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ORIGINAL ARTICLE

Influence on fertilization regime on spring barley yields in the southern steppe of Ukraine

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Because of the high costs of fertilizers and the exacerbation of environmental problems, it is crucial not only to determine doses and timing of fertilization correctly but also to improve the absorption and assimilation of nutrients by plants. This will increase plant growth and development management efficiency and contribute to the fuller realization of the genetic potential of their performance that can be achieved only through a balanced selection of fertilizers. Simultaneously, it should be noted that for spring, barley long-acting fertilizers should be applied as essential fertilization in autumn and fast-acting ones – as supplementary foliar fertilization with soluble complexes. Combinations of these two types of fertilization ensure a highly efficient nutrition and cultivation technology in general. Our purpose was to study the complex influence of essential mineral fertilizers and foliar supplementary fertilizers (various mixtures of urea, water-soluble complex fertilizers, and humic compounds) on the grain yields and economic indicators of spring barley production in the southern steppe of Ukraine. The study was conducted in the Educational and Experimental Farm of the separate structural subdivision “Novokakhovskyi Professional College of the Tavriia State Agrotechnological University named after Dmytro Motorny” (the central part of the Kakhovkyi Raion, Khersonska Oblast) in 2018–2020. According to the conventional method, the two-factor experiment was performed in segregated plots arranged in two bands in four replications. We studied five variants of essential mineral fertilization and five variants for supplementary foliar fertilization. The plot area was 120 m^2; the recording area was 80 m^2. Various temperatures and significant fluctuations in the precipitation amount and its distribution during the spring-summer vegetation of spring barley 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. The highest gain in the spring barley grain yield was achieved due to the primary application of complex fertilizer polyphosphate at a dose of $N_{20}P_{60}K_{60}S_{22.5}$. However, through the lens of economic efficiency, a mixture of ammophos ($N_{15}P_{60}$) with potassium chloride (K_{30}) was the best basic fertilization. The difference in the spring barley grain yield between these two variants was only 0.05 t/ha, while the additional costs of applying polyphosphate at a dose of 250 kg/ha were 1820 UAH/ha higher than the costs of ammophos + potassium chloride mixture. The use of ammophos ($N_{15}P_{60}$) + potassium chloride (K_{30}) significantly reduces the chemical load on the soil compared to traditional fertilizer doses, as it decreases the nitrogen inflow, which, when applied in autumn, can pollute groundwater or evaporate. The number of applied potassium decreases because 30 and 60 kg/ha of potassium on the grain yields are very similar. Of the studied foliar supplementary fertilization, the most significant rise in the yield and the highest economic efficiency were recorded after a single application of urea at a dose of N_{10} in a mixture with growth stimulant EFISOIL Renovation at a dose of 0.4 L/ha and concentrated fertilizer Foliq Micro at a dose of 1.5 L/ha during microphase 31 and the second fertilization with a mixture of EFISOIL Renovation at a dose of 0.4 L/ha and highly concentrated fertilizer Foliq Micro at a dose of 3.0 L/ha during microphase 39.
Keywords: spring barley, nutrition, grain yield, profit, basic fertilization, foliar supplementary.

Introduction

In adaptive crop production, among the measures aimed at increasing spring barley grain yields, fertilization, which increases grain yields in all cultivation zones, is of great importance. Simultaneously, the share of fertilizers in the yield formation is 40–75 % (Titova & Vnukova, 2011). Because of the high costs of fertilizers and the exacerbation of environmental problems, it is essential to determine doses and timing of fertilization correctly and improve the absorption and assimilation of nutrients by plants. This will increase the efficiency of plant growth and development management and contribute to the fuller realization of the genetic potential of their performance, which can be achieved only through a balanced selection of fertilizers. Simultaneously, it should be noted that for spring barley, the long-acting fertilizers should be applied as basic fertilization in

autumn and fast-acting ones – as supplementary foliar fertilization with soluble complexes. Combinations of these two types of fertilization ensure a highly efficient nutrition and cultivation technology in general.
Recently, the weather conditions in the southern steppe of Ukraine have become less favorable for growing spring cereals on the whole and barley in particular. The precipitation amount during the spring-summer period decreased significantly, and the temperature increased compared to the multi-year average. Plant growth and development get worse; crop yields decline significantly; and product quality deteriorates (Belyaev et al., 2018; Yeremyeyev & Yefimov, 2003; Morozov et al., 2014).
This problem can be solved by introducing innovative technological approaches to agricultural crop cultivation and improving the existing farming techniques, including the optimization of plant nutrition (Mackay et al., 2011; Ahlemeyer & Friedt, 2012). It was proven that generally, spring barley plants responded positively to increased doses of fertilizers (Panfilova & Hamaiunova, 2018). Simultaneously, their excessive doses can decrease grain yields, primarily due to the crop lodging, the "Achilles' heel" of spring barley. Spring barley is far "ahead" of other spiked cereals by this parameter.
A review of Ukrainian scientists' recent results shows that it is sufficient to apply $N_{60}P_{60}K_{60}$ before spring barley sowing. An increase in the dose to ≥ $N_{90}P_{90}K_{90}$ does not result in a significant gain in the yield (Sardak et al., 2016), and sometimes leads to its reduction due to lodging (Gamayunova & Smirnov, 2015; Kalenska et al., 2015; Kalenska & Tokar, 2015). The only way to rectify some nutrients during the spring barley vegetation period is supplementary foliar fertilization. Its effectiveness is exceptionally high in arid and hot areas, as it increases the availability of nutrients and stimulates their assimilation by plants from the soil. This, in turn, promotes more efficient use of water, which is especially important under arid conditions.
Foliar supplementary fertilization within the optimal timeframe for plants can increase yields by ≥ 10–20 %. This improves the environmental safety of fertilizers for the soil, atmosphere, and groundwater (Sanin, 2012; Chaban et al., 2013; Lihochvor, 2014; Loginova & Bilera, 2014). Studying doses of complex micro fertilizers for additional foliar fertilization (Gorash, 2016) noted the need to take basic mineral fertilization into account. When the essential fertilizer dose is increased, this scientist recommends increasing doses of complex micro fertilizers during foliar fertilization. The efficiency of additional foliar fertilization increases if macro-and micronutrients intended to relieve stress in plants and regulate their growth and development processes are added to working mixtures. These substances include humic compounds, melanin acids, amino acids, biostimulants, correctors, phytohormones. At present, an extensive assortment of agents, which are highly effective in different regions, are offered to production (Titova & Vnukova, 2011; Bakry et al., 2013; Chaban et al., 2013; Girka et al., 2017). Particular attention should be paid to fertilizers based on humic acids – humates. They have high biological activity and can increase the resistance of plants to climatic stresses (high temperatures, drought). Humates help increase plant yields by releasing minerals and nutrients from bound states and forming readily available plants. Iranian researcher R. Shahryari (Shahryari, 2017) noted a reduction in water discharge from plants by ≥ 20 % due to the use of humates, which is very important under arid conditions. The effectiveness of humic compounds increases when combined with mineral fertilizers (Bakry et al., 2013; Girka et al., 2017). Indian scientists found that such combinations ensured a significantly higher increase in wheat grain yields than humic compounds alone. Such combinations helped increase the contents of nutrients and organic carbon in the soil (Manzoor et al., 2014; Bharali et al., 2017; Marenich et al., 2018). Under conditions of unstable precipitation and high temperatures, the optimization of fertilization is of particular importance. It involves selecting scientifically reasonable doses of essential fertilizers, prompt rectification of nutrient deficits, and overcoming the effects of stressors during the spring-summer growing period by foliar supplementary fertilizations. However, the review of available information on the effects of additional foliar fertilization with different mixtures of mineral fertilizers supplemented with humic compounds, biostimulants, and amino acids combined with various essential fertilization on spring barley grain yields has shown that this issue is insufficiently investigated.
Our purpose was to study the complex influence of essential mineral fertilizers and foliar supplementary fertilizers (various mixtures of urea, water-soluble complex fertilizers, and humic compounds) on the grain yields and economic indicators of spring barley production in the southern steppe of Ukraine.

Materials and Methods

The study was conducted in the Educational and Experimental Farm of the separate structural subdivision "Novokakhovskyi Professional College of the Tavriia State Agrotechnological University named after Dmytro Motorny" (the central part of the Kakhovkyi Raion, Khersonska Oblast) in 2018–2020. The soil was meadow-soloth chernozem. The humus content in the arable layer averages 2.4 %; the easily hydrolyzed nitrogen content (Cornfield's method) – 8.8 mg/100 g of soil; the mobile phosphorus and exchangeable potassium contents (Chirikov's method) are 10.7 and 64.4 mg/100 g soil, respectively. The acidity is neutral (pH of the salt extract is 6.4–6.7). These soils occur in steppe areas; they are moistened by mineralized groundwater; thus, they can turn into various solonchaks or soloth and gleyic soils.

Table 1. Supplementary fertilization (factor B)

Variant No	Phases of supplementary fertilization (according to the international BBCH-scale)	
	31	39
1 (Control)	–	–
2	N_{10}	N_{10}
3	N_{10} + EFISOIL Renovation (0.4 L/ha) + Foliq Micro (1.5 L/ha)	N_{10} + EFISOIL Renovation (0.4 L/ha) + Foliq Micro (1.5 L/ha)
4	N_{10} + EFISOIL Renovation (0.4 L/ha) + Foliq Micro (1.5 L/ha)	EFISOIL Renovation (0.4 L/ha) + Foliq Micro (1.5 L/ha)
5	N_{10} + EFISOIL Renovation (0.4 L/ha) + Foliq Micro (1.5 L/ha)	EFISOIL Renovation (0.4 L/ha) + Foliq Micro (3.0 L/ha)

According to the conventional method, the two-factor experiment was performed in segregated plots arranged in two bands in four replications (Dospekhov, 1985). We studied five variants of basic mineral fertilization (factor A): 1 – control (without fertilizers); 2 – $N_{30}P_{30}K_{30}$ (190 kg/ha of nitroammophoska); 3 – $N_{60}P_{60}K_{60}$ (380 kg/ha of ammonium nitrate phosphate fertilizer); 4 – $N_{20}P_{60}K_{60}S_{22.5}$ (250 kg/ha of polyphosphate); 5 – $N_{15}P_{60}K_{30}$ (115 kg/ha of ammophos + 50 kg/ha of potassium chloride). We also studied five variants of foliar fertilization (factor B) (Table 1). The plot area was 120 m^2; the recording area was 80 m^2.
For foliar fertilization, we used urea at a dose of 10 kg/ha of nitrogen (N_{10}), EFISOIL Renovation (ER) (a growth stimulant based on a humic extract with high contents of fulvic acids [manufacturer – Fertchem LLC]), and highly concentrated suspension fertilizer Foliq Micro (FM) with a balanced composition of macro-and microelements selected for cereals (manufacturer – Agrii). Growth stimulant EFISOIL Renovation contains 45 % of fulvic acids, 9 % of humic acids, 10 % of potassium, and 0.05 % iron. Highly concentrated suspension Folq Micro contains 7.0 % of nitrogen, 7.0 % of phosphorus, 14.0 % of potassium, 4.8 % of magnesium, 3.5 % of sulfur, 0.2 % of boron, 1.0 % of copper, 0.5 % of iron, and 1.5 % of magnesium. Micronutrients are EDTA-chelated. Surfactants, humectants, anti-evaporators, and adhesion promoters are also added to the suspension.
The research was conducted on highly productive, lodging- and drought-resistant spring barley variety – Avatar, which was bred at the Plant Breeding and Genetics Institute of NAAS and included in the Register of Plant Varieties of Ukraine in 2014. This variety is recommended for cultivation in all the agro-climatic zones of Ukraine. The farming techniques in the experiment were traditional for the study location, except for the factors under investigation. Spring barley was sown as soon as the soil had become mature. It was sown in drills with a seeding rate of 4.5 million seeds/ha. The forecrop in the experiment was grain corn, which was grown by intensive technology (complex fertilizers were applied at a dose of $N_{90}P_{90}K_{60}$; pesticides were used as needed; inter-row grubbing was performed). The study location is known to suffer from a precipitation deficit. In different years, the precipitation amounts during the growing period of plants deviated significantly from the multi-year average. 2019 was the more favorable year for spring barley.
In April and May 2018, the precipitation amount was three times as little as the multi-year average: 27 and 77 mm, respectively. Dry weather was associated with high temperatures. On some days of the first and third ten days of May, it exceeded 31.0 °C, which, combined with water lack, complicated the growth processes in spring barley plants. In June, the precipitation amount was 20 mm higher than the multi-year average; mainly, there were showers at the end of the first and third ten days. There was no precipitation in the first and second 10 days of July. In the summer, plants vegetated at high temperatures. The hottest periods were the second and third ten days of June, with the mean air temperature of 24.8 and 23.8 °C, 2.8 and 1.6 °C higher than the multi-year average.
In 2019, the precipitation amount was almost 250 mm from April to July, twice as much as the multi-year average. It is also important to note the relatively even distribution of precipitation during the growing period of spring barley plants, which contributed to obtaining high grain yields compared to other years. Temperatures generally favored the ordinary course of growth processes in the crop. Only in the second and third ten days of June, high temperatures did cause stress to plants. Simultaneously, during this heat, the fields were sufficiently provided with water, which attenuated the harmful effects of high temperatures. During the growing period of spring barley plants in 2020, the precipitation amount was only 58.0 mm – the lowest value. However, the precipitation was distributed much more evenly than in 2018. As to temperature, the growing period in 2020 was more favorable than that in the previous years. The maximum temperature in May did not exceed 27.0 °C, which is very important for the optimal growth of spring barley. In June, temperatures were compared with those in the previous years. Only at the end of the first 19 days of July, the temperature abnormally high (on some days, the temperature reached 37.0 °C), which led to a decrease in the barley grain yield. Various temperatures and significant fluctuations in the precipitation amount and its distribution during the spring-summer vegetation of spring barley 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.

Results and Discussion

The weather conditions varied during the study. The 2018 vegetation period was the least favorable for the growth and development of spring barley plants because of the precipitation amount and distribution, and temperature. In 2018, the mean grain yield was only 2.56 t/ha (Table 2). In 2019, spring barley fields were sufficiently provided with water during the growing period, which ensured the highest grain yield. The mean grain yield was 40 % higher than that in 2018. In 2020, the mean grain yield from spring barley was 2.89 t/ha.
Despite the significant differences in the spring barley grain yields in the study years, which resulted from mixed precipitation and temperature, the effectiveness of the studied fertilizations was high. In all the years, the grain yields significantly changed under the influence of both studied factors – essential mineral fertilization (factor A) and additional foliar fertilization (factor B). The highest grain yield from spring barley was achieved after application of complex fertilizer polyphosphate at a dose of 250 kg/ha ($N_{20}P_{60}K_{60}S_{22.5}$) in the autumn. In 2018, 2019, and 2020, the mean yield was 2.80, 3.83, and 3.14 t/ha, respectively, for factor B (Table 2). Statistical analysis using the Duncan range test showed that in 2019 and 2020, the grain spring barley yield in this variant was significantly higher than in other variants. In 2018 it was similar to the value after basic application of ammonium nitrate phosphate fertilizer at a dose of 380 kg/ha ($N_{60}P_{60}K_{60}$) (variant 3) and ammophos at a dose of 115 kg/ha ($N_{15}P_{60}$) plus potassium chloride at a dose of 50 kg/ha (K_{30}) (variant 5).
Thus, the spring barley grain yield primarily depended on the dose of phosphorus and was higher in the variants with a higher dose of this element – 60 kg/ha. An increase in the dose of nitrogen to 60 kg/ha or in the dose of potassium from 30 to 60 kg/ha was ineffective in all the study years because the yield did not change significantly after various doses of these elements, provided that 60 kg/ha of phosphorus was applied.

Table 2. Spring barley grain yield depending on different fertilization, t/ha

Basic fertilization (factor *A*)	Foliar supplementary fertilization (factor *B*)	Year 2018 Yield	2018 HS[a]	2019 Yield	2019 HS	2020 Yield	2020 HS
No fertilizers (Control) (I)	1	1.54	*	2.85	*	2.13	*
	2	1.70	**	3.02	*	2.22	*
	3	2.17	***	3.27	**	2.46	**
	4	2.11	***	3.21	**	2.46	**
	5	2.25	***	3.35	***	2.58	***
$N_{30}P_{30}K_{30}$ (II)	1	2.16	*	3.29	*	2.55	*
	2	2.31	**	3.42	*	2.69	*
	3	2.67	***	3.67	**	3.02	**
	4	2.64	***	3.65	**	2.97	**
	5	2.75	***	3.69	**	3.09	***
$N_{60}P_{60}K_{60}$ (III)	1	2.42	*	3.57	*	2.79	*
	2	2.59	**	3.64	*	3.01	**
	3	2.91	***	3.85	**	3.13	**
	4	2.87	***	3.88	**	3.08	**
	5	2.98	***	3.94	**	3.20	***
$N_{20}P_{60}K_{60}S_{22.5}$ (IV)	1	2.51	*	3.71	*	2.91	*
	2	2.65	**	3.73	*	2.99	*
	3	2.93	***	3.90	**	3.24	**
	4	2.91	***	3.85	**	3.22	**
	5	2.99	***	3.94	**	3.31	***
$N_{15}P_{60}K_{30}$ (V)	1	2.45	*	3.63	*	2.83	*
	2	2.58	**	3.70	*	3.08	**
	3	2.90	***	3.86	**	3.10	**
	4	2.91	***	3.80	*	3.07	**
	5	3.02	****	3.92	**	3.15	***
Factor *A* average	I	1.95	*	3.14	*	2.37	*
	II	2.51	**	3.54	**	2.87	**
	III	2.75	***	3.77	***	3.04	***
	IV	2.80	***	3.83	****	3.14	****
	V	2.77	***	3.78	***	3.05	***
Factor *B* average	1	2.21	*	3.41	*	2.64	*
	2	2.37	**	3.50	**	2.80	**
	3	2.72	***	3.71	***	2.99	***
	4	2.69	***	3.68	***	2.96	***
	5	2.80	****	3.77	****	3.07	****
	LSD_{05} for the main effect *A*	0.05		0.07		0.09	
	LSD_{05} for the main effect *B*	0.05		0.08		0.08	
	LSD_{05} for partial comparisons *A*	0.11		0.16		0.19	
	LSD_{05} for partial comparisons *B*	0.12		0.18		0.18	

Notes: Foliar supplementary fertilization: 1 – without fertilizers (control); 2 – two fertilizations with urea (N_{10}) in microphases 31 and 39 (BBCH-scale); 3 – two fertilizations with tank mixture containing urea (N_{10}) + growth stimulant EFISOIL Renovation (ER) (single dose 0.4 kg/ha) + highly concentrated fertilizer Foliq Micro (FM) (single dose 1.5 kg/ha); 4 – 1st fertilization with mixture containing urea (N_{10}) + ER (0.4 kg/ha) and FM (1.5 kg/ha) in microphase 31, then the 2nd fertilization with mixture containing ER (0.4 kg/ha) + FM (1.5 kg/ha) in microphase 39; 5 – treatment 4, but the FM dose in microphase 39 was increased to 3.0 kg/ha. [a] HS = homogeneous subsets (Duncan range test).

There was an upward trend in the spring barley yield after applying polyphosphate at a dose of 250 kg/ha, attributed to the fact that, in addition to NPK, 22.5 kg/ha of sulfur was applied. Under more favorable weather conditions during the growing period in 2018, the factor B average (grain yield) after this treatment was significantly higher than the other treatments. There was a statistically insignificant upward trend in the grain yield under less favorable conditions compared to the other treatments.

Of the studied foliar fertilization, the highest grain yield from spring barley was recorded when the fields were fertilized with a mixture of urea (N_{10}), growth stimulant EFISOIL Renovation (0.4 kg/ha), and highly concentrated suspension Foliq Micro (3.0 kg/ha) during microphase 39. In 2018, 2019, and 2020, with this foliar fertilization, the grain yield averaged across basic fertilizations 2.80, 3.77, and 3.07 t/ha, respectively. Statistical analysis using the Duncan range test showed that the grain yield in this variant belonged to a separate homogeneous subset, i.e., it was significantly higher compared to the other foliar fertilization. In 2018, the basic application of complex fertilizers had the most significant effect on the variability of the spring barley yield. The grain yield variability range under the influence of this factor was 42.1 % in 2018, while in 2019 and 2020, it was 22.0 % and 28.7 %, respectively. The effect of foliar fertilization was also more pronounced in 2018. The most significant difference between the yield values under the influence of this factor and the weather conditions in 2018, 2019, and 2020 was 26.7 %, 10.6 and 16.3 %, respectively. On average across the three study years, the most significant gain in the spring barley grain yield compared to the control (1.24 t/ha) was observed after basic application of complex fertilizer polyphosphate at a dose of 250 kg/ha and foliar fertilization with a mixture of urea N_{10} + EP (0.4 kg/ha) + FM (1.5 kg/ha) during microphase 31 and with a mixture of EP (0.4 kg/ha) + FM (3.0 kg/ha) during microphase 39 (Table 3).

Table 3. Spring barley grain yield depending on different fertilization, the average for 2018–2020, t/ha

Essential fertilization (factor *A*)	Foliar supplementary fertilization (factor *B*)	Grain yield, t/ha	The gain in the yield		
			Related to the factor *A* control	Related to the factor *B* control	Related to no fertilizer control
No fertilizers (Control) (I)	1 (Control)	2.17	–	–	–
	2	2.31	–	+ 0.14	+ 0.14
	3	2.63	–	+ 0.46	+ 0.46
	4	2.59	–	+ 0.42	+ 0.42
	5	2.73	–	+ 0.56	+ 0.56
$N_{30}P_{30}K_{30}$ (II)	1 (Control)	2.67	+ 0.50	–	+ 0.50
	2	2.81	+ 0.50	+ 0.14	+ 0.64
	3	3.12	+ 0.49	+ 0.45	+ 0.95
	4	3.09	+ 0.50	+ 0.42	+ 0.92
	5	3.18	+ 0.45	+ 0.51	+ 1.01
$N_{60}P_{60}K_{60}$ (III)	1 (Control)	2.93	+ 0.76	–	+ 0.76
	2	3.08	+ 0.77	+ 0.15	+ 0.91
	3	3.30	+ 0.67	+ 0.37	+ 1.13
	4	3.28	+ 0.69	+ 0.35	+ 1.11
	5	3.37	+ 0.64	+ 0.44	+ 1.20
$N_{20}P_{60}K_{60}S_{22.5}$ (IV)	1 (Control)	3.04	+ 0.87	–	+ 0.87
	2	3.12	+ 0.81	+ 0.08	+ 0.95
	3	3.36	+ 0.73	+ 0.32	+ 1.19
	4	3.33	+ 0.74	+ 0.29	+ 1.16
	5	3.41	+ 0.68	+ 0.37	+ 1.24
$N_{15}P_{60}K_{30}$ (V)	1 (Control)	2.97	+ 0.80	–	+ 0.80
	2	3.12	+ 0.81	+ 0.15	+ 0.95
	3	3.29	+ 0.66	+ 0.32	+ 1.12
	4	3.26	+ 0.67	+ 0.29	+ 1.09
	5	3.36	+ 0.63	+ 0.39	+ 1.19
Factor *A* average	I (Control)	2.49	–	–	
	II	2.97	+ 0.48	–	
	III	3.19	+ 0.70	–	
	IV	3.25	+ 0.76	–	
	V	3.20	+ 0.71	–	
Factor *B* average	1 (Control)	2.76	–	–	–
	2	2.89	–	+ 0.13	–
	3	3.14	–	+ 0.38	–
	4	3.11	–	+ 0.35	–
	5	3.21	–	+ 0.45	–
Average across the experiment		3.02		–	

Notes: Foliar supplementary fertilization: 1 – without fertilizers (control); 2 – two fertilizations with urea (N_{10}) in microphases 31 and 39 (BBCH-scale); 3 – two fertilizations with tank mixture containing urea (N_{10}) + growth stimulant EFISOIL Renovation (ER) (single dose 0.4 kg/ha) + highly concentrated fertilizer Foliq Micro (FM) (single dose 1.5 kg/ha); 4 – 1st fertilization with mixture containing urea (N_{10}) + ER (0.4 kg/ha) and FM (1.5 kg/ha) in microphase 31, then the 2nd fertilization with mixture containing ER (0.4 kg/ha) + FM (1.5 kg/ha) in microphase 39; 5 – treatment 4, but the FM dose in microphase 39 was increased to 3.0 kg/ha.

Essential fertilization had a more significant impact on the spring barley grain yield variability since essential fertilizers create the basis for plant growth and development, while supplementary foliar fertilization mainly adjust the plant nutrition and alleviate weather stresses. Thus, the most significant difference between the yield values under the influence of the studied variants of basic fertilization was 0.76 t/ha, while this parameter was only 0.45 t/ha under the influence of the studied variants of foliar fertilization. The effect of foliar fertilizers was most substantial in control (without fertilization in autumn). We think this is quite natural because the effect of additional fertilization on unfertilized soil is stronger. On average across the three years, the difference between the grain yield values under the influence of foliar fertilization and without essential fertilization was 0.56 t/ha (25.8 %), while after basic application of $N_{30}P_{30}K_{30}$, $N_{60}P_{60}K_{60}$, $N_{20}P_{60}K_{60}S_{22.5}$, and $N_{15}P_{60}K_{30}$, this parameter was 0.51 t/ha (19.1 %), 0.44 (15.0 %), 0.39 (12.2 %) and 0.3 t/ha (13.1 %), respectively. Analysis of the studied factors showed the dominant role of weather conditions in the spring barley grain yield variability. During the study, the share of this factor in the grain yield variability was 63.1 % (Fig. 1).

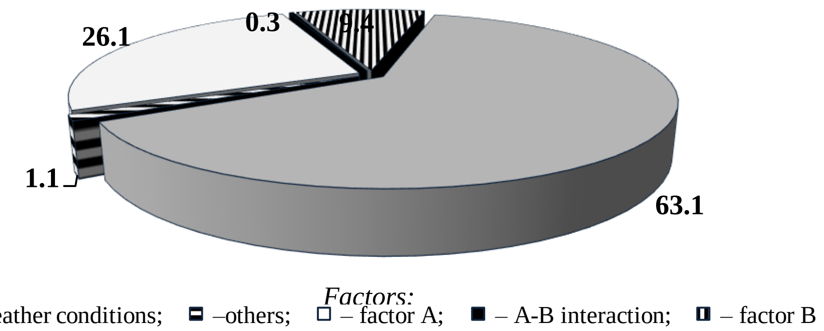

Fig. 1. Factors influenced the yield variability in the spring barley, %

Table 4. Economic efficiency of the studied fertilization of spring barley, the average for 2018–2020

Basic fertilization (factor *A*)	Foliar supplementary fertilization (factor *B*)	The gain in the yield, t/ha	Fertilizer input, t/ha	Cost of the gain, UAH/ha	Profit, UAH/ha
No fertilizers (Control) (I)	1	–	–	–	–
	2	+ 0.14	250	840	590
	3	+ 0.46	1240	2760	1520
	4	+ 0.42	1120	2520	1400
	5	+ 0.56	1490	3360	1870
$N_{30}P_{30}K_{30}$ (II)	1	+ 0.50	2370	3000	630
	2	+ 0.64	2620	3840	1220
	3	+ 0.95	3610	5700	2090
	4	+ 0.92	3490	5520	2030
	5	+ 1.01	3860	6060	2200
$N_{60}P_{60}K_{60}$ (III)	1	+ 0.76	4550	4560	10
	2	+ 0.91	4800	5460	660
	3	+ 1.13	5790	6780	990
	4	+ 1.11	5670	6660	990
	5	+ 1.20	6040	7200	1160
$N_{20}P_{60}K_{60}S_{22.5}$ (IV)	1	+ 0.87	3600	5220	1620
	2	+ 0.95	3850	5700	1850
	3	+ 1.19	4840	7140	2300
	4	+ 1.16	4720	6960	2240
	5	+ 1.24	5090	7440	2350
$N_{15}P_{60}K_{30}$ (V)	1	+ 0.80	1780	4800	3020
	2	+ 0.95	2030	5700	3670
	3	+ 1.12	3020	6720	3700
	4	+ 1.09	2900	6540	3640
	5	+ 1.19	3270	7140	3870

Notes: Foliar supplementary fertilization: 1 – without fertilizers (control); 2 – two fertilizations with urea (N_{10}) in microphases 31 and 39 (BBCH-scale); 3 – two fertilizations with tank mixture containing urea (N_{10}) + growth stimulant EFISOIL Renovation (ER) (single dose 0.4 kg/ha) + highly concentrated fertilizer Foliq Micro (FM) (single dose 1.5 kg/ha); 4 – 1st fertilization with mixture containing urea (N_{10}) + ER (0.4 kg/ha) and FM (1.5 kg/ha) in microphase 31, then the 2nd fertilization with mixture containing ER (0.4 kg/ha) + FM (1.5 kg/ha) in microphase 39; 5 – treatment 4, but the FM dose in microphase 39 was increased to 3.0 kg/ha.

Of the studied technological factors, the primary application of mineral fertilizers had the most significant impact on the grain yield variability. Their share was 26.1 %. In general, the share of fertilization of the spring barley fields in the yield variability adjusted for the main effects, and their interaction was 35.8 %. It should be noted that the technological factor interaction was fragile (0.3 %) and statistically insignificant. Simultaneously, a tendency in this interaction was seen, as the efficiency of foliar fertilization on essential fertilization slightly differed. However, the distribution of the grain yield values under the influence of this factor was similar for all the variants of essential fertilization. Under market relations, the profitability of cultivation is of paramount importance, and crop competitiveness is one of the most critical factors. The selection of cost-effective technologies that ensure return on investment with maximum efficiency should be based on evaluating research results and analysis of elements of the technological process (Polovij et al., 2020). This will increase the product output, improve its quality and reduce production costs. To justify the optimal combination of farming techniques, we calculated the economic efficiency of the studied variants of essential mineral fertilizers and additional foliar fertilizers (Table 4). The most significant grain yield from spring barley was achieved with the primary application of 250 kg/ha of polyphosphate. Simultaneously, due to much lower costs, the most significant profit was obtained where a mixture containing ammophos (115 kg/ha) and potassium chloride (50 kg/ha) was applied. Through the lens of economic efficiency of cultivation, the application of ammonium nitrate phosphate fertilizer at a dose of 380 kg/ha was the least profitable. Of the studied foliar fertilization, variant 5, where we did without the 2nd application of urea and increased the Foliq Microdose to 3.0 kg/ha, provided the highest yield, regardless of the primary application complex fertilizers. In general, on average across the three years of the experiment, the highest profit compared to the control (3870 UAH/ha) was achieved after essential fertilization with $N_{15}P_{60}K_{30}$ (115 kg/ha of ammophos + 50 kg/ha of potassium chloride) in combination with two foliar fertilization (the 1st fertilization with tank mixture containing urea solution (N_{10}) + ER (0.4 L/ha) and FM (1.5 L/ha) in microphase 31 and the 2nd fertilization with ER (0.4 L/ha) + FM (3.0 L/ha) in microphase 39).

This foliar fertilization was the most expensive due to the high cost of high-concentrated suspension fertilizer Foliq Micro. However, compared to the other variants, foliar fertilization gave the highest additional profit because of significantly higher yields. Compared with the nearest grain yield value, which was obtained via two foliar fertilization (single dose of urea [N_{10}] in tank mixture containing ER (0.4 L/ha) and FM (1.5 L/ha)), regardless of essential fertilization, the profit in variant 5 was higher by 170–350 UAH/ha.

Conclusions

In order to increase grain yields and receive the most significant profit, a mixture of ammophos (115 kg/ha) and potassium chloride (50 kg/ha) ($N_{15}P_{60}K_{30}$) should be applied before spring barley sowing in autumn. Two foliar fertilization is recommended (the 1st fertilization with a mixture containing urea (N_{10}), growth stimulator EFISOIL Renovation (0.4 L/ha), and highly concentrated fertilizer Foliq Micro (1.5 L/ha) in microphase 31 and the 2nd fertilization with a mixture containing growth stimulant EFISOIL Renovation (0.4 L/ha) and highly concentrated fertilizer Foliq Micro (3.0 L/ha) in microphase 39). This fertilization algorithm provides an additional income from fertilizers of 3870 UAH/ha.

It should be noted that the proposed fertilization algorithm significantly reduces the chemical load on soil compared to traditional fertilizer doses, as nitrogen application is decreased, and a considerable portion of nitrogen applied in autumn can contaminate groundwater or evaporate. Also, it is expected to reduce the potassium dose since the increase in the grain yield after 30 kg/ha and 60 kg/ha of potassium was very similar.

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