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Microfertilizer Mixture Megamix Application On Spring Wheat.

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ABSTRACT

Application of mineral fertilizers is one of the most efficient way to intensify the production of spring wheat. One of the challenges in current agriculture is to increase food production through a rational use of mineral fertilizers. The main objective of this study is to improve the fertilization method in spring wheat by evaluating the different application stages. The research was performed in the "Korma" laboratory of the Department of Plant Breeding and Selection, Samara State Agricultural Academy. For this study, a variety of spring wheat, Kinelskaya 59, and microfertilizers of Stimul LLC were used. Our results revealed that spring wheat shows high preservation up to 81.4% and upon fertilizer application, the species preservation is even higher. Due to severe weather conditions, the fertilizer application did not significantly affect the maximum area of leaves; however, it did increase species stability by conveying a photosynthetic potential to the equivalent of 1113.1 thousand m2/ha per day. The greatest effect on crop yield was achieved with the joint application of fertilizers and MEGAMIX products. The best results were obtained by fertilizing the crops with MEGAMIX pre-sowing 2 l/t and MEGAMIX universal 1.0 l/t, providing the yield of 2.3 t/ha and 2.2 t/ha with an increased fertilizer application. Fertilization with MEGAMIX also improved the technological properties of spring wheat; the weight of 1000 grains, the natural weight, and vitreousness increased. In addition, the mass fraction of gluten increased by 2.6%–3.7%.

Keywords: spring wheat; microfertilizers; area of leaves; photosynthetic potential; yielding capacity; mineral nutrition.

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INTRODUCTION

The food production challenge around the world has a dual nature: it is conditioned by socio-economic factors associated with the mode of production and distribution of food products and by the finite character of the natural resources that may be allocated to food production [1]. In many countries, the production of agricultural crops remains highly dependent on the weather conditions. In Russian Federation, the solution of the foodstuffs problem, is determined, mainly by the level of technological development applied to grain production. The level of technological development determines the efficiency of functioning of the whole agro-industrial complex.

Wheat is one of the main food crops in the world, providing 20% of the energy requirements in the human diet. In addition, wheat is the main source of protein in developing countries.

In the Middle Volga region, spring wheat remains the most commonly used for bread making. In Samara region, the yield of spring wheat in the last decade was at the level of 9.6–16.3 t/ha. To increase the yield, an important place should be assigned to the use of microfertilizers, in particular, their chelated forms.

At present, fertilizers, acting as a source of biogenic elements for plants, are crucial to sustain crop yields and quality [2; 3]. The use of fertilizers is aimed at obtaining high and stable yields with good quality products and improving soil fertility thus sustaining the future economic viability in the farm [4; 17].

There are 4 rules about fertilizer application: the right dose, the right type of fertilizer, at the right place, and at the right time. These rules are inter-dependent, and rules alone cannot work [1].

According to current understanding, a third of crop production is now obtained through the use of mineral fertilizers, and in the future, their importance will grow as an essential factor of sustainability and high productivity of crops. [5; 6; 7; 8; 9]. The use of microelements as part of the fertilization regime has to be considered. Microelements Fe, Cu, Zn, Mn, Co, Mo, and B are the most important of this group and have an essential biological role in plant growth and crop yield. Microelements are an indispensable source of nutrition.

The efficiency of microfertilizers depends on many conditions, such as the content of each microelement in the soil, the dose, the method of application of microfertilizers, the culture, variety used, weather conditions during the growing season, as well as the application rates of mineral fertilizers.

Microfertilizers are important for increasing crop yields, especially if the soil does not contain the necessary microelements. The advantages of microelements, such as Mo, Mn, Cu, Zn, B and Co, have been reported in several studies and include the stimulation of photosynthetic activity, increased yield, improved crop quality, and a shortened maturation period [10-12; 13–16; 17; 18–20]. Microelements also increase the resistance of plants to unfavorable environmental conditions (drought and extreme temperature), and under their influence, the consumption of water is decreased. The use of microelements in plant nutrition has been reported to increase yield by 10%–18% [21; 22; 23].

Therefore, expediently to apply fertilizer formulation MEGAMIX to assess spring wheat yield and quality as well as the effect of microelements on the prophylaxis of diseases. MEGAMIX, which includes microelements that are, most often, in scarce supply on various types of soils has been reported to contribute to the rapid vegetative growth of plants, the vigorous development of the root system, and the faster initiation of the reproductive organs.

The aim of this study was to optimize a method for the application of MEGAMIX microfertilizer in spring wheat cultivation, including in the pre-sowing treatment of seeds and during vegetative growth and crop quality, taking into account the expected optimized yield for the conditions of the forest steppe of the Middle Volga region.

The objectives include the following: (1) to assess plant development, including vegetative growth and photosynthetic activity of spring wheat plants upon the use of MEGAMIX microfertilizer; (2) to determine the productivity potential of agrophytocenosis of wheat and the level of program implementation for the planned yield; (3) to assess crop yield and quality under different application rates of MEGAMIX; and (4) to conduct an economic analysis and assess the efficiency of MEGAMIX in terms of cost-benefit.

MATERIALS AND METHODS

These studies were conducted at the Federal State Budgetary Educational Institution of the Higher Professional Education Samara State Agricultural Academy. In the experimental region, the average annual precipitation is 410 mm, but during the growing season, it is 234 mm. The average duration of the warm period is 145–150 days.

However, recently climate change has been taking place in this region. According to the automated meteorological station of Ust-Kinelskaya, over the past 30 years, there has been an average increase of 1.6°C. The average annual temperature was 5.4°C, during the experimental period, as opposed to the normal annual temperature of 3.8°C. This increase of 1.6°C in annual average temperatures is mainly due to the increase in average monthly temperatures in the winter and spring months. In addition, precipitation exceeded the average annual value of 124 mm and amounted to 534 mm, mainly due to a higher level of precipitation in the winter months. However, the amount of precipitation during the vegetation period increased by only 15 mm and amounted to 225 mm. The duration of the active vegetation period with a temperature above 5°C increased by 10 days. The sum of the temperatures for this active growth period was 2734°C, compared with the average annual value of 2550°C.

The assessment of the weather conditions in the experimental region during the experimental period (2011–2013) indicates that this period was characterized by weather conditions that did not fully meet the requirements of cereal cultivation. Achieving high productivity potential was limited by moisture deficit and high temperature during the vegetation period.

The studies were conducted in the crop rotation of the Korma research laboratory (Department of Plant Breeding and Selection, The Samara State Agricultural Academy). The soil type of the experimental site was a typical residual-carbonate, medium-humic, medium-power, heavy, loamy chernozem. The content of humus was 6.5%, that of easy hydrolysable nitrogen was 15.3 mg, and that of labile phosphorus was 8.6 mg, and the exchange potassium was 23.9 mg/100 g soil. The bulk mass of the soil layer was 1.27 g/cm^3, taken from the 0 to 1.1 mm layer, pH_{sal} 5.8.

In the experiments, the variety of spring wheat, Kinelskaya 59, was used.

<u>Experiment 1. Seed treatment with MEGAMIX</u>

1. No fertilizer application (A)
2. NPK application for the planned yield of 2.0 t/ha
3. NPK application for the planned yield of 2.4 t/ha

- Control (without seed treatment) (B);
- MEGAMIX-pre-sowing treatment 2.0 l/t;
- MEGAMIX-universal 0.5 l/t;
- MEGAMIX-universal 1.0 l/t;
- MEGAMIX-N10 1 l/t.

<u>Experiment 2. Treatment of wheat crops with MEGAMIX formulations</u>

1. No fertilizer application
2. Application of $N_{45}P_{45}K_{45}$ (A)

- MEGAMIX-foliar fertilizing 0.5 l/ha (B);
- MEGAMIX-foliar fertilizing 0.2 l/ha;
- MEGAMIX-N10 0.5 l/ha;
- MEGAMIX-N10 0.2 l/ha;
- MEGAMIX-universal 0.5 l/ha;
- MEGAMIX-universal 0.2 l/ha;
- Albite;
- Control (without plant treatment).

The processing of crops was performed during the tillering phase of wheat.

The soil preparation for cultivation consisted of peeling of 6–8 cm after the harvesting of the previous crop, moldboard plowing of 20–22 cm, and early spring casing harrowing. Seeds were sowed at a depth of 6–8 cm. The sowing was performed with the use of the AMAZONE D9-25 drill in the usual row cropping pattern.

For the pre-treatment of seeds, seeds were treated with MEGAMIX before sowing.

For the treatment of vegetative plants, MEGAMIX application was performed at the tillering phase.

Plot harvesting was performed after complete ripeness of the grain.

Estimated fertilizer doses in experiment 1 were applied for the planned yield of 2.0 t/ha and 2.4 t/ha. Here, the fertilizers ammonium nitrate and diammophos were used. The rates of application varied annually and were within the range of 40–86 kg/ha for ammonium nitrate and 60–114 kg/ha for diammophos. The soil potassium supply was high; therefore, potash fertilizers were not required.

In the fertilization experiments, the following formulations of Stimul LLC were used:

MEGAMIX-pre-sowing treatment: The formulation contained the following microelements in g/l: B (4.6), Cu (33), Zn (31), Mn (3.0), Co (2.8), Fe (4.0), Mo (7.0), Cr (0.5), Se (0.1), Ni (0.1). The macroelements included the following in g/l: N (58), P (6), K (58), S (50), Mg (22).

MEGAMIX–N10: The formulation contained the following microelements in g/l: B (0.8), Cu (2.5), Zn (2.5), Mn (1.0), Fe (1.0), Mo (0.6), Co (0.12), Se (0.06). The macroelements included the following in g/l: N (116), S (8), Mg (6).

MEGAMIX-foliar fertilizing: The formulation contained the following microelements in g/l: B (1.7), Cu (7.0), Zn (14), Mn (3.5), Fe (3.0), Mo (4.6), Co (1.0), Cr (0.3), Se (0.1), Ni (0.1). The macroelements included the following in g/l: N (6), S (29), Mg (15).

MEGAMIX-universal: The formulation contains the following microelements in g/l: B (1.7), Cu (12), Zn (11), Mn (2.5), Fe (2.0), Mo (1.7), Co (0.5), Se (0.06). The macroelements included the following in g/l: N (2.5), S (25), Mg (17).
The field experimental work was conducted according to the methodology described by Dospehov (1985).

RESULTS

Agrophytocenosis analysis of spring wheat during the growing season revealed that stability can be kept high in a non-fertilization regime (68.7%–79.5%) or when N45P45K45 is applied (70.3%–81.4%).

The maximum leaf area was observed in the stalk-shooting phase (12.3–13.2 thousand m2/ha); in the earing phase, it decreased to 8.2–8.9 thousand m2/ha (due to summer drought).

The effect of the use of MEGAMIX formulations in pre-sowing treatment, in terms of PP and NPP, is higher on wheat crops cultivated in a non-fertilization regime. On average, across all variants of seed treatment, PP was 56,000 m2/ha per day and NPP was 0.66 g/m2 per day.

The best variants were those treated with MEGAMIX-foliar fertilizing and MEGAMIX-N10, and upon fertilizer (N45P45K45) application at a rate of 0.2 l/ha, PP may vary from 1113.1 to 1045.9 thousand m2/ha per day.

The best variants for the pre-sowing seed treatment were MEGAMIX-pre-sowing formulation at 2.0 l/t and MEGAMIX-universal 1.0 l/t under the non-fertilization regime. In this regime, yields of 16.47 q/ha (MEGAMIX-pre-sowing formulation) and 16.23 q/ha (MEGAMIX-universal 1.0 l/t) were obtained. In background 1, these values were 18.13 and 18.16 q/ha, respectively. At an elevated level (background 2), MEGAMIX-universal 1.0 l/t and MEGAMIX-N10 provided yields of 23.92 q/ha and 22.56 q/ha, respectively.

These results suggest that the planned increase in yield of 2.4 t/ha was achieved by 99.7% and 94.0% for these variants, respectively.

The yield of spring wheat crops is determined by the number of plants present at harvesting, the number of grains per ear, and the weight of grains per ear. The use of fertilizers and MEGAMIX products increased the value of all these indicators.

MEGAMIX formulations improved the technological properties of spring wheat grain, namely, the weight of 1000 grains, natural weight, and vitreousness increased. Importantly, the mass fraction of gluten increased by 2.6%–3.7% compared with the control.

Economically, it is efficient to treat plants with MEGAMIX-universal 0.5 Mg/ha (profitability level, 97.8%; non-fertilization group), as well as with MEGAMIX-foliar fertilizing 0.5 l/ha (profitability level, 94.2%) and MEGAMIX-universal 0.5 l/ha (profitability level, 90.4%; fertilization group).

In terms of the agro-energetic efficiency of the different variants analyzed in this study, it was found that the most efficient variants are MEGAMIX-universal applied to seeds at a rate of 1 l/t and the same formulation applied to growing vegetation at a rate of 0.5 l/ha.

DISCUSSION

During 2011–2013, we studied the effect of pre-sowing seed treatment and fertilizer application on the growth, development, and productivity of the spring wheat variety Kinelskaya 59.

The results from experiment 1 revealed that the crop yield depends largely on the density of the grass stand. Under high-density sowing, crops significantly reduce the unproductive evaporation of soil moisture and occupy the soil without leaving space for weed development. Due to the effect of crop shading, the soil surface in densely sowed stands heats less than in sparsely sowed ones.

Our results showed that the plants in the MEGAMIX-treated seed group achieved shooting completeness earlier and greater canopy density than the plants in the control group. Seed treatment with MEGAMIX formulations without fertilization increased species stability. Although, upon the application of the fertilizer for the planned yield of 2.0 t/ha, the seed treatment with MEGAMIX did not affect species stability, and the application of fertilizers for the planned yield of 2.4 t/ha led to a decrease in plant stability observed at harvesting.

The length of the wheat stalk significantly increased with the application of fertilizers and reached a maximum with the application of fertilizers for the planned yield of 2.4 t/ha (background 2). Our results suggest that the application of a pre-sowing seed treatment with MEGAMIX promotes growth processes, which increases the length of the stem by 3.3–6.0 cm. The most intensive growth processes were noted on the variants undergoing seed treatment with MEGAMIX-N10 1 l/t.

On average, for the 2011–2013 growing seasons, our results revealed that the weather conditions in 2012 and 2013 (with an acute shortage of precipitation in May and June) significantly reduced the overall leaf area. The average maximum leaf area for three years occurred in the phase of stalk-shooting. Fertilizer application had practically no effect on the formation of the leaf area. In the control plants, at the phase of stalk-shooting, the maximum leaf area was 13.36 thousand m^2/ha, with fluctuations from 9.78 to 15.46 thousand m^2/ha. In background 1, the maximum leaf area reached 12.50 thousand m^2/ha, with fluctuations from 11.55 to 13.36 thousand m^2/ha. In background 2, the maximum leaf area was 12.86 thousand m^2/ha, with fluctuations from 12.44 to 13.47 thousand m^2/ha.

Seed treatment with MEGAMIX promoted the growth of the leaf surface of wheat. However, with the application of fertilizers, the effect of the MEGAMIX pre-sowing treatment on the growth of the leaf area diminishes. In the control, the increment was 4.5 thousand m^2/ha. In background 1, the maximum leaf surface was 1.2 thousand m^2/ha, and in background 2, it was 0.6 thousand m^2/ha. Only in the phase of stalk-shooting, there was a tendency for the leaf area to increase when applying MEGAMIX-universal 1.0 l/t and MEGAMIX-N10 to seeds.

An important indicator characterizing the efficiency of the leaf apparatus is the magnitude of the photosynthetic potential (PP) that depends on the size of the leaf and the duration of the high-efficiency time window. Over the period of 2011–2013, our results revealed that the PP magnitude is largely affected by the weather conditions of the growing season. It is quite understandable that in the favorable year 2011, PP was significantly higher than its value in 2012 and 2013. In 2011, fertilizers had a significant impact on PP, which in the treated groups was consistently higher than in the controls. In the drier years, these differences were not observed

However, on average, over the three years, the application of fertilizers led to an increase in PP. In the control (without fertilizers), PP of the variants that were treated with MEGAMIX was within the range of 667–703 thousand m^2/ha per day. In background 1, it was 746–823 thousand m^2/ha per day, and in background 2, it was 770–845 thousand m^2/ha per day (Table 1).

The indicator of net productivity of photosynthesis (NPP) depends on a variety of factors, such as illumination, temperature, moisture content, placement of plants, location of the leaf apparatus, etc. Therefore, this indicator is the least stable, but the general patterns of its dynamics were clearly observed during this study. Thus, in the favorable year 2011, the leaf apparatus worked efficiently, reaching an average NPP level of 7.00–9.84 g/m^2 per day. In contrast, in 2012, the leaf efficiency reduced, with an NPP value of 2.14–3.73 g/m^2 per day. It should be noted that due to the peculiarities of the weather in 2011 and 2012, dry matter accumulation was more intensive during the period of sprouting and stalk-shooting, whereas in 2013, it peaked during the period of stalk-shooting and flag emergence.

Table 1: Photosynthetic potential (thousand m^2/ha per day), average for 2011–2013

Level of mineral nutrition	Variant of treatment	Sprouting–stalk-shooting (10–31)	Stalk-shooting–flag emergence (31–37)	Flag emergence–earing (37–55)	Total
Without fertilizer application	Control	202.89	305.30	291.83	626.89
	MEGAMIX-pre-sowing treatment 2.0 l/t	201.12	144.96	324.98	671.6
	MEGAMIX-universal 0.5 l/t	234.13	142.86	326.04	703.03
	MEGAMIX-universal 1.0 l/t	234.35	140.72	318.13	693.2
	MEGAMIX-N10.1 l/t	249.32	140.96	277.08	667.36
Background 1	Control	185.67	352.5	240.00	778.17
	MEGAMIX-pre-sowing treatment 2.0 l/t	198.91	353.85	270.90	823.66
	MEGAMIX-universal 0.5 l/t	197.45	324.21	224.49	746.15
	MEGAMIX-universal 1.0 l/t	207.74	323.78	231.52	763.04
	MEGAMIX-N10.1 l/t	202.77	330.90	279.07	812.74
Background 2	Control	198.76	380.16	261.51	826.85
	MEGAMIX-pre-sowing treatment 2.0 l/t	199.29	321.17	264.16	784.62
	MEGAMIX-universal 0.5 l/t	203.67	358.44	283.37	845.47
	MEGAMIX-universal 1.0 l/t	211.71	333.45	268.41	813.57
	MEGAMIX-N10.1 l/t	204.69	318.22	247.76	770.67

On average, over the three years of this experimental study, NPP was always high. The results show that for all the variants, the efficiency of the leaf apparatus decreased with the advancement of the developmental stages of the wheat plants. During the period of sprouting and stalk-shooting [10–31 BBCH (BBCH: Bayer, Basf, Ciba-Geigy, and Hoechst classification system)], the efficiency of the leaf apparatus ranged from 7.20 to 15.48 g/m^2 per day. During the period of stalk-shooting and flag emergence (31–37 BBCH), the efficiency of the leaf apparatus varied from 4.59 to 9.87 g/m^2 per day, and during the period of flag emergence and earing (37–55 BBCH), it varied from 3.80 to 5.63 g/m^2 per day. In addition, in the first period (10–31 BBCH), the effect of fertilizers was clearly traceable; in the control group, NPP was 7.20–8.58 g/m^2 per day,

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whereas in background 1, it was 9.69–10.78 g/m^2 per day, and in background 2, it was 10.82–15.48 g/m^2 per day.

It should be noted that without the application of fertilizers, the use of MEGAMIX formulations in pre-sowing seed treatment somewhat reduced NPP during this period, and in background 1, NPP increased by 0.6–1.09 g/m^2 per day, whereas in background 2, NPP increased by 1.59–4, 66 g/m^2 per day. Obviously, an additive effect was observed due to the combined application of macro elements and NPK fertilizers.

The main indicator of the economic value of spring wheat is the size of the crop. Observations in experiments revealed that the productivity of crops depends largely on the level of mineral nutrition, pre-sowing seed treatment, and weather conditions.

Due to unfavorable weather conditions in 2011–2013, the yield of wheat was at an average level. Nevertheless, our results show that fertilizer application significantly increases crop yield. Without the use of fertilizers, the average yield over three years amounted to 12.75 q/ha in the control; however, in background 1, it was 14.90 q/ha, and in background 2, it was 17.22 q/ha (Table 2). Pre-sowing treatment of seeds significantly increased the yield. Therefore, without the use of fertilizers, the average yield over three years and across all variants amounted to 16.08 q/ha, which exceeds that of the control group by 3.33 q/ha. In background 1 (planned productivity of 2.0 t/ha), the average yield over three years and across all variants was 17.84 q/ha, which exceeds that of this group's control by 2.94 q/ha. In background 2, the average yield over three years and across all variants amounted to 22.56 q/ha, which exceeds that of this group's control by 5.3 q/ha.

Our results showed that in the control (without fertilizer application) and background 1 groups, the highest yields were provided by the spring wheat seeds that were treated with MEGAMIX-pre-sowing treatment 2.0 l/t and MEGAMIX-universal 1.0 l/t. In the control group, the yields were 16.47 q/ha (control) and 18.13 q/ha (MEGAMIX), whereas in background 1, the yields were 16.23 q/ha (control) and 18.16 q/ha (MEGAMIX), respectively.

It is generally accepted that when 90% of the planned yield increase is achieved, the fertilization treatment was successful. In our studies, in the first level (background 1), the 90% mark was reached by only two variants: MEGAMIX-pre-sowing treatment 2.0 l/t (91.5%) and MEGAMIX-universal 1.0 l/t (90.8 %). In the second level (background 2), the 90% mark was exceeded by practically all variants of pre-sowing treatment, and almost 100% was achieved by the treatment of seeds with MEGAMIX-universal 1.0 l/t (99.7%) and also MEGAMIX-N10 1.0 l/t (94.0%).

Across the three years (2011–2013), the results suggest that the yield of spring wheat is formed by two components: the density of the plant stand and the weight of 1000 grains. Fertilizer application consistently increased the number of plants at harvest. The same is seen by the use of MEGAMIX formulations in pre-sowing seed treatment. The weight of 1000 grains was also significantly increased compared with the variants without fertilizer application. Therefore, it is possible to observe the additive effects of fertilization and seed treatment with MEGAMIX formulations, the combination of which further increases the weight of 1000 grains. However, no prominent emphasis on these parameters of separate variant of seed treatment is found. In the control (without fertilizer application), the weight of 1000 grains averaged 42.0 g (40.5–43.8 g). In background 1, it was 44.2 g (43.1–45.1 g), and in background 2, it was 44.5 g (42.0 to 46.1 g)

Table 2: Wheat yield in 2011–2013, q/ha

Level of mineral nutrition	Variant of treatment	2011	2012	2013	average	Program execution
Without fertilizer application	Control	12.7	13.24	12.30	12.75	-
	MEGAMIX-pre-sowing treatment 2.0 l/t	17.3	16.71	15.40	16.47	-

	MEGAMIX-universal 0.5 l/t	16.1	15.59	16.50	16.06	-
	MEGAMIX-universal 1.0 l/t	15.2	17.12	16.36	16.23	-
	MEGAMIX-N10l/t	15.3	16.17	15.28	15.58	-
Background 1 (planned yield of 2.0 t/ha)	Control	15.2	15.41	14.08	14.90	74.5
	MEGAMIX-pre-sowing treatment 2.0 l/t	19.6	17.16	17.64	18.13	91.5
	MEGAMIX-universal 0.5 l/t	18.3	17.08	17.50	17.62	88.1
	MEGAMIX-universal 1.0 l/t	18.3	18.02	18.17	18.16	90.8
	MEGAMIX-N10 l/t	17.6	17.36	17.44	17.47	87.4
Background 2 (planned yield of 2.4 t/ha)	Control	17.3	18.66	15.70	17.22	71.8
	MEGAMIX-pre-sowing treatment 2.0 l/t	24.7	20.35	19.90	21.65	90.2
	MEGAMIX-universal 0.5 l/t	22.9	23.42	20.06	22.13	92.2
	MEGAMIX-universal 1.0 l/t	24.9	24.35	22.50	23.92	99.7
	MEGAMIX-N10 l/t	24.4	24.12	19.16	22.56	94.0
	$LSD_{0.5\ o6}$	0.49	0.27	0.15		
	A	0.22	0.12	0.07		
	B. AB	0.28	0.15	0.09		

When evaluating the technological properties of the grain by years, it was found that in the favorable year 2011, the grain natural weight was higher and the vitreousness and gluten content were lower than those levels in the drier years 2012 and 2013. In 2011, the gluten quality met the requirements of only group III. In contrast, in 2012 and 2013, the grain natural weight was lower, the vitreousness and gluten content increased, and the gluten quality met the requirements of group II.

On average, over the three years, the vitreousness only slightly improved with an increase in the level of mineral nutrition; the mass fraction of gluten in the variants undergoing pre-sowing seed treatment tended to be higher. Without the use of fertilizers, the mass fraction of gluten in the control was 27.6%, and in the variants undergoing seed treatment with MEGAMIX, it was 30.4%–31.3%. On the other hand, the mass fraction of gluten in the control group of background 1 was 28.7%, and in the treatments, it varied from 31.4% to 33.5%. In the control group of background 2, the mass fraction of gluten was 29.7%, and in the treatments, it varied from 32.1% to 33.6%.

The research in experiment 2 revealed that the passage through the phenological phases of development and the duration of the vegetative period of the spring wheat variety Kinelskaya 59 is largely determined by the weather conditions during the vegetative period. In this study, it ranged from 92 to 102 days. The application of fertilizers and treatment of crops with the MEGAMIX formulations prolonged the vegetative period by 1–3 days.

Our results revealed that the formation of the leaf apparatus is highly dependent on the agrotechnical methods used and on the weather conditions of the growing season. In 2011, under favorable weather conditions, the averaged leaf area at the stalk-shooting phase in all the variants without fertilizer application was 12.7 thousand m^2/ha. After fertilizer application, the leaf area naturally increased to 14.3 thousand m^2/ha. At the time of flag emergence, the leaf area increased and reached 15.4 thousand m^2/ha and 16.2 thousand

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m^2/ha, respectively. By the earing phase, it decreased ever so slightly to 15.1 thousand m^2/ha and 16.0 thousand m^2/ha, respectively.

Under severe weather conditions of 2012, the leaf area was much smaller at the stalk-shooting phase, and the high level of mineral nutrition had a negative impact on its formation. Without fertilizer application, the average leaf area across all the variants amounted to 9.7 thousand m^2/ha, and upon fertilizer application, it decreased to 6.1 thousand m^2/ha.

The leaf area formation in 2013 was similar to that in 2012, although the overall leaf area in 2013 was significantly higher than that in 2012. In the fertilization groups, in the stalk-shooting phase, the leaf area was 16.8–17.6 thousand m^2/ha (average indicators for the level of mineral nutrition); by the stage of flag emergence, it almost halved, amounting to 9.0 thousand m^2/ha (the average of the variants). In the non-fertilization groups, the leaf area was 8.5 thousand m^2, whereas upon $N_{45}P_{45}K_{45}$ fertilization, it reached 6.1 thousand m^2/ha and 6.4 thousand m^2/ha, respectively.

Over the three years of research (2011–2013), the maximum leaf area was obtained in the stalk-shooting phase and amounted to 13.2 thousand m^2/ha, on average, in the variants without fertilizer application. The maximum leaf area reached 12.3 thousand m^2/ha upon $N_{45}P_{45}K_{45}$ application. Then, it decreased by the time of flag emergence (37 BBCH) to 10.2 and 11.0 thousand m^2/ha, respectively. By the time of earing, the maximum leaf area (55 BBCH) decreased to 8.2 and 8.9 thousand m^2/ha, respectively (Table 3).

Table 3: Leaf area (thousand m^2/ha), average for 2011–2013

Variant		Stalk-shooting (31)	Flag emergence (37)	Earing (55)
Without application of NPK	MEGAMIX-foliar fertilizing 0.5 l/ha	15770.5	10184.6	8358.1
	MEGAMIX-foliar fertilizing 0.2 l/ha	14621.7	10558.1	8004.7
	MEGAMIX-N10 0.5 l/ha	11216.3	10876.7	8446.6
	MEGAMIX-N10 0.2 l/ha	13911.9	10543.7	9239.6
	MEGAMIX-universal 0.5 l/ha	14898.5	9683.3	8589.7
	MEGAMIX-universal 0.2 l/ha	14276.9	10300.7	8618.7
	Albite	10635.8	9911.7	7074.3
	Control	10369.2	9704.9	7379.1
With application of $N_{45}P_{45}K_{45}$	MEGAMIX-foliar fertilizing 0.5 l/ha	12317.5	11113.6	11097.7
	MEGAMIX-foliar fertilizing 0.2 l/ha	11748.8	10964.2	8710.3
	MEGAMIX-N10 0.5 l/ha	13751.6	11403.7	8941.1
	MEGAMIX-N10 0.2 l/ha	12693.2	11284.0	9659.8
	MEGAMIX-universal 0.5 l/ha	12863.6	11360.3	9318.8
	MEGAMIX-universal 0.2 l/ha	11887.4	10696.3	8735.0
	Albite	11570.6	11267.3	7786.0
	Control	11236.13	9960.9	7137.1

Our studies revealed that PP is highly affected by agrometeorological conditions. In the favorable year 2011, PP was much higher than in the drier years of 2012 and 2013. Regarding 2011, a total PP of 2039.1 thousand m^2/ha per day was obtained on fertilizer application in the variant of MEGAMIX-N10 0.5 l/ha. Without fertilizer application, the same variant of MEGAMIX-N10 and the variants at 0.2 l/ha and MEGAMIX-foliar fertilizing 0.5 l/ha resulted in a total PP of 1581.7 thousand m^2/ha per day.

On average (2011–2013), the results indicated that the application of mineral fertilizers causes an increase in PP. Thus, on average, for all variants without fertilizer application, PP amounted to 831 thousand m^2/ha per day, whereas upon $N_{45}P_{45}K_{45}$ fertilization, it amounted to 893 thousand m^2/ha per day.

The best variants for cultivation of wheat were MEGAMIX-foliar fertilizing and MEGAMIX-N10, combined with fertilizer application at the rate of 0.2 l/ha, which allowed PP to reach 1113.1 and 1045.9 thousand m^2/ha per day, respectively.

The efficiency of the leaf apparatus was estimated using NPP, which depends on many factors and is the least stable indicator in terms of weather conditions and growth seasons. However, the general patterns were quite evident. Thus, in the favorable year 2011, the leaf apparatus was most efficient in the initial period (sprouting–stalk-shooting). At this stage, NPP was in the range 8.2–11.9 g/m^2 per day. Subsequently, the rate of accumulation of aboveground dry biomass dropped at the earing phase to 2.4–4.0 g/m^2 per day. In 2012, NPP was low and unstable, particularly upon fertilizer application.

In 2011, under favorable conditions, the crop yield was significantly higher than that in 2012 and 2013 (Table 4).

The maximum yield was observed on the variants MEGAMIX-foliar fertilizing 0.5 l/ha and MEGAMIX-N10 0.5 l/ha and amounted to 25.6 q/ha and 25.8 q/ha without fertilizer application and 29.0 q/ha and 28.9 q/ha with fertilizer application. The lowest yield was observed in the control group and amounted to 20.3 q/ha and 23.5 q/ha, respectively. The crop yield of the other variants was similar and varied from 24.0 to 24.8 q/ha in variants without the use of fertilizers and from 26.6 to 28.7 q/ha in variants with the use of fertilizers.

The crop yield in 2012 was slightly lower, and in the non-fertilization group, the best effect on yield was shown with the application of MEGAMIX-foliar fertilizing at 0.5 and 0.2 l/ha. In the fertilization group, MEGAMIX N10 at 0.5 l/ha and MEGAMIX-universal at 0.2 l/ha provided high yields of 23.9 and 21.3 q/ha, respectively. In 2013, the yields were much lower, particularly in the experiment groups where variants were combined with fertilizer application.

The low responsiveness of spring wheat to fertilization may be attributed to the unfavorable weather conditions in 2013. Thus, the average yield across all variants in the non-fertilization group amounted to 17.75 q/ha. On the other hand, the average yield across all variants with fertilizer application amounted to 21.22 q/ha, which represents an increase of 3.47 q/ha. Almost the same level of discrepancy was observed with the other MEGAMIX variants, which amounted to 18.25 q/ha (non-fertilization group) and 24.00 q/ha (fertilization group), which represented a difference of 3.75 t/ha.

The non-fertilization regime is the most efficient when either MEGAMIX-foliar fertilizing 0.5 l/ha (18.6 q/ha) or MEGAMIX-N10 0.5 l/ha (18.5 q/ha) and MEGAMIX-universal 0.5 l/ha (19.0 q/ha) are applied. Combined with the application of $N_{45}P_{45}K_{45}$, MEGAMIX-N10 0.5 l/ha produced a yield of 22.0 q/ha and MEGAMIX-universal 0.5 l/ha produced a yield of 23.4 q/ha These MEGAMIX variants in wheat crop cultivation are likely to increase yield.
Therefore, the treatment of crops with MEGAMIX formulations promotes yield increase, particularly when combined with the application of fertilizers.

Table 4: Yielding capacity of wheat depending on the treatment of plants in the vegetation period (2011–2013), q/ha

Level of mineral nutrition	Variant of treatment	Obtained from 1 ha, center			
		2011	2012	2013	Average
Without fertilizer application	MEGAMIX-foliar fertilizing 0.5 l/ha	25.6	15.9	14.3	18.6
	MEGAMIX-foliar fertilizing 0.2 l/ha	25.5	15.2	13.1	17.9
	MEGAMIX-N10 0.5 l/ha	25.8	14.2	15.6	18.5
	MEGAMIX-N10 0.2 l/ha	24.8	14.3	14.8	18.0

	MEGAMIX-universal 0.5 l/ha	24.8	16.4	15.8	19.0
	MEGAMIX-universal 0.2 l/ha	24.1	14.4	14.1	17.5
	Albite	24.0	14.9	14.2	17.7
	Control	20.3	12.0	12.6	15.0
With fertilizer application	MEGAMIX-foliar fertilizing 0.5 l/ha	29.0	19.8	16.3	21.9
	MEGAMIX-foliar fertilizing 0.2 l/ha	28.7	19.7	14.8	21.1
	MEGAMIX-N10 0.5 l/ha	28.9	20.7	16.4	22.0
	MEGAMIX-N10 0.2 l/ha	28.5	20.9	15.1	21.5
	MEGAMIX-universal 0.5 l/ha	28.0	23.9	18.3	23.4
	MEGAMIX-universal 0.2 l/ha	27.7	21.3	17.4	22.1
	Albite	26.6	17.6	15.8	20.0
	Control	23.5	16.8	13.2	17.8
LSD_{tot}		0.19	0.20	0.16	
A		0.07	0.07	0.06	
A,AB		0.14	0.14	0.11	

The crop structure, estimated by the number of plants per m^2; the productive tillering capacity; the number of grains; and the weight of grains from one ear varied significantly throughout the years of research.

On average, over 2011–2013, our results reveal that the number of plants per m^2 at harvesting increased with fertilization, and the number of grains per ear also increased. Across all the variants in the non-fertilization group, the average grain content amounted to 19.5 grains/ear. Upon fertilizer application, the average grain content amounted to 21.1 grains/ear. This led to an increase in the weight of grain per ear across the variants in the non-fertilization group; the weight of grain per ear was 0.76 g. Upon fertilizer application, the weight of grain per ear reached 0.86 g.

Thus, the advantages of the use of MEGAMIX formulations are clearly noticeable. The number of plants in the control group (non-fertilization group) was 241 pcs/m^2 and those in the fertilization group ($N_{45}P_{45}K_{45}$ application) was 258 pcs/m^2. In the variants undergoing application of formulations without fertilizers, this parameter was 247–256 pcs/m^2, whereas upon fertilizer application, it was 265–298 pcs/m^2.

The number of grains per ear was 19.1 (non-fertilization group) and 19.5 pieces/ear (fertilization group). The weight of grain per ear was 0.72 g (non-fertilization group) and 0.77 g (fertilization group).

Grain quality is largely determined by the weather conditions during the growing season. Thus, in 2011, favorable weather in terms of humidity and temperature resulted in larger, fuller grains with the weight of 1000 grains reaching 40.3–45.1 g. The natural weight was 714–737 g/l. In dry 2013, the grains were smaller, the weight of 1000 grains was between 36.1 and 38.4 g, and the natural weight was 636–651 g/l. Conversely, the vitreousness, mass fraction of gluten, and grain quality in 2011 were lower. In 2011, the vitreousness was 64%–70% and the mass fraction of gluten was 26.1%–30.6% (quality group III). In 2013, these indicators were better; the vitreousness was 70.0%–80.0% and the mass fraction of gluten was 29.4%–33.8%, with the gluten deformation index reaching 74–80 units (quality group II).

In 2012, the amount of gluten was at the same level as that in 2013 (30.3%–34.8%) (quality group II).

The analysis of data produced by three years of research (2011–2013) highlights the following features: 1) when fertilizers are applied, the weight of 1000 grains tends to increase, although the natural weight practically does not change, and the vitreousness slightly decreases. Therefore, on average, across the variants treated with MEGAMIX formulations, the weight of 1000 grains was 39.7 g (non-fertilization group) and 40.7 g (fertilization group), the natural weight was 677g/l (non-fertilization group) and 679 g/l (fertilization group), and the vitreousness was 74.6% (non-fertilization group) and 73.5% (fertilization group).

Upon fertilizer application, the gluten content practically did not change, but the quality of the grain increased. On average, across all variants, the gluten deformation index was 89.0 units (non-fertilization group) and 86.5 units (fertilization group).

The treatment of crops with MEGAMIX formulations positively affected the quality of the spring wheat grain. The weight of 1000 grains, as well as the natural weight, vitreousness, and the mass fraction of gluten increased. Thus, the weight of 1000 grains on average across all variants of crop treatment in the non-fertilization group amounted to 39.7 g, compared with the control, where it amounted to 37.7 g. Upon fertilizer application, these values were 40.7 g and 39.2 g, respectively.

Our results suggest that the cost of production increases with an increase in productivity. Moreover, in background 2 (planned yield of 2.4 t/ha), the level of this indicator in all variants increased significantly. The most profitable variant was that treated with MEGAMIX-pre-sowing treatment 2.0 l/t (62.2%) combined with the background 1 addition of MEGAMIX-universal 1 l/t (47.2%) or with the background 2 addition of MEGAMIX-universal (82.2%) and MEGAMIX-N10 (72.5%).

Economically, the most profitable solution without fertilizer application is to treat the crops with MEGAMIX-universal 0.5 l/ha (a profitability level of 97.8%) and also with MEGAMIX-foliar fertilizing 0.5 l/ha (a profitability level of 94.2%). When in combination with fertilizer, the most profitable solution is to treat the crops with MEGAMIX-universal 0.5 l/ha (a profitability level of 90.4%).

In general, the use of MEGAMIX formulations in the pre-sowing treatment of spring wheat is agro-energetically justified.

The coefficient of energy efficiency varied from 1.86 to 2.71 during the treatment of spring wheat with different MEGAMIX formulations. The highest value of the agro-energetic index of 2.71 GJ/t belongs to the variant MEGAMIX-universal 0.5 l/ha, without fertilizer application. The lowest energy cost per ton of spring wheat was 6.87 GJ/t for the same variant of MEGAMIX-universal 0.5 l/ha, upon fertilizer application.

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