ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 64 8 Number 1, 2016

http://dx.doi.org/10.11118/actaun201664010081

DETERMINATION OF THE TITANIUM CONTENTS IN THE WINTER OILSEED RAPE PLANTS (*BRASSICA NAPUS* L.) BY THE APPLICATION OF FERTILIZER CONTAINING TITANIUM

Peter Kováčik[1], Vladimír Šimanský[2], Pavel Ryant[3], Marek Renčo[4], Jozef Hudec[1]

[1] Department of Agrochemistry and Plant Nutrition, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 01 Nitra, Slovak Republic

[2] Department of Soil Science, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic

[3] Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

[4] Department of Plant Nematology, Institute of Parasitology, Slovak Academy of Sciences, Hlinkova 3, 040 01 Košice, Slovak Republic

Abstract

KOVÁČIK PETER, ŠIMANSKÝ VLADIMÍR, RYANT PAVEL, RENČO MAREK, HUDEC JOZEF. 2016. Determination of the Titanium Contents in the Winter Oilseed Rape Plants (*Brassica napus* L.) by the Application of Fertilizer Containing Titanium. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 64(1): 81–90.

In order to obtain the information about changes of titanium contents in the phytomass during the growing season of winter oilseed rape and about the titanium contents drawn by the rape yield during two farming years the small plot field trial was established. In the trial the fertilizer Mg-Titanit (MgTi) containing 8.5 g of titanium in 1 liter was used. The experiment consisted of 5 treatments. 0 – control treatment without MgTi fertilizer; 2xTi0.2 – two applications of MgTi in the dose of 0.2 l/ha; 3xTi0.2 – three applications of MgTi in the dose of 0.2 l/ha; 2xTi0.4 – two applications of MgTi in the dose of 0.4 l/ha; 3xTi0.4 – three applications of MgTi in the dose of 0.4 l/ha. The fertilizer was applied in spring during two, or three different growth stages: BBCH 50, BBCH 59, BBCH 66. The first plant sampling was carried out shortly before the first application of fertilizer (BBCH 50). The second, third and fourth sampling was taken 2–3 weeks after the application of Mg-Titanitu (BBCH 59, BBCH 66, BBCH 71). The obtained results showed that the titanium content in the phytomass of rape was falling during the monitored period. The titanium content in the rape aboveground phytomass varied in the interval from 16.81 to 67.6 mg/kg and in the root in the interval from 56.6 to 258.81 mg/kg. The titanium application on plant leaves in the quantities from 3.4 to 10.2 g per hectare of soil did not have the unambiguous impact on the titanium content in the rape phytomass. In the yield of one tonne of seed and appropriate quantity of rape straw on average 20 grams of titanium was taken in.

Keywords: fertilizing, Mg-Titanit, stimulant, titanium, winter rape

INTRODUCTION

The essential part of elements occurring in plants is taken in by plant roots from soil, apart from C, O and partially also H and S. The quantity of a particular nutrient taken into a plant depends on many factors. One of them is the quantity of the available form of nutrient in soil. The titanium availability in acid, neutral and alkaline soils is low. Therefore its content in plants is low and it usually varies in the interval 0.1–12.0 mg/kg of dry matter (Ceccantini *et al.*, 1995; Tlustoš *et al.*, 2005). However, some authors recorded higher contents at the level of 20–28 $mg.kg^{-1}$ Ti (Terlikowski and Górnicki, 1993; Lopez-Moreno *et al.*, 1996) even 120 mg/kg

(Czekalski, 1987). The titanium content is lower in the generative organs than in the vegetative ones (Ercoli *et al.*, 2008). Kováčik *et al.* (2014) recorded 5.77 times more titanium in the rape straw than in the seed. In the experiments of Hara *et al.* (1976) the titanium content in cabbage was increased from the outside leaves towards the cabbage centre with the highest contents in stump from 1 to 10 mg/kg Ti. The titanium content in the cabbage roots varied in the interval from 70 to 3,960 mg/kg Ti. The critical concentration of titanium – its overrun would mean the plant damage – occurred in the inner leaves of cabbage at the level of 4 mg/kg and in the roots 3,000 mg/kg (Hara *et al.*, 1976).

The low solubility of the titanium compounds in soil and consequently the low bio-availability of titanium allow to use the metallic shavings of the titanium content (1% content Ti) in the compost production. Ercoli *et al.* (2008) have detected the positive impact of those shavings applied into soil in the doses of 15 and 30 t/ha on the maize grain yield.

In spite of several data about the positive impact of the titanium application into soil, but predominantly on the plant leaves, on the height and yield quantity of the cultivated crops (Traetta-Mosca, 1913; Pais, 1983; Simon *et al.*, 1988; Balík *et al.*, 1989; Tichý and Tóth, 1990; Matuškovič, 1995; Carvajal and Alcaraz, 1998; Skupień and Oszmianski, 2007), so far neither evaluation criteria has been elaborated of the available titanium in soil nor criteria for the evaluation of total titanium content in the particular agricultural important crops. Similarly, the information is missing about the titanium intakes from the soil of the cultivated crops. Therefore, the objective of the submitted experiment was to obtain the basic information about the dynamics of the titanium contents changes in the oilseed rape plants during the growing season, and thus to contribute to the creation of the emerging information base related to the titanium contents in plants and the titanium quantities needed for the yield formation of one tonne of rape seed and the appropriate quantity of the vegetative matter.

MATERIAL AND METHODS

The dynamics of the titanium contents changes in the plants of oilseed rape and its determination by the application of fertilizer containing titanium was studied in the small field experiment (20 m^2 per one plot) realized on the Haplic Chernozem (48°42´ N, 17°70´ E – western Slovakia) during two farming years (2010/2011 and 2011/2012). The agrochemical parameters of Haplic Chernozem taken from soil layer 0.0–0.6 m are given in Tab. I. They were determined by the following methods: N_{min} = N-NH_4^+ + N-NO_3^-, N-NH_4^+ – colorimertically by Nessler's agent, N-NO_3^- – colorimertically by the phenol 2.4 disulphonic acid, P – colorimertically (extract Mehlich 3 – Mehlich, 1984), K and Ca – flame photometry (extract Mehlich 3 – Mehlich, 1984), Mg – AAS (extract Mehlich 3 – Mehlich, 1984), S – spectrometrically ICP OES (water extract – Zbíral *et al.*, 2011a), Ti – spectrometrically ICP MS (extract Mehlich 3 – Zbíral *et al.*, 2011b). C_{ox} – oxidometrically by Ťjurin in modification of Nikitin (Dziadowiec and Gonet, 1999), N_t – by distilling (Kjeldahl – Bremner, 1960), pH/KCl – potentiometrically (1.0 mol/dm^3 KCl).

In the trial used fertilizer was Mg-Titanit (MgTi) containing 8.5 g of titanium in 1 liter. Mg-Titanit is dark brown liquid fertilizer (stimulant) with bulk density 1.36 kg/l. Titanium is in form of titanium ascorbate and sulfur with magnesium are in form of magnesium sulphate ($MgSO_4$).

The model crop was winter oilseed rape, cultivar Chagal, which was sown in the third decade of August – 50 individuals per m^2 every year. Experiment consisted of 5 treatments described in Tab. II.

I: *Soil agrochemical parameters before the foundation of experiments in a soil layer 0.0–0.6 m*

Year	N_{min}	P	K	Ca	Mg	S	Ti	N_t	C_{ox}	pH_{KCl}
	mg/kg							%		
2010/2011	13.05	23.0	160	7,650	505	34.5	1.18	0.100	1.25	6.95
2011/2012	19.85	48.5	184	4,413	474	9.7	1.77	0.127	1.38	6.90

N_{min} – inorganic nitrogen; P, K, Ca, Mg – available phosphorous, potassium, calcium, magnesium; S – water soluble sulphur, Ti – bioavailable titan, N_t – total nitrogen, C_{ox} – total (oxidizable) carbon

II: *Treatments of experiment*

Treatment		Growth phase			Total application dosage of Mg-Titanit	Total dosage of Ti
		BBCH 50	BBCH 59	BBCH 66		
Number	Designation	Mg-Titanit application dosage (l/ha)			l/ha	g/ha
1	0	0	0	0	0	0
2	2 x $Ti_{0.2}$	0.2	0.2	0	0.4	3.4
3	3 x $Ti_{0.2}$	0.2	0.2	0.2	0.6	5.1
4	2 x $Ti_{0.4}$	0.4	0.4	0	0.8	6.8
5	3 x $Ti_{0.4}$	0.4	0.4	0.4	1.2	10.2

The samplings of the plant material (aboveground and underground oilseed rape phytomass) were carried out in the growth stages by spade BBCH 50, BBCH 59, BBCH 66, BBCH 71 (Tab. III). After each sampling of the plant material, apart from the last sampling, the application by Mg-Titanit was used on the same day. Besides the first sampling, the other samplings of the plant material were carried out 2 or 3 weeks after Mg-Titanit application. In the first and second sampling 20 middle individuals were taken and in the third and fourth sampling 10 middle individuals were taken from each small field.

The weather conditions from the rape sowing till harvest in the particular years of the experiment are recorded in the new Tab. IV.

In order to determine Ti content in the aboveground and underground phytomass during the oilseed rape growing season and in seed and straw of oilseed rape the inductively coupled plasma atomic emission spectroscopy (ICP-AES) method was used (Yang *et al*., 2012). The titanium sampling from the green oilseed rape phytomass, seed and straw was calculated from the data of its weight, titanium contents and the number of individuals per 1 square metre (29 individuals/m^2). Acquired results were processed by mathematical and statistical method, by analysis of variance (ANOVA) using Statgraphics PC program, version 5.0.

RESULTS AND DISCUSSION

The titanium content in the aboveground and underground oilseed rape was falling during the monitored period (from the growing period BBCH 50 to BBCH 71) – (Tab. V). These data correspond with the information that in the majority of annual crops the nutrients content decreases along with the following growing period (Scaif and Turner, 1983). The titanium content in the aboveground phytomass varied in the interval from 16.81 to 67.6 mg/kg and in the roots in the interval from 56.6 to 258.81 mg/kg. The titanium accumulation in roots was from 1.53 to 9.9 times higher than in the aboveground phytomass (Tab. V and VI).

After the first application of Mg-Titanit the titanium content was increased in the plants of oilseed rape in both years of the experiment (treatment 2 to 5 versus treatment 1). Paradoxically, the titanium content was increased more considerably in plant roots in those treatments where a lower dose of Mg-Titanit was applied (treat. 2 and 3) than in ones where a higher dose of Mg-Titanit was applied (treat. 4 and 5). The effect of the second spraying by Mg-Titanit (applied in the growing period BBCH 59) on the titanium content in the oilseed rape plants did not correspond with the effect of the first spraying (applied in the growing period BBCH 50). The second spraying caused that

III: *Growth stages of sampling of winter oilseed rape plant and spraying fertilizer Mg-Titanit*

Type of treatment			
1st sampling and subsequent 1st Ti spray	2nd sampling and subsequent 2nd Ti spray	3rd sampling and subsequent 3nd Ti spray	4th sampling
Growth phase			
occurrence of the inflorescence BBCH 50	yellow bud BBCH 59	flowering BBCH 66	end of flowering BBCH 71

IV: *Evaluation of respective months and years (2010–2012) according to long-term average of precipitation and temperature in Jaslovské Bohunice (8 km far from experimental station)*

Month	Precipitation (mm)					Temperature (°C)				
	lt. normal	2010/2011		2011/2012		lt. normal	2010/2011		2011/2012	
		mm	char.	mm	char.		°C	char.	°C	char.
VIII.	54.87	117.2	EWet	17.5	VDry	19.10	19.65	Nor	20.84	Worm
IX.	44.07	98.4	EWet	23.0	Dry	14.95	14.20	Nor	17.39	Vworm
X.	40.58	28.2	Dry	35.2	Dry	9.77	7.82	Cold	9.50	Nor
XI.	49.52	79.5	VWet	1.0	VDry	4.29	7.50	VWarm	2.74	Cold
XII.	41.99	54.7	Wet	31.3	VDry	0.16	–2.83	Cold	1.87	Warm
I.	28.04	37.4	Wet	57.6	Nor	–1.77	–1.20	Nor	1.09	Warm
II.	32.36	9.8	VDdry	29.0	VDry	0.31	–0.83	Nor	–2.99	Cold
III.	31.41	39.5	Wet	5.9	EDry	4.45	6.17	Warm	6.90	Warm
IV.	39.95	18.6	VDry	15.5	VDry	9.76	13.30	EWarn	11.32	Warm
V.	51.11	51.8	Nor	45.1	Dry	14.71	15.75	Nor	16.87	Warm
VI.	71.76	134.9	VWet	40.1	Dry	17.62	19.20	Warm	20.07	VWarm
VII.	62.78	113.9	VWet	81.9	Nor	19.49	19.14	Nor	22.05	EWarm

lt. normal – long time normal (1961–1990); char. – characteristic; Nor – normal data; V – very; E – extremly

V: *Dynamics of titanium contents changes in oilseed rape plant during growing season*

Treatment		Growth stage	Abovegroung phytomass			Undeground phytomass		
			Ti (mg/kg – 100% dry matter)					
No.	Marking		2011	2012	Mean	2011	2012	Mean
1–5	0Ti	BBCH 50	64.60	67.60	66.10	258.81	119.87	189.34
1	0Ti	BBCH 59	44.22	49.41	46.81	223.70	89.52	156.61
2–3	$Ti_{0.2}$		48.41	61.71	55.06	249.90	94.22	172.06
4–5	$Ti_{0.4}$		58.71	57.29	58.00	234.81	91.33	163.07
1	0Ti	BBCH 66	34.31	35.83	35.07	204.21	71.87	138.04
2–3	$Ti_{0.2}$		28.90	23.50	26.20	197.00	87.86	142.43
4–5	$Ti_{0.4}$		28.11	26.69	27.40	194.21	88.03	141.12
1	0	BBCH 71	22.41cd ^{bc}	16.81a ^{a}	19.61a ^{a}	200.70c ^{c}	56.60a ^{a}	128.65a ^{a}
2	2 x $Ti_{0.2}$		19.62a ^{a}	20.01c ^{d}	19.81a ^{a}	194.31b ^{b}	58.11a ^{a}	126.21a ^{a}
3	3 x $Ti_{0.2}$		20.61b ^{a}	19.49c ^{cd}	20.05a ^{a}	186.21a ^{a}	62.93b ^{b}	124.57a ^{a}
4	2 x $Ti_{0.4}$		21.71c ^{b}	18.51b ^{bc}	20.11a ^{a}	183.10a ^{a}	65.58c ^{bc}	124.34a ^{a}
5	3 x $Ti_{0.4}$		22.81d ^{c}	17.99b ^{ab}	20.40a ^{a}	184.70a ^{a}	67.54c ^{c}	126.12a ^{a}
$LSD_{0.05}$			0.732	0.886	1.383	3.369	1.960	6.425
$LSD_{0.01}$			1.026	1.242	1.861	4.723	2.748	8.644

$LSD_{0.05}$, $LSD_{0.01}$ – limits of significant differences at the levels α = 0.05 and α = 0.01 (LSD test), different letter behind a numerical value respond to the statistically significant difference at the level 95.0% and superscript behind a numerical value respond to the statistically significant difference at the level 99.0%

VI: *Ratio between Ti contents in underground and aboveground phytomass*

Treatment		Growth stage	Year		Mean
No.	Marking		2011	2012	
1–5	0Ti	BBCH 50	4.01	1.77	2.89
1	0Ti	BBCH 59	5.06	1.81	3.44
2–3	$Ti_{0.2}$		5.16	1.53	3.35
4–5	$Ti_{0.4}$		4.00	1.59	2.80
1	0Ti	BBCH 66	5.95	2.01	3.98
2–3	$Ti_{0.2}$		6.82	3.74	5.28
4–5	$Ti_{0.4}$		6.91	3.30	5.11
1	0	BBCH 71	8.96	3.37	6.17
2	2 x $Ti_{0.2}$		9.90	2.90	6.40
3	3 x $Ti_{0.2}$		9.03	3.23	6.13
4	2 x $Ti_{0.4}$		8.43	3.54	5.99
5	3 x $Ti_{0.4}$		8.10	3.75	5.93
Mean			6.86	2.71	5.21

in the growth stage BBCH 66 the titanium contents were lower in the aboveground phytomass of the plants treated by Mg-Titanit in comparison with the contents of the untreated variant. Similarly, the impact of the third spraying (treat. 3 versus treat. 2 and treat. 5 versus treat. 4) was as ambiguous as the impact of the first two sprayings. It is evident that in the given experiment the unambiguous impact of the application by fertilizer containing titanium was not proved on the titanium content in the aboveground and underground oilseed rape phytomass in the growth stage BBCH 50 to 71. The probable reason of this finding consists in the relatively low titanium quantities added to the plants by the fertilizer Mg-Titanit. The individual variants were added in this way from 3.4 to 10.2 g of titanium per one hectare of soil, which means less than 0.5 mg per one plant (Tab. II).

The titanium contents in the plants of oilseed rape, which were detected in the particular experimental years (Tab. V), validate the well-known importance of the impact of the farming year on the nutrients intake by plants (Marschner, 2005). In the year 2011 there 6.86 times more titanium was present in roots than in the aboveground phytomass (on average valid for all samplings of the plant material). However, in the following year it was only 2.71 times more, which is related to considerably lower

VII: *Average content of titanium in oilseed rape plants in particular years of experiment in growth stage BBCH 71*

Year	Ti in abovegroung phytomass	Ti in undeground phytomass	Ratio 2011 : 2012	
	mg/kg – 100% dry matter		Aboveground	Undeground
2011	21.43 b ^{b}	189.80 b ^{b}	1.15	3.05
2012	18.56 a ^{a}	62.15 a ^{a}		
$LSD_{0.05}$	0.875	4.063		
$LSD_{0.01}$	1.177	5.467		

$LSD_{0.05}$, $LSD_{0.01}$ – limits of significant differences at the levels α = 0.05 and α = 0.01 (LSD test), different letter behind a numerical value respond to the statistically significant difference at the level 95.0% and superscript behind a numerical value respond to the statistically significant difference at the level 99.0%

VIII: *Dose and date impact of Mg-Titanit application on dynamics of oilseed rape aboveground phytomass formation*

Treatment		Growth stage (BBCH)							
		50	59	66	71	50	59	66	71
No.	Marking	2011				2012			
		Weight of one plant at gram (100% dry matter)							
1	0	3.67	5.70	11.44	26.53 a ^{a}	1.18	5.08	9.04	30.69 a ^{a}
2	2 x $Ti_{0.2}$	3.67	5.74	26.30	55.33 b ^{b}	1.18	7.60	22.61	32.35 a ^{ab}
3	3 x $Ti_{0.2}$	3.67	5.74	26.30	59.35 c ^{c}	1.18	7.60	22.61	35.88 b ^{c}
4	2 x $Ti_{0.4}$	3.67	8.22	24.52	55.26 b ^{b}	1.18	6.22	21.62	32.48 a ^{ab}
5	3 x $Ti_{0.4}$	3.67	8.22	24.52	58.95 c ^{c}	1.18	6.22	21.62	34.62 b ^{bc}
$LSD_{0.05}$					1.05				1.940
$LSD_{0.01}$					1.53				2.823

$LSD_{0.05}$, $LSD_{0.01}$ – limits of significant differences at the levels α = 0.05 and α = 0.01 (LSD test), different letter behind a numerical value respond to the statistically significant difference at the level 95.0% and superscript behind a numerical value respond to the statistically significant difference at the level 99.0%

IX: *Dose and date impact of Mg-Titanit application on dynamics of oilseed rape underground phytomass formation*

Treatment		Growth stage (BBCH)							
		50	59	66	71	50	59	66	71
No.	Marking	2011				2012			
		Weight of one plant at gram (100% dry matter)							
1	0	1.61	2.59	3.18	3.96 a ^{a}	0.26	0.93	1.23	2.63 a ^{a}
2	2 x $Ti_{0.2}$	1.61	2.74	5.10	6.37 bc ^{b}	0.26	1.18	1.57	3.05 b ^{b}
3	3 x $Ti_{0.2}$	1.61	2.74	5.10	6.65 c ^{b}	0.26	1.18	1.57	3.67 e ^{d}
4	2 x $Ti_{0.4}$	1.61	3.35	5.96	6.35 b ^{b}	0.26	1.14	1.75	3.19 c ^{bc}
5	3 x $Ti_{0.4}$	1.61	3.35	5.96	6.50 bc ^{b}	0.26	1.14	1.75	3.33 d ^{c}
$LSD_{0.05}$					0.293				0.124
$LSD_{0.01}$					0.426				0.180

$LSD_{0.05}$, $LSD_{0.01}$ – limits of significant differences at the levels α = 0.05 and α = 0.01 (LSD test), different letter behind a numerical value respond to the statistically significant difference at the level 95.0% and superscript behind a numerical value respond to the statistically significant difference at the level 99.0%

accumulation of titanium in roots in 2012 (Tab. VI). In 2012, in the growth stage BBCH 71, the titanium content in the roots of oilseed rape was 3.05 times lower than in 2011 (Tab. VII).

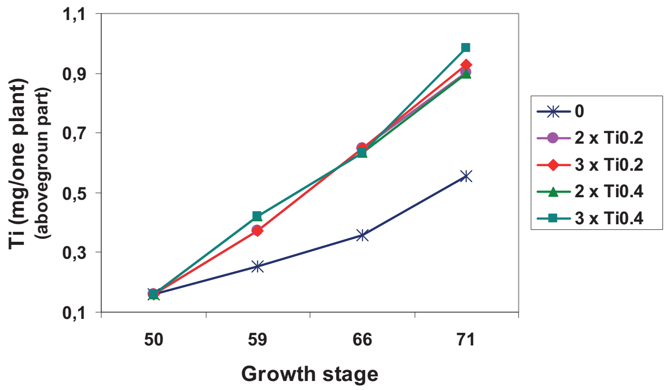
During the growth stages BBCH 50 to 71 the titanium contents varied around the following (average) values in the oilseed rape aboveground phytomass. In the growth stage BBCH 50 it was around the value 66.10 mg/kg, in BBCH 59 around the value 53.29 mg/kg, in BBCH 66 around the value 29.56 mg/kg and in BBCH 71 around the value 20 mg/kg. These data can serve as the basic information for the criteria creation about the sufficient titanium content in oilseed rape plants in the growing periods BBCH 50–71, there in the growing stages BBCH 50–59 the realization of the corrective measures related to the insufficient nutrition by rape microelements is very effective (Richter *et al.*, 2001; Kováčik, 2009).

The Tab. VIII. and IX. shows that the Mg-Titanit application, carried out in the growing period BBCH 50 (column BBCH 59), stimulated unequaly the formation of the aboveground and underground winter oilseed rape phytomass. The growth of the aboveground phytomass varied in the relatively wide interval from 0.7 to 49.61% and the root growth varied in the interval from 5.79 to 29.34%. The impact of the lower (0.2 l/ha) and higher (0.4 l/ha) application dose of Mg-Titanit on the stimulation of aboveground and underground oilseed rape phytomass was different in the particular years.

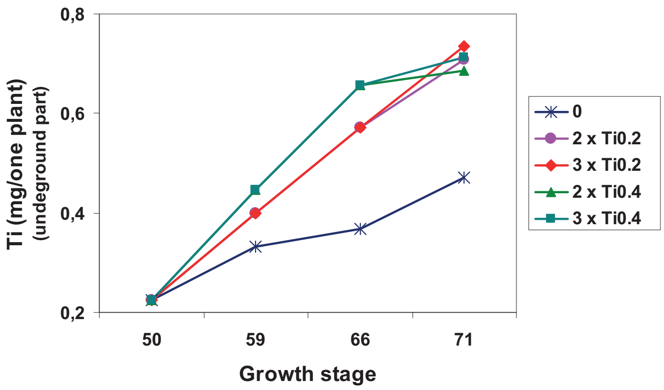
The second Mg-Titanit application intensified the positive impact of the first Mg-Titanit application. After two Mg-Titanit applications the weight growth of the aboveground phytomass was from 114.34% to 150.11% in comparison with the control weight and the weight growth of roots achieved from 27.64% to 87.42%.

These data prove that the second application by Mg-Titanit emphasized the differences between the phytomass weight formed in the variants treated by Mg-Titanit (treat. 2 to 5) and the untreated variant (treat. 1). The Mg-Titanit impact on the aboveground phytomass was more considerable than the impact on the underground phytomass. A lower dose of Mg-Titanit (treat. 2 and 3) had a more positive impact on the formation of aboveground phytomass than a lower dose of Mg-Titanit (treat. 4 and 5). On the contrary, the root formation was increasing along with the growth of the application dose of Mg-Titanit (Tab. VIII and IX, column BBCH 66).

The third spraying also increased the weight of the whole oilseed rape phytomass (analysis in BBCH 71). The weight increase of the aboveground phytomass in both years was significant and the root weight increase was significant only in the second year of experiment (treat. 3 versus treat. 2 and treat. 5 versus treat. 4). As a result of the positive impact of the third spraying on the oilseed rape phytomass a bigger aboveground and also underground phytomass was formed in the variants where three sprayings were used (treat. 3 and 5) in comparison with the variants where two sprayings were carried out (treat. 2 and 4). The presented finding does not correspond with the data given by Kováčik *et al.* (2014), who recorded the inhibition of the formation of wheat aboveground phytomass after the third spraying by Mg-Titanit, applied in the growing period BBCH 55. These data point out that there is the evident need to test the different dates of applications and the different doses of fertilizers with the different crops. On the contrary, the positive impact of the fertilizer Mg-Titanit, which was recorded in all samplings, on the formation of oilseed rape phytomass corresponds with the data presented by several authors (Traetta-Mosca, 1913; Pais 1983; Dumon and Ernst, 1988;



1: *Dynamics of changes of titanium intakes by aboveground part of one plant during oilseed rape growth stage*



2: *Dynamics of changes of titanium intakes by undeground part of one plant during oilseed rape growth stage*

Dobromilská, 2007) about the positive impact of fertilizers containing titanium on the plant phytomass.

It is evident from Fig. 1 and 2 that the positive impact of Mg-Titanit on the oilseed rape phytomass formation appeared in the significant difference in the titanium intake by one plant, in spite of the unevidential impact on the titanium content in plants. The lowest intake of titanium was recorded in the control variant. In this variant the titanium intake did not exceed 0.6 mg of titanium by the aboveground phytomass of one plant and 0.5 mg of titanium by the underground phytomass. The titanium intakes by the aboveground phytomass treated by Mg-Titanit were higher and varied around the value 0.9 mg/plant and the root intakes varied about the value of 0.7 mg/plant.

The titanium contents in the oilseed rape seed varied in the interval from 0.78 to 2.94 mg/kg and in straw from 8.75 to 12.90 mg/kg (Tab. X) during two years. This corresponds with the data of Lopez-Moreno *et al.* (1996), Tlustoš *et al.* (2005) about the titanium content in plants. On average the titanium quantity in the oilseed rape seed was increased proportionally along with the total quantity of the applied fertilizer during two years of experiment. However, this information was not valid in both years of the experiment. Each year the highest titanium content was detected in the treatment 5 where the total higest dose of Mg-Titanit was applied (1.2 l/ha).

Every year the titanium content in the oilseed rape straw was higher in all variants fertilized by Mg-Titanit than in the unfertilized variant. The titanium content in straw was not increased proportionally along with the growing dose of Mg-Titanit. Every year the highest quantity of titanium in straw was detected in the variant where Mg-Titanit was applied three times in the dose 0.2 l/ha (treat. 3) with the total dose of 0.6 l/ha.

In the oilseed rape straw there occurred from 3.98 to 12 times more titanium than in seed. The titanium contents in straw and seed of oilseed rape and subsequently the titanium intakes by seed and straw were determined significantly by the farming year (Tab. XI and XII).

The seed intakes varied in the relatively wide scale from 3.21 to 16.55 g/ha, with the average at the level of 8.62 g/ha (Tab. XIII). The straw intakes were significantly higher and achieved the value of 63.70–102.09 g/ha. On average 84.65 g/ha of titanium was taken in by straw. Apart from one case, it was detected that the titanium intake by seed and straw was higher in the variants treated by Mg-Titanit than in the control variant, which corresponds with the general principles of plant nutrition (Epstein and Bloom, 2005).

X: *Titanium content in oilseed rape seeds and straw at the end of experiment*

Treatment		**Ti in seeds mg/kg**			**Ti in straw mg/kg**		
No.	**Marking**	**2011**	**2012**	**Mean**	**2011**	**2012**	**Mean**
1	0	1.79 b ^{b}	0.78 a ^{a}	1.29 a ^{a}	8.75 a ^{a}	9.10 a ^{a}	8.93 a ^{a}
2	2 x $Ti_{0.2}$	1.02 a ^{a}	1.84 c ^{c}	1.43 ab ^{a}	10.91 b ^{b}	11.33 b ^{b}	11.12 b ^{b}
3	3 x $Ti_{0.2}$	1.90 b ^{b}	1.52 b ^{b}	1.71 bc ^{ab}	12.11 c ^{c}	12.90 c ^{c}	12.51 c ^{c}
4	2 x $Ti_{0.4}$	2.40 c ^{c}	1.74 c ^{cb}	2.07 cd ^{bc}	11.78 c ^{c}	12.78 c ^{c}	12.28 c ^{c}
5	3 x $Ti_{0.4}$	2.94 d ^{d}	1.80 c ^{c}	2.37 d ^{c}	11.69 c ^{c}	12.40c ^{bc}	12.05 c ^{c}
$LSD_{0.05}$		0.154	0.159	0.416	0.491	0.927	0.480
$LSD_{0.01}$		0.216	0.224	0.559	0.688	1.300	0.645

$LSD_{0.05}$, $LSD_{0.01}$ – limits of significant differences at the levels α = 0.05 and α = 0.01 (LSD test), different letter behind a numerical value respond to the statistically significant difference at the level 95.0% and superscript behind a numerical value respond to the statistically significant difference at the level 99.0%

XI: *Ratio between Ti contents in straw and seeds*

Treatment		**Year**		
No.	**Marking**	**2011**	**2012**	**Mean**
1	0	4.9 b ^{b}	12.00 c ^{b}	8.46 b ^{a}
2	2 x $Ti_{0.2}$	10.75 d ^{d}	6.18 a ^{a}	8.46 b ^{a}
3	3 x $Ti_{0.2}$	6.38 c ^{c}	8.53 b ^{a}	7.45 ab ^{a}
4	2 x $Ti_{0.4}$	4.91 b ^{b}	7.34 ab ^{a}	6.13 ab ^{a}
5	3 x $Ti_{0.4}$	3.98 a ^{a}	6.90 ab ^{a}	5.44 a ^{a}
$LSD_{0.05}$		0.647	2.045	2.372
$LSD_{0.01}$		0.908	2.867	3.191

$LSD_{0.05}$, $LSD_{0.01}$ – limits of significant differences at the levels α = 0.05 and α = 0.01 (LSD test), different letter behind a numerical value respond to the statistically significant difference at the level 95.0% and superscript behind a numerical value respond to the statistically significant difference at the level 99.0%

XII: *Content, proportion of titanium content in straw and seeds and titanium intake by seeds and straw on average in treatments in particular years of experiment*

Year	Ti content (mg/kg)		Ratio between Ti content in straw : seeds	Ti intake (g/ha)	
	Seeds	Straw		Seed	Straw
2011	2.01 b [b]	11.05 a [a]	5.50 a [a]	10.79 b [b]	89.41 b [b]
2012	1.54 a [a]	11.70 b [b]	7.60 b [a]	6.44 a [a]	79.88 a [a]
$LSD_{0.05}$	0.263	0.303	1.500	1.340	2.593
$LSD_{0.01}$	0.354	0.408	2.018	1.803	3.489

$LSD_{0.05}$, $LSD_{0.01}$ – limits of significant differences at the levels $\alpha = 0.05$ and $\alpha = 0.01$ (LSD test), different letter behind a numerical value respond to the statistically significant difference at the level 95.0% and superscript behind a numerical value respond to the statistically significant difference at the level 99.0%

XIII: *Titanium intake by seeds and straw*

Treatment		Seeds			Straw		
No.	Marking	2011	2012	Mean	2011	2012	Mean
		Ti (g/ha)					
1	0	8.40 b b	3.21 a [a]	5.81 a [a]	67.99 a [a]	63.70 a [a]	65.85 a [a]
2	2 x $Ti_{0.2}$	5.32 a a	7.54 c [c]	6.43 a [ab]	87.83 b [b]	70.59 b [b]	79.21 b [b]
3	3 x $Ti_{0.2}$	11.15 c c	6.61 b [b]	8.88 b [bc]	102.09 e [d]	92.20 d [d]	97.15 d [d]
4	2 x $Ti_{0.4}$	12.55 d d	7.27 c [c]	9.91 b [cd]	92.36 c [bc]	90.10 d [d]	91.23 c [c]
5	3 x $Ti_{0.4}$	16.55 e e	7.56 c [c]	12.06 c [d]	96.79 d [c]	82.83 c [c]	89.81 c [c]
mean				8.62			84.65
$LSD_{0.05}$		0.339	0.322	2.120	3.507	4.486	4.101
$LSD_{0.01}$		0.472	0.452	2.852	4.917	6.289	5.517

$LSD_{0.05}$, $LSD_{0.01}$ – limits of significant differences at the levels $\alpha = 0.05$ and $\alpha = 0.01$ (LSD test), different letter behind a numerical value respond to the statistically significant difference at the level 95.0% and superscript behind a numerical value respond to the statistically significant difference at the level 99.0%

XIV: *Total titanium intake by aboveground phytomass (by seeds and straw together)*

Treatment		Titanium intake per hectare		
No.	Marking	2011	2012	Mean
			g/ha	
1	0	76.39	66.91	71.65
2	2 x $Ti_{0.2}$	93.15	78.13	85.64
3	3 x $Ti_{0.2}$	113.24	98.81	106.03
4	2 x $Ti_{0.4}$	104.91	97.37	101.14
5	3 x $Ti_{0.4}$	113.34	90.39	101.87

The total titanium intake by the aboveground oilseed rape phytomass (seed + straw) was in the interval 66.91 to 113.34 g/ha (Tab. XIV). This is the evidence that the titanium intakes are significantly higher than the molybdenum and cobalt intakes with the majority of the farm crops (Cook, 1982), however, they are also higher than the copper and boron intakes with cereals (Baier *et al.*, 1988). The presented quantities of titanium, taken in by the aboveground oilseed rape phytomass range titanium among microelements from the viewpoint of the element division according to the content in a plant.

In the agricultural practice of the Czech Republic, the Slovak Republic and the whole Central Europe the methodology is utilized to calculate the nutrient doses, taking into account the need of macroelements for the formation of the unit yield of the main and the appropriate quantity of the side product (Ivanič *et al.*, 1984; Vaněk *et al.*, 2007). The same principle is being used in order to create also the methodology of the plant nutrition by microelements (Kováčik, 2014). If this methodology of the plant nutrition by titanium is to be created, it is necessary to obtain the information about the need of titanium for the formation of one tonne of the main product and the appropriate quantity of the side product.

The titanium intake by the yield of one tonne of the rape seed varied in the interval from 0.78 to 2.94 grams (Tab. XV). The titanium intake by the yield of one tonne of the seed (main product) along with the appropriate quantity of the side product (straw) achieved the value of 16.24 to 23.29 grams, where

XV: *Titanium intake by one tonne seeds yield and titanium intake by one tonne seeds and appropriate quantity of straw*

Treatment		Titanium intake by one tonne of seeds			Titanium intake by one tonne of seeds and appropriate quantity of straw		
No.	Marking	2011	2012	Mean	2011	2012	Mean
		g/t seeds					
1	0	1.79	0.78	1.29	16.29	16.24	16.27
2	2 x $Ti_{0.2}$	1.02	1.84	1.43	17.84	19.06	18.45
3	3 x $Ti_{0.2}$	1.90	1.52	1.71	19.29	22.71	21.00
4	2 x $Ti_{0.4}$	2.40	1.74	2.07	20.06	23.29	21.68
5	3 x $Ti_{0.4}$	2.94	1.80	2.37	20.13	21.52	20.83

the average intake was at the level 19.65 grams. It is evident that the oilseed rape plants need cca 80 grams of titanium (from 65 to 93 grams) in order to achieve 4 tonnes of rape seed yield. For this purpose it is possible to use several titanium compounds, predominantly titanium citrate, titanium ascorbate, titanylsulphate chelated with tartaric acid (Kováčik *et al.*, 2014).

The presented data can be utilized in the creation of the methodology on the oilseed rape nutrition by titanium, taking into consideration the rape requirements for the total quantity of the available titanium, and also in the creation of the methodology studying the problems of the additional fertilizing of rape by titanium during the growing season.

CONCLUSION

The small plot field trial (20 m^2 per one plot) was carried out on the Haplic Chernozem (48°42´ N, 17°70´ E) during two farming years (2010/2011 and 2011/2012) in order to achieve the information about the titanium contents changes in the aboveground and underground phytomass during the growing season of the oilseed rape and about the contents of titanium taken in by the rape yield. The fertilizer Mg-Titanit (MgTi) containing 8.5 g of titanium in 1 liter was used in the experiment. The experiment consisted of 5 treatments. 0 – control treatment without MgTi fertilizer; 2xTi0.2 – two applications of MgTi in the dose of 0.2 l/ha^{-1}; 3xTi0.2 – three applications of MgTi in the dose of 0.2 l/ha^{-1}; 2xTi0.4 – two applications of MgTi in the dose of 0.4 l/ha^{-1}; 3xTi0.4 – three applications of MgTi in the dose of 0.4 l/ha^{-1}. The fertilizer was applied in the spring in two or three different growth stages: BBCH 50, BBCH 59, BBCH 66. The first plant sampling was carried out short time before the first application of the fertilizer (BBCH 50). The second, third and fourth sampling was taken 2 or 3 weeks after MgTi application (BBCH 59, BBCH 66, BBCH 71). The obtained results showed that the titanium content in the aboveground and underground phytomass of oilseed rape was decreased in the monitored period (from the growth stage BBCH 50 to BBCH 71). During the given period the titanium content in the aboveground phytomass of rape varied from 16.81 to 67.6 mg/kg and in roots in the interval from 56.6 to 258.81 mg/kg.

In the seed and straw less titanium occurred than in the physiologically active organs of oilseed rape. The titanium content did not exceed the level 2.94 mg/kg in seed and 12.90 mg/kg in straw. The application of fertilizer Mg-Titanit had the positive impact on the formation of the aboveground and underground phytomass of winter oilseed rape, and at the same time it increased the titanium intake by the given phytomass. The titanium application on plant leaves in quantities from 3.4 to 10.2 g per hectare did not have the unambiguous impact on the titanium content in the aboveground and underground phytomass of oilseed rape. The oilseed rape vegetation nourished sufficiently by titanium should have the titanium content at the level of 66, 53, 30 and 20 mg/kg in the growth stages BBCH 50, 59, 66 and 71. In order to form one tonne of seed and the appropriate quantity of straw the aboveground phytomass of rape takes in on average 20 grams of titanium.

Acknowledgement

This research was supported by the projects VEGA 1/0591/13 and VEGA 1/0704/16.

REFERENCES

BALÍK, J., VOSTAL, J. and TLUSTOŠ, P. 1989. Results of Titavin tests for chosen crops. In: *Sborník VŠZ, Praha, Řada A*, 50: 143–155.

BAIER, J., SMETÁNKOVÁ, M. and BAIEROVÁ, V. 1988. *Plant nutrition diagnostic*. Praha: Institut výchovy a vzdělávání MZVž ČSR.

BREMNER, J. M. 1960. Determination of nitrogen in soil by the Kjeldahl method. *Journal of Agricultural Science*, 55(1): 11–33.

CARVAJAL, M., ALCARAZ, C. F. 1998. Why titanium is a beneficial element for plants. *Journal of Plant Nutrition*, 21: 655–664.

CECCANTINI, G., FIGUEIREDO, A. M. G., SONDAG, F. and SOUBIES, F. 1995. Rare earth elements and titanium in plants, soils and groundwaters in the alkaline-ultramafic complex of Salitre, MG, Brazil. In: *Contaminated Soils*. 3rd international Conference on the Biogeochemistry of Trace Elements Paris (France), May 15–19, 1995. INRA, Paris, 1997, pp. 197–208.

CZEKALSKI, A. 1987. Titanium in soils and plants. *Prace Komisji Nauk. Pol. Tow. Gleb.*, 4/9: 66–74.

COOK, G. W. 1982. *Fertilizing for maximum yield*. 3rd edition. Granada: LSBS.

DOBROMILSKA, R. 2007. The influence of tytanit application on the growth of cherry tomatoes. *Roczniki Akademii Rolniczej w Poznaniu CCCLXXXIII*, 41: 451–454.

DUMON, J. C., ERNST, W. H. O. 1988. Titanium in plants. *J. Plant Physiol.*, 133(3): 203–209.

DZIADOWIEC, H., GONET, S. S. 1999. Methodical guide-book for soil organic matter studies. *Prace Komisji Nauk. Pol. Tow. Gleb. Warszawa*, II/16: 42–43.

EPSTEIN, E., BLOOM, A. J. 2005. *Mineral Nutrition of Plants: Principles and Perspectives.* 2nd edition. Sunderland, MA, USA: Sinauer Associates.

ERCOLI, L., MARIOTTI, M., NICCOLAT, L. et al. 2008. The use of titanium shavings as a fertilizer alternative for maize production. *Agrochimica*, LII(2): 1–17.

HARA, T., SONODA, Y. and IWAI, I. 1976. Growth response of cabbage plants to transition elements under water culture conditions. *Soil. Sci. Plant Nutr.*, 22(3): 307–315.

IVANIČ, J., HAVELKA, B. and KNOP, K. 1984. Plant nutrition and fertilizing. Bratislava and Praha: Príroda – SZN.

KOVÁČIK, P. 2009. *Plant nutrition and methods of plant fertilizing*. České Budějovice: Kurent s. r. o.

KOVÁČIK, P. 2014. *The principles and methods of plant nutrition*. Nitra: SPU v Nitre.

KOVÁČIK, P., HUDEC, J., ONDRIŠÍK, P. and POLLÁKOVÁ, N. 2014. The effect of liquid fertilizer Mg-Titanit on creation of winter wheat phytomass. *Research Journal of Agricultural Science*, 46(2): 125–130.

LOPEZ-MORENO, J. L., GIMÉNEZ, J. L., MORENO, A. et al. 1996. Plant biomass and fruit yield induction by Ti(IV) in P-stressed pepper crops. *Fertilizer Research,* 43: 131–136.

MARSCHNER, H. 2002. *Mineral nutrition of higher plants*. 2nd edition. London: Elsevier Academic Press.

MATUŠKOVIČ, J. 1995. Evaluation of yield and selected quality parameters interactions of strawberry variety „Senga Sengana“ as influenced by utilization of „Titavin“ preparator. *Acta fytotechnica LI Universitatis agriculturae Nitra – Slovakia*, 51: 105–110.

MEHLICH, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communication in Soil Science and Plant Analysis,* 15: 1409–1416.

PAIS, I. 1983. The biological importance of titanium. *Journal of Plant Nutrition*, 6: 3–131.

RICHTER, R., HŘIVNA, L. and CERKAL, R. 2001. Nutrition and fertlization of winter rape. Praha: SZPO Svaz pěstitelů a zpracovatelů olejnin Praha.

SIMON, L., BALOGH, A., HAJDU, F. et al. 1988. Effect of titanium on growth and photosynthetic pigment composition of *Chlorella pyrenoidosa* (green alga). II. Effect of titanium ascorbate on pigment content and chlorophyll metabolism of Chlorella. *New Results in the Research of Hardly Known Trace Elements and Their Role in the Food Chain,* I. Pais, ed., University of Horticultural and Food Science, Budapest, 87–101.

SCAIF, A., TURNER, M. 1983. *Diagnosis of mineral disorders in plants. Volume 2, Vegetables*. London: Her Majesty's Stationery Office.

SKUPIEŃ, K., OSZMIAŃSKI, J. 2007. Influence of titanium treatment on antioxidants content and antioxidant activity of strawberries. *Acta Sci. Pol., Technol. Aliment.*, 6(4): 83–94.

TERLIKOWSKI, F., GÓRNICKI, T. 1993. Content of titanium in some fields crops. *Rocz. Nauk. Inst. Rolnego i Leśnego.*, 1: 29–32.

TICHÝ, I., TÓTH, J. 1990. Titavin test results in suggar beat. *Agrochémia*, 30(8): 225–229.

TLUSTOŠ, P., CÍGLER, P., HRUBÝ, M. et al. 2005. The role titanium in biomass production and its influence on essential elements' contents in field growing crops. *Plant Soil Environment*, 51(1): 19–25.

TRAETTA-MOSCA, F. 1913. Titanium and the rare metals in the ash of the leaves of Kentucky tobacco cultivated in Italy. *Gazzetta Chimica Italiana*, 43: 437–440.

VANĚK, V., BALÍK, J., PAVLÍKOVÁ, D. and TLUSTOŠ, P. 2007. *Nutrition of field and garden plants.* Praha: Profi Press.

ZBÍRAL, J., MALÝ, S., VÁŇA, M., ČUHEL, J., FOJTLOVÁ, E., ČIŽMÁR, D., ŽALMANOVÁ, A., SRNKOVÁ, J., OBDRŽÁLKOVÁ, E. 2011a. *Analýza půd III. Jednotné pracovní postupy.* Brno: ÚKZÚZ.

ZBÍRAL, J., TIEFFOVÁ, P., PLHALOVÁ, Š., URBÁNKOVÁ, E., NIEDOBOVÁ, E., SRNKOVÁ, J., STRÍŽOVÁ, I. 2011b. *Analýza půd II. Jednotné pracovní postupy.* Brno: ÚKZÚZ.

YANG, G., YUAN, D. G., ZHONG, G. J., WU, J. 2012. Determination of heavy metals in dominant plant species in Vanadium/Titanium mine area by microwave digestion-ICP-AES. *Guang Pu Xue Yu Guang Pu Fen Xi.*, 32(5): 1391–1393.

Contact information

Peter Kováčik: peter.kovacik@uniag.sk