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EFFECT OF UREA AND UREA WITH UREASE INHIBITOR ON YIELDS AND NITROGEN AND CADMIUM CONTENT IN POTATOES

WPŁYW MOCZNIKA I MOCZNIKA Z INHIBITOREM UREAZY NA PLONOWANIE ORAZ ZAWARTOŚĆ AZOTU I KADMU W ZIEMNIAKACH

Abstract: Worldwide the urea fertilisers are the fastest growing and most commonly used source of nitrogen in agriculture. The benefits of using urea as a fertiliser are due to its high nitrogen content (approximately 46 % nitrogen), non polarity, high solubility, and low costs for manufacture, storage, and transport. Among the various available mitigation tools, urease inhibitors like NBPT (N-(n-butyl) thiophosphoric triamide) have the highest potential to improve the efficiency of urea by reducing N losses, mainly via ammonia volatilization. In 2011 and 2012 a small-plot experiment was established with the potato ‘Karin’ variety. The experimental locality was Zabcice, ca 30 km south of Brno, a maize-growing region. Prior to planting both mineral fertilisers (urea and urea with urease inhibitor NBPT – UREA stabil) were applied to the soil surface. During planting these fertilisers were incorporated into the soil. The experiment involved 7 treatments: 54, 72, 90 kgN $\cdot$ ha^{-1} as urea, 54, 72, 90 kgN $\cdot$ ha^{-1} as UREA stabil and unfertilised control. Each treatment was repeated 4 times. The focus of the experiment was to monitor the effect of two different fertilisers and different N-doses on the yields of potato tubers and content of nitrogen (N) and cadmium (Cd) in tubers and tops (stems + leaves).

In 2011 the contents of nitrogen in the tubers fluctuated between 14.3 and 15.6 g $\cdot$ kg^{-1} d.m. and in the tops between 29.7 and 40.9 g $\cdot$ kg^{-1} d.m. The contents of cadmium in tubers ranged between 0.14 and 0.17 mg $\cdot$ kg^{-1} d.m. and in tops between 0.50 and 0.72 mg $\cdot$ kg^{-1} d.m. In 2011 the tuber yields fluctuated

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irregularly, i.e. between 17.0 and 32.9 Mg · ha^{-1}. In 2012 the nitrogen contents in tubers ranged between 16.0 and 17.3 g · kg^{-1} d.m. and in the tops between 23.9 and 36.9 g · kg^{-1} d.m. Cadmium contents in tubers fluctuated between 0.13 and 0.20 mg · kg^{-1} d.m. and in the tops between 0.35 and 0.64 mg · kg^{-1} d.m. In 2012 the tuber yields fluctuated irregularly between 25.2 and 33.9 Mg · ha^{-1}.

Based on the results we can conclude that both fertilisers (urea, UREA stabil) were reflected in the N and Cd contents of the biomass of potatoes irregularly in dependence on the year, rate of fertiliser and analysed plant organ (tubers, tops). In both years the contents of N and Cd were higher in the tops. Tuber yields fluctuated irregularly in dependence on the year and rates of nitrogenous fertilisers.

Keywords: urea, urease inhibitor, tubers, tops, cadmium, nitrogen, yield

Introduction

Urea is a widely used N fertiliser in agriculture worldwide [1]. In soil, urea is hydrolyzed by urease to NH_3 and CO_2 with a rise in pH and an accumulation of NH_4^+ [2]. About 5–30 % of the urea N is lost as volatilised NH_3. Implementation of NH_3 mitigation strategies is crucial in order to reduce both the economic and environmental impact associated with NH_3 losses from urea application [3]. High concentrations of NH_3 in the atmosphere can result in formation of the greenhouse gas N_2O and acidification of soil and surface waters [4].

One of the most promising ways to improve the efficiency of urea is to use urease inhibitor. This slows the conversion of urea to NH_3, and hence reduces the concentration of NH_4^+ present in the soil solution and the potential for NH_3 volatilisation and seedling damage. Slowing the hydrolysis of urea allows more time for the urea to diffuse away from the application site or for rain or irrigation to dilute urea and NH_4^+ concentration at the soil surface and increase its dispersion in the soil [5]. One of the most frequently used inhibitors is NBPT (N-(n-butyl) thiophosphoric triamide) which reduces the rate of urea hydrolysis and ammonia losses in various soils [6]. Its only disadvantage is that its effect is time-limited and usually lasts one to two weeks [7].

Nitrogen fertilisation has a considerable effect on yields and quality of tubers, especially on the content of starch and protein. Proteins (amino acids) are compounds of potato tubers of very high quality which have a favourable effect on the human organism. Nevertheless excessive amounts of nitrogen may reduce yields [8].

Cadmium is a heavy metal and as such it is not desirable in plant products. In higher amounts Cd may jeopardise the health of humans and animals [9]. According to McLaughlin et al [10] and Oborn et al [11] the accumulation of Cd may reach dangerous levels on low-acid soils, with a low content of organic substances and high content of Cd. The Decree 13/1994 Coll. on the maximal admissible amount of heavy metals in the soils, in force in the Czech Republic [12], gives 0.4 mgCd · kg^{-1} as the maximal amount for light soils and for other soils less than 1.0 mgCd · kg^{-1}. Soils in the Czech Republic contain on average 0.13–0.52 mgCd · kg^{-1}. The heaviest contamination of plants occurs in cases when the plants take up Cd from the soil [13]. The soil pH also greatly affects the solubility and accessibility of Cd; when the pH value decreases most of the ions increase their mobility [14]. Cd is accumulated most of all in roots, next in vegetative organs and the least in generative organs [15]. Jönsson and Asp [16] reported that increasing rates of nitrogen reduced the Cd content in potato tubers.

The objective of the two-year experiments was to compare nitrogen fertilisation with urea and urea with the urease inhibitor on yields and contents of nitrogen and cadmium in tubers and tops of potatoes, ‘Karin’ variety.

Material and methods

The small-plot experiment was established at the School Farm in Zabcice near Brno (altitude 179 m) in 2011 and 2012. The locality lies in a warm maize-growing region and the soil type is gley fluvisol. The agrochemical properties of the medium heavy soil characterised as fluvisol were evaluated prior to establishment of the trial (Table 1).

Table 1

Agrochemical characteristics of the soil (Mehlich III)

Property	$pH/CaCl_2$	P	K	Ca	Mg
		$[mg \cdot kg^{-1}]$			
Value Estimation	5.9 weak acid	79 suitable	197 good	3.133 good	346 very high

The soil was leached with the Mehlich III (CH_3COOH, NH_4F, HNO_3, NH_4NO_3, EDTA) agent. K, Ca and Mg were assessed using AAS (Atomic Absorption Spectrometry), P was assessed using colorimetry.

For the experiment we used the early potato, ‘Karin’ variety, which was planted out on 7 April 2011 and 29 March 2012, spacing 750 × 250 mm. The variety is an excellent table variety. Prior to planting out the fertilisers (urea and urea with urease inhibitor NBPT-UREA stabil) were applied onto the soil surface and during planting were incorporated into the soil. The experiment consisted of 7 treatments (Table 2). Each treatment was repeated 4 times.

Table 2

Pattern of experiment

Variant	Fertilisation	N rate $[kg \cdot ha^{-1}]$
1	unfertilized control	—
2	urea	54
3	urea	72
4	urea	90
5	UREA stabil*	54
6	UREA stabil	72
7	UREA stabil	90

* Urea with urease inhibitor NBPT.

During vegetation the stands were treated with chemical preparations for weed, disease and pest control. The stands were harvested on 12 July 2011 and 14 August 2012 and samples were taken for assessments of tubers yields, and nitrogen and cadmium contents in the potato tubers and tops. The samples were dried, homogenised and wet-mineralised ($H_2SO_4 + H_2O_2$ to assess N according to the method of Kjeldahl; $HNO_3 + H_2O_2$ to assess Cd using AAS – Atomic Absorption Spectrometry). The results were processed statistically by variance analysis and then tested according to Scheffe ($p < 0.05$).

Results and discussion

Tuber yields were higher in 2012 than in 2011 (Table 3 and 4) and one of the reasons could be that the amount of rainfall during vegetation was higher.

Table 3

Tuber yields and content of N and Cd in potato tubers and tops in 2011

Variant No.	Pattern	N rate	Yields	N [g · kg^{-1} d.m.]		Cd [mg · kg^{-1} d.m.]	
		[kg · ha^{-1}]	[Mg · ha^{-1}]	tubers	tops	tubers	tops
1	unfertilized control	—	17.7 c	14.3 a	40.8 a	0.17 a	0.62 a
2	urea	54	17.0 c	14.7 a	37.7 b	0.15 a	0.66 a
3	urea	72	24.4 b	15.2 a	40.9 a	0.16 a	0.56 a
4	urea	90	32.9 a	14.5 a	32.6 c	0.16 a	0.50 a
5	UREA stabil*	54	23.4 b	14.5 a	36.4 b	0.15 a	0.72 a
6	UREA stabil	72	17.2 c	15.3 a	36.0 b	0.14 a	0.66 a
7	UREA stabil	90	18.5 c	15.6 a	29.7 c	0.16 a	0.62 a

* Urea with urease inhibitor NBPT; different letters (a, b, c) indicate significant differences between treatments.

Table 4

Tuber yields and content of N and Cd in potato tubers and tops in 2012

Variant No.	Pattern	N rate	Yields	N [g · kg^{-1} d.m.]		Cd [mg · kg^{-1} d.m.]	
		[kg · ha^{-1}]	[Mg · ha^{-1}]	tubers	tops	tubers	tops
1	unfertilized control	—	33.9 a	16.0 a	26.1 c	0.14 b	0.57 ab
2	urea	54	30.5 ab	16.4 a	30.6 b	0.17 ab	0.35 d
3	urea	72	25.2 c	16.7 a	36.9 a	0.15 ab	0.46 c
4	urea	90	28.6 b	17.2 a	30.3 b	0.20 a	0.53 b
5	UREA stabil*	54	30.4 ab	16.0 a	23.9 c	0.13 b	0.64 a
6	UREA stabil	72	30.0 ab	17.2 a	27.1 bc	0.15 ab	0.47 c
7	UREA stabil	90	25.7 c	17.3 a	33.9 ab	0.15 ab	0.50 bc

* Urea with urease inhibitor NBPT; different letters (a, b, c) indicate significant differences between treatments.

In 2011 the lowest dose of N using urea as the fertiliser to a non significant degree lowered tuber yield (by 4 %). Medium and the biggest rates of N significantly affected yields of tuber causing an increase by 38 % and 86 %, respectively, in relation to the control treatment. An opposite effect was observed in case of N in form of urea applied with urease inhibitor (UREA stabil) as the fertiliser. The lowest dose of N significantly increased tuber yield (by 32 %) but medium and the biggest ones had non significant effect on potato yielding. Medium dose in small extent lowered (by 3 %) and the biggest one it small degree increased tuber yield (by 5 %) in relation to the control treatment.

By contrast in 2012 the highest tuber yield was noted in control treatment. The smallest N doses did not significantly affect potato yielding, lowering tuber yield by 10 % in both fertiliser variants in comparison with control. The medium and biggest doses of urea dropped significantly tuber production by 26 % and 16 %, respectively. After application of medium and the biggest N doses using UREA stabil decrease of tuber yield was observed (by 12 % and 24 %, respectively) but only in case of biggest dose it triggered of significant reaction in amount of tuber yield. It could be caused by rainfall during the first days after planting the potatoes which might have flooded out some of the fertilisers from the soil.

Coelho et al [17] and Gileto et al [18] discovered that tuber yields increased with increasing rates of N fertilisers. This was confirmed by Poljak et al [19]. In their experiments tuber yields increased (34.38; 38.70; 38.92; 39.48 and 39.71 $Mg \cdot ha^{-1}$) along with rates of N (0; 100; 150; 200 and 250 $kg \cdot ha^{-1}$) and the N content in tubers enhanced as well (16.2; 17.0; 17.1; 16.4 and 17.9 $g \cdot kg^{-1}$). Jurkowska et al [20] who studied an effect of dicyandiamide and thiourea as inhibitors slowing N transformation in soil, observed significant improve of biomass yield of different plant species.

No significant differences between the two years were seen among the treatments in the N contents in tubers (Table 3 and 4). Braun et al [21] explored the effect of nitrogen fertilisers on the content of N in potato tubers. Likewise they discovered that rates of 0; 50; 100; 200 and 300 $kgN \cdot ha^{-1}$ had no effect on the N content in tubers.

The N content in potato tops was higher than in tubers, from 1.90 to 2.85 times in 2011 and from 1.49 to 2.29 times in 2012, and was very variable with regard to the rate or type of fertiliser in both years. In 2011 the biggest N content was observed in tops of control treatment. Medium N dose applied as urea did not affect N content in tops in comparison with control, and the smallest and the biggest doses substantially lowered it by 8 % and 10 %, respectively. All doses of N applied as urea with urease inhibitor significantly decreased N content in tops, especially the biggest one, by 11 %, 12 % and 10 %, respectively.

In 2012 application of the smallest, medium and the biggest doses of N as urea substantially increased N content in tops, by 17 %, 41 % and 16 %, respectively. The smallest and medium doses of N applied as UREA stabil did not affect significantly N content in tops in relation to control treatment. The highest dose of N applied in this form substantially affected N content in potato tops causing its increase by 30 %, and it was the highest N content in tops in 2012.

Poljak et al [19] in their experiments stated enhanced N content in tubers (16.2; 17.0; 17.1; 16.4 and 17.9 g · kg^{-1}) as a reaction on increased doses of N application (0; 100; 150; 200 and 250 kg · ha^{-1}). Jurkowska et al [20] observed different reactions of plants on N inhibitors application. Increase of N content in plants was an effect of dicyandiamide application, and opposite plant response was noted after thiourea use.

The Cd content in tubers ranged from 0.14 to 0.17 mg · kg^{-1} in 2011 and from 0.13 to 0.20 mg · kg^{-1} in 2012. Differences in Cd contents in the tubers between the years and among the treatments were minimal. In both years the Cd content in tops was higher than in tubers, from 3.13 to 4.80 times in 2011 and from 2.06 to 4.92 times in 2012. The year-on-year content of Cd in tops was balanced but significant differences were discovered among the treatments. However, these differences were very irregular and that it why it is difficult to reach unambiguous conclusions in terms of the type or rate of the fertiliser.

In 2011 the highest Cd accumulation was stated in tubers of control plants. Both N fertilizers application decrease Cd content in potato tubers by 6–16 %. Urea and urea with urease inhibitor application changed differently Cd content in tops. The lowest N dose applied as urea caused increase (by 6 %) but medium and the highest decreased Cd content (by 10 % and 19 %, respectively). Equivalent N doses in UREA stabil increased by 16 % and 6 % or did not change Cd content in tops, respectively. These changes were not substantial.

In 2012 all N doses applied as urea increased Cd content in potato tubers (by 21 %, 7 % and 43 %, respectively) but only the highest N dose caused substantial change. N applied in UREA stabil did not affect significantly Cd content in tubers. Increasing N doses in urea decreased Cd content in potato tops (by 39 %, 19 % and 7 %, respectively) and two smaller N doses caused substantial change. The smallest N dose applied in urea with urease inhibitor increased Cd content in tops (by 12 %), and two higher N doses decreased content of this metal (by 18 % and 12 %, respectively) but only medium dose had significant effect.

Larsson and Asp [22] reported that the Cd content in potato tubers decreased with increasing rates of nitrogen fertiliser. Hlusek et al [23] maintain an opposite opinion; the Cd content in potato tubers increased along with N rates from 60 to 120 kgN · ha^{-1}. A similar situation was monitored in the second year of the experiment after the application of urea (Table 4) when the highest concentration of Cd in the potato tubers was achieved with the highest rate of nitrogen (90 kgN · ha^{-1}). The changes in Cd content in potato organs in both years of investigation may be a result of differences in amount of precipitation during the vegetation season. Wisniowska-Kielian [24] in her studies on the effect of soil moistness on heavy metals absorption by different plants stated substantial changeability in Cd content in plant dependent on species and plant organ.

Conclusions

1. Potato tuber yields were higher in 2012 than in 2011 and one of the reasons could be bigger sum of rainfall during the vegetation season.

2. In both years the tuber yields fluctuated irregularly and the dependence on type or rate of fertiliser was different. In 2011 two bigger N rates applied in urea and the lowest dose in UREA stabil significantly increased yield of tubers, in relation to the control treatment. In 2012 two bigger N rates in urea and the biggest N doses in UREA stabil significantly reduced tuber yield.

3. The N content in potato tubers was lower from 1.49 to 2.85 times than in tops, and its content in tubers changed insignificantly in all treatments of both years.

4. N content in tops in 2011 significantly decreased after the smallest and the biggest N doses in urea and all N doses in UREA stabil, in comparison with control treatment. In 2012 application of urea and the highest N dose in UREA stabil substantially increased N content in tops.

5. The Cd content in tubers was lower from 2.06 to 4.92 times than in tops, and only in 2012 the highest N dose applied in urea significantly increased Cd content in tubers, in relation to the control treatment.

6. Substantial decrease in Cd content in potato tops was noted only in 2012 when two smaller N doses in urea and medium N dose in UREA stabil were applied.

7. Considering the effect of the weather of the year deems that it is necessary to repeat the experiments.

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WPŁYW MOCZNIKA I MOCZNIKA Z INHIBITOREM UREAZY NA PLONOWANIE ORAZ ZAWARTOŚĆ AZOTU I KADMU W ZIEMNIAKACH

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Abstrakt: Na całym świecie nawozy mocznikowe są najbardziej dynamicznie rozwijającym się i najczęściej stosowanym źródłem azotu w rolnictwie. Korzyści ze stosowania mocznika jako nawozu wynikają z dużej zawartości azotu (około 46% azotu), jego niepolarności, dobrej rozpuszczalności oraz niskich kosztów produkcji, przechowywania i transportu. Wśród różnych dostępnych narzędzi ograniczania dostępności azotu, inhibitory ureazy, takie jak NBPT (N-(n-butylo) triamid tiofosforowy) mają największy potencjał do poprawy efektywności mocznika poprzez zmniejszenie strat N, głównie przez ulatnianie amoniaku. W latach 2011 i 2012 założono małopoletkowe doświadczenie z ziemniakami odmiany 'Karin', zlokalizowane w miejscowości Žabčice, około 30 km na południe od Brna, w regionie uprawy kukurydzy. Przed sadzeniem zastosowano obydwa warianty nawożenia mineralnego (mocznik i mocznik z inhibitorem ureazy NBPT-UREA stabil) na powierzchnię gleby. W czasie sadzenie nawozy zostały wymieszane z glebą. Doświadczenie obejmowało 7 obiektów: 54, 72, 90 kgN $\cdot$ ha^{-1} jako mocznik, 54, 72, 90 kgN $\cdot$ ha^{-1} jako UREA stabil oraz nienawożony obiekt kontrolny, każdy w 4 powtórzeniach. Celem doświadczenia było zbadanie działanie dwóch różnych nawozów i różnych dawek N na wielkość plonu bulw ziemniaka oraz zawartość azotu (N) i kadmu (Cd) w bulwach i łętach (łodygi + liście).

W 2011 r. zawartość azotu w bulwach wahała się od 14,3 do 15,6 g $\cdot$ kg^{-1}, a w łętach od 29,7 do 40,9 g $\cdot$ kg^{-1} s.m. Zawartość kadmu w bulwach wahała się od 0,14 do 0,17 mg $\cdot$ kg^{-1}, a w łętach od 0,50 do 0,72 mg $\cdot$ kg^{-1} s.m. W 2011 r. plony bulw zmieniały się nieregularnie, tj. od 17,0 do 32,9 t $\cdot$ ha^{-1}. W 2012 r. zawartość azotu w bulwach wahała się od 16,0 do 17,3 g $\cdot$ kg^{-1}, a w łętach od 23,9 do 36,9 g $\cdot$ kg^{-1} s.m. Zawartość kadmu w bulwach wahała się od 0,13 do 0,20 mg $\cdot$ kg^{-1}, a w łętach od 0,35 do 0,64 mg $\cdot$ kg^{-1} s.m. W 2012 r. plony bulw zmieniały się nieregularnie, od 25,2 do 33,9 Mg $\cdot$ ha^{-1}.

Na podstawie uzyskanych wyników można stwierdzić, że obydwa warianty nawożenia (mocznik, UREA stabil) powodowały nieregularne zmiany zawartości N i Cd w biomasie ziemniaka w zależności od roku, dawki azotu i analizowanego organu rośliny (bulwy, łęty). W obydwu latach łęty zawierały więcej N i Cd niż bulwy. Plony bulw zmieniały się nieregularnie w zależności od roku i dawki nawozów azotowych.

Słowa kluczowe: mocznik, inhibitor ureazy, bulwy, łęty, kadm, azot, plony