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THE EFFECT OF UREA WITH UREASE INHIBITORS AND UREA ON YIELD AND NITRATE CONTENT IN POTATO TUBERS

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Abstract

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The three-year field trial was established on two localities – Žabčice and Valečov in 2010–2012. Seven variants of nitrogen fertilization in four replications have been involved in this experiment – 100% of urea (U), 80% of urea, 60% of urea, 100% of UreaStabil (US), 80% of UreaStabil and 60% of UreaStabil, whilst 100% corresponded to 90 kg $N.ha^{-1}$ after subtracting the content of Nmin in the soil, and the control variant without fertilization by mineral nitrogen. The two varieties with different lengths of vegetation periods have been chosen for the experiment – the early variety Karin and the mid-early variety Red Anna. In all cases, samples for the yield and qualitative analyses have been taken according to the phenological phase – the beginning of physiological maturity. The obtained results show that the highest average yield has been achieved in the variant of 100% of urea – 40.95 $t.ha^{-1}$, the yield of this variant was statistically significantly higher than the yield of the other variants of fertilization ($P < 0.05$). Variants treated by urea without the urease inhibitor reached an average yield of 37.62 $t.ha^{-1}$. However, this yield was not statistically significantly higher when comparing to the urea with the urease inhibitor ($P > 0.05$). In regard to localities, a relatively high average yield (44.58 $t.ha^{-1}$) has been achieved on a characteristically potato-growing locality Valečov. This yield was statistically significantly higher than the one attained on the Žabčice locality ($P < 0.05$). In respect to varieties, the mid-early variety Red Anna attained a higher average yield (39.65 $t. ha^{-1}$). Likewise, this yield was statistically significantly higher than the one of the early variety Karin ($P < 0.05$). The best year was 2012, in which the average yield of 38.73 $t.ha^{-1}$ was achieved. This yield was statistically significantly higher than the yield of the year 2010 ($P < 0.05$). As far as nitrates are concerned, the lowest average nitrate content has been found in the control variant – 184.1 $mg.kg^{-1}$ of moisture content. Nevertheless, the differences of the nitrate content among all the varieties were statistically inconclusive ($P > 0.05$). When using the fertilizer consisting of urea without the urease inhibitor, a lower average content of nitrates was found – 207.8 $mg.kg^{-1}$ of moisture content, but there was no statistically significant difference in comparison to the urea with the urease inhibitor variants ($P > 0.05$). In respect to localities, lower average nitrate content was established on the Žabčice locality – 177 $mg.kg^{-1}$ of moisture content. A statistical significance in comparison to the Valečov locality was found ($P < 0.05$). The mid-early variety Red Anna had a lower average nitrate content – 167.7 $mg.kg^{-1}$ of moisture content. When compared to the early variety Karin, a statistical significance was found $P<0.05$. Two years showed the lowest average content of nitrates – 2011 (181.6 $mg.kg^{-1}$ of moisture content) and 2010 (188 $mg.kg^{-1}$ of moisture content). No statistical significance ($P > 0.05$) was found between 2010 and 2011, but in contrast to the year 2012, a statistical significance in regard to the nitrate content was established ($P < 0.05$).

potatoes, urea, UreaStabil, yield, nitrate content

Being a fundamental macrobiogenic nutrient, nitrogen is vital for biomass creation in potatoes as well as other plants (Vaněk *et al.*, 2002). An appropriate dose of a nitrogen-based fertilizer favorably affects the yield and the quality of potato tubers. An increasing dose of nitrogen promotes the yield of tubers. The recommended dose of nitrogen ranges between 60–120 kg.ha^{-1} depending on the amount of the applied fertilizer (Diviš *et al.*, 2005). High nitrogen doses also reduce the starchiness of potatoes at the expense of creation of nitrates that are undesirable (Westermann *et al.*, 1994). From this viewpoint, it is obvious that inappropriate doses of nitrogen deteriorate not only the quantitative but also the qualitative parameters of potato tubers (Roinila *et al.*, 2003).

The nitrogenous fertilizer UreaStabil is urea enriched with the inhibitor of urease NBPT (N-(n-butyl)-thiophosphoric triamide). It is a new fertilizer that was registered in the Czech Republic in 2006. Its main advantage in comparison to the commonly used mineral nitrogenous fertilizers is its high content of nitrogen (46%), a very good solubility (after only 5 mm precipitation in comparison to LAV when 10 mm precipitation is required), when the transport of the nonpolar urea molecule to the roots of the plant takes place (Mráz, 2007). During the transport through the soil profile, a separation of the urease inhibitor from the urea occurs. Urea is absorbed by the roots of plants or is broken down into ammonium carbonate and is further absorbed by the plant in the form of the ammonium ion, and after increasing the soil temperature, it is absorbed by the roots in the form of nitrate. In contrast to the classical urea, the urease inhibitor eliminates the nitrogen losses caused by ammonium volatilization and creates better preconditions for transporting the nonhydrolyzed urea to the roots (Růžek *et al.*, 2006).

The nitrogenous fertilizer UreaStabil is suitable for most crops and applications, mainly for regeneration fertilization of winter crops, production and qualitative fertilization of cereals, basic fertilization and supplemental fertilization of spring crops, but also for side-band fertilization of crops (it does not inhibit germinating and emerging plants). Its usage is not recommended for very weak and damaged stands. On the other hand, it is suitable for stands affected by frequent spells of drought (Mráz, 2007).

New fertilizers based on urea with the urease inhibitor are key preconditions for The application of new technological procedures in terms of plant nutrition. The aim of the new technologies is to enhance efficacy of fertilization by nitrogen and at the same time, it strives to limit environmental pollution.

MATERIAL AND METHODS

Exact field experiments were established in 2010–2012 on two localities – Žabčice – typical corn-growing region (49°1'22.783"N 16°37'4.409"E) and Valečov – typical potato-growing region (49°38'36.839"N 15°29'48.422"E). Planting was carried out on both localities always at times when the soil and climatic conditions of a given locality allowed it. The spacing was 750 × 250 mm, so there were 53,333 tubers per hectare. On both localities, seven variants of nitrogen fertilization in four replications have been established – 100% of urea (U), 80% of urea, 60% of urea, 100% of UreaStabil (US), 80% of UreaStabil and 60% of UreaStabil whilst 100% corresponded to 90 kg of N.ha^{-1} after subtracting the Nmin content in the soil, and the control variant without fertilization by mineral nitrogen. The treatments by appropriate doses of fertilizers were conducted on the days of planting and the fertilizer was immediately put into the soil profile.

The two varieties with different lengths of the vegetation period have been selected for the trial – the early variety Karin and the mid-early variety Red Anna.

The samples for yield and qualitative analyses were always taken according to the phenological phase. In our case, it was the phenological phase at the beginning of the physiological maturity. Ten tufts were dug out manually from each plot and the analysis of the yield-forming parameters was carried out directly at the experimental station. Furthermore, the nitrate content was determined by the ion-selective electrode. (The electrode according to Šenkýř and Petr (1979) consists of a liquid membrane and an electro-conductive unit. The liquid membrane is created by the solution of 2.10-4 M nitrate ethyl violet or 10-4 M nitrate pyronine Y in nitrobenzene or other nitrated aromatic hydrocarbon.) The results have been statistically processed in the programme STATISTICA 10.0 CZ by the analysis of variance and then by the post – hoc test – the Tukey HSD test.

RESULT AND DISCUSSION

Yield

The yield belongs to the most important parameters and is decisive in terms of the economic aspects of crop growing. The yield is influenced by a number of factors including the choice of varieties, the impact of the weather, and the means of agricultural engineering. The experiment has been aimed at the agricultural engineering of growing, namely at the nitrogenous fertilization distinctly affecting the yield and quality of potatoes.

When focusing on individual results of our three-year experiment, we can see that the highest yield has been achieved at the dose of 100 U, namely 40.95 t.ha^{-1}on average for all the studied years. The yield of this variant has been statistically significantly higher than all the other variants ($P < 0.05$). In contrast, the lowest average yield has been attained in the control variant – 32.65 t.ha^{-1}.

This variant had statistically significantly lower yield in comparison to other variants, with the exceptions of the variants 60 U and 60 US compared to which no statistically significant difference was found (P > 0.05). The above mentioned findings are presented in Tab. I and Fig. 1. Finally, it can be concluded that the increasing dose of an N fertilizer increases the yield (Martin *et al.*, 2008; Zaman *et al.*, 2010).

I: *Tukey HSD test: Variants and yield (t.ha*$^{-1}$*)*

N. cell	Variant	Yield (t.ha^{-1}) Average	1	2	3
7	Control	32.64810		****	
6	60 U	34.68216	****	****	
3	60 US	34.89625	****	****	
2	80 US	36.10749	****		
1	100 US	36.74102	****		
5	80 U	37.21687	****		
4	100 U	40.95009			****

Note: confidence interval, P = 0.05

When comparing the fertilizers with and without the urease inhibitor used during all the studied periods, we have found out that a higher average yield was achieved when the fertilizer without the urease inhibitor was applied. In this case, the yield was 37.62 t.ha^{-1}. When the fertilizer with the urease inhibitor was used, an average yield of 35.91 t.ha^{-1} was achieved. The difference between the yields was not statistically conclusive (P > 0.05). Similar observations were made by Martin *et al.* (2008) who used urea with the urease inhibitor with the commercial name Agrotain and urea without the urease inhibitor in their trial.

The highest average yield out of all years, variants and replications has been attained on the Valečov locality (44.58 t.ha^{-1}), the Žabčice locality produced an average yield of 27.77 t.ha^{-1}. The difference between the yields from these two localities was statistically significant (P < 0.05). The Valečov locality is a traditional potato-growing area and this result was expected. On the other hand, the Žabčice locality is a typical maize production area.

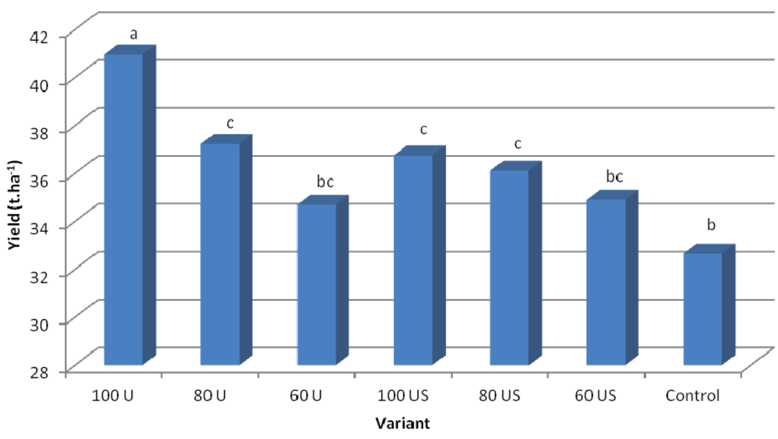
In regard to varieties, a higher average yield has been achieved by the mid.-early variety Red Anna (39.65 t.ha^{-1}) in contrast to the variety Karin that had an average yield of 32.71 t.ha^{-1} in all years, variants, and replications. This difference was statistically significant (P < 0.05). It has been confirmed that varieties with a longer vegetation period can produce higher yields.

When comparing the years, we have found out that the highest average yield was attained in 2012 (38.73 t.ha^{-1}). On the contrary, the lowest average yield was observed in 2010 (32.08 t.ha^{-1}). This difference was statistically conclusive (P < 0.05).The trial year 2011 had an average yield of 37.73 t.ha^{-1} and therefore, has become the second best year. The difference between the yield of the year 2011 and 2010 was statistically significant (P < 0.05). However, the difference between the yield of 2011 was statistically insignificant when comparing to the yield of 2012 (P > 0.05). This data are presented in Tab. II. The yields of individual years have been markedly influenced by the weather. The two extremes occurred in the course of the experiment. In 2010, there were floods that had caused a higher level of underground water so potatoes almost "stood" in water, which negatively affected the yield. Another problematic year was 2012 when there was extreme drought starting in autumn 2011. In addition, in May (18th May, 2012), the trial was struck

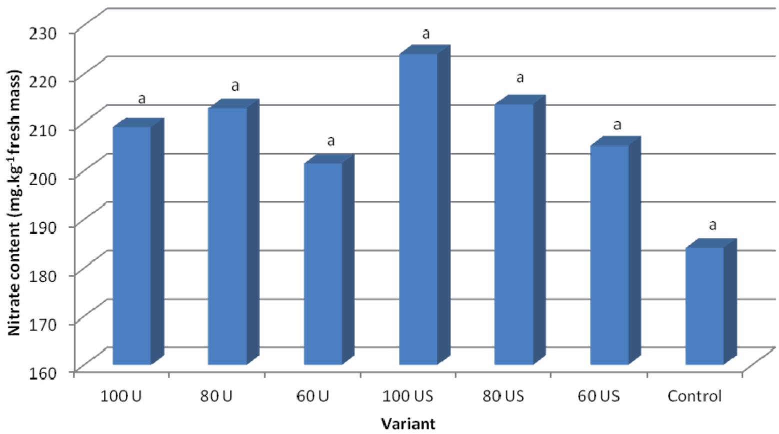
II: *Tukey HSD test: Year and yield (t.ha*$^{-1}$*)*

N. cell	Year	Yield (t.ha^{-1}) Average	1	2
1	2010	32.08035		****
2	2011	37.72593	****	
3	2012	38.72600	****	

Note: confidence interval, P = 0.05



1: *Yield and variants of nitrogen fertilization*
Note: Columns marked by the same letter did not differ significantly (P = 0.05).



2: *Nitrate content and variants of nitrogen fertilization*
Note: Columns marked by the same letter did not differ significantly (P = 0.05).

by ground frost which considerably delayed the vegetation period of the potatoes. Nevertheless, the yield of 2012 was the best out of the years included in the experiment. This can be explained by the fact that taking of samples was postponed by a month due to the bad weather. Moreover, there were precipitations in June thanks to which the potatoes had compensated for the weather-induced losses.

Nitrate content in potato tubers

Regular and high potato consumption has lead to an interest in potentially toxic substances contained in potato tubers, including nitrates. Free nitrates can be determined in every growing plant and are natural parts of plants (Putz and Bergthaller, 1989; Kalač and Míka, 1997). Potatoes are plants in which nitrates accumulate in relatively small amounts (Diviš, 1993). A similar fact is claimed by Velíšek (1999), who reports that potatoes belong to crops with the nitrate content in the middle of the values for the Hygienic limit. The Hygienic limit for the nitrate content in potato tubers is set by the act No. 298/1997 Collection of acts of the Ministry of Health to 300 $mg.kg^{-1}$ of moisture content. Currently, there is no set limit (Žižka, 2011). No direct negative effects of nitrates on human organism have been proven. Their biologically unfavorable effects are mostly connected to the phase of their transformation into nitrites. In the human organism, nitrites may connect with the iron ion of the blood pigment hemoglobin (Hb) where the so-called methemoglobin (MetHb) is formed by oxidation of the Fe^{2+} to Fe^{3+} ions. Methemoglobin is not able to bind oxygen so the blood loses its capability to transport oxygen to tissues and results in met-hemoglobinaemia (Velíšek and Hajšlová, 2009).

The results gained in our three-year trial show that the lowest average nitrate content was found in the control variant (184.1 $mg.kg^{-1}$ of moisture content), which is logical because the control variant had not been treated by nitrogen. The highest average nitrate content has been established in case of the

III: *Tukey HSD test: Variants and nitrate content ($mg.kg^{-1}$ fresh mass)*

N. cell	Variant	Nitrate content ($mg.kg^{-1}$ fresh mass) Average	1
4	Control	184.1058	****
6	60 U	201.4792	****
3	60 US	205.1250	****
7	100 U	209.0417	****
5	80 U	212.8958	****
2	80 US	213.7083	****
1	100 US	224.0000	****

Note: confidence interval, P = 0.05

variant 100 US (224 $mg.kg^{-1}$ of moisture content). The data are displayed in Fig. 2 and Tab. III. This can be explained by the fact that due to the presence of the inhibitor in the fertilizer, nitrogen stayed longer in the soil profile where potato roots were located. In contrast, urea without the inhibitor could have caused the nitrogen to be partially passed through. It is necessary to add that the differences among the individual variants were statistically indecisive ($P > 0.05$) and all measured values met the hygienic limit of 300 $mg.kg^{-1}$ of moisture content. Generally, it can be concluded that the increasing nitrogenous fertilization increases the nitrate content in tubers as has been also presented by Hofferbert and Grocholl (2000).

When comparing fertilizers with and without the urease inhibitor during all studied periods, we can see that a lower average nitrate content was found in case of the fertilizer without the urease inhibitor (207.8 $mg.kg^{-1}$ of moisture content) in comparison to the fertilizer with the urease inhibitor that had a nitrate content of 214.3 $mg.kg^{-1}$ of moisture content. However, the difference in the nitrate content was not statistically significant ($P > 0.05$). Once again, we can assume that due to the inhibitor's presence in the fertilizer, the nitrogen stayed for a longer time in the soil profile where potato roots were located.

In contrast, the urea without the inhibitor may have caused the nitrogen to flow through.

As far as localities are concerned, a lower average nitrate content was achieved on the Žabčice locality (177.4 mg.kg^{-1} of moisture content) than on the Valečov locality where the average nitrate content was 237 mg.kg^{-1} of moisture content. The difference between the two localities was statistically conclusive ($P < 0.05$). Gislason *et al.* (1984) came to a similar conclusion. In his work, he presents that the highest concentrations of nitrates in tubers were established in cooler areas. This has been confirmed by our experiment in which Valečov represents the cold locality. On the other hand, Hamouz *et al.* (2000) concluded that potatoes grown on lower-altitude localities contain higher levels of nitrates than potatoes grown in potato production areas. Their reasoning stems from the fact that the lower precipitation amounts during periods that were critical for the growth of tubers and plants caused the photosynthesis to cease and restricted nitrogen utilization by plants. We do not agree with this opinion due to the frequent dry spells (the Žabčice locality is one of the driest areas in the Czech Republic) during which the plant did not consume all nitrogen in the course of the key growth stages. This assumption is also supported by the considerably lower yield achieved in Žabčice in comparison to Valečov.

In regard to varieties, the lowest average nitrate content has been achieved in case of the mid-early variety Red Anna – 167.7 mg.kg^{-1} of moisture content. On the contrary, the early variety Karin attained an average yield of 246.7 mg.kg^{-1} of moisture content. The difference in regard to the nitrate content between the varieties was statistically significant ($P < 0.05$). It has been confirmed that varieties with a longer vegetation period contain lower levels of nitrates than varieties with a shorter vegetation period (assuming a higher yield and thus the dilution effect).This hypothesis has been supported also by Beránek, Klement (2001), who carried out a long-term variety trial in which he found out that with the increasing length of the vegetation period, the average amount of nitrates drops. A similar conclusion has been made by Shahbazi *et al.* (2009), who established that high-yielding varieties had lower nitrate contents. Due to the longer vegetation period, the potato varieties are able to build the nitrogen in their plant structures.

If we compare the individual years, we can find that the lowest nitrate content was observed in 2011, namely 181.6 mg.kg^{-1}g of moisture content, as well as in 2010, namely 188 mg.kg^{-1} of moisture content (Tab. IV). The differences in regard to the nitrate content between the years 2010 and 2011 were so marginal that they were statistically insignificant ($P > 0.05$). The year 2010 was important for its above the average precipitation amounts and the year 2011 was characteristic for its precipitation that helped the plants during their critical stages (butonisation, tuberisation phases). This assumption has been also confirmed by Míča (1990), who report that the nitrate content is not only influenced by the precipitation amounts but also by the timing of precipitations. The higher the precipitation amount, the lower the risk of a higher nitrate content in tubers. The year 2012 was a year with the highest average nitrate content, namely 251 mg.kg^{-1} of moisture content. Owing to the high nitrate content in the year 2012, a statistical significance in comparison to years 2010 and 2011 was found ($P < 0.05$). When looking at individual years in detail, the year 2010 belonged to years with the lowest nitrate content in potato tubers. This can be put down to the fact that in 2010, there were above the average precipitation amounts and as a result, the vast majority of nitrogen contained in soil had flooded out, which also corresponds with the yield that was at its lowest in 2010. Likewise, the year 2011 belonged to years with the lowest nitrate content in potato tubers. This is the result of the fact that the year 2011 was an ideal year not only for potatoes but for all agricultural crops as the temperatures as well as the precipitations were optimal and thanks to that, the dilution took place and the yield was one of the highest overall. Finally, the year 2012 will be evaluated. 2012 was characterized by extreme dryness. Nevertheless, the highest yield as well as the highest nitrate content was measured which seems illogical. However, we think there is some logic to it. Until June 2012, there was minimum rainfall (the drought had lasted since autumn 2011), so mineralization of nutrients in soil almost did not proceed at all. At the end of June, there were abundant precipitations, the mineralization started to take place and thanks to that a large amount of nutrients came loose, including nitrogen which the plants did not have the time to build in their plant tissues. This assumption is also supported by Prugar (1992), who claims that if a dry period is followed by abundant precipitations, a temporary increase in nitrate accumulation occurs because plants had not been able to absorb the nitrates due to lack of moisture. Furthermore, this statement is maintained by the reaction of farmers who grow malting barley, because in 2012 there was a main problem with malting quality – high content of N-substances.

IV: *Tukey HSD test: Year and nitrate content (mg.kg^{-1} fresh mass)*

N. cell	Year	Nitrate content (mg.kg^{-1} fresh mass) Average	1	2
2	2011	181.7500	****	
1	2010	188.8311	****	
3	2012	251.0000		****

Note: confidence interval, P = 0.05

SUMMARY

The aim of this study was to evaluate the impact of nitrogen-based fertilizers with the urease inhibitor and without the urease inhibitor on the yield and the nitrate content in potato tubers. The following conclusions have been made. The highest average yield was achieved when using the variant of 100% of urea – 40.95 $t.ha^{-1}$, this yield was statistically significantly higher than the yield of all the remaining variants ($P < 0.05$). Out of the fertilizers used in the study, the urea without the urease inhibitor attained an average yield of 37.62 $t.ha^{-1}$, however, this yield has not been statistically significantly higher than that of the urea with the urease inhibitor ($P > 0.05$). A high average yield has been attained on the traditional potato locality Valečov – 44.58 $t.ha^{-1}$. This yield was statistically decisively higher than that on the Žabčice locality ($P < 0.05$). On the average, a rather high yield has been reached by the mid-early variety Red Anna – 39.65 $t.ha^{-1}$. Likewise, the Red Anna yield was statistically significantly higher than the yield of the early variety Karin ($P < 0.05$). The best year was 2012 when the average yield was 38.73 $t.ha^{-1}$. This yield has been statistically significantly higher only in comparison to the year 2010 ($P < 0.05$).

As far as nitrates are concerned, the lowest average nitrate content has been found in the control variant – 184.1 $mg.kg^{-1}$ of moisture content. The differences in the nitrate content among the variants have been statistically insignificant ($P > 0.05$). A lower average nitrate content was established when using the fertilizer containing urea without the urease inhibitor – 207.8 $mg.kg^{-1}$ of moisture content, but no statistically decisive difference in comparison to the urea with the urease inhibitor was established ($P>0.05$). In respect to localities, a rather low average nitrate content has been found on the Žabčice locality – 177 $mg.kg^{-1}$ of moisture content, which was statistically significantly different from the nitrate content measured in Valečov $P < 0.05$. A low nitrate content was found in the mid-early variety Red Anna – 167.7 $mg.kg^{-1}$ of moisture content. A statistically significant difference in comparison to the nitrate content of the early variety Karin ($P < 0.05$) was found. As far as the years are concerned, the lower average nitrate content was achieved in 2011 – 181.6 $mg.kg^{-1}$ of moisture content, but also in 2010 – 188.8 $mg.kg^{-1}$ of moisture content. There has been no statistically significant difference between the years 2010 and 2011 ($P > 0.05$), however, in comparison to 2012, a statistically decisive difference was found ($P < 0.05$).

In summary it can be stated that the three-year monitoring was no significant difference in the average yield of tubers between the other variants with the exception of one variant and also the nitrate content showed no significant differences among variants, or used fertilizers. Significant effect of year was recorded in one case, namely the yield and nitrate content. The effectiveness of fertilizers with urease inhibitors is also significantly influenced the course of the year, especially the level and distribution of temperature and precipitation.

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