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Effect of herbicides and microfertilizers on the growth, yield and quality of spring wheat grain

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Abstract. As part of the study, analyzed the impact of herbicide and microfertilizer mixtures on wheat. Studied the effectiveness of Bomba Flo MD + Stingray KE and Balerina Super CE treatments against weeds. Identified an increase in plant height of 8 to 10 cm, increasing potential yield. Yields were examined, with increases ranging from 5.4 to 14.3 t/ha determined according to different application patterns. Grain quality was established by measuring protein, gluten, and texture, revealing significant improvements. Formulated protocol with three replications, including measurements of height, weed density, and grain analysis. Proposed a mixed statistical model to validate the reliability and robustness of the results obtained. Developed analytical framework evaluating synergistic impact of herbicides and microfertilizers on wheat productivity in agriculture.

1 Introduction

Spring wheat occupies a leading position among grain crops due to its high protein (16-18%) and gluten (28-40%) content, which determines its outstanding baking properties and nutritional value. According to the Federal State Statistics Service in the Russian Federation, in 2024, spring wheat was sown on an area of 11089 thousand hectares. This amounted to 15.3% of the total sown area of agricultural crops. The gross grain harvest amounted to 25.9 million tons. However, the average yield in Russia remains below global indicators (21.4 c/ha in 2024), which is associated with low levels of agricultural technology and high weed infestation in fields [1].

In the Orel region, the average yield of spring wheat in 2024 was 39.2 c/ha. During the period from 2019 to 2023, crop yields were higher and ranged from 40.5 c/ha in 2021 to 48.8 c/ha in 2023. This indicator largely depends on the weather conditions and the intensity of the cultivation technology.

Today, about 70% of the spring wheat harvest is feed grain, while the share of high-quality food grades (3rd and above) does not exceed 30%. This significantly limits export and processing opportunities, as 3rd grade food grain is 30% more expensive than feed grain [1].

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Successful wheat cultivation is largely determined by the phytosanitary condition of crops and optimal plant nutrition. Weeds reduce crop productivity by competing for moisture and nutrients, as well as by deteriorating the structure of the crop [2]. Effective regulation of the phytocenosis through modern herbicide treatments combined with the competent use of mineral fertilizers can significantly increase grain yield and quality [3].

Agrochemical techniques such as fractional fertilization and prolonged fertilizers play a special role in the formation of highly productive agrocenoses [4, 5, 6]. At the same time, their effectiveness directly depends on taking into account specific soil and climatic conditions and the biological characteristics of the variety [3, 7].

In the current situation, the development of scientifically based systems for mineral nutrition management and herbicide treatment is becoming a pressing task. Such systems should maximize the potential of the crop, ensuring yield growth without loss of quality indicators.

The aim of the study is to analyze the effect of various systems of herbicide and microfertilizer application on the yield and quality of spring wheat grain in the Central Black Earth Region of Russia.

2 Materials and methods

The research was conducted in 2025 on the experimental field of the Federal State Budgetary Educational Institution of Higher Education "Orel State Agrarian University named after N.V. Parakhin" (Orel, General Rodina St., 69) on dark gray forest medium loam medium-cultivated soil. The objects of the study were soft spring wheat (*Triticum aestivum* L.) of the Radmira variety, chemical plant protection products, and microfertilizers.

The herbicide Bomba Flo, MD (AVG-0346) (tribenuron-methyl, 150 g/l, thifensulfuron-methyl, 120 g/l, and florasulam, 60 g/l) is a systemic herbicide used to control a wide range of dicotyledonous weeds in cereal crops.

Herbicide Stingray, KE (pinoxaden, 50 g/l + antidote cloquintocet-mexyl, 12.5 g/l) systemic, against annual grass weeds in wheat crops.

Ballerina Super, SE (complex 2-ethylhexyl ester of 2,4-D acid, 410 g/l (in terms of 2,4-D equivalent) and florasulam, 15 g/l) – systemic, against dicotyledonous weeds in grain crops.

Rakurs, SC (epoxiconazole, 240 g/l + cyproconazole, 160 g/l) – systemic fungicide for protecting grain crops from a range of diseases.

Borey Neo, SC (alpha-cypermethrin, 125 g/l + imidacloprid, 100 g/l + clothianidin, 50 g/l) is a three-component insecticide against a complex of pests.

Bali, KME (propiconazole, 180 g/l + azoxystrobin, 120 g/l) - a premium two-component fungicide with a greening effect.

Sowing was carried out on 22.05.25, and seedlings appeared on 26.05.25. Sowing was carried out at a rate of 5 million viable seeds/ha. The size of the experimental plot was 45 m² and the accounting plot was 25 m². The repetition was 3-fold, and the plots were arranged systematically. Herbicide treatment was carried out on 11.06.25 during the tillering phase of wheat.

Experimental variants: 1. Control;

2. Bomba Flo, MD + Stingray, KE;
3. Balerina Super, SE + Stingray, KE + Adju, Zh;
4. Bomba Flo, MD + Stingray, KE + Addemiks Standard;
5. Ballerina Super, SE + Stingray, KE + Adju, Zh + Addemiks Standard.

Table 1. Elemental composition of Addemiks Standard complex fertilizer.

Composition	Amino acids	Growth stimulator	Nitrogen	MgO	SO_3	Fe	Mn	Cu	Zn	B	Mo	Co
Content, %	0.80	0.05	17	3.50	39.50	0.02	1.20	0.20	0.01	0.02	0.005	0.001

Protective measures against fungal pathogens and pests were carried out for all options.

The effectiveness of herbicides was assessed on July 7 using the phytotoxicity index:

$$IF = \frac{Dbefore - Dafter}{Dafter} \quad (1)$$

where D_{before}- weed density before treatment, D_{after}- weed density after treatment.

According to Baker (1979): insufficient (<70%), moderate (70-80%), satisfactory (80-90%), excellent (> 90%).

Plant height was measured with a tape measure (up to 1 mm) during the tillering, stem elongation, heading, flowering, and ripening phases. The average height was calculated using the formula:

$$Hm = \frac{\sum_{i=1}^{n} Hi}{n} \quad (2)$$

where *Hm*- is the average height, *Hi*- is the individual height, and n- is the number of plants measured.

The studies were conducted according to the Methodology for State Testing of Agricultural Crops [13]. Qualitative analysis of grain was performed using the Infratech 1245 device.

3 Results

On June 10, before treatment, the weed density was 245.5 plants/m²; dicotyledons predominated, especially redroot pigweed (*Amaranthus retroflexus*) – 96.2%, with a few specimens of field sow thistle (*Sonchus arvensis* L.*),* scentless chamomile (*Matricaria inodora* L.), medicinal dandelion (*Taraxacum officinale*) and field bindweed (Convolvulus arvensis). Monocotyledonous weeds were represented by barnyard grass (*Echinochloa oryzoides*) – 100%. Overall, dicotyledonous weeds accounted for 76.58% of the agrocenosis, and monocotyledonous weeds accounted for 23.42%.

The tank mixtures of herbicides used showed high phytotoxicity against weeds, with a mortality rate of over 90%. No statistically significant difference was found between options 2 and 3.

The results of the study demonstrate a significant impact of agrotechnical treatments on plant growth. The control group (without treatment) reached a maximum height of 111.7 cm on July 18, showing gradual growth from 25.12 cm (June 16) to 111.7 cm. Herbicide treatment (options 2 and 3) statistically significantly enhanced growth (Table 1): the maximum plant height in option 2 reached 119.2 cm, and in option 3 - 118.87 cm. The increase compared to the control was 7.50 and 7.17 cm, respectively.

Table 2. Dynamics of the average height of wheat plants depending on the type of agrotechnical treatment (cm).

Date	Control	Option 2	Option 3	Option 4	Option 5	NSR_{05}
16.06.2025	25.12	29.57	29.10	41.70	38.45	3,14
24.06.2025	33.45	36.62	34.60	47,89	46.90	3,04
30.06.2025	54.13	55.20	56.14	70,80	67.23	4,00
14.07.2025	96.90	98.61	97.55	101,30	100.56	3,32
18.07.2025	111.70	119.20	118.87	120.30	120.25	3,44

Combined treatment with herbicides and fertilizers (options 4 and 5) yielded the best results: in option 4, plant height reached 120.3 cm, and in option 5, 120.25 cm. The increase over the control was 8.60 and 8.55 cm, respectively. The differences between options 4 and 5 are insignificant, but option 4 showed higher growth dynamics in the early stages of development.

The economic yield in the control option was 24.95 c/ha. Due to the use of a tank mixture of herbicides according to option 2 (Bomba Flo, MD + Stingray, KE), the yield increase was 5.8 c/ha or 23.25%. In option 3 (Ballerina Super, SE + Stingray, KE + Adju, Zh.), the increase in the indicator was 5.37 c/ha or 21.52% (Fig. 1).

Two applications of foliar fertilizers during vegetation against weeds according to options 4 and 5 increased crop yield relative to the control by 14.34 and 13.62 c/ha, respectively.

The application of herbicide treatments contributed to an increase in the quality indicators of wheat grain (moisture content 14%) (Fig. 2). The weight of 1000 seeds in the control was 37.71 g. In experimental options 2 and 3, the values of the indicator were higher by 3.1 and 2.8%, respectively. In options 4 and 5 with the use of microfertilizers, the studied indicator increased by 6.9 and 2.6%, respectively.

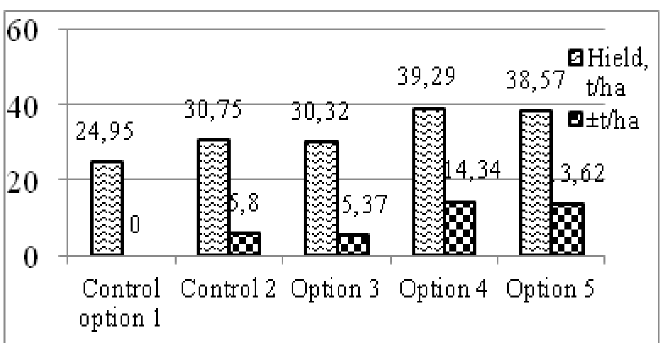

Fig. 1. Economic yield of spring wheat.

The gluten content in option 2 (Bomba Flo, MD + Stingray, KE) reached 21.12%, which is 2.7% higher than the control. In optien 3 (Ballerina Super, SE + Stingray, KE + Adju, Zh), the gluten content in the grain exceeded the control by 3.01%. The maximum gluten content was found in option 4 (Bomba Flo, MD + Stingray, KE + Addemix Standard) – 23.1%, which is 4.7% higher than the control.

In terms of protein content in grain, the experimental variants exceeded the control by 1.49, 1.42, 2.17, and 0.89%, respectively.

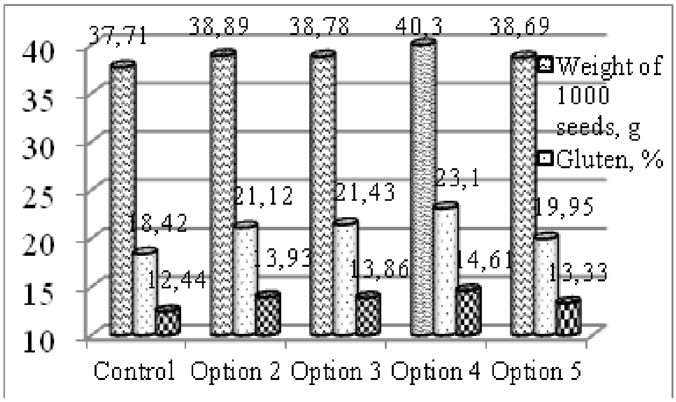

Fig. 2. Quality indicators of Radmira* spring wheat grain.

*Weight of 1000 seeds, g – $NSR_{0,95}$ =1.32
*Gluten – $NSR_{0,99}$ =0.26
*Protein – $NSR_{0,99}$ =0.29

In terms of vitreousness, the grain belongs to the medium vitreousness group (40 to 60%), since the variation in this indicator ranges from 49.78% in the control to 55.34% in option 4.

The natural grain weight in the control option was 702.78 g/l. In the experimental options, it ranged from 727.21 to 777.89 g/l. The increase in the indicator relative to the control was noted in the range from 3.5 to 10.7% in option 4.

4 Discussion

It is well established that the presence of weeds in any agricultural crop greatly influences plant health, growth activity, yield, and product quality. This influence results from reduced access to sunlight and, consequently, reduced photosynthesis intensity, increased energy consumption for respiration, and an increase in the number of pests and pathogens, especially in the presence of high humidity and temperature [8].

In our study of spring wheat, concrete observations confirm and enrich these theoretical concepts. Before any intervention, the total weed density was 245 plants m^{-2}, 96% of which were dicotyledons, notably Amaranthus retroflexus. This situation is similar to that reported by Igraev & Torshin [1], who observed an average density of 230 plants m^{-2} with a high proportion of dicotyledons in intensive cropping systems. Kremer et al. [2] showed that dicotyledons exert greater pressure on light than monocotyledons, resulting in a 5-8% reduction in wheat height when no treatment is applied. Our measurements, which show wheat height increasing from 25 cm to 112 cm in the absence of treatment, perfectly illustrate this negative impact of phytophytic competition; they concretely reflect the loss of light and increase in physiological stress described in the literature. Thus, field data reinforce the idea that integrated weed management is essential to preserve photosynthesis, limit yield losses, and improve product quality.

Spraying herbicide mixtures resulted in more than 90% mortality of weeds, with no statistically significant difference between options 2 and 3. This efficacy is comparable to that described by Shpanev et al. [8], who reported mortality from 88% to 93% with similar formulations of glyphosate + paraquat on dicotyledonous weeds. In contrast, Dongak [7] noted a slight decrease in efficacy (≈80%) when herbicide resistance was already present, highlighting the importance of rotating modes of action to ensure long-term sustainability.

Thus, our study confirms that, under conditions where resistance is not yet widely developed, herbicide treatments remain highly effective in reducing weed pressure.

In terms of wheat morphology, herbicide treatments alone (options 2 and 3) achieved maximum heights of approximately 119 cm, a gain of 7 cm compared to the control. This result is consistent with that of Zharkova & Nechayeva [5], who observed an increase of 6 to 9 cm after applying herbicides to spring wheat. The addition of fertilizer (options 4 and 5) slightly increased the height to 120 cm (+1 cm). This marginal improvement is consistent with the work of Konovalova & Okorov [4], who showed that nitrogen fertilization, when combined with good weed control, has only a slight effect on the final height of wheat, but has a more pronounced impact on the number of ears and grain mass.

Agronomic yield showed the greatest increases in the combined treatments (options 4 and 5). The control group had a yield of 24.95 $t \cdot ha^{-1}$, while option 2, based on a combination of herbicides, yielded a gain of 5.80 $t \cdot ha^{-1}$ (+23%) and option 3 a gain of 5.37 $t \cdot ha^{-1}$ (+21%). The herbicide + fertilizer combinations increased yields by 14.34 $t \cdot ha^{-1}$ (+57%) and 13.62 $t \cdot ha^{-1}$ (+55%). These increases are in line with meta-analyses of the methodology for agricultural variety trials [13], which estimated that the integration of herbicides and nitrogen fertilizers could increase spring wheat yield by 30% to 60% depending on agro-ecological conditions. In comparison, Timofeev et al. [10] reported gains of 20% to 35% with herbicides alone, which corresponds well with our options 2 and 3. The notable difference with options 4 and 5 highlights the importance of complementary fertilization, a result supported by the work of Sineshchekov & Vasilyeva [11], who showed that nitrogen application during the grain filling phase could increase yields by an additional 10% to 15%.

Grain quality also improved. The weight of 1,000 grains, which was 37.71 g in the control, increased by 3.1% and 2.8% for variants 2 and 3, and by 6.9% and 2.6% for variants 4 and 5 thanks to the use of microfertilizers. The gluten content increased by 2.7% (option. 2), 3.01% (option 3), and 4.7% (option 4, the highest). The protein content also increased, with gains ranging from 0.89% to 2.17% depending on the treatment. The bulk density of the grain increased from 702.78 $g \cdot l^{-1}$ (control) to a range of 727.21–777.89 $g \cdot l^{-1}$, representing an increase of 3.5% to 10.7%. These qualitative improvements are consistent with better plant nutrition and reduced competitive stress, which promote protein synthesis and carbohydrate reserves in the grains [9]. They are also consistent with data [2, 9] showing that chemical protection enhances plant resilience to stress, including competition from weeds. Thus, the increase in the number of productive stems (+16%), grain yield, and 1,000-grain weight (+3.1%) under the effect of herbicides translates directly into an increase in gluten (+3.01%) and protein (+1.49%). This correlation confirms the close link between agricultural technology and grain quality, as highlighted by the findings [4, 6, 12] that foliar feeding and nutritional optimization promote protein synthesis.

5 Conclusion

This study examined the synergistic effectiveness of the "Bomba Flo+ Stingray KE" and "Ballerina Super SE + Stingray KE + Adju Zh" combined with the Addemiks Standard micro-fertilizer on Radmira spring wheat grown on dark gray, moderately loamy forest soil in the central Chernozem zone. At the end of this work, it should be noted that these treatments ensure very effective weed control (control index > 90%) and lead to a significant improvement in agronomic performance: the average height of the plants increases by 8 to 10 cm, the weight of 1,000 grains increases by 3.1% to 6.9%, the gluten content rises to 23.1% (+4.7% compared to the control), the protein content increases from 0.89% to 2.17%, and the bulk density of the grain rises from 3.5% to 10.7%. The economic yield increased from 24.95 t ha^{-1} to 30.29 t ha^{-1} with herbicides alone (+≈23%) and to

39.29 t ha^{-1} when combined with Addemiks Standard (+≈57%). Among the combinations tested, the mixture “Bomba Flo MD + Stingray KE + Addemiks Standard” provided the maximum synergistic effect, combining optimal weed control and nutritional optimization, which is both a scientific and economically viable solution for modern agriculture in the of the Central Black Earth Region. However, in order to ensure the sustainability of these gains, it would be advisable to continue multi-year and multi-site trials in order to adjust doses to specific soil and climate conditions and confirm the robustness of the protocol in different agronomic contexts.

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