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The early prognosis of tuber yield based on nitrogen status in potato tops

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ABSTRACT

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The pattern of nitrogen net change (ΔN) in potato tops during the period extending from BBCH 33 to BBCH 40 is crucial for tuber yield (TY). This hypothesis was verified based on data from field experiments (2006–2008) with sequentially added nutrients (0, NP, NPK, NPKS, NPKSMg) to potato. The water shortage in June/July 2006 and in June 2008 significantly affected N content, and in turn TY. The TY was reduced by 38% in 2006 and by 23% in 2008, as compared to 2007 (53.7 t/ha). The N content in potato tops at BBCH 40 of 2.5% indicated the lowest TY, whereas 4.3% the maximum TY. The ΔN of +0.4% within the period from BBCH 33 to BBCH 40 determined the optimal range of the N content for the maximum TY (3.9–4.3%). The ΔN trend depended on the change of phosphorus and potassium contents. The key reason of N inefficiency was the shortage of potassium (K), resulting in its negligible change within this period. The pattern of zinc content at BBCH 40 reflected fairly well disturbances in N as well as K supply to potato. A good supply of K and Zn to potato can improve N management just before tuber initiation.

Keywords: *Solanum tuberosum* L., tuberous crop; nitrogen management; nutrient content

In the last 50 years, potato has become one of the most important table food crop grown worldwide (Pawelzik and Möller 2014). The harvested yields are low, even in countries with long history of this crop cultivation. The potential yields in Germany, Czech Republic and Poland are at the level of 60.9, 57.2, and 39.7 t/ha, respectively (Supit et al. 2010). The current yields are much lower; in the period 2006–2016, they amounted to 42.9 (70% of the potential), 25.9 (45%), and to 22.1 (56%) t/ha, respecitvely (FAOSTAT 2017).

There are numerous reasons for low yields of potato tubers. One of the most important is the inadequate nutrient delivery, both from soil and fertilizers. The number of young tuber shows a significant response of the plant nutritional status (Rosen and Bierman 2008). It is well documented that nitrogen (N) and potassium (K) are crucial nutrients for the tuber dry matter yield (Grzebisz et al. 2017). The content of K in the tuber increases up to the latest stages of growth (White 2013).

The process of tuber formation, i.e. stolon transformation into the tuber, is the basic stage for an effective potato production. It is induced or delayed by a set of internal and environmental factors (Jackson 1999). In the latter group, nitrogen is one of the most important factors. Its elevated supply to potato plants promotes the growth of tops in the expense of tuber formation. Jenkins and Mahmood (2003) showed in a series of experiments that the balanced supply of N, P and K does not impact the number of initiated tubers, but prevents the process of their reabsorption.

Based on the knowledge of the tuber induction as the critical stage for potato yield forecast, a hypothesis has been put forward that the game for the TY takes place just before the stolon transformation into the tuber (BBCH 40). The key yield-

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forming factor is the supply of N to potato tops and its efficiency, which depends on the supply of other nutrients. The objective of the study was to evaluate the change in the content of nitrogen N as the key predictor of the tuber yield, concomitant with trends of P, K, Ca, Mg, Zn and Cu contents in potato tops during the period extending from BBCH 33 to BBCH 40.

MATERIAL AND METHODS

The present study is based on data obtained from field trials with potato (*Solanum tuberosum* L.), which were carried out in 2006–2008 in the Brody Experimental Farm (Poznan University of Life Sciences, 52°44'N, 16°28'E). The field experiment was completed on soils developed from sandy loam over loam in the subsoil, classified as Haplic Luvisols. The content of available nutrients, measured each year before the application of fertilizers in the top-soil, was in the high/very high class for phosphorus (80–95 mg P kg/soil), medium for potassium (130–150 mg K kg/soil) (double lactate method), medium for magnesium (58–62) Schachtschabel method). The amount of mineral N (N_{min}) was 23–30 kg/ha (0.01 mol/L $CaCl_2$). Soil pH was 5.6–6.0 (1 mol/L KCl). Meteorological data, concerning precipitation, were variable in June and July, months critical for tuber formation (Figure 1).

A field trial consisting of five treatments, differing in the composition of sequentially added sets of nutrients, arranged in a randomized complete block, and replicated four times, was a source of data for the study. The fertilized groups were as follows: control (AC – no fertilizers added); NP; NPK1 (NPK – K as muriate of potash, MOP); NPK2 (NPKS – K as potassium sulfate, SOP); NPK3 (NPKSMg, Patentkali). Phosphorus (38.7 kg P/ha), and K (166 kg/ha) fertilizers were applied two weeks before potato planting. The rate of S applied with SOP and with Patentkali amounted to 69.1 and 110.7 kg/ha, respectively. The rate of Mg was 39.1 kg/ha. Nitrogen in the form of ammonium nitrate (34% N) was applied twice: (i) before planting; (ii) BBCH 20 (70 + 60 kg/ha). The total area of a plot was 58.5 m^2. The cv. Corona of potato was planted in the second half of April and harvested from an area of 19.5 m^2 at the end of September.

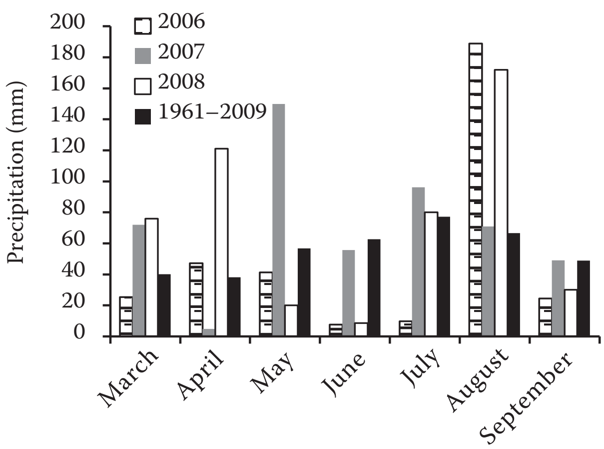

Figure 1. Total monthly precipitation during growing seasons 2006–2008

Plant material used for the determination of dry matter and nutrients content was collected from an area of 1.0 m^2. Plants were sampled at two stages: BBCH 33 and BBCH 40 (the beginning of tuberization). Nitrogen content was determined using a standard macro-Kjeldahl procedure. For other nutrients, the harvested plant sample was dried at 65°C and then mineralized at 600°C. The obtained ash was then dissolved in 33% HNO_3. The P concentration was measured by the vanadium-molybdenum method using a Specord 2XX/40 (Analytik Jena, Jena, Germany) at a wavelength of 436 nm. Potassium concentration was measured by the flame-photometry and other nutrients by atomic-absorption spectrometry – flame type.

The obtained data were subjected to the analysis of variance (Statistica 10. StatSoft. Inc., Tulsa, USA), and the differences between treatments were evaluated with the Tukey's test. The simple and stepwise regression was applied to define the optimal set of variables for plant characteristics. The best regression model was selected based on the highest *F*-value for the entire model.

RESULTS AND DISCUSSION

The tuber yield on the control plot (AC) ranged from 27.8 to 40.1 t/ha (Figure 2). This range indicates a high natural productivity of soil under study. The impact of fertilizing treatments on the yield depended on weather (Table 1, Figure 1). The lowest yield was recorded in 2006, with shortage of precipitation in June and July (17.6 mm). This period of potato growth is crucial for tuber initiation (Jackson 1999). In spite of a deep drought, the significant yield increase of 10 t/ha with respect

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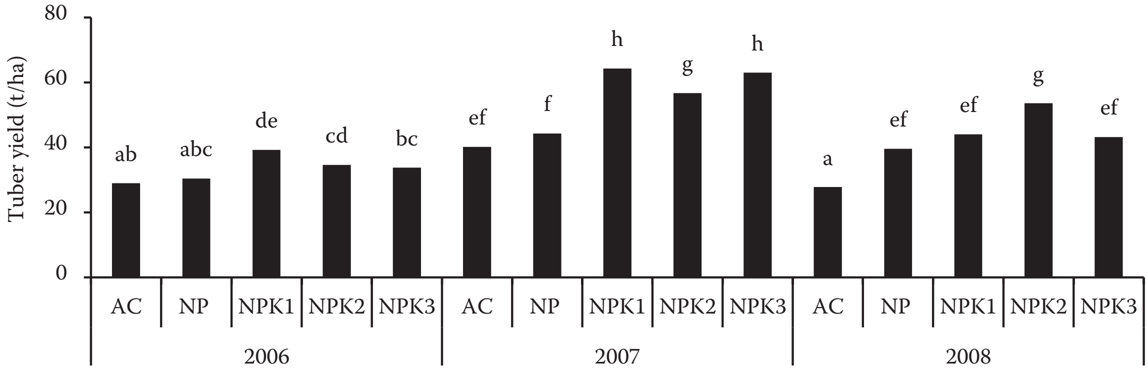

Figure 2. Effect of fertilizing treatments on the tuber yield in consecutive growing seasons. AC –control (no fertilizers added); NPK1 (NPK – K as muriate of potash, MOP); NPK2 (NPKS – K as potassium sulfate, SOP); NPK3 (NPKSMg – Patentkali)

to the AC and also to the NP was recorded on the NPK plot. This type of response is similar to those recorded for other crops (Grzebisz et al. 2013). In 2007, the average yield reached 54 t/ha. The applied NP increased the yield by 10% and NPK by 60%, compared to the AC. The reason of such increase was the amount and distribution of precipitation in June and July (162 mm). In 2008, the yield was lower compared to 2007 due to water shortage in June (9 mm). In this year, potato responded significantly to the type of applied K fertilizer. The yield harvested on the NPKS plot was by 93% higher with respect to the AC and by 22% higher compared to the NPK plot.

The biomass of tops at BBCH 33 was 2-times larger in 2007 compared to 2008 (Table 1). The highest was recorded on the NPK plot, being highly variable during the period, extending from BBCH 33 to BBCH 40. Its increase was almost negligible in 2006, whereas in 2007 it doubled within this period. The highest net increase of biomass was recorded on the NPKS plot.

The content of N in potato tops at BBCH 33 was variable in consecutive growing seasons (Table 2). It showed a significant response to the applied fertilizers, but not to interaction with years. The lowest N content was recorded in 2008, a year with drought in May and June (Figure 1). As it has

Table 1. Characteristics of potato nitrogen in two consecutive growth stages and tuber yield

Factor	Level of factor	Yield (t/ha)	Yield of tops BBCH (kg DM)			Nitrogen (BBCH, % DM)		Nitrogen uptake (BBCH, kg/ha)		
			33	40	Δ40–33	33	40	33	40	Δ40–33
Year (Y)	2006	33.4[a]	596[b]	608[b]	12[a]	3.95[b]	3.40[a]	23.4[b]	20.6[a]	–2.8[a]
	2007	53.7[c]	750[c]	1858[c]	1108[c]	4.37[c]	4.51[c]	32.9[c]	84.0[b]	51.1[c]
	2008	41.6[b]	386[a]	527[a]	141[b]	3.29[a]	3.81[b]	12.7[a]	20.9[c]	8.1[b]
Fertilization treatment (FT)	AC	32.3[a]	518[a]	886[a]	368[ab]	3.32[a]	2.93[a]	17.4[a]	29.0[a]	11.6[a]
	NP	38.1[b]	587[bc]	1015[b]	428[bc]	4.03[bc]	4.06[b]	24.4[b]	42.5[b]	18.2[b]
	NPK1	49.2[d]	598[bc]	920[a]	322[a]	3.98[bc]	4.14[b]	24.6[b]	40.0[b]	15.5[ab]
	NPK2	48.3[cd]	549[ab]	1087[b]	538[d]	4.14[c]	4.18[b]	23.2[b]	48.8[c]	25.6[c]
	NPK3	46.7[c]	634[c]	1080[b]	446[c]	3.87[b]	4.22[b]	25.5[b]	48.8[c]	23.3[c]
Source of variance										
Y		***	***	***	***	***	***	***	***	***
FT		***	***	***	***	***	***	***	***	***
Y × FT		***	***	***	***	ns	***	***	***	***

***P < 0.001; **P < 0.01; *P <0.05; ns – not significant. [a]The same letter indicates a lack of significant differences within the treatment; AC –control (no fertilizers added); NPK1 (NPK – K as muriate of potash, MOP); NPK2 (NPKS – K as potassium sulfate, SOP); NPK3 (NPKSMg – Patentkali); DM – dry matter

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Table 2. The nutrient content in potato tops at BBCH 33

Factor	Level of factor	P	K	Ca	Mg	Zn	Cu
		(% DM)				(mg/kg)	
Year (Y)	2006	0.14[a]	2.78[c]	0.42[a]	0.31[b]	11.0[a]	3.68[a]
	2007	0.18[b]	2.40[a]	0.53[b]	0.25[a]	13.4[b]	4.65[b]
	2008	0.14[a]	2.52[b]	0.41[a]	0.26[a]	13.3[b]	6.35[c]
Fertilizing treatment (FT)	AC	0.13[a]	2.24[a]	0.36[a]	0.24[a]	11.0[a]	4.16[a]
	NP	0.16[b]	2.38[a]	0.49[b]	0.27[b]	12.3[b]	4.69[b]
	NPK1	0.15[b]	2.55[b]	0.49[b]	0.28[bc]	13.4[c]	5.54[d]
	NPK2	0.16[b]	2.84[c]	0.49[b]	0.30[c]	12.8[b]	4.95[bc]
	NPK3	0.16[b]	2.81[c]	0.44[b]	2.7[b]	13.5[c]	5.14[c]
Source of variance							
Y		***	***	***	***	***	***
FT		***	***	***	***	***	***
Y × FT		ns	***	***	**	***	***

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; ns – not significant. [a]The same letter indicates a lack of significant differences within the treatment; AC –control (no fertilizers added); NPK1 (NPK – K as muriate of potash, MOP); NPK2 (NPKS – K as potassium sulfate, SOP); NPK3 (NPKSMg – Patentkali); DM – dry matter

been hypothesized by Forde (2014), the shortage of water in the soil solution slows down the rate of nitrate-N movement from the soil solution at the root surface, thus worsening the N nutritional status within the plant. The effect of fertilizing treatments was variable, stressing N shortage on the AC plot and its sufficient concentration in plants grown on other plots, especially fertilized with NPKS. The N content in tops at BBCH 40 as compared to BBCH 33, showed an increase in 2007 and particularly in 2008, compared to a decrease in 2006. This drop resulted from the drought that occurred in June and July. As a consequence of both potato biomass and N content, the amount of N in potato tops (Nu) was year-to-year variable. At BBCH 33, the highest Nu was recorded in 2007, being by 40% higher with respect to 2006 and 2.5-times higher compared to 2008. These large differences can be explained by redirection of both dry matter and N partitioning between above- and under-ground organs of potato plant (Forde 2014) in response to water shortage.

The N content in potato tops at BBCH 33 was positively but weekly correlated with the tuber yield (Table 3). In contrast, its content at BBCH 40 revealed as the key yield predictor. As shown in Figure 3, the TY response to the N content can be explained by the quadrate regression model. The lowest, i.e. stagnating TY was the attribute of plants containing 2.51% of N in tops. Any further N progressive change resulted in the exponential increase in the tuber yield. This type of response was due to the net change of N uptake (ΔNu) by plants during the period BBCH 33–40. The ΔNu

Table 3. Correlation matrix of nutrient content at BBCH 33 and the yield

	N	P	K	Ca	Mg	Zn	Cu
Yield	0.47***	0.68***	0.09	0.57***	–0.18	0.72***	0.34**
N	1.00	0.73***	0.01	0.73***	0.27*	0.18	–0.38**
P		1.00	–0.14	0.68***	–0.09	0.41**	–0.02
K			1.00	–0.07	0.55***	–0.05	–0.03
Ca				1.00	0.05	0.41**	–0.18
Mg					1.00	–0.19	–0.40**
Zn						1.00	0.70***

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; ns – not significant

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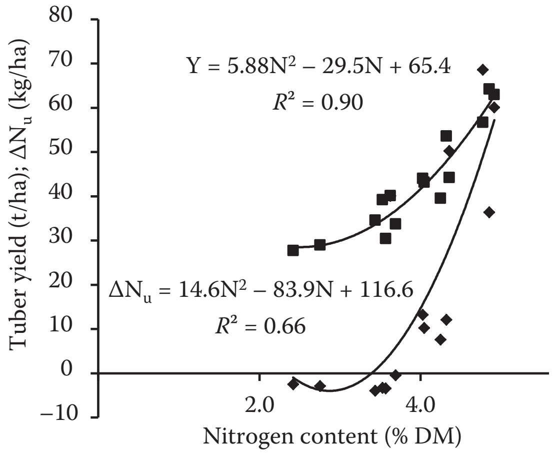

Figure 3. Nitrogen content at BBCH 40 versus tuber yield (Y) and net nitrogen (N) uptake change. DM – dry matter

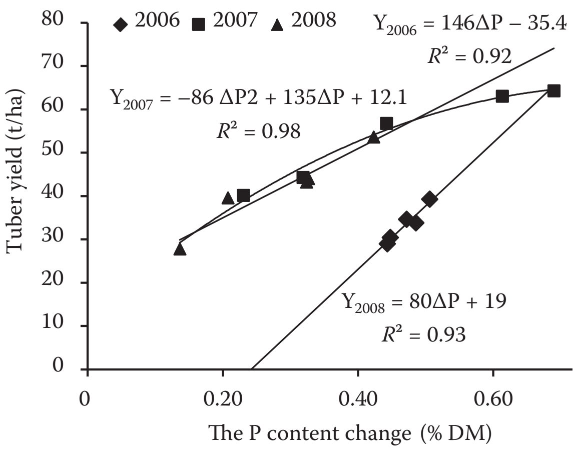

Figure 4. Tuber yield as a function of net phosphorus (P) content change during BBCH 33–40. DM – dry matter

was recorded, provided that N content in the tops exceeded 3.4%. The negative ΔNu during BBCH 33–40 revealed in 2006 and on the AC plot also in 2008. The supposition that N content in potato tops at BBCH 40 leads to exponential increase of tuber yield has been verified. The procedure for determination of the upper N content range is shown in Figure 4. The tuber yield progressed in accordance to the net N content increase (ΔN) up to +0.41% with respect to its content at BBCH 33 (3.91%). This small increase resulted in the maximum theoretical tuber yield of 51.4 t/ha. Any further N content increase, i.e. above 4.32% at BBCH 40, resulted in the yield drop.

In the light of the above presented data, there remains a question of the set of nutrients limiting, both the tuber yield and N content in potato tops during the studied period. The stepwise regression analysis showed that at BBCH 33, the tuber yield was significantly driven by P and Zn, but the N content by P, Mg, Zn and Cu contents:

$$Y = -37.7 + 229P + 3.6Zn$$
for $R^2 = 0.70$ and $n = 60$;

$$N = -0.16 + 13.6P + 0.06Mg + 0.15\ Zn - 0.28Cu$$
for $R^2 = 0.80$, and $n = 60$.

These two equations clearly stress the most limiting effect of P and Zn on N supply to potato

Table 4. Nutrient content in potato tops at BBCH 40

Factor	Level of factor	P	K	Ca	Mg	Zn	Cu
		(% DM)				(mg/kg)	
Year (Y)	2006	0.19^b	2.73^a	0.46^b	0.30^c	11.9^a	3.45^a
	2007	0.23^c	3.60^c	0.50^c	0.26^a	13.5^b	4.93^c
	2008	0.17^a	3.12^b	0.42^a	0.28^b	13.1^b	4.65^b
Fertilizing treatment (FT)	AC	0.16^a	2.92^a	0.43	0.23^a	10.9^a	3.96^a
	NP	0.19^b	3.01^b	0.47	0.26^b	12.3^b	4.27^b
	NPK1	0.20^c	3.27^c	0.47	0.28^c	13.5^c	4.60^d
	NPK2	0.21^c	3.23^c	0.46	0.30^{cd}	14.0^c	4.36^{bc}
	NPK3	0.21^c	3.31^c	0.47	0.32^d	13.6^c	4.52^{cd}
Source of variation							
Y		***	***	***	***	***	***
FT		***	***	ns	***	***	***
Y × FT		***	***	ns	**	***	***

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; ns – not significant. [a]The same letter indicates a lack of significant differences within the treatment; AC –control (no fertilizers added); NPK1 (NPK – K as muriate of potash, MOP); NPK2 (NPKS – K as potassium sulfate, SOP); NPK3 (NPKSMg – Patentkali); DM – dry matter

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Table 5. Correlation matrix of nutrient content at BBCH 40 and tuber yield

	N	P	K	Ca	Mg	Zn	Cu
Yield	0.88***	0.77***	0.85***	0.33*	0.17	0.83***	0.74***
N	1.00	0.74***	0.78***	0.40**	0.20	0.77***	0.66***
P		1.00	0.67***	0.65***	0.28*	0.61***	0.38**
K			1.00	0.40**	–0.05	0.56***	0.72***
Ca				1.00	–0.01	0.11	0.07
Mg					1.00	0.41**	–0.09
Zn						1.00	0.52***

***P < 0.001; **P < 0.01; *P <0.05; ns – not significant

plants before tuber induction (Table 4). The content of P was low, indicating its shortage (Jenkins and Mahmood 2003). The low P content in tops as recorded in 2007, a year with the highest yield, can be explained by a dilution effect resulting from the large biomass (Table 1, Figure 4). It was significantly and positively correlated with the Zn, which revealed as the second element limiting yield (Table 5). The content of Mg was considerably higher in the dry 2006, compared to other years. This type of response corroborates the hypothesis by Grzebisz (2013), who stresses the importance of Mg supply to crops under water shortage. In contrast to Zn, copper showed an antagonistic impact on N management by potato at BBCH 33. Its content was the highest in 2008, a year with a deep water shortage in May and June.

The stepwise regression analysis showed that the tuber yield at BBCH 40 was significantly limited by a broad set of nutrients. In contrast, the N content in potato tops was considerably governed by K and Zn:

$$Y = -51.7 + 79.2P + 9.5K + 2.8Zn + 2.9Cu$$
for R^2 = 0.94 and n = 60;

$$N = -1.69 + 0.91K + 0.21Zn$$
for R^2 = 0.77 and n = 60.

The importance of P for the tuber yield was crucial, but variable in consecutive growing seasons. The net change of the P content (ΔP), irrespectively of the growing season, resulted in the yield increase (Figure 4). It followed the linear regression model in years with water shortage, being concomitant with lower yields. It has been explained by Barber (1984) that the rate of P ion diffusion toward the root surface is both low, and undergoes a great reduction under water shortage. In 2007, the pattern of the P content change followed the quadrate regression model, indicating a saturation status at ΔP equal to +0.076%. It resulted in the tuber yield of 63.8 t/ha. The observed pattern of response means that under favourable growth conditions, the P content of 0.25% at BBCH 40 was sufficiently high to effectively exploit yielding potential of potato (Rosen and Bierman 2008).

The net K content change (ΔK), in contrast to P, was not consistent during the period extending from BBCH 33 to BBCH 40 (Figure 5). In 2006, it was recorded only for plants fertilized with K, but ΔK was almost negligible. In spite of that, the yield raised from 29 to 39 t/ha in response to K application. In the wet 2007, the net K change resulted in the progressive yield increase. The reverse model appeared in 2008, when the highest yield of tuber was harvested on the NPKSMg plot with both high and stabile K content within BBCH 33–40. The same situation was recorded in 2006 on the NPK plot. These two facts indicate importance of K supply to potato plants in years with drought, in the period preceding tuber induction.

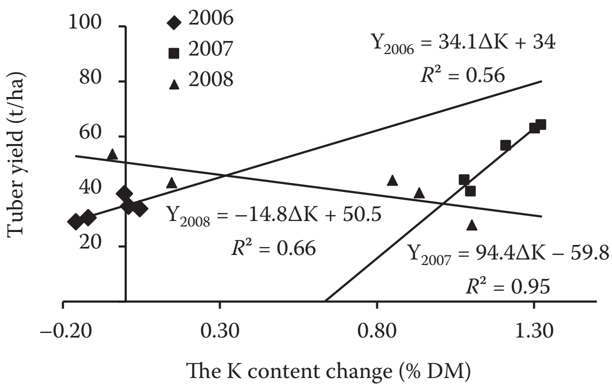

Figure 5. Tuber yield (Y) as a function of net potassium (K) content change during BBCH 33–40; DM – dry matter

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The simple evaluation of the Zn content impact on the tuber yield in the studied stages is difficult due to its inconsistent change in consecutive years of study. A clear pattern has been delivered by analysis of its impact on the N content at BBCH 40. At this stage, the Zn content of 15.7 mg/kg resulted in the saturation status of N, reaching 4.68%. Based upon the model in Figure 3, this value is equal to the yield of 56 t/ha. Therefore, it can be concluded that the N saturation status by plants can be achieved provided an adequate supply of N and K, which is controlled by auxins, and in turn it depended on the Zn content (Krouk 2016, Li et al. 2017). Thus, a good supply of K and Zn before the onset of tuber induction is crucial for effective N management by potato, especially under unfavourable conditions, like water shortage.

REFERENCES

Barber S.A. (1984): Soil Nutrient Bioavailability. New York, Wiley, 398.

FAOSTAT (2017): Food and Agriculture Organization of the United Nations. Available at: http, //faostat.fao.org/site/567/default.aspx#ancor (accessed 2017-04-05)

Forde B.G. (2014): Nitrogen signalling pathways shaping root system architecture: An update. Current Opinion in Plant Biology, 21: 30–36.

Grzebisz W. (2013): Crop response to magnesium fertilization as affected by nitrogen supply. Plant and Soil, 368: 23–39.

Grzebisz W., Gransee A., Szczepaniak W., Diatta J. (2013): The effects of potassium fertilization on water-use efficiency in crop plants. Journal of Plant Nutrition and Soil Science, 176: 355–374.

Grzebisz W., Čermák P., Rroco E., Szczepaniak W., Potarzycki J., Füleky G. (2017): Potassium impact on nitrogen use efficiency in potato – A case study from the Central-East Europe. Plant, Soil and Environment, 63: 422–427.

Jackson S.D. (1999): Multiple signaling pathways control tuber induction in potato. Plant Physiology, 119: 1–8.

Jenkins P.D., Mahmood S. (2003): Dry matter production and partitioning in potato plants subjected to combined deficiencies of nitrogen, phosphorus and potassium. Annals of Applied Biology, 143: 215–229.

Krouk G. (2016): Hormones and nitrate: A two-way connection. Plant Molecular Biology, 91: 599–606.

Li J., Wu W.H., Wang Y. (2017): Potassium channel AKT_1 is involved in the auxin-mediated root growth inhibition in *Arabidopsis* response to low K^+ stress. Journal of Integrative Plant Biology, 59: 895–909.

Pawelzik E., Möller K. (2014): Sustainable potato production worldwide: The challenge to assess conventional and organic production systems. Potato Research, 57: 273–290.

Rosen C.J., Bierman P.M. (2008): Potato yield and tuber set as affected by phosphorus fertilization. American Journal of Potato Research, 85: 110–120.

Supit I., van Diepen C.A., de Wit A.J.W., Kabat P., Baruth B., Ludwig F. (2010): Recent changes in the climatic yield potential of various crops in Europe. Agricultural Systems, 103: 683–694.

White P.J. (2013): Improving potassium acquisition and utilization by crop plants. Journal of Plant Nutrition and Soil Science, 176: 305–316.

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