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# THE TECHNOLOGY OF PROLONGED NITROGEN-MAGNESIUM FERTILIZERS AND ASSESSMENT OF THEIR AGROCHEMICAL EFFICIENCY

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## Abstract

*A method is proposed for obtaining prolonged nitrogen-magnesium fertilizers by «cementing» industrial nitrogen fertilizers ( urea – Ur, ammonium nitrate – AN) with some magnesium hydroxide salts [$nMg(OH)_2{\cdot}Mg(NO_3)_2{\cdot}mH_2O$, $nMg(OH)_2{\cdot}MgSO_4{\cdot}mH_2O$ – also known as «Sorel's cement» (SC)]. The components of «Sorel cement» contain the main elements of plant nutrition (N, Mg, S), the resulting complex N(Mg)- and N(MgS) fertilizers are alkaline [due to the presence of $Mg(OH)_2$], which contributes to the neutralization of soil acidity. The proposed method allows you to obtain a granular urea-ammonia mixture (UAM) instead of its solution. The main criteria for the quality of prolonged N(Mg)- and N(MgS)-fertilizers are the ratio «MgO:UAM»; «SC:UAM»; «MgO:N». The total content of $\Sigma$ N(Mg) $\approx 20\div30$ % with the optimal ratio «MgO:N» = ($0{,}2\div0{,}6$) mass. It has been established that the strength of granules of N(Mg)- and N(MgS)-fertilizers is much higher (compared to granules of urea), and the dissolution rate is 10-50 times less. The pot experiments show that the new fertilizer contribute to a substantial increase in weight of wheat (at 26-49 %) and the yield of green mass Sudan grass (at 28-35%).*

**Keywords:** *prolonged nitrogen-magnesium fertilizers, Sorel's cement, neutralization of soil acidity, granular urea-ammonia mixture*

## 1. INTRODUCTION

In 2020, ~133 million tons of grain were harvested in Russia (world grain production in 2020 is ~ 2744 million tons, including wheat – 766 million tons). Russia is one of the three leaders in wheat production: China ~ 136 million tons, India ~ 107 million tons, Russia ~ 86 million tons [1]. In terms of wheat exports, Russia is also a leader – in 2019, exports amounted to ~ 35 million tons (total world wheat exports ~ 160 million tons) and, according to forecasts, wheat exports in the current agricultural year will amount to ~ 39 million tons. In 2020, agricultural products were exported to 86 countries of the world for $ 30.4 billion (77 items of processed products with a volume of more than 78 million tons) with imports of $ 29.8 billion.

At the same time, the average yield in Russia (20-27 c/ha) is significantly lower than the world average annual yield (~ 33 c/ha), although the maximum yield in the southern regions of the country reaches ~ 60 c/ha. For comparison, the leaders in recent years in terms of yield (Ireland, New Zealand, Netherlands, Belgium) receive 90-99 c/ha, in EU countries and some African countries (Germany, France, Great Britain, Denmark, Egypt) it reaches ~ 70-80 c/ha [2].

It is well known that one of the main reasons for increasing grain yield is maintaining the fertility of arable land by applying fertilizers (the share of mineral fertilizers in the total cost of grain production is ~ 14%). Despite the fact that Russia is one of the leaders in the production of mineral fertilizers (~ 22 million tons of active ingredient with a total world volume of NPK production of ~ 200 million tons), only 40-50 kg of NPK ( since 70-80% of fertilizers are exported). According to forecasts for 2021, it is planned to apply ~ 55 kg/ha or a total of 4.5 million tons of fertilizers (for comparison, in the USA and EU countries ~ 130-140 kg/ha) [2].

High productivity is ensured not only by the amount of fertilizers applied (under favorable weather and climatic conditions), but also by the efficiency of their use. Currently, along with an increase in yields, an increase in the utilization of fertilizer nutrients (i.e., a decrease in the chemical load on the soil), as well as an increase in the quality of grain (in 2020, the gross harvest of wheat of grades 1-4 was only 72 % of the total). The country's farmers were instructed to ensure the receipt of wheat with a high gluten content (in 2019, the share of wheat with gluten above 25% was only ~ 11%, by the beginning of 2021 the average gluten content in wheat was 22.4%).

With the wheat crop, nitrogen is removed from the soil more than phosphorus and potassium ($N:P_2O_5:K_2O \approx (30\div35):(10\div12):(20\div25)$ kg / 1 ton), although when growing some fodder and nodule crops, nitrogen removal is less (for example, for potatoes $N:P_2O_5:K_2O \approx 5:1,5:7$ kg / 1 ton) [3]. Currently, the industry produces the most nitrogen fertilizers (~ 50% of the total NPK fertilizers). The predominant use of physiologically acidic nitrogen fertilizers led to soil acidification in many regions of the country, and the NPK ratio in the soil became suboptimal (for most crops, the scientifically grounded NPK ratio in the soil is $N:P_2O_5:K_2O \approx 1:0,9:0,7$ mass .).

When nitrogen fertilizers are applied to the soil, depending on the amount of precipitation and the type of soil, nitrogen losses reach 40-80% (due to their high solubility). Taking into account that the world production of nitrogen fertilizers is N ~ 110 million tons, it is easy to calculate economic losses (the average price of nitrogen fertilizers is ~ $ 200 per 1 ton) [2]. To reduce the loss of nitrogen fertilizers, it is recommended to apply them to the soil in portions during the growing season (with a single application in large doses, they also have a negative effect on plants – cause burns, inhibit their development).

The main environmental consequences of the use of large doses of fertilizers in countries with highly developed intensive agriculture are as follows: significant pollution of artesian drinking water with $NH_4$- and $NO_3$-ions; eutrophication of terrestrial water basins; the disappearance of many species of living organisms in them.

Tightening environmental protection measures is one of the trends in the mineral fertilizers market. In this regard, a balanced consumption of mineral fertilizers (i.e. with minimal losses and least harm to the environment) is becoming increasingly important in the world. Currently, within the framework of the UN Environment Program, significant work is being done in this direction (a resolution on nitrogen fertilizers was adopted, the first international rules for the use of fertilizers were approved, the effect of fertilizers on human health is being studied, etc.).

Today there is interest in «stabilized» or «prolonged» fertilizers (that is controlled release of nutrients). Although at present their share is small (~ 5%), however, consumer interest in them is growing.

Thus, the development of methods for obtaining prolonged alkaline nitrogen fertilizers, simultaneously containing all the main forms of nitrogen $NH_4$, $NO_3$, $NH_2$), is an urgent task. Newly developed fertilizers should be not only prolonged, but also defender fertilizers, i.e. defenders of the soil (elimination of acidity, beneficial effects on soil microflora) and plants (against diseases and pests).

Among the industrial nitrogen fertilizers-defender can be attributed lime-ammonia mixture – LAM (N ≈ 27%, Ca + Mg ≈ 10-20%), containing $NH_4$- and $NO_3$-forms of nitrogen (NAC «Azot», Novomoskovsk) [4].

UAM solution containing all three major forms of nitrogen [5], to some extent also be attributed to the number of extended (since the $NH_2$-form nitrogen must first pass into $NH_4$-form, and then in the $NO_3$-shape - provided thereby its long-term effect on the soil).

Urea-formaldehyde fertilizer – UFF is prolonged (N ~ 40%, including slowly dissolving N ~ 28%), its main disadvantage is the presence of only $NH_2$-form of nitrogen in it (at the beginning of the growing season, plants require mainly $NO_3$- the form). Pilot production of UFF was mastered back in the 1970-s, at present it is not produced on an industrial scale (due to the lack of reliable data on its agrochemical efficiency for various regions of the country) [6-7].

Prolonged nitrogen fertilizers include encapsulated fertilizers (sulfur compounds, paraffin, polyethylene emulsion, etc. are used as granule coatings), as well as fertilizers with a small amount of nitrification inhibitors (designed to inhibit nitrification processes during the period of intensive nitrogen consumption by plants for 1.5-2 months) [8-14]. A significant number of studies are devoted to the issues of obtaining high-strength granules with a low rate of release of nutrients from them (NPK) [15-16].

Analysis of literature data shows that the main declared advantages of prolonged fertilizers are: higher nitrogen utilization rate; reduction of environmental pollution; reduction of labor costs when replacing fractional application at one time; as well as improving the quality of products (due to a decrease in the amount of nitrates in it) and some others. At the same time, it should be noted that there are relatively few works that provide data confirming the agrochemical efficiency of the developed fertilizers.

The aim of this work is to develop methods for producing prolonged alkaline N(Mg)- and N(MgS)-fertilizers based on industrial nitrogen fertilizers (urea and ammonium nitrate) using «Sorel cement», as well as to assess their agrochemical efficiency.

## 2. MATERIALS AND METHODS

### *2.1 Materials*

To obtain prolonged N(Mg)- and N(MgS)-fertilizers, industrial nitrogen fertilizers were used (urea – GOST 2081-2010, ammonium nitrate – GOST 2-2013). The main components for obtaining «Sorel's cement» were: magnesia binder (MB), mainly caustic magnesite powder – PMC according to GOST 1216 (MgO ~ 85%, $R_2O_3$ ~ 2 %, $CaCO_3$ ~ 3%, other substances ~ 10%); crystalline magnesium nitrate [CMN – $Mg(NO_3)_2 \cdot 6H_2O$]; epsomite ($MgSO_4 \cdot 7H_2O$).

To assess the agrochemical efficiency of fertilizers, we used the gray forest soil of the experimental fields of the Kazan Agrarian University (pH – 5,7; $N:P_2O_5:K_2O$ = 90:150:60 mg / kg soil).

### *2.2. Methods*

Fertilizers containing all 3 forms of nitrogen (urea-nitrate-magnesia fertilizer – UNMF) were obtained by «mixing» the mixture «urea+ammonium nitrate» with a suspension «$MgO+Mg(NO_3)_2$» (or «$MgO+MgSO_4$») according to the developed by us methodology [16]. Similarly, urea-magnesian fertilizers (UMF) were obtained by mixing urea with a suspension of «$MgO + (Mg(NO_3)_2; MgSO_4)$».

The block diagram of obtaining UNMF and UMF is shown in Fig. 1.

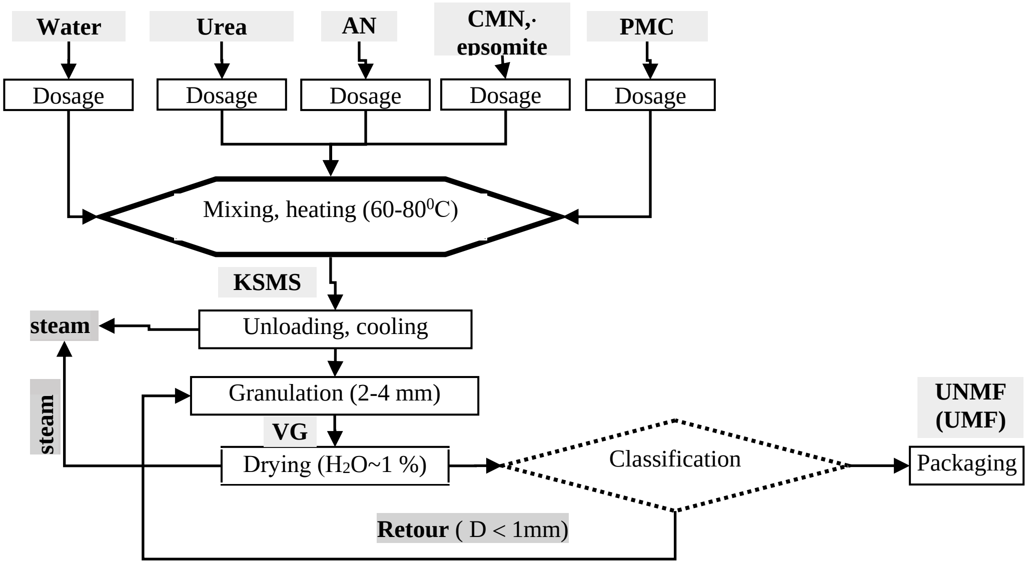

**Fig. 1.** Scheme of material flows for obtaining N(Mg)- and N(MgS)-fertilizers

(KSMS – urea-nitrate-magnesia mixture, VG – wet granules)

To obtain fertilizers, the raw mixture was heated (until the fertilizers were completely dissolved), kept until the beginning of the setting of Sorel's cement, then the thick hardening mass was granulated by various methods (mainly by extrusion). The granules were kept for some time (1-20 hours to set the minimum strength) and the commercial fraction of 1-4 mm was selected by classification (the small part was returned to the cycle).

In the obtained N(Mg)- and N(MgS) fertilizers, the nitrogen content was determined by standard methods [17], and their basic physicochemical properties (pH of a 1% solution, moisture absorption at air humidity W = 90%, strength and the rate of dissolution of the granules).

The agrochemical efficiency of fertilizers was evaluated in vegetation experiments with various grain and forage crops in greenhouse conditions (main assessment criteria were thus grain crop or green mass yield).

## 3. RESULTS

The formation of Sorel's cement occurs as a result of the following reactions:

$$nMg(OH)_2 + Mg(NO_3)_2 + mH_2O = nMg(OH)_2 \cdot Mg(NO_3)_2 \cdot (m-n)H_2O$$

(conditionally MHN – magnesium hydroxide nitrate);

$$nMg(OH)_2 + MgSO_4 + mH_2O = nMg(OH)_2 \cdot MgSO_4 \cdot (m-n)H_2O$$

(conditionally MHS – magnesium hydroxide sulfate).

In this case, the most stable are «Sorel's cements» of composition MHN-3 [i.e. $3Mg(OH)_2 \cdot Mg(NO_3)_2 \cdot 8H_2O$] and MHN-5 [$5Mg(OH)_2 \cdot Mg(NO_3)_2 \cdot 8H_2O$], as well as MHS-3 and MHS-5.

The main optimization criteria for N(Mg) fertilizers (for the indicated compositions of Sorel's cement MHS-3 and MHS-5) and N(MgS) fertilizers (MHS-3 and MHS-5) are as follows:

minimum nitrogen content N ≥ 20 %, MgO:N = (0,2÷0,6) wt; $NH_4:NO_3:NH_2$ ~ 1:1:(1÷2) wt.

Before the start of the experiments, material balances were compiled for obtaining each of the fertilizer samples in order to determine the mass of the initial components depending on the composition of the PMC (taking into account the specified ratios «MgO:N», «$NH_4:NO_3:NH_3$», «Ur:AN», providing the minimum content N ≥ 20 %).

Table 1 shows, as an example, the material balances for obtaining 1000 g of N(Mg)-fertilizers [$MgO:Mg(NO_3)_2$ = 3:1 mol] and N(MgS)-fertilizers [$MgO:MgSO_4$ = 5:1 mol].

**Table 1.** Material balance for obtaining 1000 g of N(Mg)-fertilizer (MHN-3, MgO:N = 0.4 wt, $NH_4:NO_3:NH_3$ ~ 1:1:1 wt) and N(MgS)-fertilizer (MHS-5, MgO:N = 0.4 wt, $NH_4:NO_3:NH_3$ ~ 1:1:2 wt.)

| N(Mg)- fertilizer (MHN-3) at $MgO:Mg(NO_3)_2$ = 3:1 mole | | | | | | % from N(Mg) | N(MgS)- fertilizer (MHS-5) at MgO:MgSO4 = 5:1 mole | | | | | | % from (MgS) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | incoming | | | consumption | | | | incoming | | | consumption | | |
| Raw material | g | % | Product | g | % | | Raw material | g | % | Product | g | % | |
| **1. PMC** | **89** | **8** | **1. N(Mg)** | 1000 | **90** | **100** | **1. PMC** | **104** | **9,3** | **1. N(MgS)** | 1000 | **90** | **100** |
| **2. CMN** | 162 | **14,5** | incl. MHN-3 | 295 | 26,4 | 30 | **2.Epsomite** | 109 | **9,8** | incl. MHS-5 | 245 | 22 | 24 |
| **3. Ur** | 168 | **15** | incl. impurities | 12 | 1 | 1 | **3. Ur** | 259 | **23,4** | incl. impurities | 14 | 1,2 | 1 |
| **4. AN** | 523 | **46,9** | incl. Cmd | 168 | 15 | 17 | **4. AN** | 481 | **43,3** | incl. Cmd | 259 | 23,4 | 26 |
| | | | incl. AN | 523 | 47 | 52 | | | | incl. AN | 481 | 43,3 | 48 |
| **5. Water** | 172 | **15,4** | **2. Steam** | 116 | **10** | | **3. Water** | 157 | **14,1** | **2. Steam** | 109 | **10** | |
| Amount | 1114 | 100 | Amount | 1114 | 100 | | Amount | 1110 | 100 | Amount | 1110 | 100 | |

The conditions for obtaining and compositions of N(Mg)-fertilizers with different ratios of 3 forms of nitrogen ($NH_4:NO_3:NH_2$ = 1:1:1 wt. and $NH_4:NO_3:NH_2$ = 1:1:2 wt.) are presented in table 2.

**Table 2.** Production conditions and compositions of N(Mg)-fertilizers (MgO:N = (0.2÷0.6) wt.)

| Fertilizer | $MgO:Mg(NO_3)_2$,mole | **Ur** : AN, wt. | Raw material, g | | | | | Fertilizer composition, % | | | | Nutrition elements, % | | | | | | | MHN:UAM | $NH_4:NO_3:NH_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PMC | CMN | **Ur** | AN | Water | MHN | **Ur** | AN | impurities | $NH_4$ | $NO_3$ | $NH_2$ | $N_{MHN}$ | MgO | Amount N | N(Mg) | | |
| UNMF-0,2 | 3:1 | 0,5 | 100 | 181 | 376 | 1238 | 274 | 17 | 20 | 62 | 0,9 | 9,4 | 9,4 | 9,3 | 1 | 6 | **29** | 35 | 0,2 | 1:1,1:1 |
| UNMF-0,4 | | | 100 | 181 | 188 | 586 | 193 | 30 | 17 | 52 | 1,4 | 7,9 | 7,9 | 7,8 | 1,8 | 10 | **25** | 35 | 0,4 | 1:1,2:1 |
| UNMF-0,6 | | | 100 | 181 | 125 | 369 | 157 | 39 | 15 | 44 | 1,9 | 6,6 | 6,6 | 6,9 | 2,4 | 14 | **23** | 36 | 0,7 | 1:1,4:1 |
| UNMF-0,2 | 3:1 | 0,8 | 100 | 181 | 546 | 987 | 274 | 18 | 29 | 53 | 0,9 | 7,9 | 7,9 | 13,6 | 1,1 | 6 | **30** | 36 | 0,2 | 1:1,1:1,7 |
| UNMF-0,4 | | | 100 | 181 | 273 | 467 | 193 | 30 | 25 | 43 | 1,5 | 6,5 | 6,5 | 11,7 | 1,8 | 10 | **27** | 37 | 0,5 | 1:1,3:1,8 |
| UNMF-0,6 | | | 100 | 181 | 180 | 300 | 157 | 40 | 22 | 36 | 1,9 | 5,4 | 5,4 | 10,3 | 2,4 | 14 | **24** | 37 | 0,7 | 1:1,5:2 |
| UNMF-0,2 | 5:1 | 0,5 | 100 | 109 | 342 | 1095 | 240 | 15 | 21 | 64 | 1 | 9,6 | 9,6 | 9,7 | 0,7 | 6 | **30** | 36 | 0,2 | 1:1,1:1 |
| UNMF-0,4 | | | 100 | 109 | 176 | 545 | 165 | 25 | 18 | 55 | 1,6 | 8,3 | 8,3 | 8,4 | 1,2 | 10 | **26** | 37 | 0,3 | 1:1,2:1 |
| UNMF-0,6 | | | 100 | 109 | 116 | 347 | 133 | 34 | 16 | 48 | 2,2 | 7,2 | 7,2 | 7,5 | 1,6 | 14 | **23** | 37 | 0,5 | 1:1,2:1 |
| UNMF-0,2 | 5:1 | 0,8 | 100 | 109 | 471 | 902 | 240 | 15 | 29 | 55 | 1 | 8,3 | 8,3 | 13,5 | 0,7 | 6 | **31** | 37 | 0,2 | 1:1,1:1,6 |
| UNMF-0,4 | | | 100 | 109 | 243 | 449 | 165 | 26 | 25 | 47 | 1,6 | 7,1 | 7,1 | 12 | 1,2 | 11 | **27** | 38 | 0,4 | 1:1,2:1,7 |
| UNMF-0,6 | | | 100 | 109 | 160 | 286 | 133 | 35 | 23 | 40 | 2,2 | 6 | 6 | 11 | 1,7 | 14 | **24** | 39 | 0,6 | 1:1,3:2 |

Conditions for obtaining and compositions of N(MgS)-fertilizers with a ratio of MgO:N = 0.4 wt. (for the case of $NH_4:NO_3:NH_2$ = 1:1:1 wt. and $NH_4:NO_3:NH_2$ = 1:1:2 wt.) are presented in Table 3.

**Table 3.** Production conditions and compositions of N(Mg)-fertilizers (MgO:N = 0.4 wt.)

| Fertilizer | $MgO:MgSO_4$, mole | Ur : AN, wt. | Raw material, g | | | | | Fertilizer composition, % | | | | Nutrition elements, % | | | | | | | MHS:UAM | $NH_4:NO_3:NH_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PMC | Epsomite | Ur | AN | Water | MHS | Ur | AN | impurities | $NH_4$ | $NO_3$ | $NH_2$ | MgO | S | Amount N | N(MgS) | | |
| UNMF-0,4 (MHS-3) | 3:1 | 0,3 | 100 | 174 | 201 | 633 | 180 | 27 | 17 | 55 | 1,4 | 8,2 | 8,2 | 8,1 | 10 | 2 | **25** | 36 | 0,4 | 1:1:1 |
| | | 0,6 | 100 | 174 | 286 | 514 | 180 | 28 | 25 | 46 | 1,4 | 6,8 | 6,8 | 11,9 | 10 | 2 | **26** | 38 | 0,4 | 1:1:2 |
| UNMF-0,4 (MHS-5) | 5:1 | 0,3 | 100 | 105 | 182 | 563 | 150 | 24 | 18 | 57 | 1,6 | 8,48 | 8,5 | 8,5 | 10 | 1,4 | **26** | 37 | 0,3 | 1:1:1 |
| | | 0,6 | 100 | 105 | 250 | 464 | 151 | 24 | 26 | 48 | 1,6 | 7,2 | 7,2 | 12,1 | 11 | 1,4 | **27** | 39 | 0,3 | 1:1:2 |

## 4. DISCUSSION

The proposed method for producing granular UAM (instead of its solution) is quite simple and includes the operations of dosing the components, mixing them (UAM solution with a suspension of MgO in solutions of magnesium salts) and granulation during the hardening of the mixture. Ammonium nitrate and urea are washed out very slowly from the resulting composition («UAM» + «Sorel's cement») by the soil solution (the rate of dissolution of fertilizer granules decreases with an increase in the proportion of MHN or MHS).

To obtain NMg fertilizers containing Sorel's cement of various compositions, the following ratios of raw materials are required:

– in the case of MHN-3, the ratio «PMC:CMN» = 100:181 wt .;

– for MHN-5, the ratio «PMC:CMN» = 100:109 wt.

To regulate the ratio of nutrients MgO:N (in the range MgO:N = 0.2÷0.6 wt.), the ratio of nitrogen fertilizers («Ur:AN») should be changed within the limits indicated in table 2 (while the minimum nitrogen content is 23%, the maximum – 31%).

It is well known that the «Ur:AC» mixture intensively absorbs moisture from the air and turns into a non-freezing solution (crystallization temperature « – $26^0$C»). Consequently, an attempt to obtain N(Mg)- and N(MgS)-fertilizers with a higher nitrogen content (with a MgO: N ratio of <0.2 wt.) based on only a small amount of magnesia binder leads to the formation of fragile granules. During storage (especially in conditions of high humidity), due to the absorption of moisture from the air, they turn into a suspension (a mixture of fertilizer solution with hardly soluble «Sorel cement»).

The strength of granules of N(Mg)- and N(MgS)-fertilizers is determined by the ratio «MHN:UAM» and «MHN:UAM» (the greater the proportion of Sorel's cement relative to fertilizers, the greater the strength).

In order to obtain particularly strong granules of N(Mg)-fertilizers with a higher nitrogen content, the suspension «$MgO+Mg(NO_3)_2$» can be mixed only with urea ($NH_4:NO_3:NH_2$ = 0:0:1 wt.) or ammonium nitrate ($NH_4:NO_3:NH_2$ = 1: 1: 0 wt.).

The conditions for obtaining and the calculated composition of N(Mg)-fertilizers using only urea (in the range MgO:N = 0.2÷0.6 wt.) are presented in table 4.

**Table 4.** Production conditions and compositions of UMF based on urea

| Fertilizer | $MgO:Mg(NO_3)_2$, mole | Raw material, g | | | | Fertilizer composition, % | | | Nutrition elements, % | | | | | MHN : Ur |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PMC | CMN | Ur | Water | MHN | Ur | impurities | $NH_2$ | N(MHN) | MgO | Amount N | N(Mg) | |
| UMF-0,2 | 3:1 | 100 | 181 | 1137 | 222 | 22 | 77 | 1,1 | 35,8 | 1,3 | 8 | **37** | 45 | **0,3** |
| UMF-0,4 | | 100 | 181 | 568 | 168 | 36 | 62 | 1,7 | 29,1 | 2,2 | 12 | **31** | 44 | **0,6** |
| UMF-0,6 | | 100 | 181 | 364 | 146 | 47 | 51 | 2,2 | 24 | 2,8 | 16 | **27** | 43 | **0,9** |
| UMF-0,2 | 5:1 | 100 | 109 | 1070 | 206 | 19 | 80 | 1,2 | 37,5 | 0,9 | 8 | **38** | 46 | **0,2** |
| UMF-0,4 | | 100 | 109 | 520 | 143 | 32 | 66 | 2 | 31 | 1,5 | 13 | **33** | 46 | **0,5** |
| UMF-0,6 | | 100 | 109 | 413 | 133 | 37 | 61 | 2,3 | 28,6 | 1,8 | 15 | **30** | 46 | **0,6** |

The choice of raw materials within the specified limits ensures the production of N(Mg)-fertilizers with an amide nitrogen content of up to 27-37% ($NH_4:NO_3:NH_2 = 0:0:1$ wt.).

To obtain N(MgS)-fertilizers containing «Sorel cement» of the composition MHS-3 [$3Mg(OH)_2{\cdot}MgSO_4{\cdot}8H_2O$] and MHS-5 [$5Mg(OH)_2{\cdot}MgSO_4{\cdot}8H_2O$], almost the same amount of epsomite is required ($MgSO_4{\cdot}7H_2O$), as well as $Mg(NO_3)_2{\cdot}6H_2O$ (Tables 2 and 3). Nitrogen content in N(MgS)- fertilizers at selected ratios MgO:N = 0.2÷0.6 wt. also practically the same (additional amount of sulfur ranges from 1 to 2.5%).

Changing the ratio «MHN:UAM» and «MHS:UAM» in a wide range (for UNMF – 0.2÷0.6 wt., for UMF – 0.2÷0.9 wt.), you can get N(Mg)- and N(MgS)-fertilizer with controlled dissolution rate (Table 5).

**Table 5.** Composition and properties of granules of N(MgS)-fertilizers (system «PMC-epsomite-urea-water»)

| Measurements | N(MgS)-fertilizers | | | Urea (for comparison) |
|---|---|---|---|---|
| | UMF-0,2 (MHS-3) | UMF-0,4 (MHS-3) | UMF-0,6 (MHS-3) | |
| Ratio N:MgO, wt % | 25:6 | 23:8 | 18:10 | – |
| Dissolution time of granules by 50%, min | 45 | 60 | 90 | 2 |
| pH (1 % solution) | 10,3 | 10,4 | 10,5 | 6,5 |
| Moisture absorption, % (W = 90%, 5 mon.) | 108 | 102 | 95 | 153 |
| Strength, kg / granule (d = 2-3 mm) | 3,5 | 3,6 | 3,8 | 1,2 |

As you can see from the table 5, due to the poorly soluble «cement Sorel», the dissolution rate of granules of urea-magnesia fertilizer is 20-50 times less (relative to urea granules). Due to the presence of $Mg(OH)_2$, these fertilizers are alkaline (pH ~ 10), which makes it possible to neutralize the acidity of the soil. At the same time, Sorel's cement provides a higher strength of granules (2-3 times relative to urea) and a lower rate of moisture absorption (which helps to reduce the caking of granules).

The agrochemical efficiency of the developed fertilizers was evaluated in vegetation experiments (Table 6).

**Table 6.** Influence of N(Mg)-fertilizers on wheat yield and green mass yield of Sudanese grass (vegetation experiments on gray forest soil)

| Version (fertilizer) | Wheat yield, g/vessel (grain 14% moisture) | | Version (fertilizer) | Green mass yield Sudanese grass (breed «Aida»), g/vessel | | |
|---|---|---|---|---|---|---|
| | breed «Amir» | breed «Ekada 66» | | 1 mowing | 2 mowing | Amount |
| Monitoring | 9,3 (–22%) | 6,7 (– 44%) | Monitoring | 60 | 10 | 71 (– 63%) |
| AN (N~34%) | 13,4 (+11%) | 10,9 (– 10%) | AN (N~34%) | 128 | 63 | 191 (+1%) |
| **Ur** (N~ 46%) | **12 (±0 %)** | **12,1 (±0 %)** | **Ur** (N~46%) | **119** | **71** | **189 (±0 %)** |
| UMF-1 (N~35%) | 15,2 (+26%) | 15,8 (+30%) | UMF-1 (N~30%) | 141 | 105 | 246 (+30%) |
| UMF-2 (N~29%) | 14,8 (+24%) | 16,4 (+35%) | UMF-2 (N~26%) | 140 | 102 | 242 (+28%) |
| UMF-3 (N~24%) | 15,1 (+27%) | 18,1 (+49%) | UMF-3 (N~23%) | 159 | 97 | 256 (+35%) |

As you can see from the table 6, the grain weight is determined by the wheat variety: the weight gain was from +26 to +49% in relation to urea (in experiments with Sudanese grass, the green weight gain was also approximately within these limits).

It cannot be argued that only the low rate of dissolution of the granules contributed to the increase in yield. Most likely, the presence of magnesium and sulfur, neutralization of soil acidity, as well as some other factors play a significant role. These factors include, first of all, a change in the $N:P_2O_5:K_2O$ ratio in the soil. With the initial ratio in the soil $N:P_2O_5:K_2O$ = 0.6:1:0.4 wt. the introduction of only 1 dose of nitrogen in the experiments leads to the ratio $N:P_2O_5:K_2O$ = 1.6:1:0.4 wt., which is very far from optimal (the optimum can be achieved with the additional introduction of 1 dose of $K_2O$ – $N:P_2O_5:K_2O$ = 1.6:1:1 wt.).

Consequently, when carrying out subsequent experiments to assess the agrochemical efficiency of the developed fertilizers in the field, this should be given special attention.

## 5. CONCLUSIONS

- a new approach to the production of N(Mg)- and N(MgS)-fertilizers with a controlled dissolution rate was proposed, which is based on the «tempering» of industrial instant nitrogen fertilizers (urea, ammonium nitrate) with «Sorel cement»;
- on the basis of this approach, prolonged-release «urea-magnesia» («$NH_4:NO_3:NH_2$ = 0:0:1 wt») and «urea-nitrate-magnesia» fertilizers («$NH_4:NO_3:NH_2$ = 1:1:1 wt.», «$NH_4:NO_3:NH_2$ = 1:1:2 wt.») with a total nitrogen content ΣN ~ 20-30 % at the optimal ratio «MgO:N» = (0.2÷0.6) mass;
- in vegetation experiments, these fertilizers contributed to an increase in the mass of wheat grain by 24-49 %, and the green mass of Sudan grass – by 28-35 %.

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