the importance of optimum nutrient content in the soil on the additional effect of foliar application on the yield of the crops. Figure 1 shows the mean yield of all three growing crops. Soil dress N application led to mean no significant effect on the yield of tubers as well as winter wheat grain, but other investigated yield parameters like barley grain

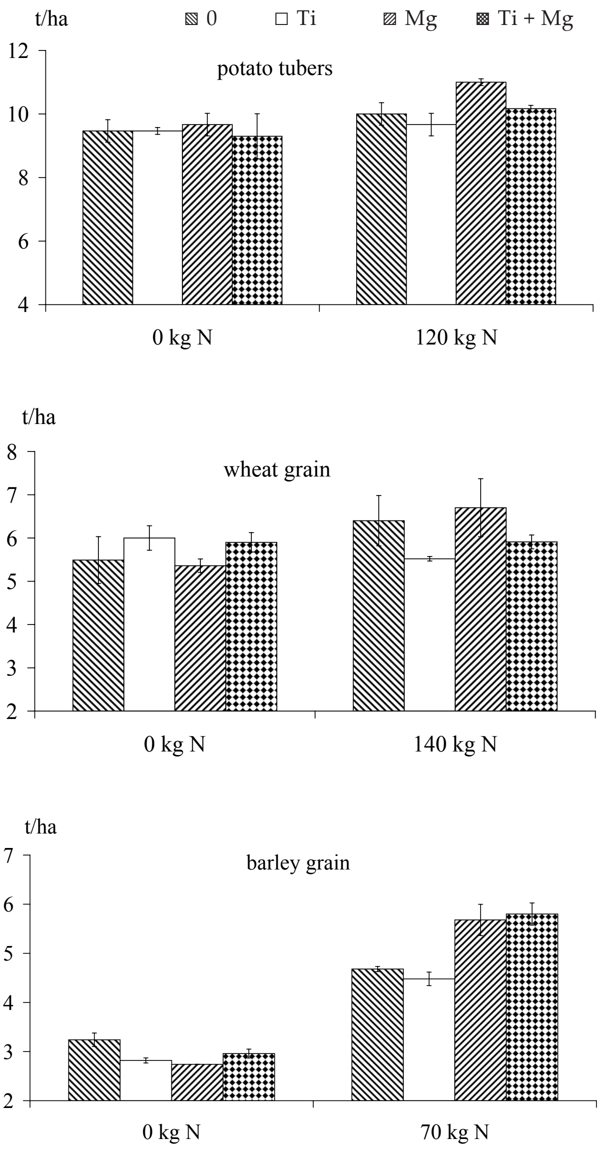

Figure 1. The yield of dry weight (t/ha) of consumable parts of investigated crops

and the straw of wheat as well as barley showed significantly increased biomass after N application. Results have confirmed high soil fertility of Chernozems having the capacity to supply potatoes and partly wheat under similar conditions on both unfertilised and fertilized treatments. Only a low response of N fertilizers to biomass yield was also reported by (Vaněk et al. 1997). The reduction of N availability could be easily seen on the yield of straw and especially on both straw and grain yield of barley growing on partly depleted treatments. Foliar element application has more competitors in the field compared to the model experiments. Plants usually stayed in the field up to their maturity compare to shorter growing cycles in the model experiments and have a higher capacity to eliminate nutrient disorders due to lower plant density per area and possibility to take elements from deeper soil layers. Our experimental site represents a soil with deep Ap profile developed above loess with a capacity to bind nutrients and functioning as an additional nutrient supply source.

Foliar application of tested elements did not show a consistent effect on the different nitrogen treatments. The yield of all tested plants was not significantly changed from non-fertilized treatments. Our results have confirmed that under nutrient deficiency only a deficient element can increase development of plant biomass. In the case of nonfertilized treatments N mainly affected plant development and the application either Mg or Ti has not stimulated plant development. Mg was not the limiting element within the experiment (Table 1) and Ti application did not show any significant effect under N limited conditions. Ti toxicity (Cígler et al. 2005) was not proved un-

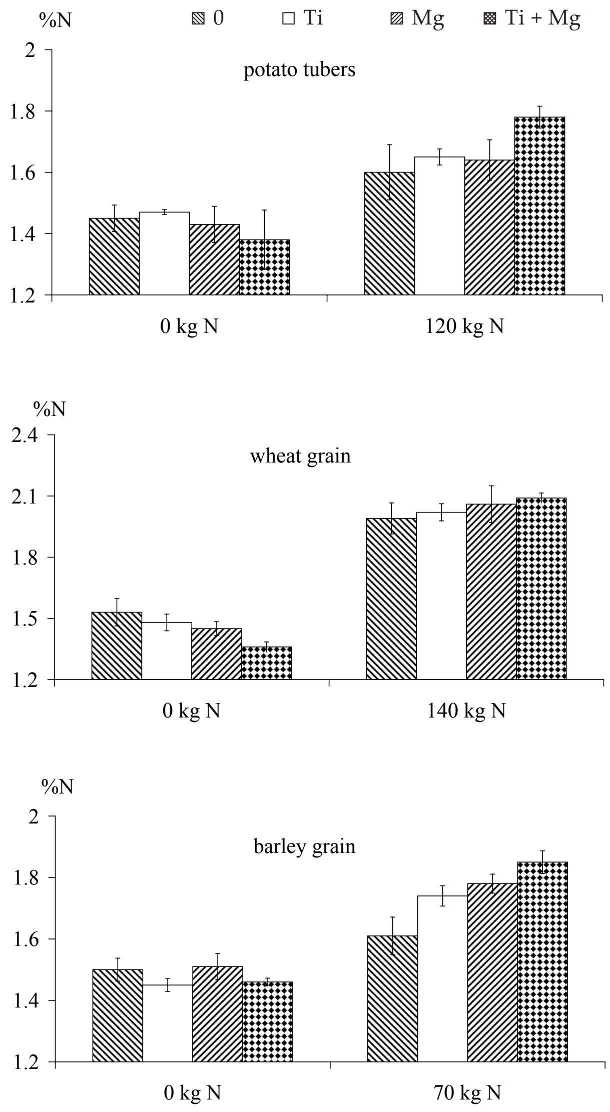

Figure 2. The content of total nitrogen (% N) in dry weight of crop consumable parts

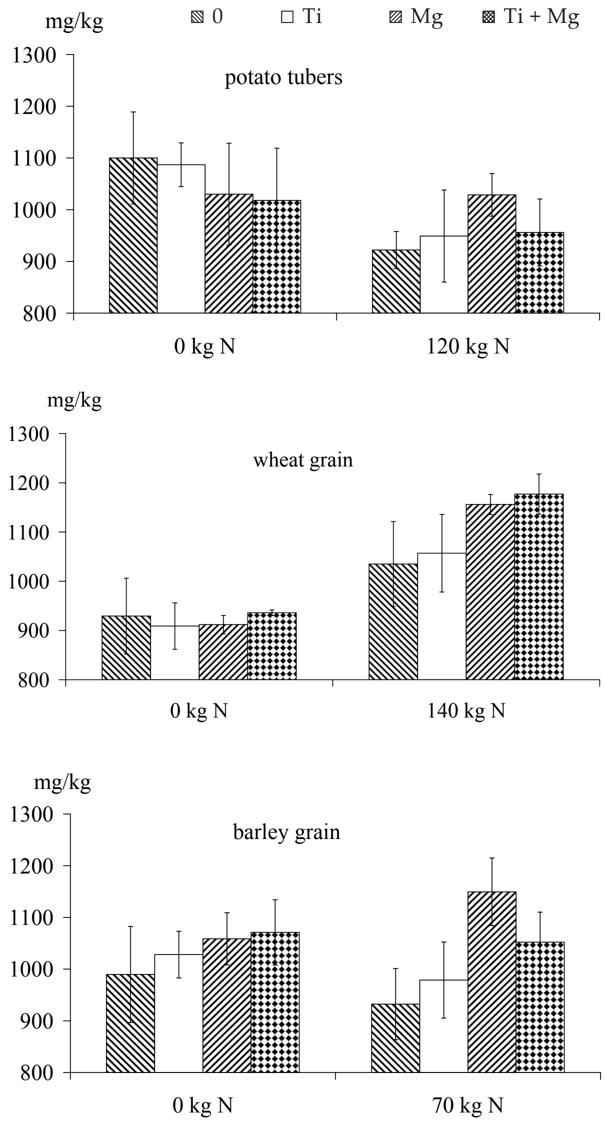

Figure 3. The content of total magnesium (mg/kg) in dry weight of crop consumable parts

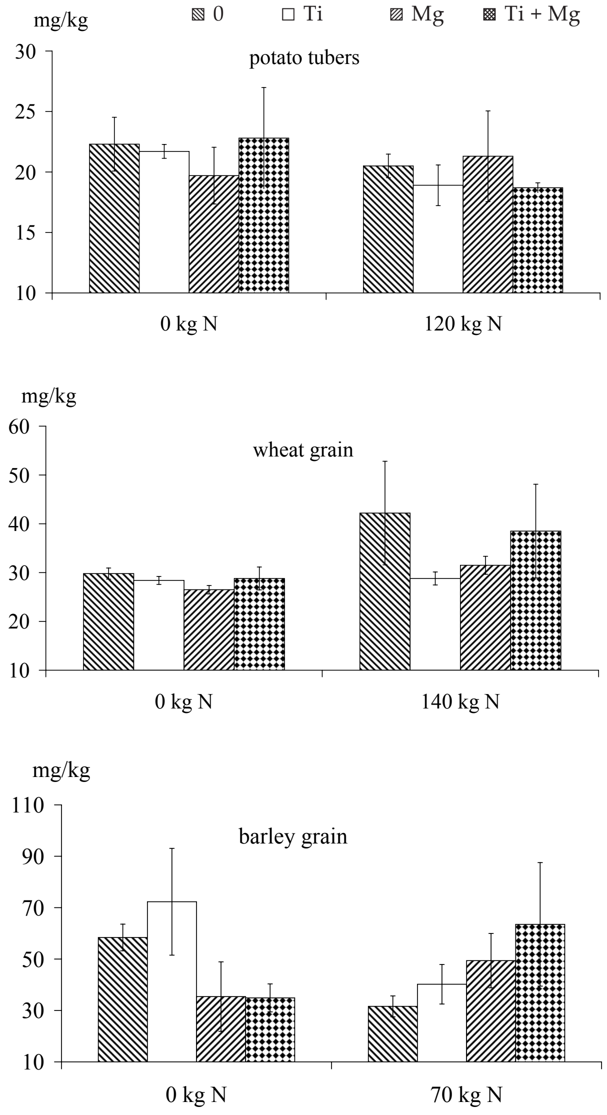

Figure 4. The content of total iron (mg/kg) in dry weight of crop consumable parts

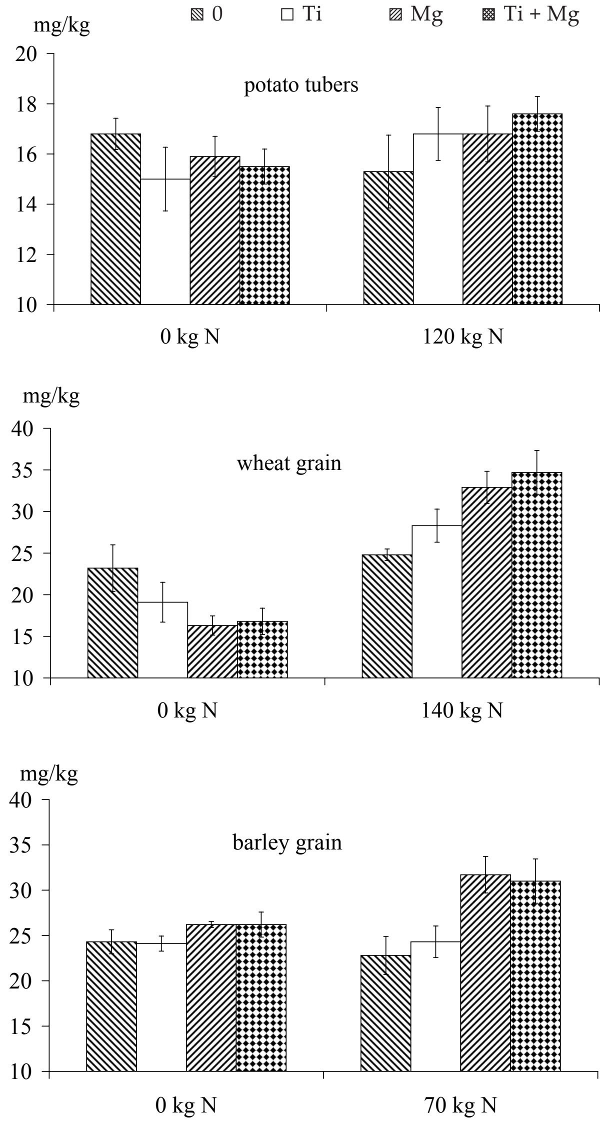

Figure 5. The content of total zinc (mg/kg) in dry weight of crop consumable parts

der the tested conditions. The foliar application showed a different yield pattern at treatments receiving N. In most cases a positive influence of Mg application was found and treatments showed in all cases to have the highest yield. Good yield response of Mg led to interpretation that under higher N availability Mg was the element reducing yield development. Titanium was the element of main importance in this experiment and showed mainly consistent results among the crops. Weak yield reduction was observed for all crops. A similar tendency was also found for the comparison of Mg + Ti addition with the treatment sprayed by Mg solution only. In two cases a yield reduction was found. The effect of yield reduction found in the field experiment was lower compared to the pot experiment with oat (Hrubý et al. 2002). Maroti et al. (1984) observed high reduction of tobacco biomass yield in a hydroponical experiment if the nutrient solution contained 5 ppm Ti. The experiments are difficult to compare but the mean tendency to biomass reduction after Ti application was also introduced in our case in the field experiment.

N side dress application has significantly affected the content of total N in consumable parts of all tested plants (Figure 2). Similar results also found Setatou and Simonis (1996) for maize and Yang-Yuen et al. (1999) for oil seed rape. Foliar application did not affect nitrogen content in all crops at treatments without N application. The above-mentioned N deficiency at these treatments describing yield stability was also confirmed by almost equal N content there. Treatments tested at plots with elevated N application showed a slightly different pattern. The application of Ti as well Mg or their mixture led to a steady slight increase in the N content. The application of Mg was able to increase the chlorophyll's biosynthesis and therefore also N content in the analysed tissues. Similar results were also found by Yang-Yuen et al. (1999) for oil seed rape. The application of Ti alone or together with Mg showed for all plants slight but consistent growth of N content in plant biomass.

The determination of Mg in plant biomass showed two slightly different patterns (Figure 3) again. The treatments receiving no soil N fertilizers were not able to introduce any significant Mg content change either with treatments foliarly sprayed with Mg or Mg + Ti solutions, again confirming major role of the lack of N. Ti application either alone or with Mg did not show any clear tendency for all the tested plants. Treatments with side dress N application did not show much different Mg plant content compare to N unfertilised treatments but due to higher N status plant response was easily recognizable. Mg plant content responded well to Mg or Mg + Ti foliar application showing the highest Mg content among investigated treatments. The individual Ti application showed only a slight tendency to stimulate Mg content in the investigated parts of plants. The comparison of Mg + Ti to Mg treatment did not show any clear trend.

Iron content was similar in plants at both N untreated and treated treatments (Figure 4). The response of plants to foliar application was not much different in both N treatments. In the case of a single Ti application we got the same trend for potato tubers as well as for wheat grain showing a slight reduction in plant iron content. These results support the conclusion of Kužel et al. (2003a, b) showing the reduction of Fe concentration in biomass after Ti foliar application. The iron pattern was opposite for the barley grain. The application of Ti together with Mg did not present clear results at all. The field environment, causing high changes within individual experimental years, can significantly modify conditions of optimum element uptake.

The accumulation of zinc in the investigated plant parts was more affected by N fertilization than iron (Figure 5) but a majority of the expressed trends is not supported by significant differences coming from statistical analyses. At N unfertilised treatments Ti application either alone or combined with Mg slightly decreased or did not change the Zn content in plant parts. The response in the Zn content to foliar Ti application tested at N fertilized treatment was just the opposite. In most cases Zn content in the plant parts grew up due to Ti or Ti + Mg application which is in agreement with Kužel et al. (2003a, b). The effect of foliar Ti application was substantially influenced by nutrient status (above all N) of individual plants. The plant response to Ti application was almost negligible under N deficiency. At N treated plots the responses were much clearer but not many significant differences were found.

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ABSTRAKT

Úloha titanu při tvorbě výnosu a jeho vliv na obsah živin v konzumních částech rostlin pěstovaných v polních podmínkách

Význam titanu v metabolismu rostlin není dosud uspokojivě objasněn a celá řada pozitivních reakcí, stejně jako některé nepříznivé odezvy po jeho aplikaci byly prezentovány ve světové literatuře. Cílem naší práce bylo zjistit vliv samotné aplikace titanu a aplikace spolu s hořčíkem na výnos a obsahy vybraných živin v konzumních částech brambor, ozimé pšenice a jarního ječmene pěstovaných v tříletém pokusu za podmínek úplného vynechání dusíkatého hnojení v celém intervalu a při optimálním hnojení dusíkem. Různé dusíkaté hnojení významně ovlivnilo výnos sledovaných částí rostlin a obsah dusíku v nich. Hnojení dusíkem mělo významný vliv i na reakci foliárně ošetřovaných rostlin. Na nehnojené části pokusu nebyla zjištěna žádná významná odezva na foliární aplikaci. V podmínkách zabezpečené výživy dusíkem byla reakce na foliární aplikaci mnohem významnější, i když v řadě případů neprůkazná. Méně významná odezva na aplikaci titanu v polních podmínkách v porovnání s modelovými byla způsobena vysokou pufrační schopností půdy, vysokou půdní úrodností a řadou vedlejších vlivů.

Klíčová slova: titan; brambory; ozimá pšenice; jarní ječmen; výnos; obsah živin; foliární aplikace

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