A new approach to obtaining prolonged nitrogen fertilizers and appraisal of their agrochemical efficiency

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Abstract. A new approach to obtain prolonged nitrogen fertilizers, based on the “gauging” of industrial instant nitrogen fertilizers (ammonium nitrate and urea) by Sorel cement, is proposed. The resulting alkaline complex N(Mg)-fertilizers help neutralize soil acidity (“Sorel cement” - nMg(OH)₂ • Mg(SO₄, NO₃) • nH₂O also contain plant nutrients). The main quality criteria for prolonged N(Mg)-fertilizers have been developed. The results of evaluating the agrochemical effectiveness of prolonged N(Mg)-fertilizers (as well as urea-formaldehyde fertilizers - UFF) are presented. In the growing experiments the application of these fertilizers contributed to increase in the yield of wheat and green mass of Sudan grass by 20-30%. In the weather and climatic conditions of Tatarstan, prolonged UFF make it possible to obtain a full second mowing of Sudan grass in the autumn period and N(Mg)-fertilizers contributed to an increase in wheat yield by 15%.

1. Introduction

Key indicators of the state of the grain complex of the Russian Federation in the end of 2018: gross grain harvest of ~ 114 million tons including wheat ~ 70 million tons with its average yield of 27.8 c/ha.

In the period 2000-2015 there was an intensive development of the grain complex (grain harvest in 2000 year amounted to only 65 million tons, the maximum in 2017 - 135 million tons). At present, Russia has grown from an importer (in 1992, imports of ~ 30 million tons) and has become the main global exporter of grain (30-40 million tons to 90 countries of the world) [1]. One of the reasons for this success is to maintain the fertility of arable land by applying mineral and organic fertilizers. Despite the fact that since 2000 the volume of applied fertilizers has increased almost 2 times, in terms of 1 hectare of soil, relatively little is applied - 40-50 kg ae (USA and European Union ~ 130-140 kg ai/ha) (table 1).

Table 1. Grain yield in 2018 (world grain production in 2018 - 2081 million tons).

| Country | Area, million hectares | Fertilizers, d. | Grain harvest |
|---------|------------------------|-----------------|--------------|
|         | total                  | arable | land | total, mln. tons | kg/ha | total, mln. tons | yield, c/ha |
| China   | 950                    | 135    | 124  | 50              | 53    | 432             | 47          |
| Russia  | 1712                   | 125    | 79   | 3-4             | 40-50 | 114             | 24          |
As is seen from the table 1, for 79 million hectares of sown area, only ~ 3-4 million tons are fertilizers, although total production reaches -18-19 million tonnes (~ 70-80% of fertilizer is exported) [2].

High yield is ensured not only by the amount of fertilizer applied (along with climatic conditions), but also by the efficiency of their using. The amount of fertilizers used per 1 ha in Russia and China is comparable, but the yield in our country is lower.

The scientifically based ratio of the main nutrients in the soil for most crops is N:P₂O₅:K₂O = 1:0:9:0.7 mass. At the same time, with the yield of grain crops, the most nitrogen is removed: in the case of wheat (the main grain crop), the removal of N: P₂O₅: K₂O=1:0.9:0.7 kg / 1 ton [N (2.5 ± 3): P₂O₅: K₂O (2 ± 2.5) wt.] [3]. When growing some fodder and nodule crops, nitrogen removal may be less: for example, for potatoes - N: P₂O₅: K₂O ~ 5: 1.5: 7 kg / 1 ton (with an average yield of 15 tons total removal of N (75 kg): P₂O₅ (22 kg): K₂O (105 kg)) [3].

The solubility of all major types of nitrogen fertilizers is very high: ammonium sulfate at 200 °C – 75 g / 100 g of water, urea (U) - 108 g / 100 g of water, ammonium nitrate (AN) - 190 g / 100 g of water. Because of this, in field conditions, depending on the amount of precipitation and the type of soil, nitrogen losses reach 40-80%. At present, the global production of nitrogen fertilizers is N ~ 109 million tons (total NPK ~ 183.7 million tons of barrel, in 2020 it will reach ~ 199 million tons of core). In Russia, the production of nitrogen fertilizers is ~ 50% of the total amount of mineral fertilizers (N ~ 7-9 million tons): ammonium nitrate ~ 9 million tons, urea ~ 6 million tons, urea-ammonia mixture (UAM) 2 million tons, ammonium sulfate ~ 1.5 million tons. Consequently, with an average price of nitrogen fertilizers 200 dollars. for 1 ton, losses even at the minimum amount of 40% are equivalent to a loss of 8.000 million dollars by year [2].

Countries with highly developed intensive agriculture have already faced the negative consequences of applying large doses of fertilizers: groundwater and surface water basins contain significant amounts of NH₄ and NO₃ ions, which leads to the disappearance of many living organisms in them (irreversible processes of ecological imbalance are threat to human health and life).

To provide plants with nitrogen throughout the growing season, conventional nitrogen fertilizers are introduced into the soil in fractional portions (which requires additional labor costs for transportation and fertilization). In the case of application to the soil in large doses, they have a negative effect on plants (cause burns, inhibit their development), are washed out of the soil, in addition, part of the NH₄ form of nitrogen of easily soluble fertilizers in the soil is quickly nitrified.

The carbide-ammonia mixture (N ~ 28-32%) that is optimal for the content of various forms of nitrogen under normal conditions can only be found in form of a solution (solid mixture U: AC = (50±30%) : (50±70%) melts already at ~40°C, and then, greedily absorbing moisture from the air, turns into antifreeze solution with a minimum crystallization temperature of “~26.2°C”) [4]. Other disadvantages of UAM include the presence of large amount of ballast water, the need of huge storage tanks, as well as special equipment for depositing it on the field.

On an industrial scale, lime-ammonia mixture - IAS (N~27%, Ca~20%), alkaline fertilizer containing NH₄ and NO₃ forms of nitrogen (NAK Azot, Novomoskovsk) is currently being produced [5]. Produced in large volumes, an alkaline solution of CAS contains all 3 basic forms of nitrogen, but is quick-acting. Pilot production of a slow-acting urea-formaldehyde fertilizer - UFF (NOSt. ~38-40%, including slowly soluble nitrogen ~28%) was mastered back in the 1970s [6-8]. However, due to lack of the reliable data on its agrochemical effectiveness (for various regions of the country, significantly differing in soil and climatic conditions), it is not currently being produced in industrial scale.

A review of the literature shows that research in this area is carried out in various directions, the main of which are the following: encapsulation; addition of nitrification inhibitors; technology of urea-formaldehyde fertilizers (UFF), technology of lime ammonium nitrate (AN) and some others [4-8]. The main advantages of all prolonged fertilizers: increased nitrogen utilization; reduction of environmental pollution; reduction of labor costs when replacing fractional introduction at the same time; improvement of product quality due to a decrease in the amount of nitrates in it, etc.
In encapsulated fertilizers, aqueous solutions penetrate through the film layer rather slowly, thereby they are used by plants better and more evenly during the growing season (sulfur compounds, paraffin, polyethylene emulsion, etc. are used as coatings) [9]. Nitrogen fertilizers with nitrification inhibitors in amount of 0.5-3% by weight of fertilizers (mainly preparations from Japan and the USA) are designed to inhibit nitrification processes for 1.5-2 months (i.e. during the period of intensive nitrogen consumption by plants).

A significant number of studies are devoted to the development of various modifications of urea and ammonium nitrate [10-13]. However, most of the work is related to the development of complex fertilizer technologies containing not only the main nutrition elements (MNE), but also meso- and microelements. For example, various methods have been proposed for producing fertilizers with microelements [14], organo-mineral fertilizers [15], fertilizers with an adjustable ratio of nutrients [16] and others [17].

Much attention is paid to the issues of obtaining high-strength granules with a low rate of release of nutrients from them, as well as the selection of appropriate additives (binders, hardening, biologically active, etc.). Almost all the leading countries (China, the USA, Russia, Canada) in the production of fertilizers and grain are actively working in the field of the development of reagents aimed at improving the physic-mechanical properties of granules [18-25].

The analysis of literature data shows that most of the proposed complex fertilizers have an equal ratio of nutrients N: P\sub{2}O\sub{5}: K\sub{2}O ~ 1: 1: 1 wt. At the same time, the need of various crops in these elements is different (for most grains, for example, N: P\sub{2}O\sub{5}: K\sub{2}O ~ 0.9: 0.7 wt.). Therefore, when applying triple fertilizers to the soil, achieving the optimal ratio of all 3 main elements (taking into account the NPK content in the soil and their removal with the crop of a particular crop) is almost impossible. At the same time, it is known that excess of one element may impede the entry of another into the plant. Therefore, the production of double fertilizers is more appropriate, since in this case, the optimization problem over 2 components is solved relatively easily [18, 19].

The main claimed advantages of the new proposed prolonged fertilizers in the above works are as follows: increased nitrogen utilization; reduction of environmental pollution; reduction of labor costs when replacing fractional application at one time; improving product quality due to a decrease in the amount of nitrates in it, etc.

However, the main of these works it is that there is no data on the agrochemical effectiveness of the developed fertilizers. The introduction of various kinds of additives (soil deoxidizers, strengthening additives, nitrification inhibitors, etc.), on the one hand, can contribute to the production of fertilizers with good physicochemical properties. On the other hand, in practice, when cultivating crops in various soil and climatic conditions, these additives can have a very significant negative effect on both the yield and the quality of the products.

The aim of this work is to develop a method of producing prolonged alkaline nitrogen fertilizers with an adjustable dissolution rate containing all 3 main forms of nitrogen (NH\sub{4}, NO\sub{3}, NH\sub{2}) based on industrial nitrogen fertilizers (urea and ammonium nitrate) and evaluate their agrochemical effectiveness.

2. Materials and methods

Prolonged N(Mg)-fertilizers were obtained by "shutting" industrial nitrogen fertilizers (urea – GOST 2081-2010, ammonium nitrate – GOST 2-2013) by suspension of magnesium binder (MgO) in solutions of sodium salts [MgSO\sub{4}, Mg (NO\sub{3})\sub{2}] according to the method developed by us [26]. Industrial "caustic magnesite" (GOST 1216 "caustic magnesite Powder", MgO ~ 80 %, MgCO\sub{3} ~ 9%) and dolomite roasting products (MgO ~20%, CaCO\sub{3} ~70%) were used as a magnesium binder.

For comparison, samples of slowly soluble UFF were obtained by reacting a urea melt with formalin using a well-known technique [6].

The fertilizers obtained were used to determine the nitrogen content, the pH of the solution, the strength of the granules, as well as their rate of moisture absorption and dissolution. Samples of N(Mg)-fertilizers also estimated the ratio of nutrients ("N: MgO", wt.) And in samples of UFF - the
ratio (water-soluble nitrogen of urea, hardly soluble nitrogen of monomethyl carbamide). Samples of NMg fertilizers were obtained by mixing a solution of CAS first with grouters [MgSO₄, Mg(NO₃)₂], and then with a magnesia binder (figure 1).

![Diagram](image)

**Figure 1.** Block diagram of obtaining N(Mg)-fertilizers in the system “MgO - Mg(NO₃, SO₄) - H₂O”.

The resulting suspension was heated, kept until the setting of Sorel cement, and then the thick mixture was granulated with an extruder. The granules were kept for 1 day (for hardening) and a commodity fraction of 1-4 mm was selected by classification (a small part was returned to the cycle; a large part was re-crushed).

Carbamide was pre-dissolved (or heated until melting), the calculated amount of formalin was added, mixed until a thickened mass was formed, cooled before setting, and granulated by extrusion during the hardening of the mixture.

Agrochemical efficiency of the developed fertilizers [27] was evaluated in the vegetation and field experiments with various grain and fodder crops in greenhouse conditions and on the experimental fields of the Kazan State Agrarian University Uchkhooz (gray forest soil: pH – 5.7; NSPHG – 90 mg/kg; P₂O₅ - 150 mg/kg; K₂O - 60 mg/kg). The main evaluation criteria were: grain yield (g/vessel, kg/m², c/ha); green mass yield (wet and dry); the content of NO₃– ions (in the green mass of feed).

X-ray phase analysis of urea and KFU samples was carried out on a Rigaku Smart Lab diffractometer (Japan) using CoK radiation (interval - 3-650 with increments of 0.020, exposure time at a point - 1 s).

3. Results

Urea-formaldehyde fertilizer, obtained with minor addition of formaldehyde, visually crystallizes as urea; with an increase in the amount of formaldehyde, a homogeneous composition of urea with monomethyl carbamide is formed (figure 2).
Figure 2. Appearance of UFF-1 (1:0.1 mol) and UFF-2 (1:0.25 mol).

X-ray phase analysis shows that UFF is a mixture of “Urea + MMK”, and the interaction product of urea with a stoichiometric amount of formaldehyde (“Urea: F = 1: 1 mol”) is an amorphous product containing only a small amount of impurity of the original urea (figure 3).

Figure 3. Diffractogram of the starting carbamide, UFF (“Kmd: F = 1: 0.2mol”) and MMK (“Kmd: F = 1: 1 mol”).

By analogy with urea-formaldehyde fertilizer, we have proposed a method for obtaining the so-called urea-magnesia fertilizer (UMF) by mixing industrial instant nitrogen fertilizers (ammonium nitrate and carbamide) with Sorel cement (CS) in interaction of magnesia binder (Mg), magnesium salt solutions:

\[
\text{nMg(OH)}_2 + \text{Mg(NO}_3\text{, SO}_4\text{)} + \text{mH}_2\text{O} = \text{nMg(OH)}_2\text{Mg(NO}_3\text{, SO}_4\text{)-mNH}_2\text{O.}
\]

In UFF, the dissolution rate is achieved due to poorly soluble monomethyl carbamide, and in the proposed method, the dissolution rate of ammonium nitrate and urea is reduced due to the poorly soluble “Sorel cement”.

The innovative granular CAM technology developed by us (instead of its solution) is quite simple and consists of mixing the CAM solution (or separately and AC) before granulating with suspension of MgO in solutions of magnesium salts [MgSO₄ or Mg(NO₃)₂] [10]. As a result of the slow hardening of the mixture, a homogeneous composition is formed, which during its solidification can be granulate in various ways (eg, extrusion). The final product after curing (2-4 weeks) is a strong granule with a low dissolution rate and less moisture absorption.
The resulting homogeneous composition of ammonium nitrate and carbamide with “Sorel cement” should be called complex N(Mg)-fertilization, since Magnesium is also an important nutrient [1]. The nitrogen content in N(Mg)-fertilizers is less than in UFF (MgO: N = 0.2 ± 0.6 wt.). However, it is alkaline [due to the presence of Mg(OH)2], which allows neutralizing the acidity of the soil. Among other drawbacks of N(Mg) fertilizers is the possibility of no additional effect of yield increase in a dry year although this neutralizes the excess acidity of the soil). At the first stage, 3 samples of UFF (for comparison) and N(Mg)-fertilizers with different ratios were obtained (table 2).

**Table 2.** Composition and properties of granules UFF and N(Mg)-fertilizers.

| Indicators                      | Urea | UFF | N(Mg)-fertilizer |
|---------------------------------|------|-----|------------------|
|                                 | 1    | 2   | 3               |
| **UFF- UFF- UFF- CMF-1 CMF-2 CMF-3** |     |     | (MgO:N=0.2) (MgO:N=0.4) (MgO:N=0.6) |
| Ratio N\textsubscript{KNO}_{3}:N\textsubscript{MMK}, max % | 34:8 | 25:14 | 16:20 |
| Ratio N: MgO, mas %             | –    | –   | –               |
| pH (1 %)                        | 6.5  | 6.5 | 6.5             |
| Dissolution time on 50 %        | 2    | 5   | 18              |
| Moisture absorption (W=90%, %)  | 153  | 106 | 81              |
| Strength kg/granule (d = 2-3 mm)| 1.2  | 1.3 | 1.6             |

The proposed N(Mg)-fertilizers have a low dissolution rate. At the same time, the presence of MgO gives an additional positive effect on the neutralization of soil acidity. The high strength of granules N(Mg)-fertilizers helps reduce dust formation, and the relatively low absorption rate reduces the caking of the granules.

Agrochemical efficiency of the developed fertilizers was evaluated in the vegetation and field experiments (table 3-7).

**Table 3.** The effect of UFF and N(Mg)-fertilizers on the yield of wheat of the variety ‘Amir’ in the vegetation experiments (gray forest soil).

| Option (fertilizer) | Harvest, g/vessel (dry weight) | Grain: straw |
|---------------------|---------------------------------|--------------|
|                     | grain (14% ow.) straw grain + straw |  |
| 1. Control          | 9.3 (-22%) 7.4 (-21%) 16.7 (-22%) | 1.25 |
| 2. AC (N=34%)       | 13.4 (+11%) 10.6 (+12%) 24 (+12%) | 1.25 |
| 3. K (N= 46%)       | 12                             | 9.4          |
| 4. UFF-1 (N=42%)    | 12.8 (+6%) 9.2 (-2%) 22 (+3%) | 1.37 |
| 5. UFF-2 (N=39%)    | 12.9 (+7%) 9.9 (+5%) 22.8 (+6%) | 1.29 |
| 6. UFF-3 (N=35%)    | 14.8 (+24%) 10.6 (+13%) 25.4 (+19%) | 1.39 |
| 7. CMF-1 (N=35%)    | 15.2 (+26%) 11 (+17%) 26.2 (+22%) | 1.36 |
| 8. CMF-2 (N=29%)    | 14.8 (+24%) 11.2 (+19%) 26 (+22%) | 1.3 |
| 9. CMF-3 (N=24%)    | 15.1 (+27%) 10 (+6%) 25.1 (+17%) | 1.5 |

As was to be expected, the mass of the grain when UFF and N (Mg) fertilizers are introduced is much higher. Experiments with spring wheat varieties ‘Ekada 66’ were carried out for 2 years in the same vessels (table 4) with the introduction in the 2nd year of the same doses of nitrogen fertilizers (without potassium and phosphorus).
Calculations show that, provided an additional 1 dose of K would be relatively optimal. As can be seen from the table 4, in the 1st -year, the maximum increase in the mass of grain with the introduction of UFF was 21% relative to urea (practically the same results were obtained in experiments with barley), and with the addition of N(Mg)-fertilizers reached +49%. In the 2nd year of the experiments, the increase in the mass of grain with the introduction of KF/ was only 3-11%, and with the introduction of the CMF, the result was even negative. This can be explained by the lack of other major nutrients (potassium and phosphorus), as well as an excess of magnesium relative to NPK. Calculations show that, provided an additional 1 dose of K₂O is applied, the N: P: K₂O ratio in the soil would be relatively optimal — N: P₂O₅: K₂O = 1.6: 1: 1 (the initial ratio N: P₂O₅: K₂O = (90: 150 : 60 mg/kg) = 0.6: 1: 0.4 wt., With the introduction of 1 dose of nitrogen - N: P₂O₅: K₂O = 1.6: 1: 0.4 wt.).

The results of vegetation experiments with Sudanese grass are presented in table 5.

### Table 4. Effect of UFF and N (Mg) fertilizers on the yield of wheat varieties ‘Ekada 66’ in the vegetation experiments (gray forest soil).

| Option (fertilizer) | Harvest, g/vessel (dry weight) | Corn 2 years (average) |
|---------------------|--------------------------------|------------------------|
|                     | 1 year grain (14% ow.) | 2 year grain + straw | 1 year grain (14% ow.) | 2 year grain + straw |
| 1. Control          | 67.6 (–44%)          | 15.3 (–47%)          | 10.4 (–44%)          | 21.3 (–39%)          | 17.1 (–44%)          |
| 2. AC (N=34%)       | 10.9 (–10%)          | 26 (–10%)           | 18.7 (+1%)           | 36.1 (+3%)           | 29.6 (–3%)           |
| 3. K (N= 46%)       | 12.1                | 28.8                | 18.5                | 35.1                | 30.6                |
| 4. UFF-1 (N=43%)    | 12.9 (+7%)           | 29.6 (+3%)          | 19 (+3%)            | 35.8 (+2%)           | 31.9 (+4%)           |
| 5. UFF-2 (N=41%)    | 11.5 (–5%)           | 30 (+4%)            | 20.1 (+9%)          | 37.5 (+7%)           | 31.6 (+3%)           |
| 6. UFF-3 (N=39%)    | 14.7 (+21%)          | 34 (+18%)           | 20.5 (+11%)         | 38.2 (+9%)           | 35.2 (+15%)          |
| 7. CMF-1 (N=35%)    | 15.8 (+30%)          | 35.4 (+23%)         | 18.4 (–1%)          | 34 (–3%)             | 34.2 (+12%)          |
| 8. CMF-2 (N=29 %)   | 16.4 (+35%)          | 37.4 (+30%)         | 17 (–8%)            | 32.9 (–6%)           | 33.4 (+9%)           |
| 9. CMF-3 (N=24 %)   | 18.14 (+49%)         | 37.1 (+29%)         | 17.7 (–6%)          | 34.4 (–2%)           | 35.8 (+17%)          |

As can be seen from the table 4, in the 1st -year, the maximum increase in the mass of grain with the introduction of UFF was 21% relative to urea (practically the same results were obtained in experiments with barley), and with the addition of N(Mg)-fertilizers reached +49%. In the 2nd year of the experiments, the increase in the mass of grain with the introduction of KF/ was only 3-11%, and with the introduction of the CMF, the result was even negative. This can be explained by the lack of other major nutrients (potassium and phosphorus), as well as an excess of magnesium relative to NPK. Calculations show that, provided an additional 1 dose of K₂O is applied, the N: P: K₂O ratio in the soil would be relatively optimal — N: P₂O₅: K₂O = 1.6: 1: 1 (the initial ratio N: P₂O₅: K₂O = (90: 150 : 60 mg/kg) = 0.6: 1: 0.4 wt., With the introduction of 1 dose of nitrogen - N: P₂O₅: K₂O = 1.6: 1: 0.4 wt.).

The results of vegetation experiments with Sudanese grass are presented in table 5.

### Table 5. Effect of UFF and N(Mg)-fertilizers on the yield of wet weight of Sudan grass variety ‘Aida’ in vegetative experiments.

| Option (fertilizer) | 1st year (soil - 8 kg), g / vessel | 2nd year (soil - 8 kg), g / vessel | NO₃, mg/kg |
|---------------------|-----------------------------------|-----------------------------------|-----------|
|                     | mowing | Amount | mowing | Amount | mowing | Amount | Amount |
| 1. Control          | 60     | 10     | 71 (–63%) | 118 | 140 | 4.9 | 263 (–36%) | 263 |
| 2. AC (N=34%)       | 128    | 63     | 191 (1%)  | 146 | 267 | 26 | 440 (+7%) | 346 |
| 3. K (N= 46%)       | 119    | 71     | 189 (1)   | 144 | 255 | 11 | 410 (2) | 707 |
| 4. UFF-1 (N=42%)    | 125    | 89/    | 214 (+13%) | – | – | – | – | – |
| 5. UFF-2 (N=39%)    | 114    | 106    | 221 (+17%) | 129 | 286 | 18 | 433 (+6%) | 297 |
| 6. UFF-3 (N=35%)    | 139    | 87     | 226 (+20%) | 157 | 318 | 22 | 497 (+21%) | 376 |
| 7. CMF-1 (N=35%)    | 141    | 105    | 246 (+30%) | – | – | – | – | – |
| 8. CMF-2 (N=29%)    | 140    | 102    | 242 (+28%) | 139 | 305 | 31 | 475 (+16%) | 376 |
| 9. CMF-3 (N=24%)    | 159    | 97     | 256 (+35%) | 129 | 304 | 28 | 462 (+13%) | 278 |
As can be seen from the table 5, when adding ammonium nitrate and urea, almost the same results were obtained, and the addition of UFF and N(Mg)-fertilizers contributes to increase in the yield of green mass by 20–35%. In the control experiment in the 1st year to get 2 cuttings almost failed. With the introduction of prolonged fertilizers, as expected, in 2 mowing the mass yield was significantly higher (relative to ammonium nitrate and urea).

In the vegetation experiments, the residual content of NO$_3^-$ ions in green fodder was also evaluated simultaneously (NO$_3^-$ = 600 mg/kg of green mass). When urea is applied (option No. 3), the green mass of Sudanese grass contains NO$_3^-$ = 707 mg/kg, i.e. exceeds (even more than when making ammonium nitrate in option No. 2), while using UFF and N(Mg)-fertilizers (options No. 5 and No. 9) - only NO$_3^-$ = 297 mg/kg and 278 mg/kg, respectively (which is comparable with the control experience). Consequently, if it is necessary to increase the green mass yield of feeds, prolonged N(Mg)-fertilizers can be applied to the soil even in excessive doses, without fear of exceeding of NO$_3^-$ ions.

In real soil and climatic conditions, the Ancestors of the Republic of Tatarstan (on the fields of the KSAU in the series of experiments with the introduction of ammonium nitrate, the yield of green mass relative to urea was usually higher by about 10% (due to the presence of 2 basic nitrogen forms in it). However, when using UFF, despite the presence of only NH$_2$-forms of nitrogen in it, a different picture was observed: for 2 mowing’s, the total green mass of Sudanese grass when introducing urea, ammonium nitrate and KFU-1 was, respectively, 412 c/ha, 442 c/ha and 453 c/ha.

Field experiments with Sudan grass were also carried out with the introduction of various doses of nitrogen fertilizers. In the first year, the yield of green mass of Sudanese grass in the amount of 2 cuttings in the control experiment was 188 centners/ha, with the addition of urea – 211 centners/ha, in the case of UFF-2 – 253 centners/ha (an increase of +35% relative to the control or +20 % relative to urea). The results of field experiments in the second year (when rape is seeded to Sudan grass and various doses of urea) are presented in table 6.

**Table 6. The effect of UFF on the yield of green mass of Sudan grass of the variety ‘Aida’ in field experiments (gray forest soil, state agricultural enterprise KSAU, repetition –3).**

| Option (fertilizer) | Nitrogen dose kg N / ha | The yield of green mass, kg / ha |
|--------------------|------------------------|---------------------------------|
|                    |                        | 1 mowing (2 months) | 2 mowing (4 months) | Amount 2 mowing |
| 1. Control         | –                      | 188 (–28%)          | 120 (–28%)          | 308 (–28%)      |
| 2. Urea            | 60                     | 263 (+5%)           | 168 (+2%)           | 430 (+4%)       |
| 3. Urea            | 90                     | 277 (+5%)           | 171 (+2%)           | 448 (+4%)       |
| 4. UFF-1           | 60                     | 269 (+2%)           | 218 (+30%)          | 487 (+13%)      |
| 5. UFF-2           | 60                     | 276 (+5%)           | 209 (+24%)          | 485 (+12%)      |

As can be seen from the table 6, the maximum yield of green mass of Sudan grass was obtained when applying UFF (~ 487 c/ha). It should be emphasized that the increase in green mass from the introduction of 1.5 doses of carbamide nitrogen contributed to an increase in yield only by + 4% (option No. 3).

The results of field experiments to assess the effect of nitrogen fertilizers on wheat yield are presented in Table. 7 (when this was also put additional experience to assess the impact on the yield of the mechanical mixture "urea + cement Sorel").
Table 7. Influence of UFF and N(Mg)-fertilizers on the yield of wheat of the ‘Ekada 66’ variety in field experiments (gray forest soil, KSAU Uchkhoz, plot - 10 m², repetition –3).

| Option (fertilizer) | Amount of plants (1 m²) | Mass 1 plants sheaf (with roots) | Mass 1 plants grains (g/m²) | Harvest centners per hectare |
|---------------------|--------------------------|---------------------------------|-----------------------------|-----------------------------|
| 1. Control          | 241                      | 1138                            | 4.7                         | 160 (+30%)                  |
| 2. AC (N=34%)       | 261                      | 1358                            | 5.2                         | 226 (+1%)                  |
| 3. K (N= 46%)       | 255                      | 1198                            | 4.7                         | 230 (-2%)                  |
| 4. UFF-1 (N=43%)    | 345                      | 1280                            | 3.7                         | 264 (+15%)                 |
| 5. UFF-2 (N=41%)    | 254                      | 1228                            | 4.8                         | 225 (-2%)                  |
| 6. UFF-3 (N=39%)    | 281                      | 1333                            | 4.7                         | 203 (-12%)                 |
| 7. CMF-1 (N=35 %)   | 271                      | 1338                            | 4.9                         | 261 (+14%)                 |
| 8. CMF-2 (N=29 %)   | 300                      | 1159                            | 3.9                         | 201(-12%)                 |
| 9. CMF-3 (N=24 %)   | 251                      | 1176                            | 4.7                         | 190 (-17%)                 |
| 10. “Carbamide + Sorel cement” | 270   | 1410                            | 5.2                         | 172 (-25%)                 |

As can be seen from the table 7, prolonged fertilizers with an optimal dissolution rate (UFF-1 and UMF-1) contribute to an increase in wheat yield by 14–15% relative to urea (it should be noted that some fertilizers are spent on the development of weeds that suppress the development of wheat). Samples of fertilizers with a very low dissolution rate (experiments No. 5, 6, 8, 9) already lead to a negative result. It should also be emphasized that with the use of the mechanical mixture “Urea + Sorel cement”, the weight of the plants was maximum, and the yield of grain was minimal (only slightly higher than the control experiment). When industrial nitrogen fertilizers were applied, the grain quality in almost all indicators exceeded the required indicators in accordance with GOST R 52554-2006 for soft wheat. When UFF-2 was introduced, the maximum virtuousness of the grain was reached - 84% (nature - 770 g/l, raw gluten quality, 67 units of the IDK device), and in the case of urea, the quality indicators are lower: 72%, 758 g/l, 81 units. IDK device, respectively (required performance for class 1 and 2: 60%, 750 g/l, 45-75 units. IDK device).

4. Conclusions
A new approach to obtain prolonged nitrogen fertilizers, based on the “gauging” of industrial instant nitrogen fertilizers (ammonium nitrate and urea) by “Sorel cement”, is proposed. On the basis of this approach, new prolonged N(Mg)-fertilizers have been developed, containing all forms of nitrogen - granulated “CAM” instead of its solution [NMg 20-30% with “MgO: N” = (0.2-0.6) mass.].

In vegetative experiments, application of prolonged nitrogen fertilizers contributed to an increase in the grain of wheat and green mass of Sudan grass by an average of 20–30%. It was established that in weather and climatic conditions of the Predkamsky zone of Tatarstan, prolonged UFF allow to get a full-fledged 2nd mowing of Sudan grass in autumn (30-50 c/ha of dry weight).

In field experiments the use of N(Mg)-fertilizers increased the wheat yield by 15%.

The quality of grain when applying UFF meets the requirements of GOST R 52554-2006 for soft wheat (and significantly higher relative to urea).

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