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ECOLOGICAL PLASTICITY AND STABILITY OF WINTER WHEAT VARIETIES IN THE CONDITIONS OF THE SOUTHERN STEPPE OF UKRAINE (PART 3 – YEARS WITH DIFFERENT MOISTURE SUPPLY)

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Wheat (*Triticum aestivum* L.) is one of the most important crops in maintaining food security, which ensures the existence of a significant part of the world's population [4, 5, 8]. Scientific forecasts indicate that with a significant increase in the population on Earth, the production of food products will not coincide with such growth and, under the current dynamics, the food problem may turn into a deep international crisis [20, 23, 26]. Scientists' calculations show that at the current rate of population growth, in the future, world grain production per person will decrease [2].

Currently, the annual gross production of wheat is increasing by about 0.9%, but this is much slower than the growth rate of the population and, accordingly, its quantity is insufficient to meet their needs [9, 25]. Therefore, humanity must find a solution to this problem, since the rate of population growth remains too high [6].

Along with population growth, climate changes, the so-called global warming, have been observed in recent decades, which leads to significant fluctuations in the yield of winter wheat both in space and time [1, 14, 24]. Therefore, the efforts of breeders should be directed to the creation of not only high-yielding varieties, but also those that ensure the stability of the harvest in different agro-climatic conditions [11, 15, 19, 22]. To date, scientists have already investigated the agronomic and physiological mechanisms responsible for the stability of the crop [7, 16, 17, 21]. Therefore, different varieties can show contrasting reactions to environmental conditions due to their interaction [13, 18, 27].

The purpose of our research was to study and analyze the environmental stability and adaptability to different environments of winter wheat varieties selected by the Institute of Climate-oriented Agriculture of the National Academy of Sciences and the Selection and Genetic Institute of the National Center for Seed Science and Varietal Research of the National Academy of Sciences in the conditions of the Southern Steppe of Ukraine.

Materials and methods. The reaction of winter wheat varieties to different growing conditions was studied at the Askanian State Agricultural Research Station in the village of Tavrychanka, Kherson region (46°33'12"N; 33°49'13"E; 39 m above sea level) during 2015/16–2019/20. Research was conducted under different conditions of irrigation: with irrigation and without irrigation. Under conditions of natural moisture, the yield strongly depended on the amount of precipitation during the growing season, especially during the critical growing season (April–May). Average temperatures and total precipitation for all experimental seasons are shown in Table 1 along with long-term average values (1961–2005). The seasons of 2016/2017 and 2018/19 were the most favorable for natural moisture conditions, as the precipitation that fell during the growing season contrib-

Table 1

Weather conditions for research (2015–2020)

	1961-2005		2015/2016		2016/2017		2017/2018		2018/2019		2019/2020	
	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)
October – December	4.8	98.0	6.0	81.2	3.4	42.0	5.9	75.0	5.5	53.4	7.4	67.9
January	-3.1	30.0	-3.1	59.9	-3.9	14.4	0.7	24.1	-0.3	33.8	1.0	18.3
February	-2.0	29.0	3.9	32.9	-0.9	22.0	0.1	47.0	1.1	10.6	2.2	59.6
March	2.2	26.0	6.1	20.3	6.6	10.2	1.5	35.1	5.5	5.7	7.5	3.5
April	9.6	28.0	12.4	50.5	8.5	81.8	12.9	2.7	10.3	38.9	9.5	7.5
May	15.6	38.0	15.9	95.7	15.5	25.8	19.5	13.0	17.4	72.4	14.9	42.4
June	20.0	46.0	21.5	76.2	21.7	8.0	22.4	23.0	24.5	14.1	22.2	59.3
January – June	7.1	197.0	9.5	335.5	7.9	162.2	9.5	144.9	9.8	175.5	9.6	190.6
October – June	6.0	295.0	7.8	416.7	5.7	204.2	7.7	219.9	7.7	228.9	8.5	258.5

uted to the replenishment of moisture in the soil for normal plant growth and development. The index of environmental conditions for these years was: for natural moisture 0.32 and 0.87, for irrigation 0.94 and 1.32, respectively. The 2017/18 and 2019/20 seasons were very dry, especially the critical growing season (April–May), in which air and soil drought was observed due to insufficient precipitation and high average daily temperature, and the indices of environmental conditions for natural moisture were equal to -1.85 and -1.43 and for irrigation 0.51 and 0.89, respectively. Therefore, we calculated and analyzed the parameters of stability, adaptability and ecological plasticity of 18 varieties of winter wheat separately in dry years, wet years and during the five-year period (2015/16–2019/20), which included the year 2015/2016 with too high a number precipitation (index of environmental conditions for natural moistening – -1.17, for irrigation – -0.41), which led to the laying of crops and crop losses.

They studied 18 varieties of winter wheat, which are usually grown in the south of Ukraine and are listed in the State Register of Plant Varieties. Varieties were tested on plots with an area of 50 m^2 in three repetitions by the method of randomized repetitions (blocks), the sowing rate was adjusted to 4.5 million viable seeds per ha. Research was conducted according to generally accepted methods, the amount of fertilizers and chemical treatments was adjusted according to growing conditions and the presence of diseases and pests. The studied samples were sown in the first decade of October, and the harvest was done in July.

Statistical analysis. The reaction of winter wheat varieties to growing conditions was determined by: index of environmental conditions (environmental index), obtained as the average value of all varieties in the *j*-th environment minus the overall average (Ij), coefficient of regression of the variety on the environment (b_i), variance of deviations from regression lines, second stability parameter (s^2_{di}) [3], an indicator of resistance to stress (*RS*), genetic flexibility (*Gf*) [10], general homeostasis (*Hom*), breeding value (*Sc*), adaptability coefficient (*CA*), the effects of general adaptive capacity (GAC_i), specific adaptive capacity (SAC_i), variance of interaction between genotype and environment ($\sigma^2_{(G\times E)gi}$), variance of specific adaptive capacity (σ^2_{SACi}), relative stability of the genotype (s_{gi}), selection value of the genotype (SVG_i), coefficient of compensation-destabilization of the genotype (K_{gi}), coefficient of non-linearity of the response of the genotype to the environment (l_{gi}) [12].

A correlation analysis was conducted between grain yield and drought resistance indices to determine the best drought-resistant varieties and indices. Principal component analysis (PCA) was performed on the observations. Correlation, cluster analyses, and PCA were performed using Microsoft ® Excel 2016/XLSTAT © -Pro (Version 2016.02.28451, 2016, Addinsoft, Inc., Brooklyn, NY, USA), Statistica data analysis software system v.8. (Sta Stof Inc., North Melbourne, Australia) and SPSS 20.00 statistical software (SPSS/PC-20, SPSS Inc., Chicago, IL, USA).

Research results and their discussion. The obtained experimental data allow us to distinguish the varieties of winter wheat with the highest productivity according to the minimum productivity (*Ymin*) *Konka* – 4.75 t/ha and *Lira odes'ka* – 4.99 and according to the maximum productivity (*Ymax*) *Burhunka* – 8.46 t/ha, *Harantiia odes'ka* – 8.23, *Tradytsiia odes'ka* – 8.32 and *Schedrist' odes'ka* – 8.58. The lowest productivity was characterized by varieties *Rosynka* – 3.87 t/ha and *Harantiia odes'ka* – 3.01 t/ha at the minimum (*Ymin*) and varieties *Ledia* – 6.59 t/ha and *Rosynka* – 6.66 t/ha at the maximum (*Ymax*) (Table 2).

The highest average yield (*Ymean*) was characterized by the varieties *Koshova* – 6.69 t/ha, *Lira odes'ka* – 6.76 and *Schedrist' odes'ka* – 6.64 t/ha, while the lowest were the varieties *Ledia* – 5.66 t/ha and *Rosynka* – 5, 35 t/ha.

The highest level of resistance of the investigated winter wheat varieties to stress conditions (*RS*), and accordingly the lowest value, was characterized by the variety *Ledia* – 2.58. The variety *Harantiia odes'ka* with a value of 5.22 was the most unstable to stressful conditions.

According to the selection value of the variety (Sc), the selected variety *Lira odes'ka* is 5.81.

According to the high values of genetic flexibility (*Gf*), which reflects the degree of correspondence between the genotype of the variety and environmental factors, the winter wheat varieties *Lira odes'ka* – 6.54 and *Schedrist' odes'ka* – 6.62 were selected, which form a higher yield in contrasting conditions compared to other varieties.

According to the regression coefficient (b_i), which is a criterion for assessing the level of ecological plasticity and

Table 2

Homeostaticity, ecological plasticity and adaptability of winter wheat varieties based on grain yield (2016–2020)

Variety	Designation	Yield, t/ha		Adaptability parameters						
		Ymin-Ymax	*Ymean*	*RS*	*Sc*	*Gf*	b_i	s^2_{di}	*CA*	*Hom*
Anatoliia	G1	4.47–8.04	6.29	3.57	5.27	6.26	0.97	0.109	99.5	28.7
Burhunka	G2	4.32–8.46	6.38	4.14	5.30	6.39	1.12	0.538	100.9	28.1
Konka	G3	4.75–7.51	6.34	2.76	5.33	6.13	0.88	0.070	100.2	29.9
Kokhana	G4	4.61–7.98	6.59	3.37	5.40	6.30	0.84	0.161	104.2	26.9
Koshova	G5	4.67–7.94	6.69	3.27	5.52	6.31	0.97	0.101	105.8	28.2
Mariia	G6	4.29–7.80	6.59	4.32	5.14	6.45	1.05	0.345	104.3	21.5
Ledia	G7	4.00–6.59	5.66	2.58	4.71	5.29	0.79	0.168	89.6	25.0
Rosynka	G8	3.87–6.66	5.35	2.79	4.73	5.27	0.66	0.271	84.6	35.1
Khersons'ka bezosta	G9	4.07–7.63	6.14	3.56	5.10	5.85	1.11	0.249	97.1	26.8
Askaniis'ka	G10	4.50–7.97	6.60	3.47	5.35	6.24	1.02	0.040	104.4	25.5
Harantiia odes'ka	G11	3.01–8.23	6.10	5.22	4.62	5.62	1.28	0.600	96.4	17.9
Zysk	G12	4.67–7.53	6.34	2.89	5.02	6.12	0.88	0.241	100.3	22.1
Lira odes'ka	G13	4.99–8.09	6.76	3.10	5.81	6.54	0.86	0.204	106.9	36.3
Mudrist' odes'ka	G14	4.06–7.89	6.46	3.83	4.97	5.98	1.14	0.245	102.1	20.0
Nyva odes'ka	G15	4.16–7.67	6.45	3.88	5.06	6.10	1.13	0.232	102.0	21.6
Pylypivka	G16	4.44–7.23	5.89	2.79	4.83	5.84	0.93	0.173	93.1	24.2
Tradytsiia odes'ka	G17	4.32–8.32	6.55	4.00	5.41	6.32	1.16	0.262	103.6	27.7
Schedrist' odes'ka	G18	4.65–8.58	6.64	3.93	5.07	6.62	1.21	0.657	105.1	20.0
Medium grade		**4.33–7.85**	**6.32**	**3.53**	**5.15**	**6.09**	**1.00**	**0.259**	**100.0**	**25.9**
V, %			5.93	19.12	6.02	6.38	16.35	67.53	5.94	19.26
$S\dot{x}_{absolute}$			0.09	0.16	0.07	0.09	0.04	0.04	1.40	1.17
$S\dot{x}_{reletive}$			1.40	4.51	1.42	1.50	3.85	15.92	1.40	4.54
LSD_{01}			0.28	0.50	0.23	0.29	0.12	0.13	4.44	3.72
LSD_{05}			0.20	0.36	0.17	0.21	0.09	0.09	3.21	2.69

indicates the reaction of the genotype to the change in environmental conditions, the varieties of intensive type (b_i > 1) *Harantiia odes'ka* – 1.28 and *Schedrist' odes'ka* – 1.21, stable type (b_i < 1) varieties *Rosynka* – 0.66 and *Ledia* – 0.79. If b_i = 1, then the genotype is well adapted to various growing conditions, the closest to this are the *Askaniis'ka* varieties – 1.02.

If we compare the analysis for years with different moisture availability and with dry years (part 2 – drought years), there are differences: in the variety *Harantiia odes'ka*, the regression coefficient (b_i) for dry years was equal to 1.55, and for years with different moisture availability – 1.28. Although the variety is intensive in both samples, wet years have their effect. The variety *Schedrist' odes'ka* in drought years belongs to the plastic type (b_i = 1.01), and in years of different moisture supply to the intensive type (b_i = 1.21). The variety *Burhunka* in dry years belongs to the stable type (b_i = 0.84), and in years of different moisture supply to the intensive type (b_i = 1.12). The variety *Mariia* in dry years belongs to the intensive type (b_i = 1.23), and in years of different moisture supply it is already approaching the plastic type (b_i = 1.05). The variety *Lira odes'ka* in both samples is of a stable type, but in dry years bi – 0.69, and in years with different moisture supply b_i – 0.86. That is, years with sufficient moisture affected adaptability, ecological plasticity and choice of cultivar type and lead to errors in the analysis, although they have a smaller effect than when determining drought tolerance. Therefore, it is necessary to exclude these years when analyzing the adaptability and ecological plasticity of plants, if you analyze the resistance of plants to drought stress in two environments (irrigation and natural humidification). If the analysis is carried out under conditions of natural moisture, then years with sufficient moisture are considered optimal, and dry years are considered stressful or limited.

During the analysis of winter wheat varieties, according to the variance of the deviation from the regression line (s^2_{di}), *Konka* – 0.070 and *Askaniis'ka* – 0.040 were selected as the varieties with the highest predicted stability, while the lowest predicted stability was characterized by the varieties *Harantiia odes'ka* – 0.600 and *Schedrist' odes'ka* – 0.657.

According to the coefficient of adaptability (*CA*), the varieties *Koshova* – 105.8, *Lira odes'ka* – 106.9 and *Schedrist' odes'ka* – 105.1 stood out.

Rosynka – 35.1 and *Lira odes'ka* – 36.3 possessed the highest values of homeostaticity (*Hom*), which indicates the resistance of plants to adverse environmental factors and characterizes the ability of plants to develop normally under adverse environmental conditions.

The highest effect of the general adaptive capacity (GAC_i) was noted by the variety of winter wheat *Lira odes'ka* – 0.44, the lowest value – variety *Rosynka* – -0.97 (Table 3).

The stability of the reaction of the genotype to changes in environmental conditions in terms of productivity is determined by the value of the variance (σ^2_{SACi}), which charac-

Table 3

Parameters of adaptive properties of winter wheat varieties based on grain yield (2016–2020)

Variety	Designa-tion	Yield, t/ha		Adaptability parameters						
		Ymin-Ymax	*Ymean*	GAC_i	$\sigma^2_{(G\times E)gi}$	σ^2_{SACi}	s_{gi}	SVG_i	K_{gi}	I_{gi}
Anatoliia	G1	4.47–8.04	6.29	-0.03	0.07	1.27	17.9	3.35	1.02	0.058
Burhunka	G2	4.32–8.46	6.38	0.05	0.47	2.06	22.5	2.64	1.64	0.230
Konka	G3	4.75–7.51	6.34	0.01	0.06	1.04	16.1	3.68	0.83	0.053
Kokhana	G4	4.61–7.98	6.59	0.27	0.15	1.01	15.3	3.96	0.81	0.151
Koshova	G5	4.67–7.94	6.69	0.37	0.07	1.27	16.9	3.75	1.02	0.052
Mariia	G6	4.29–7.80	6.59	0.27	0.29	1.69	19.7	3.20	1.35	0.169
Ledia	G7	4.00–6.59	5.66	-0.66	0.18	0.92	16.9	3.17	0.73	0.200
Rosynka	G8	3.87–6.66	5.35	-0.97	0.37	0.77	16.4	3.06	0.61	0.478
Khersons'ka bezosta	G9	4.07–7.63	6.14	-0.19	0.21	1.77	21.7	2.67	1.42	0.121
Askaniis'ka	G10	4.50–7.97	6.60	0.28	0.01	1.34	17.5	3.59	1.07	0.010
Harantiia odes'ka	G11	3.01–8.23	6.10	-0.23	0.61	2.59	26.4	1.90	2.07	0.234
Zysk	G12	4.67–7.53	6.34	0.02	0.21	1.17	17.1	3.52	0.94	0.179
Lira odes'ka	G13	4.99–8.09	6.76	0.44	0.18	1.10	15.6	4.02	0.88	0.165
Mudrist' odes'ka	G14	4.06–7.89	6.46	0.13	0.22	1.85	21.0	2.92	1.48	0.118
Nyva odes'ka	G15	4.16–7.67	6.45	0.12	0.21	1.83	21.0	2.93	1.46	0.113
Pylypivka	G16	4.44–7.23	5.89	-0.44	0.14	1.22	18.8	3.01	0.98	0.113
Tradytsiia odes'ka	G17	4.32–8.32	6.55	0.23	0.24	1.94	21.3	2.92	1.55	0.126
Schedrist' odes'ka	G18	4.65–8.58	6.64	0.32	0.62	2.44	23.5	2.57	1.95	0.253
Medium grade		**4.33–7.85**	**6.32**	**0.00**	**0.24**	**1.52**	**19.2**	**3.16**	**1.21**	**0.157**
V, %			5.93	-67692	73.40	34.75	16.18	17.16	34.72	66.87
$S\dot{x}_{absolute}$			0.09	0.09	0.04	0.12	0.73	0.13	0.10	0.02
$S\dot{x}_{reletive}$			1.40	-15955	17.30	8.19	3.81	4.05	8.18	15.76
LSD_{01}			0.28	0.28	0.13	0.39	2.32	0.41	0.31	0.08
LSD_{05}			0.20	0.20	0.09	0.28	1.68	0.29	0.23	0.06

terizes the specific adaptive capacity, that is, in favorable environmental conditions, a variety with a high value of this indicator forms a relatively high yield. The most stable *Rosynka* varieties were established – 0.77. Varieties *Harantiia odes'ka* – 2.59 and *Schedrist' odes'ka* – 2.44 are unstable.

According to the indicator of relative stability of the genotype (s_{gi}), the varieties *Koshova* – 15.3 and *Lira odes'ka* – 15.6 were selected, which characterizes them as the most stable.

Varieties *Anatoliia*, *Konka*, *Koshova* and *Askaniis'ka* were characterized by the smallest values (0.01–0.07) of the variance of the interaction of genotype and environment ($\sigma^2_{(G\times E)gi}$), and had a linear response (I_{gi}) to changes in environmental conditions (0.010–0.058). However, only in the variety *Konka* K_{gi} < 1, and in the others it was more than one, which indicates the predominance of the destabilization effect. The lowest values of the compensation coefficient (K_{gi}) were characterized by varieties *Ledia* – 0.73 and *Rosynka* – 0.61. Varieties *Harantiia odes'ka* and *Schedrist' odes'ka* were characterized by the largest values (0.61–0.62) of the variance of the interaction of genotype and environment ($\sigma^2_{(G\times E)gi}$) and the compensation coefficient (K_{gi}) – 2.07 and 1.95, respectively, which characterizes them as the most unstable. When selecting stable varieties, preference should be given to varieties with K_{gi} <1.

The variety *Lira odes'ka* were characterized by a high selection value of the genotype (SVG_i) – 4.02. Varieties of this type are the most valuable and can give maximum yields even under adverse conditions.

According to adaptability parameters, varieties *Rosynka* and *Lira odes'ka* were selected as the most stable, while *Harantiia odes'ka* and *Schedrist' odes'ka* were selected as intensive type varieties. The variety *Askaniis'ka* was classified as plastic.

Between the maximum (*Ymin*) and the minimum yield (*Ymax*) there is no dependence r = 0.174, but it has increased compared to dry years. The level of maximum yield (*Ymax*) of winter wheat varieties was characterized by a high positive relationship (r = 0.791–0.794) with the average yield (*Ymean*), genetic flexibility (*Gf*), adaptability coefficient (*CA*) and general adaptive capacity (GAC_i), on the other hand, the level minimum yield (*Ymin*) was characterized by an average positive dependence (r = 0.544–0.679) with these parameters (Table 4).

The level of minimum productivity (*Ymin*) was characterized by an average positive correlation (r = 0.412) with homeostaticity (*Hom*), but with maximum productivity (*Ymax*) it had a low negative dependence (-0.222).

The level of the minimum yield (*Ymin*) was characterized by a high positive correlation (r = 0.758–0.779) with the selection of the variety (*Sc*) and the selection value of the genotype (SVG_i), on the other hand, with the maximum yield (*Ymax*), the selection value of the variety (*Sc*) had an average dependence (0.515), and with the selection value of the genotype (SVG_i) – a low negative dependence (-0.169).

Table 4

Matrix of correlations between the maximum and minimum yield of winter wheat varieties and homeostaticity, ecological plasticity and adaptability parameters (2016–2020)

	Ymin	*Ymax*	*Ymean*	*RS*	*Sc*	*Gf*	b_i	s^2_{di}	*CA*	*Hom*	GAC_i	$\sigma^2_{(G\times E)gi}$	σ^2_{SACi}	s_{gi}	SVG_i	K_{gi}	l_{gi}
Ymin	**1.000**	0.174	0.544	-0.530	0.758	0.679	-0.340	-0.429	0.546	0.412	0.548	-0.511	-0.436	-0.616	0.779	-0.433	-0.404
Ymax	0.174	**1.000**	0.793	0.688	0.515	0.794	0.725	0.447	0.792	-0.222	0.791	0.320	0.688	0.496	-0.169	0.690	-0.292
Ymean	0.544	0.793	**1.000**	0.345	0.766	0.918	0.445	0.004	1.000	-0.139	1.000	-0.138	0.314	0.052	0.329	0.317	-0.580
RS	-0.530	0.688	0.345	**1.000**	-0.092	0.263	0.853	0.671	0.344	-0.541	0.341	0.607	0.881	0.832	-0.653	0.881	0.025
Sc	0.758	0.515	0.766	-0.092	**1.000**	0.782	-0.046	-0.342	0.765	0.514	0.768	-0.433	-0.174	-0.391	0.662	-0.172	-0.490
Gf	0.679	0.794	0.918	0.263	0.782	**1.000**	0.352	0.093	0.919	-0.001	0.919	-0.056	0.268	0.019	0.321	0.270	-0.438
b_i	-0.340	0.725	0.445	0.853	-0.046	0.352	**1.000**	0.586	0.444	-0.654	0.438	0.476	0.957	0.895	-0.676	0.958	-0.244
s^2_{di}	-0.429	0.447	0.004	0.671	-0.342	0.093	0.586	**1.000**	0.005	-0.429	0.002	0.980	0.791	0.799	-0.761	0.789	0.560
CA	0.546	0.792	1.000	0.344	0.765	0.919	0.444	0.005	**1.000**	-0.140	1.000	-0.137	0.313	0.051	0.329	0.316	-0.578
Hom	0.412	-0.222	-0.139	-0.541	0.514	-0.001	-0.654	-0.429	-0.140	**1.000**	-0.135	-0.361	-0.636	-0.636	0.551	-0.638	0.154
GAC_i	0.548	0.791	1.000	0.341	0.768	0.919	0.438	0.002	1.000	-0.135	**1.000**	-0.140	0.308	0.045	0.335	0.311	-0.577
$\sigma^2_{(G\times E)gi}$	-0.511	0.320	-0.138	0.607	-0.433	-0.056	0.476	0.980	-0.137	-0.361	-0.140	**1.000**	0.710	0.746	-0.765	0.707	0.688
σ^2_{SACi}	-0.436	0.688	0.314	0.881	-0.174	0.268	0.957	0.791	0.313	-0.636	0.308	0.710	**1.000**	0.961	-0.792	1.000	0.032
s_{gi}	-0.616	0.496	0.052	0.832	-0.391	0.019	0.895	0.799	0.051	-0.636	0.045	0.746	0.961	**1.000**	-0.925	0.960	0.148
SVG_i	0.779	-0.169	0.329	-0.653	0.662	0.321	-0.676	-0.761	0.329	0.551	0.335	-0.765	-0.792	-0.925	**1.000**	-0.790	-0.372
K_{gi}	-0.433	0.690	0.317	0.881	-0.172	0.270	0.958	0.789	0.316	-0.638	0.311	0.707	1.000	0.960	-0.790	**1.000**	0.027
l_{gi}	-0.404	-0.292	-0.580	0.025	-0.490	-0.438	-0.244	0.560	-0.578	0.154	-0.577	0.688	0.032	0.148	-0.372	0.027	**1.000**

** − Confidence interval (%): 95*

The level of minimum productivity (*Ymin*) was characterized by an average negative correlation (r = -0.340–-0.616) with the level of resistance to stress conditions (*RS*), the regression coefficient (b_i), the variance of the deviation from the regression line (s^2_{di}), the stability of the genotype response (σ^2_{SACi}), the relative stability of the genotype (s_{gi}), the variance of the interaction between the genotype and the environment ($\sigma^2_{(G\times E)gi}$) and the compensation coefficient (K_{gi}), on the other hand, the level of the maximum yield (*Ymax*) with these indicators had an average positive relationship (r = 0.320–0.690), except for the regression coefficient (b_i) with which the correlation was 0.725. That is, if the varieties are characterized by high values of these parameters, then such varieties are classified as intensive, if they are low, they are stable. However, comparing the dependence between these parameters and the level of minimum productivity (*Ymin*) with dry years (Part 2) are characterized by weaker dependences.

According to the results of the GGE biplot analysis, winter wheat varieties *Konka* (G3), *Zysk* (G12) and *Lira odes'ka* (G13), located in one quarter of the vector of the minimum yield level (*Ymin*) and as close as possible to it, form a high yield under stressful conditions and can be considered stable (Fig. 1).

The varieties *Burhunka* (G2), *Tradytsiia odes'ka* (G17) and *Schedrist' odes'ka* (G18), which are in one quarter with the maximum yield level vector (*Ymax*) and are as close as possible to it, form a high yield under optimal conditions and can be considered intensive type varieties.

The varieties *Anatoliia* (G1), *Kokhana* (G4), *Koshova* (G5) and *Askaniis'ka* (G10), which are between the vectors of yield levels, can be distinguished as plastic, that is, those that form high yields under different growing conditions.

The winter wheat variety *Harantiia odes'ka* (G11), located in the III quarter and characterized by genetic divergence in terms of intensity, i.e., the greatest decrease in yield when conditions worsen, is the most intensive variety, but it is inferior to the varieties *Burhunka* (G2), *Tradytsiia odes'ka* (G17) and *Schedrist' odes'ka* (G18) by performance under optimal conditions.

Winter wheat varieties *Ledia* (G7) and *Rosynka* (G8), which are in the IV quarter and are characterized by genetic divergence regarding stability, i.e. the smallest decrease in yield when conditions deteriorate, are the most stable, but have the lowest yield under stress.

Cluster analysis allows identification of winter wheat varieties based on genetically determined drought resistance. The advantage of the cluster analysis method is that its mathematical apparatus allows you to find and highlight the accumulation of objects (points) that actually exists in the feature space based on simultaneous grouping by a large number of features. Construction and analysis of dendrograms details information about the nature of relationships between lineages at the cluster level and specifies relationships between populations within their boundaries. On the dendrogram, the numbers of the objects being merged and the distance at which the merger took place are indicated (Fig. 2).

The varieties that formed four subclusters were the closest in terms of productivity and adaptability parameters: G1 – *Anatoliia* and G3 – *Konka* united at a distance of 4, G4 – *Kokhana* and G5 – *Koshova* united at a distance of 4, and at a distance of 5 they were joined by a variety G10 – *Askaniis'ka* and varieties G2 – *Burhunka* and G17 – *Tradytsiia odes'ka*, united at a distance of 7, were further grouped into 1 cluster, G14 – *Mudrist' odes'ka* and G15 – *Nyva odes'ka* were united at a distance of 4 and further grouped into 2 cluster Genetic divergence in terms of productivity and adaptability parameters was shown by the variety G8 – *Rosynka*. In general, four clus-

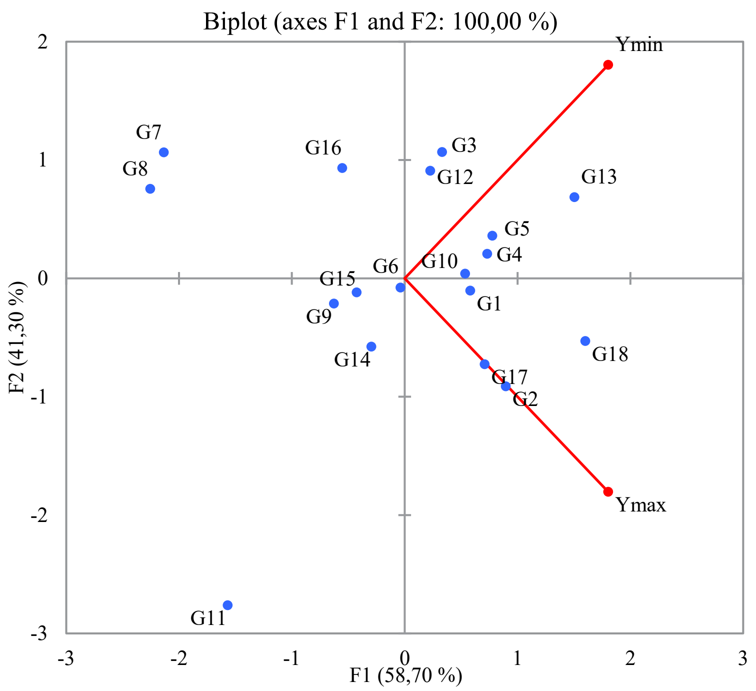

Fig. 1. Genotype-environment interaction of winter wheat varieties and environments (biplot analysis method). The lines show the eigenvectors of the leading factor loads for the environments: ● – yield level; ● – varieties

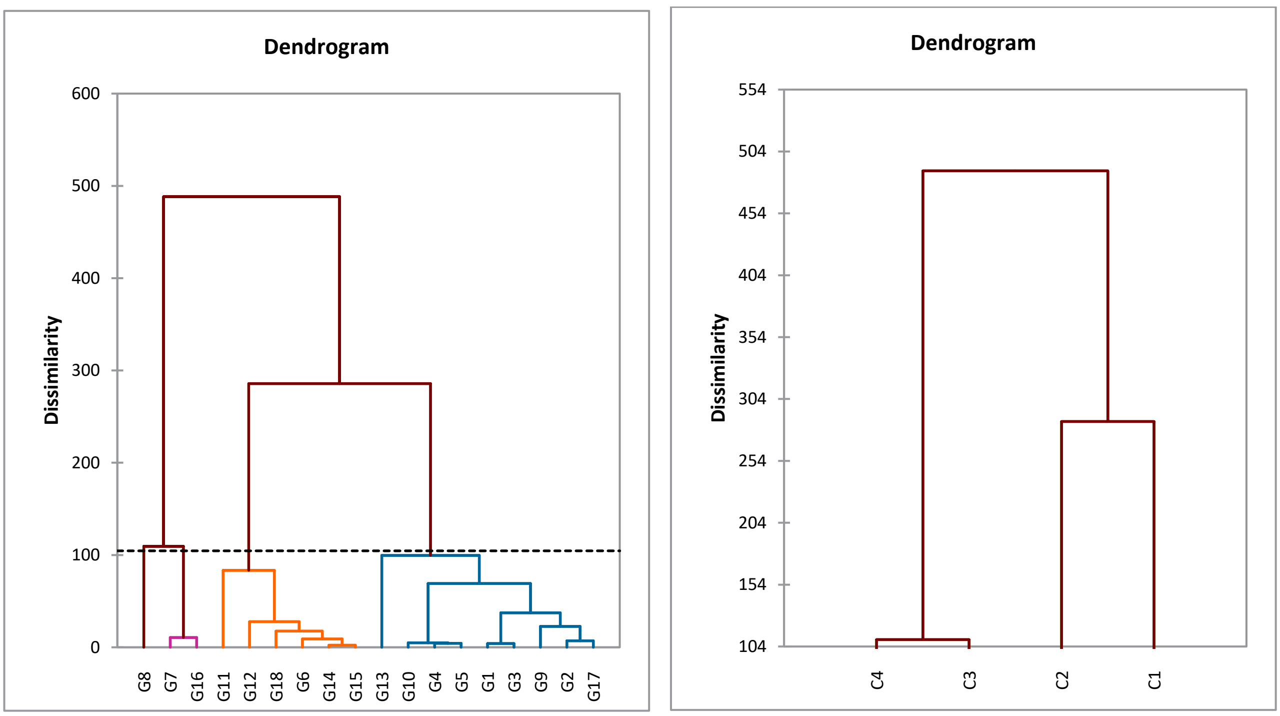

Fig. 2. Clustering dendrogram of eighteen winter wheat varieties according to drought resistance

ters were formed: in the first cluster nine varieties of the plastic type were united at a distance of 100, in the second cluster six varieties of the intensive type were united at a distance of 83, in the third cluster two varieties were united at a distance of 11 and in the fourth *Rosynka* variety entered (Table 5).

A cluster analysis of winter wheat varieties was also carried out using the k-means method. This method differs in that before starting, you need to choose the number of clusters yourself. Based on the agglomerative hierarchical cluster analysis described above, we proposed four clusters.

Table 5

Clustering of eighteen varieties of winter wheat according to drought resistance by the method of k-means and agglomerative hierarchical cluster analysis

Variety	Designation	k-means clustering		Agglomerative hierarchical clustering
		Cluster	Distance to the center of the cluster	Cluster
Anatoliia	G1	1	4.543	1
Burhunka	G2	2	5.332	1
Konka	G3	1	3.281	1
Kokhana	G4	3	3.824	1
Koshova	G5	1	3.915	1
Mariia	G6	3	3.864	2
Ledia	G7	4	5.736	3
Rosynka	G8	4	5.736	4
Khersons'ka bezosta	G9	2	4.919	1
Askaniis'ka	G10	3	2.029	1
Harantiia odes'ka	G11	2	8.398	2
Zysk	G12	3	3.840	2
Lira odes'ka	G13	1	6.938	1
Mudrist' odes'ka	G14	2	4.210	2
Nyva odes'ka	G15	2	3.087	2
Pylypivka	G16	2	8.119	3
Tradytsiia odes'ka	G17	2	5.895	1
Schedrist' odes'ka	G18	2	6.757	2

Cluster 1 includes four varieties *Anatoliia* (G1), *Konka* (G3), *Koshova* (G5) and *Lira odes'ka* (G13) of a plastic type with a tendency towards stability, compared to agglomerative hierarchical cluster analysis, the exceptions are the varieties *Burhunka* (G2), *Khersons'ka bezosta* (G9), and *Tradytsiia odes'ka* (G17), included in the second cluster, and *Kokhana* (G4) and *Askaniis'ka* (G10) included in the third cluster. The smallest distance to the center of the cluster was observed in the variety *Konka* (G3) at the level of 3.281, while the largest was 6.938 in the variety *Lira odes'ka* (G13) (Table 5).

Cluster 2 includes eight varieties of the intensive type. If compared with the agglomerative hierarchical cluster analysis, three varieties from the first cluster, *Burhunka* (G2), *Khersons'ka bezosta* (G9), and *Tradytsiia odes'ka* (G17), as well as *Pylypivka* (G16), which moved from the third cluster, were added instead of the variety *Mariia* (G6) and *Zysk* (G12) moved to the third cluster. The smallest distance to the center of the cluster was observed in the variety *Nyva odes'ka* (G16) at the level of 3.087, on the other hand, the largest was 8.398 in G11 – *Harantiia odes'ka*.

The third cluster included four varieties of the plastic type with a bias towards intensity. If compared with the agglomerative hierarchical cluster analysis, the varieties *Kokhana* (G4) and *Askaniis'ka* (G10) from the first cluster were added, *Mariia* (G6) and *Zysk* (G12) from the second, instead, the varieties *Pylypivka* (G16) moved to the second, and *Ledia* (G7) to the fourth. The smallest distance of 2.029 to the center of the cluster was observed in the *Askaniis'ka* variety (G10), and the largest was 3.864 in the *Mariia* variety (G6).

The fourth cluster was formed by the most stable varieties *Ledia* (G7) and *Rosynka* (G8), with the same distance to the center of the cluster – 5.736.

Conclusions. The selected parameters of adaptability are the level of resistance to stressful conditions (*RS*), the regression coefficient (b_i), the variance of the deviation from the regression line (s^2_{di}), the sign of the stability of the genotype response (σ^2_{SACi}), the variance of the interaction between the genotype and the environment ($\sigma^2_{(G\times E)gi}$), compensation coefficient (K_{gi}), relative stability of the genotype (s_{gi}), selection value of the genotype (SVG_i), selection value of the variety (*Sc*) and homeostaticity (*Hom*) by which the type of variety can be most clearly characterized.

According to adaptability parameters, varieties *Konka* and *Lira odes'ka* were selected as the most stable, while *Burhunka* and *Schedrist' odes'ka* were selected as intensive type varieties. Varieties *Koshova* and *Askaniis'ka* are selected as plastic.

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Коновалова В.М., Тищенко А.В., Базалій Г.Г., Фундират К.С., Тищенко О.Д., Резниченко Н.Д., Коновалов В.О. Екологічна пластичність та стабільність сортів пшениці озимої в умовах Південного Степу України (Ч. 3 – роки з різним вологозабезпеченням)

Метою наших досліджень було вивчення і аналіз екологічної стійкості та адаптивності до різних середовищ сортів озимої пшениці селекції Інституту кліматично орієнтованого сільського господарства НААН та Селекційно-генетичного інституту Національного центру насіннєзнавства та сортовивчення НААН в умовах Південного Степу України. **Матеріали і методи досліджень.** Реакцію 18 сортів озимої пшениці на різні умови вирощування вивчали на Асканійській державній сільськогосподарській дослідницькій станції у с. Тавричанка, Херсонська область (46°33'12»N; 33°49'13»E; 39 м над рівнем моря) протягом 2015/16–2019/20 рр. Дослідження проводилися за різних умов зволоження: при зрошенні та без зрошення. Аналіз екологічної стійкості та адаптивності до різних середовищ сортів озимої пшениці проводили за допомогою різних параметрів. **Результати дослідження та їх обговорення.** Отримані експериментальні дані дозволяють виділити сорти озимої пшениці з найбільшою врожайністю за мінімальною продуктивністю (Ymin) Конка – 4,75 т/га і Ліра одеська – 4,99 та за максимальною продуктивністю (Ymax) Бургунка – 8,46 т/га, Гарантія одеська – 8,23, Традиція одеська – 8,32 та Щедрість одеська – 8,58. Найменшою урожайністю характеризувалися сорти Росинка – 3,87 т/га і Гарантія одеська – 3,01 т/га за мінімальною (Ymin) та сорти Ледя – 6,59 т/га і Росинка – 6,66 т/га за максимальною (Ymax). За параметрами адаптивності, як найбільш стабільні, виділені сорти Росинка та Ліра одеська, натомість Гарантія одеська та Щедрість одеська були виділені як сорти інтенсивного типу. Сорт Асканійська була віднесена до пластичних. Сформовано чотири кластери: в перший кластер об'єдналися на відстані 100 дев'five сортів пластичного типу, в другий кластер об'єдналися на відстані 83 шість сортів інтенсивного типу, в третій кластер об'єдналися на відстані 11 два сорти та в четвертий увійшов сорт Росинка. За кореляційним аналізом виділені параметри адаптивності рівень стійкості до стресових умов (RS), коефіцієнт регресії (b_i), дисперсія відхилення від лінії регресії (s^2_{di}), ознака стабільності реакції генотипу ($σ^2_{CA3i}$), варіанса взаємодії генотипу та середовища ($σ^2_{(G×E)gi}$), коефіцієнт компенсації (K_{gi}), відносна стабільність генотипу (s_{gi}), селекційна цінність генотипу (СЦГі), селекційна цінність сорту (Sc) та гомеостатичність (Hom) за якими найбільш чітко можна охарактеризувати тип сорту. Висновки. Виділені параметри адаптивності, за ними та біплот-аналізом, як найбільш стабільний, були виділені сорти Конка та Ліра одеська, натомість Бургунка та Щедрість одеська виділені як сорти інтенсивного типу. Сорти Кошова та Асканійська виділені як пластичні.

Ключові слова: озима пшениця, сорт, зрошення, природнє зволоження, урожайність, адаптивність, стабільність, екоградієнт, біплот-аналіз, кластерний аналіз.

Konovalova V.M., Tyshchenko A.V., Bazalii H.G., Fundirat K.S., Tyshchenko O.D., Reznichenko N.D., Konovalov V.O. Ecological plasticity and stability of winter wheat varieties in the conditions of the Southern Steppe of Ukraine (Part 3 – years with different moisture supply)

The purpose of our research was to study and analyze the environmental stability and adaptability to different environments of winter wheat varieties selected by the Institute of Climate-oriented Agriculture of the National Academy of Sciences and the Selection and Genetic Institute of the National Center for Seed Science and Varietal Research of the National Academy of Sciences in the conditions of the Southern Steppe of Ukraine. **Research materials and methods.** The reaction of 18 varieties of winter wheat to different growing conditions was studied at the Askania State Agricultural Research Station in the village of Tavrychanka, Kherson region (46°33'12"N; 33°49'13"E; 39 m above sea level) during 2015/16–2019/20. Research was conducted under different conditions of irrigation: with irrigation and without irrigation. Analysis of environmental stability and adaptability to different environments of winter wheat varieties was carried out using various parameters. **Research results and their discussion.** The obtained experimental data allow us to distinguish the varieties of winter wheat with the highest productivity according to the minimum productivity (Ymin) Konka – 4.75 t/ha and Lira odes'ka – 4.99 and according to the maximum productivity (Ymax) Burhunka – 8.46 t/ha, Harantiia odes'ka – 8.23, Tradytsiia odes'ka – 8.32 and Schedrist' odes'ka – 8.58. The lowest productivity was characterized by Rosynka varieties – 3.87 t/ha and Harantiia odes'ka – 3.01 t/ha at the minimum (Ymin) and Ledia varieties – 6.59 t/ha and Rosynka – 6.66 t/ha at the maximum (Ymax). According to adaptability parameters, Rosynka and Lira odes'ka varieties were selected as the most stable, while Harantiia odes'ka and Schedrist' odes'ka were selected as intensive type varieties. The Askaniis'ka variety was classified as plastic. Four clusters were formed: in the first cluster nine varieties of the plastic type were united at a distance of 100, in the second cluster six varieties of the intensive type were united at a distance of 83, in the third cluster two varieties were united at a distance of 11 and in the fourth there was a variety Dewdrop. According to the correlation analysis, the parameters of adaptability were selected: the level of resistance to stressful conditions (RS), the regression coefficient (b_i), the variance of the deviation from the regression line (s^2_{di}), the sign of the stability of the genotype response (σ^2_{SACi}), the variance of the interaction between the genotype and the environment ($\sigma^2_{(G\times E)gi}$), compensation coefficient (K_{gi}), relative stability of the genotype (s_{gi}), selection value of the genotype (SVG_i), selection value of the variety (Sc) and homeostaticity (Hom) by which the type of variety can be most clearly characterized. **Conclusions.** The selected adaptability parameters, according to them and the biplot analysis, Konka and Lira odes'ka varieties were selected as the most stable, while Burhunka and Schedrist' odes'ka were selected as intensive type varieties Koshova and Askaniis'ka varieties are selected as plastic.

Key words: winter wheat, variety, irrigation, natural moisture, productivity, adaptability, stability, ecogradient, biplot analysis, cluster analysis.