Agronomy Research **18**(S2), 1388–1403, 2020
https://doi.org/10.15159/AR.20.159

Modeling the impact of weather and climatic conditions and nutrition variants on the yield of spring barley varieties (*Hordeum vulgare L.*)

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Abstract. Crop yield is a result of the interaction between plant genetic traits, soil properties, agrotechnology and climatic regimes. Low yield tend to be formed in regions where it is limited to the extent of water availability, heat stress and the short duration of the grain filling period. High temperature and drought stress are projected to reduce crop yields and threaten food security. The article presents the results of studies on the effectiveness of treatment of spring barley crops with modern growth-regulating drugs on the background of mineral fertilizers, carried out in different weather and climatic conditions in 2013–2017 yrs on the Southern chernozem in the conditions of Steppe of Ukraine. It was studied the influence of weather and climatic conditions, varietal characteristics of spring barley and nutrition variants on the formation of grain yield. It was determined that the cultivation of spring barley, the introduction of pre-sowing cultivation of mineral fertilizer at a dose of $N_{30}P_{30}$ (background) and the use of crop foliar fertilizing at the beginning of the phase of stooling and earing by the complex organo-mineral fertilizer Escort bio created favorable conditions for the growth and development of plants of the studied varieties, which in turn had a positive effect on grain yield. Thus, according to this variant of nutrition, on average, during the years of research, it was formed the yield of 3.25–3.61 t ha^{-1} grains depending on the studied variety.
Results of researches showed that weather conditions during the years of research significantly influenced on the productivity of spring barley varieties. In 2016 the amount of precipitation was the highest (174.0 mm), the temperature during vegetation of spring barley was +14.9 °C. In 2013 the amount of precipitation was the lowest (67.4 mm), the temperature was +18.5 °C. The lowest crop yield was formed in 2013, and the highest yield was formed in 2016. Studies showed that the influence of weather factors in various interfacial periods of growth and development of spring barley was significant enough for the manifestation of signs of yield and its elements and is more dependent on rainfall.

Key words: spring barley, variety, plant nutrition, weather and climatic conditions, grain yield, modeling of regularities.

INTRODUCTION

Land management for food production is a fundamental human activity, supporting the lives of nearly everyone on this planet and providing livelihoods for a large part of the population. At present, more than 1.5 billion ha – approximately 12% of the world's land area – is used for crop production (FAO 2018).

Crop yield is a result of the interaction between plant genetic traits, soil properties, agrotechnology and climatic regimes (Diacono et al., 2012; Borys & Küüt, 2016). Low yield tend to be formed in regions where it is limited to the extent of water availability, heat stress and the short duration of the grain filling period (Ewert et al., 2005). High temperature and drought stress are projected to reduce crop yields and threaten food security (Mahrookashani et al., 2017).

The impacts of climate change also have many undesirable effects on the global food supply and crop yield (Li, 2015). The average Earth surface temperature is a key indicator of climate change.

Solid evidence has shown that the global mean temperature has risen by 0.90 ±0.05 °C (95% confidence) since the 1950s, and could be rising another 1 to 3 °C by the end of this century (Hansen et al., 2010; Rohde, 2013). The Intergovernmental Panel on Climate Change (IPCC) has projected that the global warming trend from 1986–2005 to 2081–2100 will show a temperature increase of 0.3 °C to 1.7 °C based on representative concentration pathways 2.6 (RCP), 1.1 to 2.6 °C based on RCP4.5, 1.4 °C to 3.1 °C based on RCP6.0, and 2.6 to 4.8 °C based on RCP8.5 (Jonghan et al., 2019). However, temperature increases of 2–3 °C will limit the yield increases of C3 crops (such as barley, oat, and wheat) that result from elevated CO_2, and even larger temperature increases may offset CO fertilization effects altogether (Klink et al., 2014). The Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4) concluded that crop yields may increase 10–15% in the mid- to high- latitudes with rising CO_2 levels and a global average temperature increase of 1–2 °C relative to 1980–1999 (Easterling et al., 2007).

High temperature and drought often occur simultaneously, but their effects on crops are usually investigated individually (Shah & Paulsen, 2003).

Drought decreased photosynthesis, stomatal conductance, viable leaf area, shoot and grain mass, and weight and soluble sugar content of kernels but increased plant water-use efficiency. High temperature hastened the decline in photosynthesis and leaf area, decreased shoot and grain mass as well as weight and sugar content of kernels, and reduced water-use efficiency. Interactions between the two stresses were pronounced, and consequences of drought on all physiological parameters were more severe at high temperature than low temperature (Shah & Paulsen, 2003).

Interpretation the mutual relations between climate and crop yield provides useful information for enhancing resilience of agricultural production systems to global climate change (Leng & Huang, 2017). Although agricultural technologies continue to improve, previous researches have shown that temperature and precipitation variations have considerable effect on crop yields, including spring barley (Lobell, 2007; Almaraz et al., 2008; Schlenker & Roberts, 2009).

Improving the technology of spring barley growth is an extremely urgent task, since under the current climatic and economic conditions cheapening of grain production and increase of its profitability is possible only in the case of application of new agrotechnical methods which do not involve high costs. Modern intensification of crop production in the conditions of acute deficiency of organic fertilizers and too high prices for mineral fertilizers involves the development of alternative measures of technology of crop cultivating. In the context of this, the study of the influence of highly effective polymer chelate fertilizers, biopreparations, growth-regulating drugs, etc. in combination with other agrotechnical elements and climate change on the formation of biometric indices of plants, productivity and quality of production becomes of increasing importance (Rozhkov & Gutyansky, 2017). There is a need for the development and implementation of resource-saving elements in plant nutrition technology, which consists of applicating of low doses of mineral fertilizers and, on their background, using of extra-root nutrition with modern drugs in the main periods of their vegetation (Gamayunova et al., 2017).

MATERIALS AND METHODS

Experimental researches were carried out during 2013–2017 yrs in the location of the educational-scientific-practical center of the Mykolaiv National Agrarian University.

The soil of experimental sites was represented by the Chernozems Calcic (CHcc). The reaction of the soil solution was neutral (pH 6.8–7.2). The content of humus in the 0–30 cm layer was 123–125 g kg^{-1}. The arable layer of soil contained moving forms of nutrients on average: nitrates (by Grandval Liagou - this method is based on interactions between nitrates and disulpfo-phenolic acid from which trinitrophenol (picric acid) is formed (Mineev et al., 2001). In alkaline environment it gives us yellow coloring due to formation of potassium trinitrophenolate (or natrium, depending from alkali used) in quantity equivalent to nitrates content) as 15–25 mg kg^{-1}, mobile phosphorus (by Machigin - this method is based on extraction of mobile phosphorus and potassium compounds from the soils with 1% ammonium carbonate solution, pH 9.0, at 25 ±2 °C) as 41–46 mg kg^{-1}, exchangeable potassium (on a flame photometer) as 389–425 mg kg^{-1} of soil (Mineev et al., 2001).

The territory of the farm locates in the third agro-climatic region and belongs to the subzone of the southern steppe of Ukraine (Panfilova et al., 2019). The climate here is temperate-continental, warm, dry, with unstable snow cover. Weather conditions by hydrothermal indices during the research years varied, which gave an opportunity to obtain objective results.

The object of research was spring barley – varieties Adapt, Stalker and Aeneas. The technology of their cultivation, with the exception of the investigated factors, was generally accepted to the existing zonal recommendations for the Southern Steppe of Ukraine.

The total area of the experimental plot (the research work was organized by the random method of choosing the plots) was 80 m^2, the basic plot was 50 m^2 (length – 21.18 m, width – 2.36 m), repetition in the experiment was done three times. Precrops was sown peas *Pisum sativum* L. The scheme of the experiment included the following options:

Factor A – variety: 1. Adapt; 2. Stalker; 3. Aeneas.

Factor B – plant nutrition: 1. Control (without fertilizers); 2. $N_{30}P_{30}$ – under pre-sowing cultivation – background (nitrogen was used in the form of ammonium nitrate (34% N), and phosphorus was in the form of double phosphorus (46% P);

3. Background + Urea K1 (1 L ha^{-1}); 4. Background + Urea K2 (1 L ha^{-1}); 5. Background + Escort-bio (0.5 L ha^{-1}); 6. Background + Urea K1 + Urea K2 (0.5 L ha^{-1}); 7. Background + Organic D2 (1 L ha^{-1}). The standard working solution was 200 L ha^{-1}. The fertilization of crops by fertilizers was carried out at the beginning of the phases of the spring barley stooling (BBCH 31) and earing (BBCH 51).

Preparations to be used for foliar application of barley crops were listed in the List of pesticides and agrochemicals authorized for use in Ukraine. Preparations of Urea K1 and Urea K2 are registered as fertilizers containing respectively N as 11–13%, P_2O_5 as 0.1–0.3%, K_2O as 0.05–0.15%, micronutrients as 0.1%, succinic acid as 0.1% and N as 9–11%, P_2O_5as 0.5–0.7%, K_2O as 0.05–0.15%, sodium humate as 3 g L^{-1}, potassium humate as 1 g L^{-1}, trace elements as 1 g L^{-1}. Organic D2 is organo-mineral fertilizer containing N as 2.0–3.0%, P_2O_5as 1.7–2.8%, K_2O as 1.3–2.0%, total calcium as 2.0–6.0%, organic matter as 65–70% (in terms of carbon). Escort-bio is a natural microbial complex that contains strains of microorganisms of genera Azotobacter, Pseudomonas, Rhizobium, Lactobacillus, Bacillus, and biologically active substances produced by them.

In the process of research, the method of the State Variety Testing of Agricultural Cultures was used (Volkodav et al., 2001). The sowing was done during the third ten-dey period of March, harvesting – the first ten-day period of July. The yield was determined by the method of continuous harvesting of each registration area (Sampo - 130 combine harvester).

Moisture content was determined by weight method. Soil samples were taken layer by layer to a depth of 100 cm before sowing barley spring and after harvesting (Kravchenko et al., 2003).

The statistical analysis (repetition was three times during 5 years of growing grain) of the research were processed using the method of multivariate disperse analysis. The obtained data were compared using analysis of variance (ANOVA). All statistical analyses were performed with Statistica 10, Agrostat New and Microsoft Excel.

To identify the dependence of yield on weather and climatic conditions (are air temperatuure , precipitiation and air humidity) during the growth and development of spring barley, linear dependence was used:

$$\hat{y}_x = a_0 + a_1x_1 + a_2x_2 + \cdots + a_nx_n \quad (1)$$

where $\hat{y}_x$ – the dependent variable, $x_1, x_2, \ldots, x_n$ – the independent indicators, $a_0, a_1, a_2, \ldots, a_n$ – the parameters of the model (Kobets & Tesyolkin, 2018).

RESULTS AND DISCUSSION

The zone of the southern Steppe of Ukraine is characterized by quite favorable agro-climatic and soil resources for growing crops. However, the limiting factor in obtaining stable yields is insufficient rainfall and their uneven distribution during the growing season of crops. Frequent droughts reduce the intensity of plant growth and development, the availability of nutrients, the yield and the product quality, and lead to soil erosion (Shevchenko et al., 2017; Panfilova, 2019; Panfilova & Mohylnytska, 2019).

Weather and climatic conditions during the growth and development of spring barley, on average over the years of research, are presented in Figs 1–3.

The analysis of meteorological indicators found that the maximum amount of precipitation, namely 83.0 mm was received in 2016 in the interfacial period earing – full ripeness of grain. The lowest amount of precipitation fell in 2013. Thus, for the full period of vegetation of spring barley, 67.4 mm of precipitation fell, which was less than in other years of research by 37.6 up to 106.6 mm or 35.8 up to 61.3%.

In general, temperature had similar patterns, but it was noted its growth in 2013, in the interphase period from earing to full ripeness of grain spring barley. The average air temperature in this period of growth and development of plants was +21.7 °C, which exceeded the indicators of 2014–2017 yrs of studies by 0.7 up to 3.7 °C or 3.2 up to 17.1%. In 2014, the air temperature increased in the interphase period of stooling – earing. The average air temperature in this period of growth and development of plants was +21.7 °C, which exceeded the indicators of 2013 yr, 2015–2017 yrs by 0.2 up to 7.0 °C or 0.9 up to 32.3%.

The relative humidity in the years of the study also changed between the phase periods of growth and development of spring barley. Thus, in 2013–2015 yrs it was the highest in the interphase period of tillering – stooling – 57 up to 75% depending on the year. In 2016 yr this figure was the highest in the interphase period of growth and development of spring barley earing – full ripeness of grain – 77%. The highest humidity in 2017 was in the period of germination – tillering – 71%.

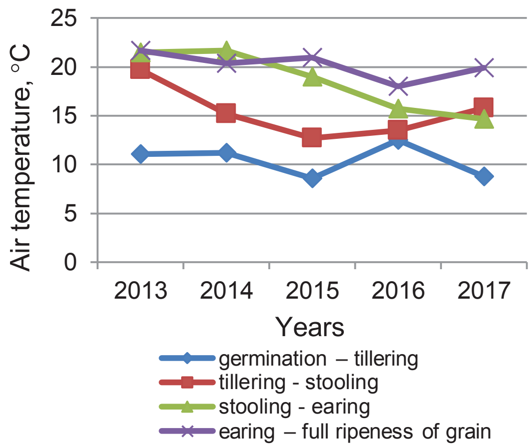

Figure 1. Air temperature, °C.

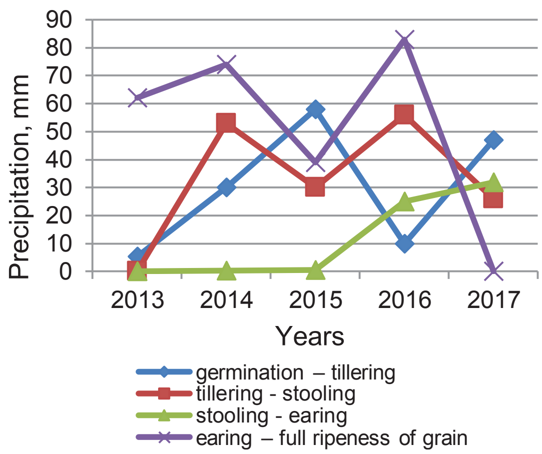

Figure 2. Precipitation, mm.

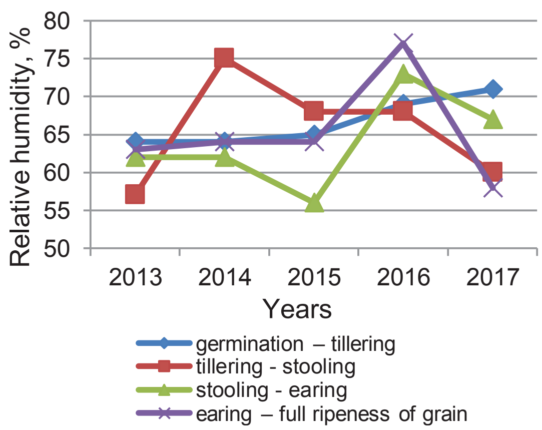

Figure 3. Relative humidity, %.

In conditions of unstable and insufficient moistening, the moisture is one of the decisive factors determining the level of crop yields. Soil moisture reserves are the major factor in the relationship between soil and plant, which is crucial for the production of strong shoots and further vegetation of plants (Kaminskyi & Gangur, 2018). Our studies determined that the water regime of the soil on the crops of spring barley had its own characteristics depending on the year of cultivation. Every year, the moisture reserves in the soil and the intensity of their spending were different, due to the amount of precipitation, temperature, humidity and so on. But the general dynamics of soil moisture on the crops of spring barley in all years of research had the same pattern. So, on average, during the years of research, the main amount of moisture in the soil accumulated in the autumn-winter period and its largest reserves reached during the sowing period, after which their amount was gradually spent by crops and decreased by the end of the growing season of the crop (Table 1). In terms of years, in 2016 yr the most moisture in the soil before sowing spring barley was 98.9 mm, in 2015 yr the slightly less moisture in the soil was 89.5 mm. Unfavorable conditions of water supply in the autumn-winter period of 2016–2017yrs provided the accumulation of the least amount of moisture in the soil as 17.5 mm. The same trend was observed after harvesting of spring barley.

It should be noted that in the variants of nutrition optimizing the total consumption of moisture during the growing season varieties of spring barley grew. So, on average, during the years of research, when applying a moderate dose of mineral fertilizers $N_{30}P_{30}$ after harvesting grain yield of Adapt variety it was remained 32.6 mm of available moisture in the meter layer of soil, after harvesting yield of Stalker it was remained 31.4 mm, and after harvesting yield of Aeneas it was remained 30.4 mm, which was less compared to the control of 3.0 up to 5.6% depending on the variety. However, the foliar fertilizing of spring barley plants during the growing season with modern growth-regulating drugs on the background of mineral fertilizers did not have a significant deterioration in the water regime of the soil and moisture reserves for the harvest period, on average, moisture reserves were 28.6 up to 31.2 mm depending on the studied variety, which was less than the control by 7.1 up to 11.2%.

On average for years of research and on the nutrition factor, it was used a few more intensively the moisture from the soil by plants of Aeneas spring barley variety. Thus, after harvesting on plots of this variety, it was remained 29.4 mm of available moisture in the soil, which was less by 1.1 up to 2.4 mm or 3.6 up to 7.5% than in other studied varieties.

According to the results of Kaminskyi & Gangur (2018) during the spring-summer vegetation period of winter wheat, it was observed the predominance of moisture consumption over its accumulation in the soil. However, during this period the productive spending of moisture dominated, thus, the soil moisture was more spent on the formation of the crop and it partly spent on physical evaporation from the soil surface. Future barley fields will decrease between 25 and 8% depending on climate projections. Barley yield will be more dependent on rainfall and extractable soil water (Cammarano et al., 2019).

Table 1. Reserves of productive moisture in the soil layer 0 up to100 cm, mm

Yrs.	Plant nutrition	Adapt Variety		Stalker Variety		Aeneas Variety	
		Terms of determination					
		before sowing	after harvesting	before sowing	after harvesting	before sowing	after harvesting
2013	Control	64.3	37.5	64.3	36.9	64.3	35.4
	$N_{30}P_{30}$ (background)	64.3	36.7	64.3	35.2	64.3	33.8
	Background + Urea K1	64.3	35.4	64.3	34.6	64.3	33.1
	Background + Urea K2	64.3	35.2	64.3	34.1	64.3	32.7
	Background + Escort-bio	64.3	33.9	64.3	32.5	64.3	31.6
	Background+UreaK1+UreaK2	64.3	34.6	64.3	33.1	64.3	32.1
	Background + Organic D2	64.3	34.3	64.3	32.8	64.3	32.0
2014	Control	70.4	38.1	70.4	37.4	70.4	36.8
	$N_{30}P_{30}$ (background)	70.4	37.5	70.4	36.2	70.4	35.5
	Background + Urea K1	70.4	36.9	70.4	35.4	70.4	34.9
	Background + Urea K2	70.4	36.5	70.4	35.0	70.4	34.6
	Background + Escort-bio	70.4	35.5	70.4	34.1	70.4	33.0
	Background+UreaK1+UreaK2	70.4	36.0	70.4	34.7	70.4	34.1
	Background + Organic D2	70.4	35.7	70.4	34.5	70.4	33.6
2015	Control	89.5	44.8	89.5	44.1	89.5	43.8
	$N_{30}P_{30}$ (background)	89.5	44.1	89.5	42.7	89.5	42.0
	Background + Urea K1	89.5	43.6	89.5	41.5	89.5	41.1
	Background + Urea K2	89.5	43.3	89.5	41.2	89.5	40.8
	Background + Escort-bio	89.5	42.2	89.5	39.8	89.5	39.1
	Background+UreaK1+UreaK2	89.5	42.7	89.5	40.4	89.5	40.0
	Background + Organic D2	89.5	42.4	89.5	40.2	89.5	39.6
2016	Control	98.9	37.6	98.9	37.0	98.9	36.5
	$N_{30}P_{30}$ (background)	98.9	36.4	98.9	35.1	98.9	33.9
	Background + Urea K1	98.9	35.9	98.9	34.4	98.9	32.1
	Background + Urea K2	98.9	35.8	98.9	34.0	98.9	31.8
	Background + Escort-bio	98.9	34.6	98.9	33.2	98.9	30.4
	Background+UreaK1+UreaK2	98.9	35.4	98.9	33.7	98.9	31.1
	Background + Organic D2	98.9	35.1	98.9	33.6	98.9	30.6
2017	Control	17.5	10.0	17.5	9.4	17.5	8.7
	$N_{30}P_{30}$ (background)	17.5	8.1	17.5	7.8	17.5	7.0
	Background + Urea K1	17.5	7.7	17.5	7.0	17.5	6.4
	Background + Urea K2	17.5	7.5	17.5	6.7	17.5	6.2
	Background + Escort-bio	17.5	6.3	17.5	5.6	17.5	5.0
	Background+UreaK1+UreaK2	17.5	7.1	17.5	6.2	17.5	5.3
	Background + Organic D2	17.5	6.5	17.5	6.0	17.5	5.3
average for 2013–2017 yrs.	Control	68.1	33.6	68.1	33.0	68,1	32.2
	$N_{30}P_{30}$ (background)	68.1	32.6	68.1	31.4	68.1	30.4
	Background + Urea K1	68.1	31.9	68.1	30.6	68.1	29.5
	Background + Urea K2	68.1	31.7	68.1	30.2	68.1	29.2
	Background + Escort-bio	68.1	30.5	68.1	29.0	68.1	27.8
	Background+UreaK1+UreaK2	68.1	31.2	68.1	29.6	68.1	28.5
	Background + Organic D2	68.1	30.8	68.1	29.4	68.1	28.2

LSD 0.5 (after harvesting)

factor A: 2013 – 0.474; 2014 – 0.375; 2015 – 0.591; 2016 – 1.042; 2017 – 0.759

factor B: 2013 – 0.709; 2014 – 0.760; 2015 – 0.844; 2016 – 0.874; 2017 – 0.774

Weather and climatic conditions of years and experience factors (variety, plant nutrition) significantly influenced on the grain yield of spring barley (Table 2).

Table 2. Yield of spring barley depending on varietal characteristics and optimization of plant nutrition, t ha^{-1}

Variety (factor A)	Plant nutrition (factor B)	Years					Average for 2013–2017 yrs.
		2013	2014	2015	2016	2017	
Adapt	Control (without fertilizers)	2.25	2.61	2.55	2.86	2.52	2.56
	$N_{30}P_{30}$ (background)	2.51	2.96	2.90	3.28	2.89	2.91
	Background + Urea K1	2.69	3.10	3.08	3.46	2.93	3.05
	Background + Urea K2	2.71	3.14	3.10	3.59	3.00	3.11
	Background + Escortbio	2.83	3.27	3.21	3.75	3.20	3.25
	Background + Urea K1 + Urea K2	2.74	3.21	3.14	3.65	3.12	3.17
	Background + Organic D2	2.79	3.24	3.18	3.71	3.18	3.22
Stalker	Control (without fertilizers)	2.34	2.69	2.62	2.88	2.64	2.63
	$N_{30}P_{30}$ (background)	2.66	3.09	3.01	3.30	3.06	3.02
	Background + Urea K1	2.79	3.20	3.18	3.65	3.15	3.19
	Background + Urea K2	2.81	3.23	3.20	3.70	3.22	3.23
	Background + Escort-bio	2.95	3.36	3.31	3.84	3.39	3.37
	Background + Urea K1 + Urea K2	2.86	3.29	3.26	3.76	3.30	3.29
	Background + Organic D2	2.91	3.32	3.29	3.80	3.35	3.33
Aeneas	Control (without fertilizers)	2.36	2.80	2.79	3.18	2.89	2.80
	$N_{30}P_{30}$ (background)	2.73	3.21	3.22	3.75	3.31	3.24
	Background + Urea K1	2.94	3.40	3.29	3.94	3.34	3.38
	Background + Urea K2	2.99	3.48	3.35	4.01	3.36	3.44
	Background + Escort-bio	3.12	3.58	3.52	4.30	3.51	3.61
	Background + Urea K1 + Urea K2	3.06	3.51	3.42	4.22	3.41	3.52
	Background + Organic D2	3.08	3.56	3.47	4.25	3.45	3.56
$LSD_{0.5}$	factor A	0.08	0.10	0.09	0.08	0.11	
	factor B	0.11	0.13	0.14	0.10	0.13	

The given data testified that plant nutrition and weather conditions during years of research significantly influenced on the productivity of spring barley varieties. In 2016 the amount of precipitation was the highest (174.0 mm), the temperature during vegetation of spring barley was +14.9 °C. In 2013 the amount of precipitation was the lowest (67.4 mm), the temperature was +18.5 °C. The lowest crop yield was formed in 2013, and the highest yield was formed in 2016.

The maximum yield of spring barley varieties in all years of our research was formed for the cultivation of culture on the background of applicating a moderate dose of mineral fertilizers and foliar nutrition of crops with Organic D2 and Escort-bio. Thus, on average, over the years of research and by factor variety, the grain yield was 3.37–3.41 t ha^{-1}, which exceeded its level in uncontrolled control by 0.71–0.75 t ha^{1} or 26.7–28.2%, and on the background of the application of mineral fertilizers in exceeded only by 0.4 t ha^{-1} or by 15.4%.

It was established by the research that application of Urea K1 and Urea K2 for foliar fertilization of plants increased the grain yield of spring barley. Thus, on average, over the years of research and by factor variety, in these experimental variants, it were formed

3.21 and 3.26 t ha^{-1}grains, which exceeded the control by 0.55–0.60 t ha^{-1} or by 20.7–22.6%, $N_{30}P_{30}$ (background) – by 0.15–0.20 t ha^{-1} or by 4.7–6.1%. But compared to the use of Organic D2 and Escort-Bio, the yield of barley was somewhat lower by 3.3–4.7 and 4.4–5.9%. The co-administration of these drugs provided the grain yield of spring barley at almost the same level as 3.33 t ha^{-1}.

Crop production per unit area (yield) is a fundamental parameter in agricultural and environmental research (Iizumi et al., 2014). The productivity as a result of functioning of agroecosystems has a complex nature and is affected by the influence of different factors. The impact of these factors can be identified through research on synchronous dynamics characteristics. The synchronous dynamics expresses itself through the forming of the correlation relationship. The correlation matrix is the basis for the principal component analysis and cluster analysis. Principal component analysis allows us to discover the main variability trends of agricultural crops' productivity (Zhukov et al., 2018). In our research we used correlation-regression analysis for study the dependence of yield on weather and climatic conditions. We see that the linear model works for the investigated varieties in the period 'tillering – stooling'.

Weather is an important factor, having an impact on the productivity and competition ability of all organisms. Because of the complexity, it is usually very difficult to find correlation between climatic conditions and stand situation in field conditions (Lillak et al., 2005).

Our studies found that for different varieties of spring barley, there is a fairly strong correlation ($0.9 \leq r \leq 0.99$) between weather and climatic conditions and the yield during the periods of 'germination-tillering', 'tillering-stooling' and 'earing – full ripeness' for the studied period (Table 3, Table 4). While the period of 'stooling-earing' is characterized by moderate and strong correlation ($0.5 \leq r \leq 0.9$).

Analyzing the obtained data we see that for establishing the dependence of grain yield on agro-climatic factors and constructing the regression equation, it is advisable to use the period of 'tillering-stooling' for Stalker and Aeneas varieties under the nutrition variant control option, since the econometric model can be considered suitable for research when the confidence probability $p \geq 0.95$.

For identifying the dependence of the yield on weather and climatic conditions during the growth and development of spring barley, we use a linear dependence. We define the variables of the econometric model: let $y -$ the yield of spring barley, t ha^{-1}; $x_1 -$ air temperature, °C; $x_2 -$ precipitation, mm; $x_3 -$ relative humidity, %.

For the Aeneas variety for the method of nutrition the control multifactorial regression has the form:

$$\hat{y} = -0.048x_1 + 0.017x_2 - 0.038x_3 + 5.45 \qquad (2)$$

The regression equation shows that with an increase of air temperature x_1 (°C) by 1, the yield of spring barley decreases by 0.048 t ha^{-1}, with an increase in x_2 (precipitation, mm) it will increase by 0.017 t ha^{-1}, and with an increase in x_3 (relative humidity, %) by 1%, the yield of wheat will decrease by 0.038%.

Table 3. The statistic of multilinear regression analysis of yields impacted by weather conditions in interphase period 'germination – stooling' (r – the coefficient of multiple correlation, R^2 – coefficient of determination, p – confidence level, S_u – standard error)

Variety (factor A)	Plant nutrition (factor B)	Interphase period							
		germination – tillering				tillering - stooling			
		r	R^2	p	S_u	r	R^2	p	S_u
Adapt	Control	0.977	0.955	0.73	0.09	0.989	0.978	0.81	0.06
	$N_{30}P_{30}$ (background)	0.979	0.959	0.74	0.11	0.995	0.9896	0.87	0.06
	Background + Urea K1	0.942	0.888	0.58	0.19	0.955	0.912	0.63	0.17
	Background + Urea K2	0.948	0.899	0.60	0.20	0.957	0.916	0.64	0.18
	Background + Escort-bio	0.963	0.927	0.66	0.18	0.976	0.952	0.72	0.14
	Background+ UreaK1+UreaK2	0.720	0.518	0.19	197.38	0.955	0.912	0.63	84.47
	Background + Organic D2	0.966	0.933	0.68	0.17	0.955	0.912	0.63	84.47
Stalker	Control	0.993	0.985	0.85	0.05	0.9998	0.9997	0.98	0.01
	$N_{30}P_{30}$ (background)	0.996	0.992	0.89	0.04	0.998	0.997	0.93	0.03
	Background + Urea K1	0.955	0.913	0.63	0.18	0.978	0.956	0.73	0.13
	Background + Urea K2	0.948	0.899	0.60	0.20	0.957	0.916	0.64	0.18
	Background + Escort-bio	0.973	0.947	0.71	0.15	0.991	0.982	0.83	0.08
	Background+ UreaK1+UreaK2	0.968	0.937	0.68	0.16	0.990	0.981	0.82	0.09
	Background + Organic D2	0.969	0.938	0.69	0.16	0.991	0.981	0.83	0.09
Aeneas	Control	0.984	0.969	0.78	0.10	0.9995	0.999	0.96	0.02
	$N_{30}P_{30}$ (background)	0.970	0.941	0.69	0.18	0.998	0.996	0.92	0.05
	Background + Urea K1	0.955	0.913	0.63	0.18	0.978	0.956	0.73	0.13
	Background + Urea K2	0.971	0.943	0.698	0.18	0.969	0.939	0.69	0.18
	Background + Escort-bio	0.947	0.897	0.60	0.28	0.951	0.905	0.61	0.26
	Background+ UreaK1+UreaK2	0.9496	0.902	0.61	0.27	0.944	0.891	0.59	0.28
	Background + Organic D2	0.949	0.900	0.60	0.26	0.941	0.885	0.58	0.28

Table 4. The statistic of multilinear regression analysis of yields impacted by weather conditions in interphase period 'stooling – earing – full ripeness of grain' (r – the coefficient of multiple correlation, R^2 – coefficient of determination, p – confidence level, S_u – standard error)

Variety (factor A)	Plant nutrition (factor B)	Interphase period							
		stooling – earing				earing – full ripeness of grain			
		r	R^2	p	S_u	r	R^2	p	S_u
Adapt	Control	0.762	0.580	0.244	0.28	0.916	0.839	0.496	0.17
	$N_{30}P_{30}$ (background)	0.766	0.586	0.24	0.35	0.917	0.842	0.51	0.22
	Background + Urea K1	0.804	0.646	0.29	0.33	0.910	0.829	0.49	0.23
	Background + Urea K2	0.833	0.694	0.33	0.35	0.942	0.887	0.58	0.21
	Background + Escort-bio	0.841	0.707	0.35	0.36	0.958	0.918	0.64	0.19
	Background+ UreaK1+UreaK2	0.666	0.443	0.15	212.12	0.910	0.829	0.49	117.58
	Background + Organic D2	0.666	0.443	0.15	212.12	0.910	0.829	0.49	117.58
Stalker	Control	0.721	0.520	0.20	0.27	0.908	0.824	0.48	0.16
	$N_{30}P_{30}$ (background)	0.708	0.502	0.18	0.33	0.902	0.813	0.47	0.20
	Background + Urea K1	0.839	0.704	0.34	0.33	0.948	0.899	0.60	0.19
	Background + Urea K2	0.833	0.694	0.33	0.35	0.942	0.887	0.58	0.21
	Background + Escort-bio	0.856	0.732	0.37	0.33	0.9699	0.941	0.69	0.15
	Background+ UreaK1+UreaK2	0.842	0.708	0.35	0.34	0.957	0.916	0.64	0.19
	Background + Organic D2	0.854	0.729	0.37	0.33	0.965	0.930	0.67	0.17
Aeneas	Control	0.813	0.661	0.30	0.34	0.940	0.884	0.57	0.20
	$N_{30}P_{30}$ (background)	0.849	0.721	0.36	0.38	0.956	0.914	0.63	0.21
	Background + Urea K1	0.839	0.704	0.34	0.33	0.948	0.899	0.60	0.19
	Background + Urea K2	0.846	0.715	0.35	0.39	0.9699	0.941	0.69	0.18
	Background + Escort-bio	0.893	0.798	0.45	0.39	0.981	0.963	0.76	0.17
	Background+ UreaK1+UreaK2	0.897	0.804	0.46	0.38	0.985	0.9695	0.78	0.15
	Background + Organic D2	0.896	0.803	0.45	0.37	0.984	0.969	0.78	0.15

The coefficient of determination $R^2 = 0.999$ indicates that the variation of spring barley yield by 99.9% is determined by the variation of weather and climatic conditions.

Multiple correlation coefficient: $R = \sqrt{R^2} = 0.9995$ is a measure of the linear relationship between the dependent variable Y and the independent variables x_1, x_2, x_3. Its value shows a close linear relationship between the relevant indicators.

Analysis of variance was used to test the null hypothesis, according to which the average yield values did not consistent with each sowing scheme.

We check the hypothesis about the significance of the relationship between independent and dependent variables $F_{fact} = 339.389$ taking the table value for a given level of significance $\alpha = 0.05$ and the number of degrees of freedom $k_1 = 2$ i $k_2 = 3$: $F_{tabl} = F_{0.05;2;3} = 9.552$.

As $F_{fact} > F_{tabl}$ since the null hypothesis is rejected and with a given probability $p = 0.95$ the econometric model can be considered adequate to the actual data, i.e. the hypothesis of the significance of the relationship between the independent and dependent variables is confirmed.

Calculation of correlation coefficients for determine the relationship between the studied variables by least squares method. In this case, between the yield and air temperature there is a negative strong correlation ($r_{yx_1} = -0.797$), there is a positive strong correlation between yield and precipitation, ($r_{yx_2} = 0.845$), and there is a noticeable positive correlation between yield and relative humidity ($r_{yx_3} = 0.495$).

Over the framework of the multicollinearity study, were researched statistical sets of factors of influence (air temperature, rainfall and relative humidity) on spring barley yield. The research of multicollinearity presence between explanatory variables was done according to the Farrar-Glober algorithm. The algorithm has three types of statistical criteria. According to them the multicollinearity was checked with the whole set of independent variables (pearson's criterion (χ^2)); with each independent variable with the remaining variables (F – criteria); with each pair of independent variables (t – criteria).

In the research of multicollinearity presence for the whole group of independent variables, advanced calculations for determination of correlation matrix, included variables normalization, which distinguish influence factors in 'Tillering-plant transformation into a tube' period for the varieties - Stalker and Aeneas in power supply Control scenario. The determinant of the correlation matrix is $det\, r = 0.118076$. Pearson's criterion χ^2 was calculated by the formula:

$$\chi^2 = -\left\{n - 1 - \frac{1}{6}(2m + 5)\right\} ln(det\, r) \quad (3)$$

$$\chi^2 = -\left\{5 - 1 - \frac{1}{6}(2 \cdot 3 + 5)\right\} \cdot 0.118076 = -0.25583 \quad (4)$$

Calculated value of χ^2 was compared with table parameters $\chi^2_{\text{кр}} = 8.7$, with three degrees of freedom, significance $\alpha = 0.05$.

Since $\chi^2 < \chi^2_{кр}$ then multicollinearity between factors is not present.

Determination of multicollinearity fact of each independent variable with the others was made by formula: $F = (C_{kk} - 1)\left(\frac{n-m}{m-1}\right)$, where C_{kk} – is the diagonal element of C matrix (aspect of inverse matrix to correlation matrix) and compared with table parameter of F – criteria $F = 19$, significance $\alpha = 0.05$: $F_1 = 1.2567$, $F_2 = 3.6769$,

$F_3 = 2.7859$. So, based on founded values was seted that multicollinearity was not present.

Founded values of t – criteria, which was used for the determination of multicollinearity of two explanatory variables, $t_{12} = 0.7019$, $t_{13} = 0.1328$, $t_{23} = -1.4769$, were compared with table parameter $t = 4.3027$ with the significance of $\alpha = 0.05$ and assures us about multicollinearity absence.

Noteworthy fact is the result of authors team study who got high values of paired correlation coefficients of independent (factor) variables. The team explored model for multicollinearity presence as well. As far as one of the multicollinearity hallmarks is a high value determination coefficient going with the insignificance of the model coefficients, it would be appropriate to determine the significance of the each coefficient of the econometric model.

The statistical significance value of the economic model parameters (factors) was verified with the help of Student's t – statistic. Due to considering hypothesis $H_0: a_i = 0$ $(i = 0,1,2,3)$ – value of the parameter is insignificant and $H_A: a_i \neq 0$ $(i = 0,1,2,3)$ – value of the parameter is significant. The actual value of t – statistic had been determinated: $t_{a_0} = 30.685$ $t_{a_1} = 9.409$ $t_{a_2} = 19.183$ $t_{a_3} = 15.007$ and compared with table parameter $t = 4.3027$ with the significance of $\alpha = 0.05$. In the process of comparing actual and table values was made a conclusion about H_0 hypothesis for parameters a_0, a_1, a_2, a_3 that would be rejected in favor of an alternative. The model mentioned parameters are considered like statistically significant that have major influence on spring barley yield.

The same behavior is observed for the Stalker variety during the 'Tubing-Exit of Plants in the Tube'.

The studies allow us to conclude that the influence of weather factors in different interfacial periods is significant enough to show signs of yield and its elements and is more dependent on the amount of precipitation. This is confirmed by the calculated correlation coefficients.

It is possible that the linear relationships between temperature and precipitation changes and changes in barley yield presented here may not be representative of future crop-climate relationships: temperatures exceeding physiological thresholds, for example, can have nonlinear effects on crop yield (Schlenker & Roberts, 2009). So that the magnitude of future climate change impacts may increase from what has been observed over the past 30 years.

According to Příkopa et al. (2005), yield variability grain barley in the course of the experimental years were most affected by the weather conditions (82.3 and 76.2% share in the total variability, respectively). In our studies, climatic conditions in the period 'tillering – stooling' by 91.2–99.9% affected the productivity of spring barley.

Barley yields in cool conditions revealed modest interactions with the climate, while in warm conditions, there were stronger relationships between climate variability and barley yield (Klink et al., 2014). Warming temperatures, particularly in mid growing season, have reduced yields at nearly all sites; increased precipitation benefited yields for some time periods and locations but was detrimental to yield at others. Yield effects (as represented by adjusted r values) are stronger at climatologically warmer sites as compared with cooler sites, possibly because at the warmer sites oat and barley may be growing nearer their physiological limit. This observation echoes the findings of Lobell et al. (2011) who noted that crop yields in climatically warm countries were more sensitive to temperature increases than yields in cooler countries, and Hakala et al. (2012) found that barley cultivars from lower latitudes were the most sensitive to high temperatures.

According to Cammarano et al. (2019), there was a 9% reduction in grain yield under climate change; but the mean yield change was -27%, +4%, +8%, for the Dry, Mid, and Wet scenarios, respectively. The results of the simulations under the Wet scenario showed a higher variability of yield response. There was an interaction between the soil type, the amount of rainfall, the extractable soil water content and the maximum air temperature. Because of these relationship water-stress during the vegetative stage was experienced, affecting expansive growth. At the same time, the high number of days with $Tmax$>34 °C caused higher soil water depletion by the plant and therefore lower yields under the Wet scenario.

CONCLUSIONS

In the conditions of southern Ukraine, the application of mineral fertilizers at a dose of $N_{30}P_{30}$ under pre-sowing cultivation and the implementation of foliar nutrition of crops at the beginning of the phase of spring barley stooling and earing with the growth-regulating preparations provides the best conditions for the growth and development of plants and, as a consequence, the formation of more grain yield. In this regard, irrespective of the year of cultivation, the highest grain yield of spring barley was formed by the application of mineral fertilizers in a dose of $N_{30}P_{30}$ and nutrition of plants with the preparation Escort- bio. On average, over the years of research, in this version of the plant nutrtion, the highest level of grain productivity among the studied varieties was provided by the variety Aeneas as 3.61 t ha^{-1}.

Weather and climatic conditions in the years of research also significantly influenced on the formation of grain yield of spring barley. Thus, the lowest yield was formed in 2013 yr, and the highest yield was in 2016 yr. We used correlation-regression analysis for study the dependence of yield on weather and climatic conditions. We see that the linear model works for the investigated varieties in the period 'tillering – stooling'. It should be noted that climatic factors that affect on the level of productivity of spring barley were tested on multicolinearity, and it was constructed a multi-factor model with a level of significance $\alpha = 0.05$. For further research the possible directions would include the following: the development of a quality management decisions for effective mechanism of crop yields forecasting; taking into account the stability of spring barley yield levels for the southern Steppe of Ukraine.

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