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# Effect of the fertilizer application rates on the performance of the winter triticale on podzolic soil

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**The aim of this work was to assess the effect of different application rates of NPK fertilizer on the productivity of winter triticale varieties in podzolic soils. In this particular study, 3 varieties of winter triticale: Guera, Nemchinovskaya 56, and Nina were evaluated in 2020-2022 on the experimental fields of FIC "Nemchinovka". The best response to mineral nutrition was observed in the Guera variety, which was also more resistant to lodging under the conditions during the trial period (2020-2022). The grain yield per hectare as a function of the application rates ranged from 6.75 to10.78 tons for the Guera variety, 5.65 to 8.84 tons for the Nemchinovskaya 56 variety, and 4.87 to 8.61 tons for the Nina variety. For two years, the average yield increase in comparison with the control was obtained by varieties through increment of NPK rates as demonstrated by the treatment percentile increases for each variety: Guera-T1-14, T2-25, and T3-56%; Nina-T1-19, T2-41 and T3-60%; and Nemchinovskaya 56-T1-22, T2-44, and T3-77%. Similarly, the application of T3 to the triticale varieties increased crude protein by 37% in Guera, 64% in Nemchinovskaya 56, and 46% in Nina variety compared with the control.**

**Key words:** Mineral fertilizer, winter triticale, yield, podzolic soil, application rates.

## INTRODUCTION

Triticale was the first cereal created by man in Sweden at the end of the 19th century by hybridising wheat (*Triticum aestivum*) with rye (*Secale cereale*) and has a number of distinctive qualities. It outperforms its parents in terms of yield and product quality, and the total area designated for production of this crop around the world is constantly increasing. According to Rosstat data in 2019, the area sown to triticale in Russia, on farms of all categories amounted to 147.7 thousand hectares, 4.0% (6.1 thousand hectares) more than in 2018. Triticale is mainly used for human consumption (in bakery products and confectionery) and animal feed.

This cereal has multiple advantages such as tolerance to abiotic stress, resistance to root rot and viruses, high competitive ability against weeds, ability to form a powerful leaf apparatus, and its ecological plasticity inherited from rye, which means it can be grown in more extreme conditions than other cereals. The chemical

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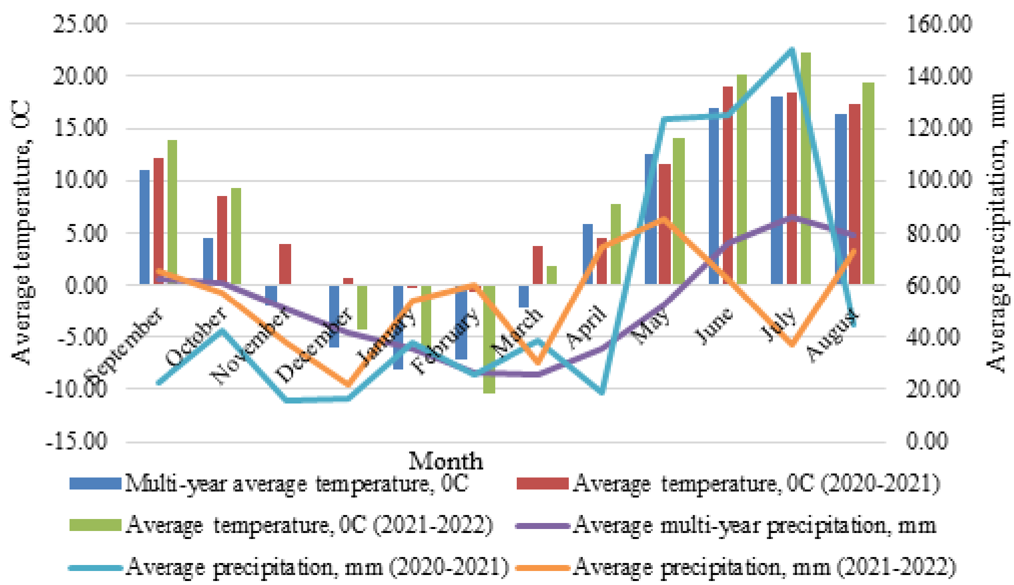


**Figure 1.** Weather conditions in 2020-2022 (Nemchinovka weather station).

composition of triticale grain is typical of cereals and is characterised by a high protein and carbohydrate content (Kononenko, 2016). The protein content of triticale grain is 1 to 2% higher than that of wheat and 3 to 4% higher than that of rye. Gluten content is higher (25-38%) than in wheat, but its quality (elasticity, extensibility) is lower, thanks to the rye genome. Triticale grain exceeds wheat grain by 9.5% in terms of protein nutrition, and barley and maize by almost 40% (Arkova et al., 2021).

The gene pool of cultivated winter triticale varieties is constantly expanding, and the need to create qualitatively new source material with high cereal productivity, adapted to local agroclimatic and soil conditions, is imperative. Triticale parent varieties had certain characteristics, in particular the appearance of wrinkled grains, which gave them a high protein content and high nutritional value. Subsequently, many triticale varieties have lost their original properties. As a result, plant breeders will have to develop new triticale varieties with wrinkled grains, without lodging and other disadvantages (Dibrova and Krylova, 2018). In addition, winter triticale is the most demanding cereal crop in terms of mineral nutrition, especially during the early growth stages. However, the issues of cultivation technology, in particular the application of NPK fertilizers, which, according to a number of authors, determine the productivity of the crop, have hardly been studied in all regions of Russia (Ramazanova et al., 2018). The optimum application rate varies greatly depending on the crop and soil/climate conditions of the plot, due to the many factors influencing the nitrogen cycle and their interactions. Fertilization standards represent the N, P and K nutrient requirements of field crops for an average yield. These standards are corrected according to various factors relating to plants, soil and/or climate (Sandukhadze et al., 2020). Thus, the aim of this work was to evaluate the effect of different NPK fertilizer application rates on winter triticale productivity under podzolic soil conditions while determining: (1) the effect of the NPK fertilizer application rate on photosynthetic activity and triticale plant growth parameters; (2) the effect of the NPK fertilizer application on yield quantity and quality.

## MATERIALS AND METHODS

### Site weather conditions during the trial period (2020-2022)

Weather conditions in the experimental period (2020-2022) for winter triticale plants were generally characterized as favorable. The hydrothermal coefficient was 2.79 in 2020-2021 and 1.52 in 2021-2022. The sugar content in the tillering node was 20 to 23%. An increase in temperature was observed. However, the average ambient temperature in research years was higher than in previous years. Snow cover was established in January 2020-2021 and December 2021-2022 with mean daily air temperatures of -4.3 and -0.2°C, respectively. The soil temperature at the tillering nodes was close to zero. The winter months (January and February) were snowy with 63.5 mm of snowfall in 2020-2021 and 114.2 mm in 2021-2022, higher than the long-term average by 1.3 and 52 mm, respectively. Particularly in terms of the amount of rainfall during the spring-summer growing season, from May to July (123-150 mm) was noted, exceeding the average annual values by almost 2 times in 2020-2022. Monthly rainfall in April was 18.6 mm, almost 2 times less than the average annual values.

The first 10 days of May, the 20-day and 30-day periods of June as well as the first 10 days of July were characterized by higher values of mean daily air temperature compared with the long-term average (Figure 1). Monthly rainfall in April was 74.6 and 18.5 mm, in May -123.8 and 85.7 mm in 2020-2021 and 2021-2022, respectively. When air temperatures were high in June and July, precipitation was less than the average annual values. The

**Table 1.** Photosynthetic activity of the winter triticale varieties (2020-2022).

| Variety | NPK dose | Photosynthetic potential (million m$^2$/ha days) | Net photosynthetic productivity (kg/thousand m$^2$ days) |
|---|---|---|---|
| Guera | T0 | 2.2 | 2.9 |
| | T1 | 2.7 | 2.9 |
| | T2 | 6.5 | 1.4 |
| | T3 | 7.5 | 1.4 |
| Nemchinovskaya 56 | T0 | 2.3 | 2.1 |
| | T1 | 2.9 | 2.3 |
| | T2 | 3.9 | 2.0 |
| | T3 | 4.5 | 1.5 |
| Nina | T0 | 2.1 | 2.8 |
| | T1 | 2.4 | 2.8 |
| | T2 | 3.8 | 1.9 |
| | T3 | 4.5 | 1.8 |

hydrothermal coefficient for the spring-summer period was 2.35 in 2020-2021 and 1.36 in 2021-2022.

### Experimental design

The experiments were carried out in 2020-2022 on the experimental fields of the Nemchinovka Federal Research Centre. The soil of the experimental plots is loamy, characterized by low natural fertility with a humus content of 2.0 to 2.5%. Soil pH ranges from 4.0 to 5.0. The experiment was carried out using a two-factor design. In the study, 3 varieties of winter triticale were grown, developed by plant breeders from the 'Nemchinovka' Federal Research Centre, resistant to lodging and excretion and to diseases Guera, Nemchinovskaya 56, and Nina (factor A), different levels of mineral fertilizer application (factor B): (control (T0), N0P0K0 (kg/ha) (T1), N90P60K90 (kg/ha) (N30P60K90 - basal application, N60 - top dressing) (T2), N120P90K120 (kg/ha) (N30P90K120 - basal application, N60 in spring to tillering and N30 priming phase), and (T3) N150P120K180 (kg/ha) (N30P120K180 - basal introduction, N60 in spring tillering, N30 emergence phase in tube, N30 heading). Winter crop varieties are sown on the annual grass predecessor. Pesticides were used to protect the plants against weeds, diseases, and pests: Impact super fungicide, SC 0.5 kg/ha (225 g/l Tebuconazole + 75 g/l Flutriafol), Lintur herbicide, VDG 180 g/ha (659 g/kg Acid Dicamba + 41 g/kg Triasulfuron), and Danadim insecticide, EC 1 l/ha (Dimethoate 400 g/l). The crops were sprayed by "Amazone US - 605". The total experimental area was 1440 m$^2$ and individual plot-size was 30 m$^2$. The experiment was replicated four times. Sowing was carried out with an Amazone seed drill at a sowing rate of 5 million seeds per hectare. Harvesting was carried out by a "Sampo-500" combine harvester.

### Observations and sample collection

During the research year, observations were made on photosynthetic activity, triticale plant growth parameters and yield components according to the methods of Blagoveschenskaya (2004). At harvest, triticale plants covering an area of 0.25 m² in each plot of all the experimental trials were obtained for measurement, counting and analysis of growth, phenological, physiological and biochemical parameters in the laboratory. The parameters measured and counted for winter triticale included plant height in cm, number of plants in m$^2$, number of stems in m$^2$, number of ears in m$^2$, number of ears per plant, and number of grains per ear. In addition, winter triticale was dried and seed samples were taken from each plot for 1000-seed weighing and yield-weighing attributes. A ruler and an electric scale were used for the measurements. Crude protein content was also analyzed in the laboratory by the conventional Kjeldahl method (N×6.25) GOST10846-91 (Kjeldahl method) and grain gluten content according to GOST R 54478-2011 (manual method).

### Statistical analysis

The statistical processing of the pooled data was carried out according to Dospekhov (1985) using the software "AGROS" 2.07.

## RESULTS

### Photosynthetic activity of triticale plants

Observations of photosynthetic activity in triticale crops under wet conditions in 2020-2022 showed that indicators of photosynthetic potential and net photosynthetic productivity varied significantly from 2.1 to 7.5 million m$^2$/ha days for varieties and NPK doses (Table 1). With increasing doses of NPK, photosynthetic potential increased leaf productivity index or net photosynthetic productivity, that is, cereal production (kg) per 1,000 units. Photosynthetic potential varied according to predecessors from 1.4 to 2.9 kg/1,000 units. Photosynthetic potential with maximum values for T1 was observed in the Guera and Nina varieties.

Thus, the photosynthetic activity of triticale plants depended on weather conditions during the growing season. With an increase in NPK application rates, the

**Table 2.** Plant height (cm) at different growth phases (2020-2022).

| Variety | NPK dose | Development phase | |
|---|---|---|---|
| | | Fruit setting | Heading |
| Guera | T0 | 46 | 88 |
| | T1 | 52 | 98 |
| | T2 | 57 | 106 |
| | T3 | 60 | 107 |
| Nemchinovskaya 56 | T0 | 53 | 93 |
| | T1 | 56 | 105 |
| | T2 | 58 | 109 |
| | T3 | 59 | 110 |
| Nina | T0 | 52 | 89 |
| | T1 | 54 | 101 |
| | T2 | 58 | 111 |
| | T3 | 61 | 112 |

main indicators of photosynthesis (leaf area, photo potential) increased. Mineral fertilizers and plant protection products played a major role, directly affecting the growth and productivity of the varieties. In terms of net photosynthesis productivity, the opposite trend can be observed.

## Effect of NPK fertilizer rate on plant height

The growth processes of winter triticale plants were monitored using linear measurements. It was established (Table 2) that with the intensification of mineral nutrition, the height of plants of the variety Nemchinovskaya 56 increased from 46 to 59 cm, in variety Nina from 52 to 61 to 60 cm with treatment (T3) N150P120K180. In the heading phase, the height of the Nemchinovskaya 56 variety with the various application rates were 93 to 110 cm, the Nina variety is from 89 to 112 cm and the Guera variety is from 88 to 107 cm. The year's conditions were characterized by excessive precipitation. As a result, lodging was observed before harvest in the Nina and Nemchinovskaya 56 varieties. The Guera variety, with its stronger stem, did not lodge, having withstood the adverse weather conditions.

## Yield and crude protein of winter triticale varieties

The yield data shows (Table 3) that the number of productive stems increased with the increase in mineral fertilizer application rates. In the Guera variety, using the T3 fertilizer regime, their number rose to 474 $m^{-2}$, the Nemchinovsky 56 variety rose to 591 $m^{-2}$, the Nina variety rose to 538 $m^{-2}$. Grain yield and quality largely depend on the 1000 grain weight (Mitura et al., 2023). A similar trend was obtained when analyzing crop-yield in terms of indicators such as grain weight per ear and 1000-grain weight. With an increase in mineral fertilizer application rates, these yield indicators improved. In the Guera variety, they were the best expressed, ear productivity was 2.22 g at T3. In the Nemchinovskaya 56 and Nina varieties, under wet conditions and with periodic winds causing lodging, ear productivity was much lower and varied with increasing application rates of mineral fertilizer from 1.50 to 1.55 g. Outdoor conditions also affected 1000-grain weight. Thus, the 1000-grain weight in the Gera variety varied depending on the fertilizer regime used from 41.3 to 49.2 g, in the Nemchinovskaya 56 variety from 40.3 to 44.4 g, and in the Nina variety from 28.3 to 40.4 g.

The main indicators of crop yield determined the organic yield of winter triticale varieties. In the Guera variety, it was the highest and was equivalent to an increase in mineral fertilizer doses from 632.7 to 1052.3 $g/m^2$, in the Nemchinovsky 56 variety from 595.8 to 916.5 $g/m^2$, and Nina variety from 602.5 to 817.2 $g/m^2$.

## Influence of NPK application rates on yield quantity

The weather conditions that prevailed throughout the experimental period had a decisive influence on crop yield. The implemented measures for the application of fertilizers and the timely treatment of plants with plant protection agents at appropriate rates allowed for increase in the yield of the winter triticale varieties. The best response to mineral nutrition was observed in the Guera variety, which was also more resistant to lodging under the conditions of the current years. The grain yield

**Table 3.** Yield components of the winter triticale varieties (2020-2022).

| Variety | Dose NPK | Number of stems (pcs/m²) | | Productive stems | Mass of seeds | | Biological yield (g/m²) |
|---|---|---|---|---|---|---|---|
| | | total | productive | | Seeds per ear | 1000 Seeds | |
| Guera | T0 | 406 | 391 | 2.4 | 1.81 | 41.3 | 632.7 |
| | T1 | 422 | 401 | 2.4 | 1.99 | 44.6 | 787.4 |
| | T2 | 448 | 444 | 2.4 | 2.04 | 46.2 | 906.2 |
| | T3 | 498 | 474 | 3.2 | 2.22 | 49.2 | 1052.3 |
| Nemchinovskaya 56 | T0 | 452 | 406 | 2.0 | 1.50 | 40.3 | 595.8 |
| | T1 | 508 | 462 | 2.8 | 1.50 | 41,6 | 692.6 |
| | T2 | 564 | 499 | 2.8 | 1.54 | 39.6 | 768.4 |
| | T3 | 620 | 591 | 3.2 | 1.55 | 44.4 | 916.5 |
| Nina | T0 | 413 | 399 | 2.0 | 1.52 | 28,3 | 602.5 |
| | T1 | 449 | 432 | 2.3 | 1.53 | 30.8 | 661.3 |
| | T2 | 528 | 477 | 3.1 | 1.53 | 38.6 | 729.4 |
| | T3 | 549 | 538 | 3.1 | 1.52 | 40.4 | 817.2 |

of the Guera variety based on the fertilizer regime used ranged from 6.75 to 10.78 t/ha, for the Nemchinovskaya 56 variety it was 5.65 to 8.84 t/ha, and for the Nina variety it was 4.87 to 8.61 t/ha (Table 4). For two years, the average yield increase over the control was obtained for the Guera variety at increasing doses of NPK and was T1-14, T2-25, and T3-56%, respectively. For the Nina and Nemchinovskaya 56 varieties, significant increases in grain yield T1-19, T2-41, and T3-60% as well as T1-22, T2-44, and T3-77%, respectively, were also obtained.

### Effect of fertilizer on grain quality of triticale

To obtain quality bread, it is necessary to have at least 14% crude protein in the grain. The grain of the studied varieties of winter triticale is characterized by low protein content. Following the conditions of a wet year, the crude protein content of winter triticale varieties with an increase in the application rates of mineral fertilizer did not change significantly. In the control (T0), it varied from 10.2 to 12.1%, T1 from 10.6 to 12.1%, T2 from 11.7 to 12.4%, and for T3 from 11.4 to 12. 9% (Table 5). Application of T3 on Guera variety increased crude protein by 37%, whilst it increased by 56-64% in Nemchinovskaya variety and by 46% in the Nina variety compared to control. Triticale showed differences in protein content depending on the fertilizer application rate.

## DISCUSSION

An important indicator of the photosynthetic activity of winter triticale crops is the size of their leaf surface, through which light energy from solar radiation is captured and converted into the potential energy of organic matter in the process of photosynthesis (Campillo et al., 2012). Depending on the leaf area index (LAI) of the winter triticale plants, a total of biological yield is created, which is determined by photosynthetic characteristics. The quality characteristics and/or yield depend largely on the agrometeorological conditions of the growing season. The rapid development of the leaf surface associated with the use of fertilizers and plant protection products plays an important role in the formation of high winter triticale yields. The photosynthetic potential shows how intensively the assimilative surface is formed during the growing season (Evans, 2013). The highest photosynthetic potential under the conditions of the year was noted in the Guera variety (Table 1). These data are similar to those of Yakovlev (2015) and Noor et al. (2023).

In this study, intensified mineral nutrition increased height, yield and grain quality of winter triticale in all varieties. Muhammad et al. (2021) also showed that the application of N60P30K30 and N120P60K60 significantly affected the plant height of wheat, triticale and oats compared with the absence of NPK. These results are similar to those of Ramazanova et al. (2018) and Obour et al. (2020). Thus, during the 2017 drought year, the grain yield of triticale with nitrogen fertilizers alone increased from 0.94 in the control to 1.20 to 1.35 t/ha and the gain in grain yield of nitrogen fertilizers with a fertilizer regime of P60 was 3.5 to 5.7 t/ha (Ramazanova et al., 2018). The application of nitrogen fertilizers in one go and split-application of phosphorus fertilizer provided an additional increase in grain yield 0.55-0.7 t/ha (Ramazanova et al., 2018). Triticale showed differences

**Table 4.** Average yield of winter triticale varieties (t/ha).

| Variety (factor A) | NPK application rate (Factor B) | Average yields per repetition | | | | Means (factor A) | Increase over control | |
|---|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | | t/ha | % |
| Nemchinovskaya 56 | T0 | 5.54 | 5.26 | 6.00 | 5.80 | 5.65 | – | – |
| | T1 | 6.48 | 6.53 | 6.42 | 6.35 | 6.45 | 0.80 | 14 |
| | T2 | 7.22 | 7.18 | 6.92 | 6.84 | 7.04 | 1.39 | 25 |
| | T3 | 8.79 | 9.00 | 8.72 | 8.84 | 8.84 | 3.19 | 56 |
| | | **Average for the variety** | | | | 6.99 | | |
| Nina | T0 | 5.00 | 4.64 | 4.85 | 4.99 | 4.87 | – | – |
| | T1 | 5.63 | 6.20 | 5.88 | 6.06 | 5.94 | 1.07 | 22 |
| | T2 | 7.30 | 6.70 | 6.90 | 7.10 | 7.00 | 2.13 | 44 |
| | T3 | 8.33 | 8.89 | 8.49 | 8.73 | 8.61 | 3.74 | 77 |
| | | **Average for the variety** | | | | 6.61 | | |
| Guera | T0 | 6.66 | 6.88 | 6.64 | 6.82 | 6.75 | – | – |
| | T1 | 7.94 | 8.20 | 7.87 | 7.99 | 8.00 | 1.25 | 19 |
| | T2 | 9.42 | 9.58 | 9.37 | 9.63 | 9.50 | 2.75 | 41 |
| | T3 | 10.63 | 10.94 | 10.56 | 10.98 | 10.78 | 4.03 | 60 |
| | | **Average for the variety** | | | | 8.52 | | |
| Mean (B factor) | | T0 | | T1 | | T2 | T3 | |
| | | 5.76 | | 6.80 | | 7.85 | 9.41 | |
| | | **Average increase** | | | | | | |
| т/ha | | - | | 1.04 | | 2.09 | 3.65 | |
| % | | - | | 18 | | 36 | 63 | |

NSR05 in the experiment = 0.47 tons/ha; NSR05 for factor A = 0.29 tons/ha; NSR05 for factor B = 0.33 tons/ha.

**Table 5.** Crude protein content and forage productivity of winter triticale varieties (2020-2022).

| Variety | Dose NPK | Crude protein (%) | Crude protein yield (kg/ha) | +/- relative to control | |
|---|---|---|---|---|---|
| | | | | kg/ha | % |
| Guera | T0 | 12.1 | 915 | - | |
| | T1 | 12.1 | 947 | +32 | 3 |
| | T2 | 12.1 | 1091 | +176 | 19 |
| | T3 | 12.4 | 1255 | +340 | 37 |
| Nemchinovskaya 56 | T0 | 11.2 | 717 | - | - |
| | T1 | 11.5 | 792 | +75 | 10 |
| | T2 | 12.4 | 949 | +232 | 32 |
| | T3 | 12.9 | 1178 | +461 | 64 |
| Nina | T0 | 10.2 | 632 | - | - |
| | T1 | 10.6 | 699 | +67 | 11 |
| | T2 | 11.7 | 849 | +217 | 34 |
| | T3 | 11.4 | 927 | +295 | 46 |

in protein content depending on the fertilizer application rate, on the P60 background, nitrogen fertilizer increased the protein content of plants from 7.6 to 9.9 to 10.7% (Ramazanova et al., 2018).

Thus, the correct application of all agro technical methods of growing winter triticale, the rational use of mineral fertilizers, and nitrogen fertilizers with the involvement of diagnostic methods of soil and plant nutrition, differentiated use of phytosanitary products is decisive factors for increasing the yield and protein content of cereal products.

## Conclusion

By increasing the application rate of NPK, the plants develop better under optimal agro-physical conditions. At the same time, plants have a well-developed root system, bushy vegetation and greater resistance to stress factors. The application of mineral fertilizers contributed to a significant increase in the weight of winter triticale grains compared to the control. The Guera variety proved to be more efficient and gave the best average yield of 8.52 t/ha compared to Nemchinovskaya 56 and Nina, which yielded 6.99 and 6.61 t/ha respectively.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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