Research article

Potential of a New Slow-release Urea Fertilizer under On-farm Conditions in a Semi-arid Environment

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Received 6 January 2016 Accepted 11 April 2016 (*Corresponding Author)

Abstract Nitrogen (N) fertilizers play an important role to increase grain yield and grain quality in crop production systems. In Western Siberia, predominantly used N-fertilizers for cereal production are urea and ammonium-nitrate ('Selitra'). Due to semi-arid climate, only one fertilizer application is common, simultaneously with sowing and directly into the seed furrow. A new kind of slow-release fertilizer is a modified urea with silicate coating and urease inhibitor and was developed at the State Agrarian University of the Northern Transurals (Russian Federation). In a field trial, the comparative performance of the novel fertilizer type was tested with spring wheat near the city of Ishim in Tyumen region (Western Siberia) on 3.4 ha under on-farm conditions. 4 levels of the slow-release urea (25/50/75/100%) were compared to 100% of conventional urea, 100% of Selitra and an unfertilized control in randomized complete block design with 4 replications. Results showed significant differences in soil nitrate availability but no differences in ammonium release. Differences between N-levels dispersed during heading, afterwards only plots with Selitra fertilization showed significant higher nitrate values. Leaf chlorophyll content as indicator for plant Nitrogen supply showed significant differences from beginning stem elongation on. The harvested grain yield showed no significant differences between the compared fertilizer types at the 100% N-level. Even if the grain yield with reduced dose of slow-release fertilizer was on the same level, it was not significantly higher than the unfertilized control. From the results of this field trial there seems to be no beneficial advantage of the tested slow-release fertilizer so far.

Keywords slow-release fertilizer, silicate coating, urease inhibitor, Nitrogen use efficiency, spring wheat, Western Siberia

INTRODUCTION

Nitrogen (N) fertilizers play an important role to increase wheat productivity and grain protein content. In Western Siberia predominantly ammonium-nitrate ('Selitra') and urea are used for N-fertilization.

Due to the dry sub-humid climate (Selezneva, 1973), only one N-application is common, simultaneously during sowing.

Also from an economic point of view, N-fertilizers play a key role in grain production processes and due to high inputs of energy, they mainly affect the total economic balance (Lubkowski, 2014). Urea is the most used Nitrogen fertilizer around the world agriculture, because of the high Nitrogen content by 46.6% (Trenkel, 1997; Zheng et al., 2009). When urea is applied to a soil, it is almost immediately hydrolysed into ammonium carbonate, which breaks down to carbon dioxide (CO_2) and ammonia (NH_3), producing high soil pH and ammonia loss (Eriksen and Kjeldby, 1987; Fenn and Kissel, 1973). The remainder of the ammonium in the soil can be converted to nitrates by the soil bacteria. Therefore, reducing water solubility of urea granules by physical or chemical inhibitors is very important and can improve the Nitrogen use efficiency (NUE) by preventing or slowing down these processes.

Such types modified fertilizers are described as ‘enhanced efficiency fertilizers’ which are able to reduce the risk of nutrient losses to the environment, retain nutrients in a less leachable forms, reduce solubility and maintain nutrients in the root zone by physical barriers (coating) (Trenkel, 2010). Furthermore, three different subtypes are characterised: (1) Stabilised fertilizers have a chemical inhibitor to slow down the hydrolysis of urea with further transformation to NH_4^+ and inhibitors to stop the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-); (2) Slow-release fertilizers are less-soluble and N is initially not plant available but needs to be converted into plant available N forms; (3) Controlled-release fertilizers are quick soluble fertilizers with a coating of hardly soluble material with a predictable rate of Nitrogen release when used at the manufacturer specified temperature (Trenkel, 1997; 2010).

Prognoses for the development of the fertilizer industry development predict an increase until 2020 to 1.9 – 2.2 million tons of slow- and controlled-release fertilizer products. One of the drawbacks, particularly for the currently most widespread polymer-coating, is the remaining amount of useless polymer that is left in the soil after nutrient consumption (Trenkel, 2010). A perspective alternative - although not yet used on a technological scale - is to produce slow-release fertilizers by using Calcium Silicate ($CaSiO_3$) as a mineral coating material, which can easily be decomposed by silicate bacteria to environmental friendly inorganic elements. The new type of such a slow-release urea fertilizer was developed at the State Agrarian University of the Northern Transurals (Russian Federation). A combination of a physical barrier by $CaSiO_3$-coating and a chemical urease inhibitor was chosen to delay the release of plant available Nitrogen.

The objective of this study was to compare the performance of the novel slow-release urea fertilizer against common practice and to evaluate the potential for improving of the Nitrogen use efficiency under practical conditions.

METHODOLOGY

Study Area

We installed a 3.4 ha field trial with spring wheat in Ishim (Tyumen province, Russia, Fig. 1) in RCBD with 4 replications to compare 4 levels of coated urea ‘CU’ (100/75/50/25%) against 100% of conventional uncoated urea ‘UU’, 100% of Selitra ‘S’ and a unfertilized control ‘C’. 100% equals 70 kg/ha N (Table 1). The fertilizer was applied directly into the seed furrow. The seed rate was constant over all variants by 240 kg ha^{-1} for 600 plants per m . The plots were sown with the regional variety ‘Ikarus‘ on May 19th, harvest took place on September 28th, weed regulation was done only once as usual for the region.

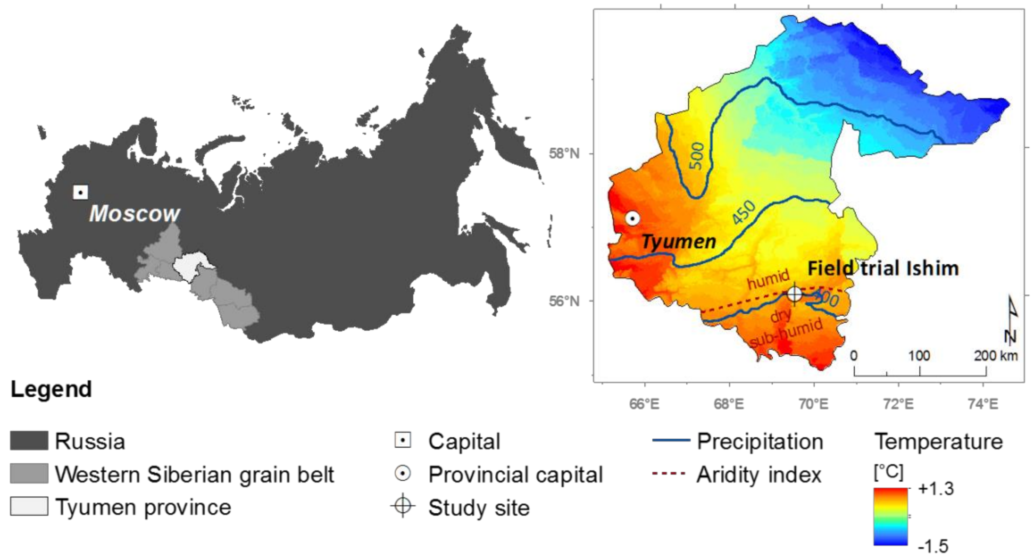

Fig. 1 Location and mean annual agro-climatic conditions of the study area
Souces: CGIAR-CSI (2009), GADM (2012), WorldClim (2013)

Table 1 Investigated variants with amounts of fertilizer and Nitrogen applied

variant		fertilizer type	N level [%]	applied fertilizer [kg ha^{-1}]	applied Nitrogen [kg ha^{-1}]
Control		no	0	0	0.0
S100		Selitra	100	203	70.0
UU100		uncoated urea	100	150	70.0
CU100		coated urea	100	153	70.0
CU75		coated urea	75	115	52.2
CU50		coated urea	50	77	35.0
CU25		coated urea	25	38	17.5

Fertilizer Production

The fertilizer was produced on the laboratory scale by 'Биотех' at the State Agrarian University of the Northern Transurals. Liquid Na_2SiO_3 was poured over usual urea in the first step. Secondly, liquid $CaCl_2$ was added which induced the drying process. Finally, urease inhibitor was applied on the coating. The coating material was between 1% and 3 % of the total mass of the fertilizer granules.

Analyses and Statistics

Soil N_{min} (NO_3 + NH_4) analysis for 0-30 cm was done reflectometric (Merck) and for determination of leaf chlorophyll content a SPAD-502 (Minolta) was used at the youngest fully developed leaf. Comparisons among means were carried out in R using the package agricolae (LSD-Test, $p<0.05$) (R Core Team, 2013). Between values with the same letter, there is no significant difference.

RESULTS AND DISCUSSION

Soil Nitrogen

The results of soil analysis showed significant differences in nitrate content but no significant differences in ammonium content (Fig. 2). Homogeneous preconditions were given by a constant level of both N_{min} fractions before fertilization. During leaf development, the variants Nitrogen availability differentiated, but only between the fertilizer types and not among the CU variants. Later in the growing season, only the S100 plots showed significant higher NO_3 content in the soil.

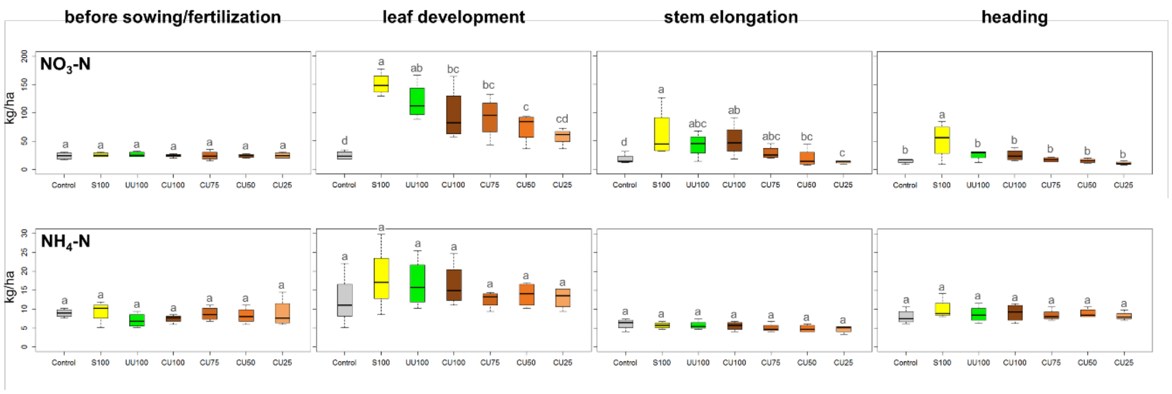

Fig. 2 Soil N_{min} components NO_3-N and NH_4-N in 0-30 cm before sowing/fertilization and at 3 development stages

Boxes show lower and upper quartiles, black line depicts the median, whiskers between min and max.

Even if there were no significant differences between soil ammonium contents, due to the differences in nitrate levels, a closer look on the proportions was necessary. Table 2 shows significant differences in the ammonium share, starting during leaf development, where values in unfertilized control plots were highest. This trend of low NH_4 proportion in conjunction with high nitrate content continued until the last measurement.

Table 2 NH_4-N proportion of total N_{min} (0-30 cm) at 3 sampling dates for all variants

development stage	Control	S100	UU100	CU100	CU75	CU50	CU25
before sowing/fertilization	28% a	27% a	21% a	23% a	27% a	26% a	26% a
leaf development	32% a	10% b	12% b	15% b	14% b	17% b	19% b
stem elongation	27% a	11% c	15% bc	13% c	16% abc	26% ab	27% a
heading	35% ab	23% b	27% ab	28% ab	33% ab	37% ab	43% a

Leaf Nitrogen

The SPAD-meter readings of the leaf-chlorophyll content are known to be a good indicator for leaf Nitrogen content (Uddling et al., 2007; Markwell et al., 1995). The results showed a plausible response according to the N-level since beginning stem elongation (Fig. 3). Reduced N levels resulted after heading in significant lower leaf chlorophyll contents.

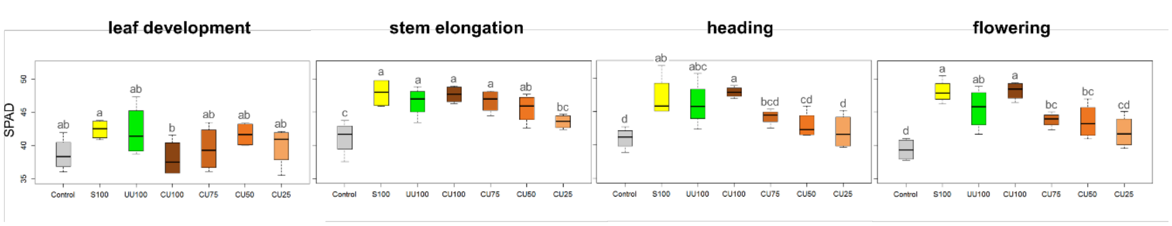

Fig. 3 SPAD-meter readings at 4 development stages

Boxes show lower and upper quartiles, black line depicts the median, whiskers between min and max

Yield Results and N Balance

The harvest results confirmed the observed soil and plant parameters, as there were no significant differences between the 100% variants of the three fertilizer types for all yield parameters (Table 3). The only significant differences occurred between unfertilized control and 75-100% fertilized plots for grain yield and the number of grains per ear.

Table 3 Selected yield parameters

	C	S100	UU100	CU100	CU75	CU50	CU25
grain yield [dt ha^{-1}]	26.7 c	39.9 a	40.2 a	39.6 a	35.1 ab	33.5 abc	30.4 bc
protein content [%]	9.3 a	8.7 a	10.8 a	9.1 a	10.2 a	9.7 a	10.6 a
1000 kernel weight [g]	38.3 abc	40.4 a	39.7 ab	39.7 ab	38.1 bc	37.2 c	39.1 abc
ears per m	356.4 a	393.3 a	398.2 a	406.2 a	361.3 a	378.2 a	357.3 a
grains per ear	19.9 c	25.2 a	25.3 a	24.6 a	25.4 a	23.7 ab	21.7 bc

All fertilizer types at 100% N-level resulted in comparable grain yields, among protein contents there were no differences at all (Fig. 4).

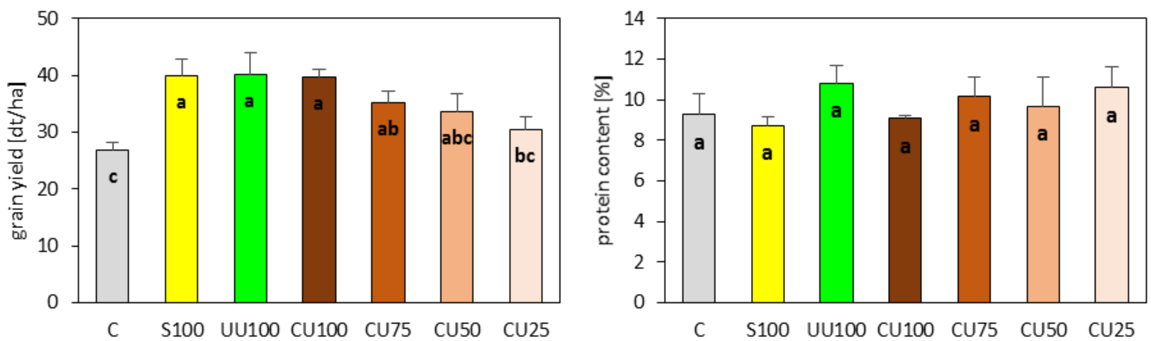

Fig. 4 Harvest results for grain yield (left) and protein content (right)
Error bars show 1 standard error of the mean

The last step was to balance the Nitrogen inputs and outputs for all variants and to calculate the N use efficiency (NUE=N uptake/fertilizer N). Table 4 shows a slight advantage for UU100 with an optimal NUE of 1.0, but also S100 and CU100 were on a good level. Higher NUE above 1.0 leads to unsustainable soil mining and should be avoided.

Table 4 Nitrogen balance and Nitrogen use efficiency (NUE)

	protein yield [dt ha^{-1}]	N uptake [kg ha^{-1}]	fertilizer N [kg ha^{-1}]	soil N [kg ha^{-1}]	balance	NUE
C	2.5	39.9	0.0	32.9	-6.9	-
S100	3.5	55.7	70.0	35.2	49.5	0.8
UU100	4.3	69.2	70.0	33.5	34.3	1.0
CU100	3.6	57.5	70.0	32.1	44.5	0.8
CU75	3.6	56.9	52.5	33.3	28.9	1.1
CU50	3.1	49.9	35.0	32.3	17.4	1.4
CU25	3.2	51.4	17.5	33.5	-0.4	2.9

CONCLUSION

The expected possibility to harvest the same with reduced fertilization by an enhanced fertilizer type did not fulfil since the grain yield was not significant higher than the unfertilized control for reduced variants. Therefore, we could not derive beneficial effects of the novel slow-release fertilizer from the results of this field trial. More field site years as well as further research on the laboratory scale to understand the short-term behaviour of the coated urea are needed.

ACKNOWLEDGEMENTS

This work was conducted as part of project SASCHA (Sustainable land management and adaption strategies under climate change for the Western Siberian grain belt). We are grateful for funding by the German ministry of education and research (BMBF) within their sustainable land management funding framework (funding reference 01LL0906D).

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