Formation of structural elements of spring wheat productivity based on foliar application

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Abstract. This article provides analyzes of data of long-term production experiments (2016-2020) conducted on peasant farm enterprise Makarenko E.I. located in Volokonovsky district of the Belgorod region. The outcomes of a comprehensive assessment of applying a growth regulator and liquid micronutrient fertilizers on the Prokhorovka spring wheat variety are presented. The available data enabled to draw conclusions concerning the positive effect of the studied growth regulators and liquid micronutrients on the length of the growing season of wheat plants, which on average tended to decrease the growing season of experimental options from 2 to 13 days. Options implying the treatment of seeds and vegetative plants of spring wheat benefited productivity. On average, the spike length was greater by one plant, the number of spikelets and grain content were better than in the control. On average, over five years, the yield in the experiment varied from 2.39 t/ha to 3.04 t/ha, the increments to the control varied from Nerthus Planta Peg – 0.14 t/ha or 5.8% to Polydon N+ – 0.65 t/ha or 27.1%.

1. Introduction
To successfully achieve the indicators of the food security doctrine of the Russian Federation, it is necessary to develop agricultural production regarding the modern achievements of scientific and technological progress. Herewith, increase in the volume of high-quality grain, which, according to the indicators of the doctrine, should be at least 95-98% makes a big difference. Traditionally, winter soft wheat is the largest part of grain. The grain of spring wheat is of paramount importance in the production of first grade flour. Despite having a lower yield in comparison with winter wheat in terms of the quality of its grain, most modern varieties of spring wheat are not inferior and even prevail over winter forms [3,5,7,11].

In addition to varietal agricultural technology in agricultural crops cultivation, the introduction of organic and mineral fertilizers aimed to increase the yield and quality of grain is considered indispensable [6,8,9].

In modern economies, characterized by the fact that farmers are increasingly faced with high variability in price of capital goods, most farms have to make a difficult choice on the use of rather expensive mineral fertilizers. Undoubtedly, their effectiveness has been proven in terms of increasing both the yield and the quality of the resulting grain. Currently, the issue of profitability of agrotechnical methods of spring wheat cultivation is relevant. Its relevance is confirmed by the...
development of new liquid forms of mineral fertilizers being an alternative to mineral fertilizers [1,2,4,10].

In a number of farms, foliar applications are used in addition to mineral fertilizers. However, the farms being economically less developed and not always able to afford mineral fertilizers, willingly consider carrying out several foliar applications of grain crops with micronutrient fertilizers, especially during periods of no precipitation when nutrients from the soil are inaccessible.

In the southwestern part of the Central Black Earth Region, many agricultural enterprises independently conduct production experiments on the use of foliar applications due to their more accurate assessment in specific soil, climatic and production conditions. Research on this topic is undoubtedly relevant, timely and provides a more accurate and objectively compared and evaluated effect of the studied foliar applications on the yield of spring wheat under certain conditions.

2. Purpose of the study

To determine the effect of the used growth stimulants and foliar applications on the growing season length, the peculiarities of the formation of the productivity structure, yield and bioenergetic efficiency of the production of spring wheat of the Prokhorovka variety amidst the peasant farm enterprise Makarenko E.I. located in Volokonovsky district of the Belgorod region.

3. Materials, conditions and research methods

Production experiments on the effect of growth regulators and microfertilizers on the production process of spring wheat were carried out in 2016-2020 with regards to the existing methodological recommendations and at the peasant farm enterprise Makarenko E.I. located in Volokonovsky district of the Belgorod region. The conditions of the growing seasons had certain differences, which determined different indicators of plant productivity according to the experiment options. The spring wheat variety Prokhorovka was used as the object of the study; it was sown in four replicates. The plot area of the experiment was 550 m$^2$, the accounted area equaled 500 m$^2$. The soil of the experimental site was chernozem being leached medium-thick, medium-humus, of light loamy granulometric composition, with 5.2% humus content and an average content of basic nutrients.

The scheme of the experiment implied the treatment of seeds in the options of the experiment with water with the exception of treating seed with the growth regulator Nertus PlantaPeg of 0.25-0.3 l/t, and double treatment by spraying during the growing season with preparations: Nertus photosynthesis – 2.0 l/ha; Polydon N$^+$ – 2 l/ha, Polydon NPK – 2 l/ha; Alfastim – 30 ml/ha; Teknokel amine mix – 1 l/ha and Fertigrain Foliar – 1.5 l/ha.

Weather conditions during production trials in 2016-2020 had insignificant deviations from the average long-term values and could be characterized as typical for the region.

Of all the analyzed growing seasons, 2020 turned out to be the most favorable for growing spring wheat, in which heavy rainfall fell during the period of filling the caryopses, which had a positive effect on the yield level. The wheat growing season of 2016 was somewhat less favorable, when the air temperature was only 1°C higher than the average annual one, and precipitation was 64 mm higher. Conditions in 2018 differed by the temperature 2.5°C being higher than the average one and amount of precipitation being 86 mm higher. They fell unevenly, and, therefore, wheat plants did not fully use them. The growing season in 2017 was characterized by annual temperature being slightly higher than the average and a deficit of precipitation (deviation by 42.4 mm from the average annual amount). In an unfavorable year 2019, when precipitation fell by 29 mm against the background of an average daily temperature of 1.4°C, the yield of spring wheat was minimal in all options. However, it had differences depending on the applied growth regulator and fertilizers.

4. Research results

In the course of the production experiments, the positive effect of the studied plant growth regulator and foliar applications on the length of the growing season of spring wheat plants was established. The
general trend was traced on average for 2016-2020 and implied the reduction of vegetation in all options of the experiment in relation to the control.

The use of only the growth regulator Nertus PlantaPeg led to a reduction in the germination-ripening period by three days, and the sowing-ripening period in that option was 1 day more than in the control (Table 1).

Table 1. Growing season of spring wheat variety Prokhorovka with the use of a growth regulator and foliar application in a farm Makarenko E.I., 2016-2020

| Experiment option                        | Seedlings-ripening, days | Sowing-ripening, days |
|------------------------------------------|--------------------------|-----------------------|
| Control                                  | 96                       | 103                   |
| Nertus PlantaPeg                         | 93                       | 104                   |
| Nertus photosynthesis                    | 87                       | 95                    |
| Polydon N⁺                               | 83                       | 93                    |
| Polydon NPK                              | 94                       | 100                   |
| Alfastim                                 | 94                       | 104                   |
| Teknokel Amino Mix                       | 90                       | 98                    |
| Fertigrain Foliar                        | 89                       | 98                    |

In other options of the experiment, even more distinct differences in the shortening of the seedling-ripening period were traced. Specifically, when using Nertus, the photosynthesis of plants ripened faster by 9 days, Polydon N⁺ – by 13 days, Fertigrain Foliar – by 7 days, Teknokel Amino Mix – by 6 days, Polydon NPK and Alfastim – by 2 days. The greatest differences in comparison with the control were noted for the Polydon N⁺ option, where the sowing-ripening period was also the shortest and amounted to 93 days.

The studied agrotechnical methods had a direct impact on forming the elements of the productivity structure of spring wheat plants both in the years of production experiments taken separately for analysis, and on average over five years. On average for 2016-2020 the length of an ear per plant on average varied from 5.3 cm (on control) to 7.7 cm (Polydon N⁺) according to the experiment options (table 2).

Table 2. Elements of the productivity structure of spring wheat plants of the Prokhorovka variety depending on foliar application, 2016-2020.

| Experiment Option                 | On average for 1 plant | Weight of 1,000 grains, g |
|-----------------------------------|------------------------|---------------------------|
|                                   | ear length, cm         | amount                   | grain weight per ear, g | grains, g |
| Control                           | 5.3                    | 14.7                      | 21.9                    | 1.19      | 36.4 |
| Nertus PlantaPeg                  | 5.4                    | 13.5                      | 24.1                    | 1.10      | 37.3 |
| Nertus photosynthesis             | 7.5                    | 17.2                      | 27.2                    | 1.24      | 37.2 |
| Polydon N⁺                        | 7.7                    | 18.8                      | 28.9                    | 1.32      | 37.5 |
| Polydon NPK                       | 5.7                    | 14.5                      | 25.5                    | 1.12      | 36.4 |
| Alfastim                          | 5.9                    | 14.5                      | 26.2                    | 1.14      | 36.2 |
| Teknokel Amino Mix                | 7.3                    | 15.7                      | 25.7                    | 1.18      | 37.3 |
| Fertigrain Foliar                 | 7.5                    | 16.5                      | 26.3                    | 1.23      | 36.7 |
| Average                           | 6.5                    | 15.7                      | 25.7                    | 1.2       | 36.9 |

The greatest differences in this indicator in comparison with the control were obtained for the option Polydon N⁺ – 2.4 cm. On average, for the experiment options, that indicator was 6.5 cm. The applied drugs influenced both the number of spikelets and the number of grains in a wheat ear. The use of only the growth regulator when treating seeds with Nertus PlantaPeg led to a decrease in the number of spikelets by 1.2 pcs., when using Polydon NPK and Alfastim during the growing season – by 0.2 pcs. However, the number of grains in these options was more than control by 2.2, 3.6 and 4.3
pieces respectively. In other options of the experiment, spring wheat plants formed a larger number of spikelets and had a better grain size on the spike. Thus, on the option of treatment for vegetation Nerthus Photosynthesis, the number of spikelets was 17.2 pieces per plant, which was 3 pieces more than in the control, and the number of grains per one ear was also 5.8 pieces per plant more. As well, one of the best indicators was obtained on the experiment option with spraying plants with Fertigrain Foliar, where the number of spikelets and the number of grains in an ear was 1.8 pieces (amounted to 16.5 pieces) and 4.4 pieces (26.3 pieces) more than in the control (14.7 pieces and 21.9 pieces). The indicator of grain mass per spike had certain differences depending on the used growth regulator and micronutrient fertilizers. More full-weight caryopses were formed when using 1.23 g of Fertigrain Foliar, 1.24 g of Nertus Photosynthesis and 1.32 g of Polydon N°, which, respectively, was 0.04 g, 0, 0.05 g. and 0.13 g more than the mass of caryopses from the control option.

The yield of spring wheat plants in the study period depended both on the conditions of the year and on the studied agrotechnical methods. In general, according to the experience, the yield varied from 2.10 t/ha to 3.89 t/ha (Table 3).

**Table 3. Productivity of spring wheat variety Prokhorovka depending on growth regulator and foliar application in the farm Makarenko E.I., t/ha, 2016-2020**

| Experiment Option          | 2016   | 2017   | 2018   | 2019   | 2020   | Average | +/- to control t/ha | %  |
|----------------------------|--------|--------|--------|--------|--------|---------|---------------------|----|
| Control                    | 2.32   | 2.27   | 2.13   | 2.04   | 3.20   | 2.39    | -                   | -  |
| Nerthus photosynthesis     | 3.18   | 2.73   | 2.89   | 2.20   | 3.76   | 2.95    | 0.56               | 23.5 |
| Nerthus PlantaPeg          | 2.42   | 2.38   | 2.35   | 2.10   | 3.39   | 2.53    | 0.14               | 5.8  |
| Polydon N+                 | 3.25   | 2.89   | 2.92   | 2.24   | 3.89   | 3.04    | 0.65               | 27.1 |
| Polydon NPK                | 2.85   | 2.52   | 2.63   | 2.10   | 3.40   | 2.70    | 0.31               | 13.0 |
| Alfastim                   | 2.56   | 2.48   | 2.55   | 2.20   | 3.42   | 2.64    | 0.25               | 10.5 |
| Teknokel Amino Mix         | 2.89   | 2.61   | 2.56   | 2.10   | 3.59   | 2.75    | 0.36               | 15.1 |
| Fertigrain Foliar          | 2.92   | 2.53   | 2.79   | 2.31   | 3.68   | 2.85    | 0.46               | 19.1 |
| LSD05                      | 0.12   | 0.24   | 0.21   | 0.10   | 0.16   |         |                     |     |

The applied agrotechnical methods influenced the yield of spring wheat in different ways in the studied years. Most of the options in all years provided a significant increase in yield in comparison with the control. The yield of spring wheat in 2016 was at a fairly good level and placed No. 2 for average yield among the experiment options of all the studied growing seasons. It varied from 3.18 t/ha to 3.25 t/ha. In all experiment options the yield was significantly higher than the control option. The increment interval was from 0.24 t/ha to 0.93 t/ha. Only in Nertus PlantaPeg the yield was within the experimental error and amounted to 2.42 t/ha with an increase of 0.1 t/ha (HCP05 0.12). In 2017, reliably large increases in yield were obtained in all experiment options, with the exception of Alfastim (2.48 t/ha), which was within the experimental error (HCP05 0.24). The yield in all options of the experiment in 2018 being favorable for wheat growing was significantly more control by 2.35 t/ha (Nertus PlantaPeg) to 2.92 t/ha (Polydon N°). In an unfavorable year 2019, not all experiment options provided a reliably large increase in yield. It was 0.06 t/ha in the options Polydon NPK, Nertus PlantaPeg and Teknokel Amino Mix, and was within the experimental error (HCP05 0.10). A reliably large increase of 0.16 t/ha was obtained in Nertus photosynthesis and Alfastim. In Fertigrain Foliar it amounted to 0.27 t/ha, and in the Polydon N° it was maximum and equaled 0.2 t/ha. The average grain yield of spring wheat in 2020 was the maximum in comparison with the level of previous years and a significantly greater increase in comparison with the control was obtained in all experiment options. The dynamics of previous years remained the same: the smallest increase was on the Nertus PlantaPeg option, specifically, 0.19 t/ha, and the maximum when increase of 0.69 t/ha was achieved with the application of Polydon N°.
On average for 2016-2020 the yield of spring wheat varied from 2.39 t/ha to 3.04 t/ha. The yield increase in relation to the control varied from 0.14 t/ha (5.8%) to 0.65 t/ha (27.1%). The maximum yield level was obtained in the Polydon N\(^+\) and equaled 3.04 t/ha with an increase 0.65 t/ha, a slightly lower yield of 2.95 t/ha was gained with the use of Nertus Photosynthesis, with an increase of 0.56 t/ha or 23.5%.

The experimental methodology provided for the assessment of the bioenergetic efficiency of these agrotechnical methods when assessing the effectiveness of agrotechnical methods in the production of grain crops, including spring wheat.

The indicators used were the yield of exchangeable energy with the crop, the total energy consumption, net energy profit, and the coefficient of energy and bioenergy efficiency. Depending on the experiment option, the costs of total energy varied from 19.34 GJ/ha to 27.72 GJ/ha. They were stipulated by both generally accepted technological methods and works on spring wheat cultivation, as well as the introduction of a growth regulator and micronutrient fertilizers. The costs were almost the same with Alfastim and Nertus PlantaPeg 21.58–21.59 GJ/ha, and were the lowest in the control option. The highest value was obtained when applying foliar applications and it varied from 21.52 GJ/ha to 21.72 GJ/ha (table 4).

Net energy profit was calculated by calculating the difference between the yield of exchangeable energy per hectare and the energy consumption for growing spring wheat in the experimental options.

| Experiment option       | Productivity, t/ha | Exchangeable energy output, GJ/ha | Total energy consumption, GJ/ha | Net energy profit, GJ/ha | Energy efficiency ratio | Bioenergy coefficient |
|-------------------------|--------------------|----------------------------------|--------------------------------|-------------------------|------------------------|----------------------|
| Control                 | 2.39               | 38.72                            | 19.34                          | 19.38                   | 2.0                    | 1.0                  |
| Nertus PlantaPeg        | 2.53               | 40.99                            | 21.58                          | 19.41                   | 1.9                    | 0.9                  |
| Nertus photosynthesis   | 2.95               | 47.79                            | 21.72                          | 26.07                   | 2.2                    | 1.2                  |
| Polydon N\(^+\)         | 3.04               | 49.25                            | 21.52                          | 27.73                   | 2.3                    | 1.3                  |
| Polydon NPK             | 2.7                | 43.74                            | 21.65                          | 22.09                   | 2.0                    | 1.0                  |
| Alfastim                | 2.64               | 42.77                            | 21.59                          | 21.18                   | 2.0                    | 1.0                  |
| Teknokel Amino Mix      | 2.75               | 44.55                            | 21.67                          | 22.88                   | 2.1                    | 1.1                  |
| Fertigrain Foliar       | 2.85               | 46.17                            | 21.61                          | 24.56                   | 2.1                    | 1.1                  |

In our experiments over five years, the average net energy profit varied from 19.38 GJ/ha to 27.73 GJ/ha, and according to the experimental options it was 22.91 GJ/ha. When only the growth regulator Nertus PlantaPeg was used, the net energy profit increased insignificantly and was at the level of 19.41 GJ/ha. Net energy profit was higher on micronutrient options and increased with increasing yield levels. It was maximum in the Polydon N\(^+\) option and equaled 27.73 GJ/ha. The energy efficiency coefficient varied from 1.9 to 2.3, which enabled to conclude that the cultivation of wheat in all experiment options was energetically beneficial. The best values of the coefficient were obtained in the experiment options Nertus Photosynthesis (2.2), Technokel Amino Mix and Fertigrain Foliar (2.0 each), the maximum coefficient of energy efficiency was obtained in Polydon N\(^+\) – 2.3.

The coefficient of bioenergy efficiency in the control and in the options with the use of Alfastim and Polydon NPK were the same, specifically, 1.0. In Nertus PlantaPeg it was less than in control, specifically, 0.9. The best coefficient of bioenergetic efficiency was obtained when having treated spring wheat crops with micronutrient fertilizer Polydon N\(^+\) and equaled 1.3.

### 5. Conclusion

Thus, the presented studies and their results are of great scientific and practical value for modern agricultural production. For 2016-2020, field experiments established a positive effect of the growth...
regulator and liquid micronutrient fertilizers on the reduction of the growing season, the formation of the productivity structure elements, increase in grain yield and bioenergetic efficiency of cultivating spring wheat Prokhorovka in different conditions of growing seasons.

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