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ORIGINAL ARTICLE

Effect of nutrition and precipitation on the grain yield at winter triticale

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Of the technological methods, fertilizers have the most significant effect on the performance of crops. However, limited resources of mineral fertilizers and their high cost necessitate research to identify the most effective options for their application. Our purpose was to optimize the nutrition system of winter triticale crops by determining the best options for the pre-sowing application of polynutrient fertilizers, establishing the effectiveness of different variants of additional fertilization that ensure the highest grain yield of winter triticale in years with various temperature and precipitation during the growing period. The study was conducted using the conventional technique in the Private Agricultural Enterprise *Imeni Shevchenka* (Kharkivska Oblast. Velykoburlutskyi Raion) in 2018–2020. The two-factor experiment was performed in segregated plots arranged in two bands in four replications. The plot area was 150 m^2; the recording area was 100 m^2. Various temperatures and significant fluctuations in the precipitation amount and its distribution during the spring-summer vegetation of winter triticale greatly influenced the growth processes in plants, which significantly affected the grain yield. Simultaneously, this made it possible to more fully determine the impact of the studied nutrition variants on the grain yield of this crop. In general, the highest grain yield of winter triticale in 2018, 2019, and 2020 (5.67 t/ha, 6.67 t/ha, and 5.72 t/ha, respectively) was achieved where the nutrition algorithm included the pre-sowing application of compound fertilizer, ammophos, at a dose of $N_{12}P_{52,}$ root application of ammonium nitrate at a dose of N_{50} at the beginning of the tillering phase (microphase 22) and two foliar treatments – at the beginning of stem elongation (microphase 31) and in the flag-leaf ligule phase (microphase 39) with the following mixture: urea ($N_{5.4}$), magnesium sulfate (1.0 kg/ha) and water-soluble compound fertilizer FerCristal SUMMUM (1.5 kg/ha). The third foliar application in the early milky ripeness phase (microphase 73) with the same fertilizer mixture did not significantly increase the grain yield. The proposed fertilization algorithm of winter triticale is of great ecological importance, as the rejection of fertilization on frozen-thawed soil lessens nitrogen outflow attributed to a possible runoff on the soil surface during thawings, and the replacement of compound fertilizer ammonium nitrate phosphate fertilizer with ammophos, due to reduction in the nitrogen dose, decreased the risk of nitrate migration into groundwater, while improving the phosphorus nutrition of plants with half the dose of fertilizer.
Keywords: winter triticale, grain yield, compound fertilizers, foliar fertilization, pre-sowing application, fertilizer doses, developmental phases.

Introduction

Triticale is a human-made genus of cereals, which gives high and stable yields, nutritional value, resistance to stressors, and the most dangerous diseases. However, this crop is little studied in agronomic practice. As a result, there is an unmet need to develop triticale cultivation technologies in the current conditions.

In the adaptive intensification of agriculture, biological factors are preferred over chemical ones, but technogenic means are not ignored. Of the technological methods, fertilizers have the most significant effect on the performance of crops. However, the limited resources of mineral fertilizers and their high cost necessitate research to identify the most effective variants for their application. It is essential to take into account the peculiarities of their impact on crop performance. The application of mineral fertilizers is one of the main ways to increase the output in plant production and improve the product quality (Sultanov & Gabdrakhimov, 2016; Petrova et al., 2019). Nitrogen nutrition is vital in plant production intensification (Lestingi et al., 2010; Zečević et al., 2010; Janušauskaite, 2013; Deki'c et al., 2014; Dumbrava et al., 2016). Selection of appropriate doses of nitrogen fertilizers and fertilization time is based on plant and soil diagnostics results by phases of plant growth and development. Researchers from the Institute of Agriculture of the Carpathian Region of NAAS (Sviderko et al., 2010) confirmed the high efficiency of foliar fertilization of winter triticale plants with urea judging from the performance elements. They obtained the highest yield and the best quality of winter triticale grain after foliar fertilization of plants with urea at the second stage of organogenesis on the primary application of mineral fertilizers ($N_{30}P_{30}K_{30}$ + N_{30}) in early spring.

Nazranov et al. (2011) noted a clear increasing pattern in the winter triticale grain yield when nitrogen fertilizers were applied in several stages. In particular, application of nitrogen at doses of $N_{40,}$ $N_{30,}$ and N_{30} during the phases III, IV, and VIII of organogenesis, respectively, increased the grain yield from winter triticale variety Samur by 0.8 t/ha compared with the same cumulative dose (N_{100}) applied in two steps: N_{70} during the basic fertilization and N_{30} during the phase III of organogenesis.

Recent studies conducted in European countries demonstrated that winter triticale was in high need of nitrogen fertilizers and could use their high doses. Thus, S. Bielski (2015) reported that it was expedient to increase the nitrogen dose to 145 kg/ha for this crop, as it provided higher yields compared to lower doses and was economically justified. In S. Bielski and J. Falkowski's experiments (Bielski & Falkowski, 2017), the highest grain yield from winter triticale variety Twingo was achieved with a nitrogen dose of 150 kg/ha (during the basic fertilization and later. during the growing period) compared with 120 kg/ha, which did not result in a significant gain in the yield. Scientists note the weather's role in the winter triticale plants' needs of nitrogen nutrition (Jankowski et al., 2018a; 2018b). In particular, in years with more abundant rainfall during the winter triticale vegetation. Bielski et al. (2020) recorded the highest statistically significant gain in the grain yield with a nitrogen dose of 160 kg/ha, while in water-deficient years – with 140 kg/ha. Đekić et al. (2014) obtained the highest grain yield from winter triticale after fractionated nitrogen application in the total dose of 80 kg/ha on the basic fertilization with $P_{60}K_{60}$. When determining nitrogen doses, one should understand that excessive nitrogen nutrition can have negative consequences. Thus, high concentrations of this element in a working solution for foliar fertilization can cause leaf burns. Excessive doses of nitrogen for root fertilization lead to significant and thin-walled cells in leaves, which are easily damaged by pests and fungi. Also, such crops can lodge or give high yields of straw with a next-to-zero increase in the grain yield (Filonenko, 2015).

Phosphorus plays a significant role in the lifecycle of winter triticale. Balanced phosphorus nutrition accelerates the formation of roots, which improves the absorption of other minerals and regulates energy metabolism in plants, increases their winter hardiness and drought resistance. A sufficient phosphorus level is basic for the efficient use of other nutrients (Spivakov, 2014; Grabovets & Biryukov, 2018). To fully reveal the genetic potential of the productivity of winter cereals, foliar application of multi-nutrient fertilizers with balanced contents of macro-and micronutrients is becoming more and more widespread (Khudolii, 2017). Recently, compound water-soluble chelated fertilizers with balanced contents essential for plant trace elements used for foliar fertilization have become widespread. Humic acid salts, amino acids, growth stimulants, phytohormones are also added to some formulae. The results of many studies show that such formulae not only provide plants with essential nutrients and stimulate growth processes but also strengthen their immunity and resistance to stressors, thereby increasing yields by 10–20 % (Ahmad & Irshad, 2011; Ahmad et al., 2012; Thakur & Mukhopadhyay, 2018). Of trace elements, boron, zinc, magnesium, manganese, and molybdenum are of the most significant importance for cereals (Ahmad & Irshad, 2011; Khudolii, 2017). Boron increases the number of set caryopses, especially under arid conditions; zinc improves carbohydrate synthesis and strengthens the resistance of plants to drought and high temperatures; molybdenum has a regulatory function in protein synthesis. Magnesium is essential for plants, as it is involved in many enzymatic reactions and stabilization of the cell structure (Guoa et al., 2016). It also increases the resistance of plants to stress factors (Mengutay et al., 2013). The application of compound fertilizers with balanced contents of micronutrients, which quite often limit the yield capacity, is expedient in intensive crop cultivation technologies. Sometimes a deficit of several tens of grams of a micronutrient limits the yield increase even on rich macronutrient nutrition (Balyuk & Fateev, 2012; Abbasi et al., 2016; Rerkasem et al., 2015; El-Dahshouri et al., 2017). During ontogenesis, plants experience numerous stresses that decrease their performance. Anti-stress biostimulants are a way to overcome stresses. Such anti-stress biostimulants are primarily based on amino acids of different origins, phytohormones, steroids, and similar compounds. The mechanism of action of anti-stress agents is to unblock enzymatic processes that were arrested by a stressor and intensify the synthesis of phytoalexins – substances that overcome sequelae of the stress (Danilov, 2017). Growth activators have complex effects on physiological and biochemical processes in plants. Their effects are seen when used in low concentrations, which enables their wide use in agricultural production. Nowadays, they are especially relevant (Yevdokymova et al., 2015) because, in some cases, plant growth and development stimulants make it possible to reduce doses of fertilizers and pesticides, improving the product quality and promoting green production (Vasyn et al., 2015). Analysis of the results of previous studies shows the importance of the nutrition system optimization for winter triticale, both in terms of making pre-sowing application of mineral fertilizers balanced and in terms of determining the amounts of foliar fertilizers, time and number of foliar fertilization, and compositions of working mixtures to ensure the highest grain yields. Besides, given the upward trend in temperatures and a downward trend in precipitation, which are added to other stressors, the relevance of evaluating the effectiveness of growth biostimulators in working solutions for foliar fertilization is increasing.

The aim of the study was to optimize the nutrition system for winter triticale by determining the best doses of compound fertilizers for pre-sowing treatment, by comparing the effectiveness of nitrogen fertilization on frozen-thawed soil and fractioned root fertilization with seeders at the beginning of tillering phase, as well as by determining the amounts of foliar fertilizers and compositions of working mixtures that ensure the highest yield of winter triticale grain in years with various temperatures and precipitation.

Materials and methods

The study was conducted by conventional technique (Dospekhov, 1985) in the fields of the Private Agricultural Enterprise *Imeni Shevchenka* (Kharkivska Oblast, Velykoburlutskyi Raion) in 2018–2020. The soil was typical, medium-humus chernozem. The humus layer thickness was 40–50 cm. The humus content in the arable layer (0–20 cm) was 3.7 %; the easily hydrolyzed nitrogen content (Cornfield's method) – 8.7 mg/100 g of soil; the phosphorus and potassium contents (Chirikov's method) were 107–120 and 125–135 mg/kg, respectively; the pH of salt extract was 6.4–6.7. The two-factor experiment was performed in segregated plots arranged in two bands in four replications. Three variants of pre-sowing application of compound fertilizers (factor A) were studied: 1) $N_{32}P_{32}K_{32}$ (200 kg/ha of ammonium nitrate phosphate fertilizer); 2) $N_{12}P_{52}$ (100 kg/ha of ammophos); 3) N_7P_{31} (60 kg/ha of ammophos). Seven variants of additional fertilization (factor B) were evaluated (Table 1). The plot area was 150 m^2; the recording area was 100 m^2.

Table 1. Scheme of the test variants of supplementary fertilization (factor B)

Variant No	On frozen-thawed soil	Phases of supplementary fertilization (according to the international BBCH-scale)			
		22	31	39	73
1	NH_4NO_3 (150 kg/ha)	–	–	–	–
2	–	NH_4NO_3 (150 kg/ha)	–	–	–
3	–		N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha)	–	–
4	–		N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha) + FS* (1.5 kg/ha)	–	–
5	–		N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha)	N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha)	–
6	–		N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha) + FS (1.5 kg/ha)	N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha) + FS (1.5 kg/ha)	–
7	–		N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha) + FS (1.5 kg/ha)	N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha) + FS (1.5 kg/ha)	N_c (10 kg/ha) + $MgSO_4$ (1.0 kg/ha) + FS (1.5 kg/ha)

* FS = FerCristal SUMMUM, a compound, water-soluble fertilizer containing micronutrients and growth stimulant.

For foliar fertilization, we used urea (N_c) at a dose of 10 kg/ha ($N_{5.4}$), magnesium sulfate ($MgSO_4$) at a dose of 1.0 kg/ha, and FerCristal SUMMUM, a water-soluble compound fertilizer with trace elements and growth stimulant ($N_{15}P_{15}K_{15}$) at a dose of 1.5 kg/ha. Innovative compound water-soluble fertilizer FerCristal SUMMUM manufactured by *Fertchem* contains nitrogen, phosphorus, potassium, several trace elements (B, Zn, Cu, Mn, Mo, Fe) chelated by lignosulfonate and EDTA, in amounts balanced for cereals. The formula also contains a growth stimulant based on plant amino acids derived from an *Ascophyllum nodosum* extract. Also, it contains phytohormones and oligosaccharides. Two innovative technologies – Microvit and Algavital – are used in the production of this fertilizer.

High-yielding, lodging, and drought-resistant winter triticale variety, Shalanda, was taken for the study. This variety was bred at the Plant Production Institute named after VYa Yuriev of NAAS, included in the Register of Plant Varieties of Ukraine in 2014, and recommended for cultivation in the forest-steppe and woodlands. The farming techniques in the experiment were conventional for the study area, except for the factors studied. Winter triticale was sown in drills with a seeding rate of 4.0 million seeds/ha on September 20. The forecrop was sugar beet, before which $N_{60}P_{60}K_{60}$ was applied. The study area is characterized by unstable precipitation. In different years, the precipitation amount during the plant growing period deviated significantly from the climatic average. The weather during the vegetation period was most favorable for winter triticale in 2019. In 2018, in April, May, and the first twenty days of June, the precipitation amount was three times as little as the climatic average. Only at the end of June, the precipitation amount was significant – about 35 mm. The drought came amid high temperatures. During the first ten days of June, the temperature sometimes reached 34 °C, which, combined with water deficit, complicated the growth processes in winter triticale. Simultaneously, no sharp decrease in the grain yield was observed, as during the winter and in March, the precipitation was sufficient, which ensured the growth and development of plants in the following dry periods. The precipitation amount during the spring-summer vegetation of winter triticale in 2019 did not exceed that in 2020, but the rainfall was more evenly distributed, so the plants did not suffer from drought. Thus, the precipitation amount in April and May was similar to the climatic average, and winter triticale plants got water in critical periods. There was only a slight water deficit between June 10 and June 30; however, it did not harm plants due to the rains in the previous months and favorable temperature.

In 2020, the precipitation amount during the spring-summer vegetation period of winter triticale plants was the greatest, but the rainfall was distributed very unevenly, and the plants experienced a lack of water in the critical phases of development. Thus, in March and April, the precipitation amount was three times as little as the climatic average, adding to the fact that in the winter months, the precipitation decreased compared to the multi-year value. During a downpour in late May (about 70 mm in 1 day), there was hail, which lasted for about a minute and damaged about 5–10 % of the plants; however, it had no critical consequences. Low temperatures during the last twenty days of May combined with significant precipitation slowed down the growth and development of winter triticale plants, but it did not harm them. Drought during the last twenty days of June and the first ten days of July came amid high temperatures (in early June, the daytime air temperature reached 36 °C), leading to reduced yields because of grain shriveling. Various temperatures, significant fluctuations in the precipitation amount, and uneven distribution of the latter during the spring-summer vegetation of winter triticale considerably affected the growth processes in plants and, consequently, the yields. At the same time, such weather conditions are becoming the norm for the eastern forest-steppe of Ukraine. The differences in temperature and precipitation made it possible to more fully evaluate the impact of the test fertilization variants on the grain productivity of winter triticale.

Results and Discussion

The study demonstrated the high efficiency of the pre-sowing application of compound fertilizer ammophos ($NH_4H_2PO_4$). When this fertilizer was applied at a dose of 100 kg/ha ($N_{12}P_{52}$), the factor A average value of the winter triticale grain yield was higher by 0.37, 0.28, and 0.21 t/ha in 2018, 2019, and 2020, respectively, than after pre-sowing application of ammonium nitrate phosphate fertilizer ($NH_4H_2PO_4 + NH_4NO_3 + KCL$; brand $N_{16}P_{16}K_{16}$) at a dose of 200 kg/ha ($N_{32}P_{32}K_{32}$), with LSD_{05} of 0.05, 0.07 and 0.03 t/ha, respectively (Table 2). Decrease in the ammophos dose to 60 kg/ha (N_7P_{31}) led to a significant reduction in the winter triticale grain yield compared to 100 kg/ha ($N_{12}P_{52}$), but in this case, the yield was similar to that after pre-sowing application of ammonium nitrate phosphate fertilizer at a dose of 200 kg/ha $N_{32}P_{32}K_{32}$). Only in 2020, the winter triticale grain yield after fertilization with 200 kg/ha of ammonium nitrate phosphate fertilizer was significantly higher than that after fertilization with 60 kg/ha of ammophos.

Table 2. Winter triticale grain yield depending on nutrition, t/ha

Pre-sowing fertilization (factor *A*)	Supplementary fertilization (factor *B*)	Year 2018 Parameter	2018 HS*	2019 Parameter	2019 HS	2020 Parameter	2020 HS
I – $N_{32}P_{32}K_{32}$	1**	4.26	*	5.76	*	4.76	*
	2	4.51	**	5.82	*	4.85	**
	3	4.76	***	6.03	**	5.15	***
	4	4.93	****	6.16	***	5.32	****
	5	5.12	*****	6.18	***	5.40	*****
	6	5.25	******	6.33	****	5.54	******
	7	5.31	******	6.36	****	5.58	******
II – $N_{12}P_{52}$	1	4.57	*	5.91	*	4.96	*
	2	4.83	**	6.05	**	5.13	**
	3	5.11	***	6.23	***	5.40	***
	4	5.33	****	6.42	****	5.53	****
	5	5.50	*****	6.51	****	5.56	****
	6	5.67	******	6.67	*****	5.72	*****
	7	5.72	******	6.80	*****	5.80	*****
III – N_7P_{31}	1	4.34	*	5.70	*	4.70	*
	2	4.48	**	5.67	*	4.88	**
	3	4.79	***	5.90	**	5.13	***
	4	4.91	****	6.05	***	5.22	***
	5	5.02	*****	6.10	****	5.30	****
	6	5.23	******	6.31	*****	5.51	*****
	7	5.25	******	6.39	******	5.53	*****
Factor *B* average	1	4.39	*	5.79	*	4.81	*
	2	4.60	**	5.85	*	4.95	**
	3	4.88	***	6.05	**	5.23	***
	4	5.06	****	6.21	***	5.36	****
	5	5.21	*****	6.27	***	5.42	*****
	6	5.39	******	6.43	****	5.59	******
	7	5.43	******	6.52	*****	5.64	******
Factor *A* average	I	4.88	*	6.09	*	5.23	*
	II	5.25	**	6.37	**	5.44	**
	III	4.86	*	6.02	*	5.18	***
Mean		4.99		6.16		5.28	
LSD_{05} for the main effect *A*		**0.05**		**0.07**		**0.03**	
LSD_{05} for the main effect *B*		**0.05**		**0.06**		**0.04**	
LSD_{05} for partial comparisons *A*		**0.12**		**0.18**		**0.09**	
LSD_{05} for partial comparisons *B*		**0.08**		**0.11**		**0.07**	

*** HS** – homogeneous subsets (Duncan's rank test). ** **Supplementary fertilization: 1 –** 150 kg/ha of NH_4NO_3 on frozen-thawed soil; **2** – 150 kg/ha of NH_4NO_3 with a seeder during the tillering phase; **3** – **treatment** 2 + foliar fertilization at the beginning of stem elongation (microphase 31, BBCH-scale) with urea (10 kg/ha) + and magnesium sulfate (1.0 kg/ha) mixture; **4 – treatment**

3 + addition to the mixture of compound water-soluble fertilizer FerCristal SUMMUM at a dose of 1.5 kg/ha; **5 – treatment 3** + foliar fertilization with urea (10 kg/ha) + magnesium sulfate (1.0 kg/ha) mixture in the flag-leaf ligule phase (microphase 39, BBCH-scale); **6 – treatment 5** + addition to the mixture of compound water-soluble fertilizer FerCristal SUMMUM at a dose of 1.5 kg/ha; **7 – treatment 6** + foliar fertilization with urea (10 kg/ha) + magnesium sulfate (1.0 kg/ha) + FerCristal SUMMUM (1.5 kg/ha) mixture during the early milky ripeness phase (microphase 73, BBCH-scale).
Pre-sowing fertilization:
I – ammonium nitrate phosphate fertilizer – 200 kg/ha of active substance; **II** – ammophos – 100 kg/ha of active substance;
III – ammophos – 60 kg/ha of the active substance.

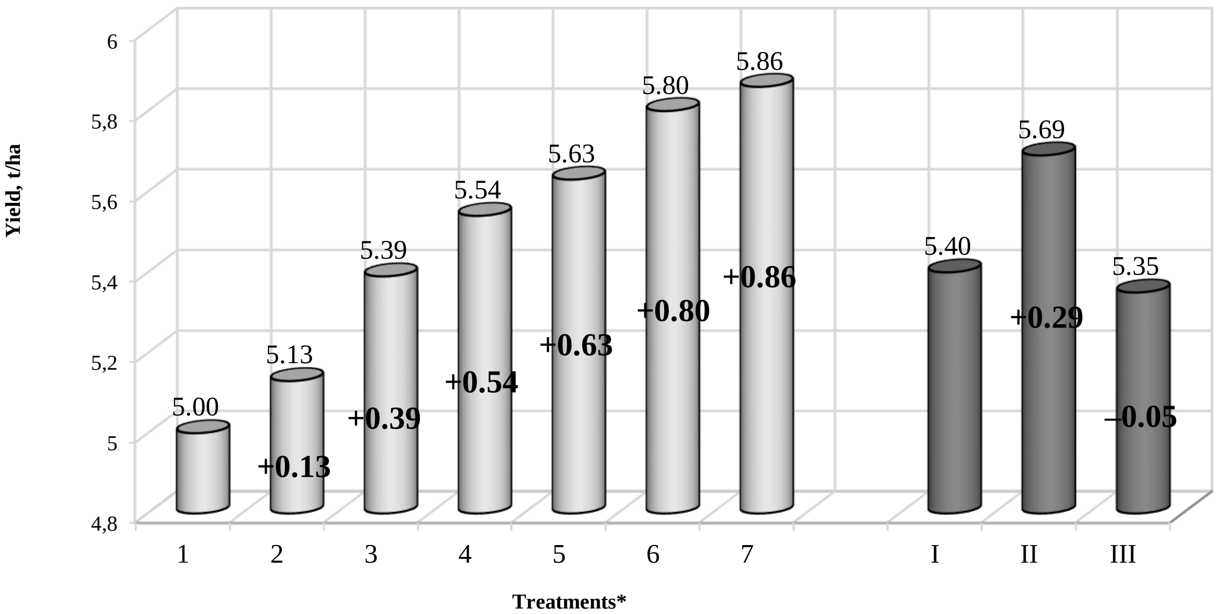

Fig. 1. Winter triticale grain yield averaged across the studied factors, t/ha (average for 2018–2020).

Supplementary fertilizations: 1 – 150 kg/ha of NH_4NO_3 on frozen-thawed soil; **2** – 150 kg/ha of NH_4NO_3 with a seeder in the tillering phase; **3** – treatment 2 + foliar fertilization with urea (10 kg/ha) + magnesium sulfate (1.0 kg/ha) mixture at the beginning of stem elongation (microphase 31, BBCH-scale); **4** – treatment 3 + addition to the mixture of compound water-soluble fertilizer FerCristal SUMMUM at a dose of 1.5 kg/ha; **5** – treatment 3 + foliar fertilization with urea (10 kg/ha) + magnesium sulfate (1.0 kg/ha) mixture in the flag-leaf ligule phase (microphase 39, BBCH-scale); **6** – treatment 5 + addition to the mixture of compound water-soluble fertilizer FerCristal SUMMUM at a dose of 1.5 kg/ha; **7** – treatment 6 + foliar fertilization with urea (10 kg/ha) + magnesium sulfate (1.0 kg/ha) + FerCristal SUMMUM (1.5 kg/ha) mixture in the early milky ripeness phase (microphase 73, BBCH-scale). **Pre-sowing fertilization**: **I** – ammonium nitrate phosphate fertilizer (200 kg/ha of active substance); **II** – ammophos (100 kg/ha of active substance); **III** – ammophos (60 kg/ha of active substance).

There was a significant advantage in the yield after the pre-sowing application of ammophos at a dose of 100 kg/ha with all the studied variants of root and foliar fertilization. The data obtained indicate that in autumn winter triticale plants should be provided with phosphorus, as generally there is enough potassium in soil due to the soil type in the study location, which is characterized by a high content of potassium. Also, a significant amount of potassium (K_{45}) was applied before the forecrop. Therefore, there is no need to use potassium in pre-sowing fertilization.
Despite adherence to the recommended sowing timeframe, triticale plants only entered the "4–5 leaves" phase (microphases 14–15 according to the international BBCH-scale) before the end of autumn vegetation. This is because the seeds did not germinate in dry soil for a long time. In the study years, there were no rains until October 5, so the plants did not have time to enter the full tillering phase before the autumn vegetation stops. Because of this, plants did not need large amounts of nitrogen. Hence, it is not advisable to apply nitrogen at a dose of $N_{32,}$ as this only increases economic losses and deteriorates the ecological status of the environment. Our results prove the crucial role of phosphorus in pre-sowing fertilization. By increasing the dose of this chemical element, we achieved a significant rise in the yield of winter triticale grain, even though the nitrogen dose was almost three-fold reduced, and no potassium was applied. Simultaneously, the winter triticale grain yield underwent much more significant changes under the influence of supplementary fertilizers (factor B). Thus, the most considerable average yearly difference between the grain yields under the influence of supplementary fertilizers was 0.86 t/ha, while under the influence of pre-sowing fertilization, this parameter was only 0.34 t/ha (Fig. 1). This is logical since pre-sowing fertilization only creates a basis for the plant growth and development, while supplementary fertilization, starting from early spring fertilization on frozen-thawed soil and ending with the last treatment during grain filling, eliminates nutrient deficiencies, regulates growth processes, diminishes the reduction of generative organs, and alleviates stresses, such as high temperature, drought, pesticides.
The highest yield of winter triticale grain was achieved after root application of nitrogen at a dose of N_{50} during the tillering phase (microphase 22) and foliar fertilization with urea ($N_{5.4}$) + magnesium sulfate (1.0 kg/ha) + compound fertilizer FerCristal

SUMMUM (1.5 kg/ha) mixture at the beginning of stem elongation (microphase 31), during the flag-leaf ligule phase (microphase 39) and the early milky ripeness phase (microphase 73). However, this treatment did not ensure a significant gain in the grain yield compared to treatment 6, where there was no supplementary fertilization during the early milky ripeness phase, while the same fertilizer mixtures were applied during the other phases. In general, across the experiment, the highest yield of winter triticale grain in 2018, 2019, and 2020 (5.67, 6.67, and 5.72 t/ha, respectively) was obtained when the nutrition algorithm consisted of pre-sowing application of ammophos at a dose of $N_{12}P_{52}$, root application of ammonium nitrate at a dose of N_{50} in microphase 22 on the international scale and two foliar fertilization with urea ($N_{5.4}$) + magnesium sulfate (1.0 kg/ha) and water-soluble compound fertilizer FerCristal SUMMUM (1.5 kg/ha) mixture in microphases 31 and 39. The third foliar fertilization with the same mixture of fertilizers did not significantly increase the grain yield. These values belonged to one homogeneous subset. The study demonstrated the high efficiency of compound water-soluble fertilizer FerCristal SUMMUM. Thus, the addition of this fertilizer to the tank mixture of urea and magnesium sulfate for foliar fertilization at the beginning of stem elongation (microphase 31) and in the flag-leaf ligule phase (microphase 39) increased the yields on average of the three years by 0.17 t/ha (Fig. 1). When FerCristal SUMMUM was once used in the working mixture of urea + magnesium sulfate at the beginning of stem elongation, it also provided a significant increase in the winter triticale grain yield. It increased by 0.15 t/ha on average of the three years (the difference between treatments 3 and 4). The grain yields significantly differed between these treatments each year.

The efficiency of the studied nutrition variants, especially additional fertilization, depended on the weather during the growing period. Thus, the most significant difference between the winter triticale yields under the influence of fertilizers in 2018, 2019, and 2020 was 1.04 t/ha (23.7%), 0.73 t/ha (12.6%), and 0.83 t/ha (17.3%), respectively (Table 2). Thus, the efficiency of root and foliar fertilization was higher in more stressful weather conditions of the spring-summer vegetation of winter triticale, which were observed in 2018; there was a water deficit, and the temperature was high in the critical phases of the plant growth and development. Our results do not agree with other researchers' results (Slovtsov et al., 2011; Biberdžić et al., 2013; Ramazanova et al., 2018; Petrova et al., 2019), who noted the opposite pattern, namely, increased efficiency of fertilization in more favorable weather conditions during vegetation. We think it is impossible to state categorically about a higher or lower efficiency of nutrition, in particular, root and foliar fertilization, in years with more favorable or, conversely, less favorable weather conditions, as many other factors must be taken into account, including fertilization time, fertilizer/mixture types doses, the phytosanitary status of crops, soil characteristics, variety features.

In our study, the most significant discrepancy in the grain yield between the best and worst fertilization in the less favorable growing conditions of 2018 was mainly because the working mixtures were better balanced, because in addition to nitrogen, they contained other substances, including trace elements, growth stimulants, and phytohormones, and their role was to overcome the sequelae of stress caused by unfavorable weather quickly. Due to this, crops treated with a mixture containing urea and magnesium sulfate and water-soluble fertilizer FerCristal SUMMUM developed better, more fully assimilated nutrients and, consequently, gave higher grain yields compared to those after application of N_{34} on frozen-thawed soil. S. Bielski, K. Romaneckas, and other researchers also noted important roles of some micronutrients, in particular magnesium, boron, and zinc, in growing highly productive winter triticale crops in years with little precipitation and high temperatures (Bielski et al., 2020; Thakur and Mukhopadhyay, 2018; Abbasi et al., 2016; Rerkasem et al., 2015). The weather during the growing period affected the winter triticale grain yield most of all. The weather accounted for 67.7 % of the variability in this parameter (Fig. 2). Pre-sowing and foliar fertilization accounted for 6.0 and 25.1 %, respectively, of the grain yield variability. Other researchers also noted the importance of weather conditions during the vegetation of winter cereals for their performance (Alaru et al., 2009; Biberdžić et al., 2013; Gamayunova & Litovchenko, 2017).

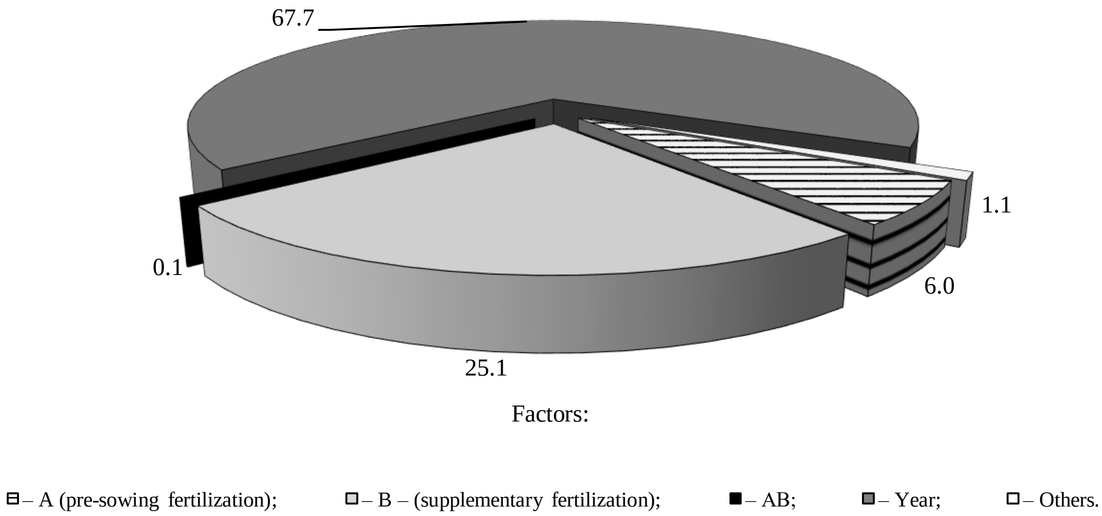

Fig. 2. Factors income into yield variability of the winter triticale, %.

The interaction of the studied factors was weak – only 0.1 %. In our opinion, this is quite natural because the effects of the root and foliar supplementary fertilizations were similar upon the pre-sowing application of compound fertilizers under investigation. Simultaneously, in the experiments, there was an upward trend in the efficiency of the studied supplementary treatments upon the pre-sowing application of ammophos at a dose of 100 kg/ha ($N_{12}P_{52}$), i.e., with increasing doses of phosphorus.

Conclusions

Having evaluated the efficiency of the various nutrition algorithms of winter triticale, we can draw the following conclusions:
- Winter triticale gives the highest grain yield after the pre-sowing application of ammophos at a dose of $N_{12}P_{52}$. It is significantly higher than that after application of ammonium nitrate phosphate fertilizer at a dose of $N_{32}P_{32}K_{32}$;
- Supplementary fertilization with ammonium nitrate on frozen-thawed soil is less effective compared with root application of ammonium nitrate with a seeder as soon as the soil matures;
- In order to increase grain yields and overcome stresses in plants caused by drought and high temperatures intrinsic to the study location, as well as to reduce the ecological load on the environment, the spring and summer nutrition algorithm of winter triticale plants should include root application of ammonium nitrate at a dose of N_{50} immediately after the crop vegetation recovery and two foliar fertilization with urea (10 kg/ha) + magnesium sulfate (1.0 kg/ha) + compound water-soluble fertilizer with growth stimulant, FerCristal SUMMUM (1.5 kg/ha) mixture at the beginning of stem elongation (microphase 31) and in the flag-leaf ligule phase (microphase 39);
- Foliar fertilization with urea (10 kg/ha) + magnesium sulfate (1.0 kg/ha) + compound water-soluble fertilizer with growth stimulant, FerCristal SUMMUM (1.5 kg/ha) mixture during the early milky ripeness phase (microphase 73) did not significantly increase the winter triticale grain yield in comparison with the two foliar fertilization with this mixture of fertilizers.

The proposed fertilization algorithm of winter triticale is of great ecological importance, as the rejection of fertilization on frozen-thawed soil lessens nitrogen outflow attributed to a possible runoff on the soil surface during thawings. The replacement of ammonium nitrate phosphate fertilizer with ammophos, due to reduction in the nitrogen dose, decreased the risk of nitrate migration into groundwater while improving the phosphorus nutrition of plants with half the dose of fertilizer.

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