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ECOLOGICAL PLASTICITY AND STABILITY OF WINTER WHEAT VARIETIES IN THE CONDITIONS OF THE SOUTHERN STEPPE OF UKRAINE (PART 1 – YEARS WITH SUFFICIENT MOISTURE)

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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 contributed 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. When analyzing the years with sufficient moisture (2016/17 and 2018/19), the indices of environmental conditions were equal to -0.55 and 0.01 for natural moisture conditions and 0.08 and 0.46 for irrigation, respectively. The obtained experimental data allow distinguishing the varieties of winter wheat with the highest productivity in terms of maximum productivity (*Ymax*) – *Burhunka* – 8.46 t/ha, *Tradytsiia odes'ka* – 8.32, and *Schedrist' odes'ka* – 8.58 t/ha, in terms of minimum productivity (*Ymin*) – *Koshova* – 7.14 t/ha, *Khersons'ka bezosta* – 7.00, *Lira odes'ka* – 7.24 t/ha and *Tradytsiia odes'ka* – 7.05 t/ha (Table 2).

According to the level of average yield (*Ymean*), winter wheat varieties *Burhunka* – 7.58 t/ha, *Koshova* – 7.61 t/ha, *Lira odes'ka* – 7.64 t/ha, *Tradytsiia odes'ka* and *Schedrist' odes'ka* – 7.68 t/ha.

The highest level of resistance to stress conditions (*RS*) was characterized by the winter wheat variety *Harantiia odes'ka* – 0.39, on the other hand, the lowest level of resistance was *Burhunka* – 2.08 and *Schedrist' odes'ka* – 3.34.

According to the breeding value of the variety (*Sc*), the varieties *Lira odes'ka* – 7.43 and *Tradytsiia odes'ka* – 7.63 were selected.

According to the indicator of genetic flexibility (*Gf*), winter wheat varieties *Lira odes'ka* – 7.67 and *Tradytsiia odes'ka* – 7.69 were selected, which formed a higher yield in contrasting conditions compared to other varieties.

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

Table 2

Homeostaticity, ecological plasticity and adaptability of winter wheat varieties based on grain yield (2017, 2019)

Variety	Designation	Yield, t/ha		Adaptability parameters						
		Ymin-Ymax	*Ymean*	RS	Sc	Gf	b_i	s^2_{di}	CA	Hom
Anatoliia	G1	6.76–8.04	7.23	1.28	6.56	7.40	1.19	0.103	100.6	104.2
Burhunka	G2	6.38–8.46	7.58	2.08	6.95	7.42	2.04	0.206	105.5	119.9
Konka	G3	6.50–7.51	7.10	1.01	6.66	7.01	1.01	0.010	98.8	155.3
Kokhana	G4	6.50–7.98	7.24	1.48	6.45	7.24	0.76	0.406	100.8	86.5
Koshova	G5	7.14–7.94	7.61	0.80	7.05	7.54	0.78	0.046	106.0	137.4
Mariia	G6	6.79–7.80	7.31	1.01	6.70	7.30	0.56	0.189	101.8	116.8
Ledia	G7	5.85–6.64	6.33	0.79	5.78	6.25	0.41	0.156	88.1	96.6
Rosynka	G8	5.62–6.66	6.12	1.04	6.02	6.14	0.08	0.305	85.1	518.6
Khersons’ka bezosta	G9	7.00–7.63	7.27	0.63	7.06	7.32	0.14	0.108	101.1	348.5
Askaniis’ka	G10	6.68–7.97	7.47	1.29	6.71	7.33	1.33	0.022	103.9	97.3
Harantiia odes’ka	G11	6.95–7.34	7.10	0.39	6.88	7.15	0.28	0.020	98.9	310.9
Zysk	G12	5.89–7.53	6.88	1.64	5.88	6.71	1.69	0.050	95.7	61.3
Lira odes’ka	G13	7.24–8.09	7.64	0.85	7.43	7.67	0.79	0.063	106.3	376.2
Mudrist’ odes’ka	G14	6.69–7.70	7.27	1.01	6.98	7.20	0.98	0.060	101.2	248.6
Nyva odes’ka	G15	6.54–7.67	7.26	1.13	6.91	7.11	1.13	0.077	101.1	200.4
Pylypivka	G16	5.92–7.23	6.56	1.31	6.31	6.58	1.22	0.206	91.3	233.8
Tradytsiia odes’ka	G17	7.05–8.32	7.68	1.27	7.63	7.69	0.16	0.392	106.9	1488.1
Schedrist’ odes’ka	G18	5.24–8.58	7.68	3.34	6.21	6.91	3.53	0.766	106.9	50.3
Medium grade		**6.49–7.73**	**7.18**	**1.24**	**6.68**	**7.11**	**1.00**	**0.177**	**100.0**	**263.9**
V, %			6.33	52.40	7.55	6.24	82.49	108.02	6.35	125.34
$S\dot{x}_{absolute}$			0.11	0.15	0.12	0.10	0.20	0.05	1.50	77.97
$S\dot{x}_{reletive}$			1.49	12.35	1.78	1.47	19.44	25.46	1.50	29.54
LSD_{01}			0.34	0.49	0.38	0.33	0.62	0.14	4.74	247.16
LSD_{05}			0.25	0.35	0.27	0.24	0.45	0.10	3.42	178.55

According to the regression coefficient (b_i), which is a criterion for assessing the level of ecological plasticity and indicates the reaction of the genotype to a change in environmental conditions, the intensive type variety ($b_i > 1$) *Schedrist’ odes’ka* – 3.53, the stable type varieties ($b_i < 1$) *Rosynka* – 0.08, *Khersons’ka bezosta* – 0.14, *Harantiia odes’ka* – 0.28 and *Tradytsiia odes’ka* – 0.16, and the plastic type variety ($b_i = 1$) *Konka* – 1.01.

During the analysis of winter wheat varieties by the variance of the deviation from the regression line (s^2_{di}), the varieties with the highest predicted stability *Konka* – 0.010, *Askaniis’ka* – 0.022 and *Harantiia odes’ka* – 0.020 were selected, on the other hand, the variety *Schedrist’ odes’ka* – 0.766 turned out to be the most unstable.

The varieties *Burhunka* – 105.5, *Koshova* – 106.0, *Lira odes’ka* – 106.3, *Tradytsiia odes’ka* and *Schedrist’ odes’ka* – 106.9 were characterized by high values of the coefficient of adaptability (*CA*).

According to homeostaticity (*Hom*), which characterizes the resistance of plants to adverse factors of the external environment, the variety *Tradytsiia odes’ka* stood out – 1488.1.

The greatest effects of general adaptive capacity (GAC_i) were noted for winter wheat varieties: *Koshova* – 0.43, *Lira odes’ka* – 0.45, *Tradytsiia odes’ka* – 0.50 and *Schedrist’ odes’ka* – 0.49. The lowest value of this characteristic was characterized by the varieties *Ledia* – -0.86 and *Rosynka* – -1.07 (Table 3).

According to the stability of the genotype reaction (σ^2_{SACi}), the most stable varieties were established: *Koshova* – 0.12, *Ledia* – 0.11, *Khersons’ka bezosta* – 0.06, *Harantiia odes’ka* – 0.01 and *Lira odes’ka* – 0.13. The variety *Schedrist’ odes’ka*, whose σ^2_{SACi} value is 2.62, is the most unstable.

According to the relative stability of the genotype (s_{gi}) the following varieties were selected as the most stable, with the lowest values of the relative stability of the genotype: *Koshova* – 4.5, *Khersons’ka bezosta* – 3.2, *Harantiia odes’ka* – 1.2 and *Lira odes’ka* – 4.7.

Varieties *Konka* – 0.01, *Koshova* – 0.02, *Askaniis’ka* – 0.01, *Mudrist’ odes’ka* – 0.02 and *Lira odes’ka* – 0.03 were characterized by the lowest values of the variance of the interaction of genotype and environment $\sigma^2_{(G\times E)gi}$, but only in *Koshova* and *Lira odes’ka* varieties, the compensation coefficient (K_{gi}) was less than one, 0.77 and 0.86, respectively, which indicates a stabilization effect. The largest value of the variance of the interaction of genotype and environment $\sigma^2_{(G\times E)gi}$ was characterized by the variety *Schedrist’ odes’ka* – 1.59, and the compensation coefficient was equal to 17.50, which indicates the predominance of

Table 3

Parameters of adaptive properties of winter wheat varieties based on grain yield (2017, 2019)

Variety	Designation	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	6.76–8.04	7.23	0.04	0.06	0.29	7.5	3.65	1.96	0.194
Burhunka	G2	6.38–8.46	7.58	0.40	0.30	0.83	12.0	1.57	5.52	0.366
Konka	G3	6.50–7.51	7.10	-0.08	0.01	0.16	5.7	4.43	1.09	0.071
Kokhana	G4	6.50–7.98	7.24	0.06	0.26	0.35	8.2	3.33	2.34	0.748
Koshova	G5	7.14–7.94	7.61	0.43	0.02	0.12	4.5	5.37	0.77	0.175
Mariia	G6	6.79–7.80	7.31	0.13	0.14	0.16	5.5	4.67	1.07	0.871
Ledia	G7	5.85–6.64	6.33	-0.86	0.14	0.11	5.3	4.10	0.76	1.277
Rosynka	G8	5.62–6.66	6.12	-1.07	0.70	0.28	8.6	2.63	1.85	2.535
Khersons'ka bezosta	G9	7.00–7.63	7.27	0.08	0.28	0.06	3.2	5.71	0.37	4.990
Askaniis'ka	G10	6.68–7.97	7.47	0.28	0.01	0.30	7.3	3.86	1.99	0.050
Harantiia odes'ka	G11	6.95–7.34	7.10	-0.08	0.08	0.01	1.2	6.55	0.05	11.654
Zysk	G12	5.89–7.53	6.88	-0.31	0.10	0.50	10.3	2.18	3.37	0.193
Lira odes'ka	G13	7.24–8.09	7.64	0.45	0.03	0.13	4.7	5.26	0.86	0.240
Mudrist' odes'ka	G14	6.69–7.70	7.27	0.09	0.02	0.19	5.9	4.42	1.24	0.114
Nyva odes'ka	G15	6.54–7.67	7.26	0.08	0.04	0.25	6.9	3.95	1.68	0.143
Pylypivka	G16	5.92–7.23	6.56	-0.63	0.13	0.37	9.3	2.53	2.48	0.342
Tradytsiia odes'ka	G17	7.05–8.32	7.68	0.50	0.25	0.47	8.9	3.14	3.15	0.524
Schedrist' odes'ka	G18	5.24–8.58	7.68	0.49	1.59	2.62	21.1	3.03	17.50	0.605
Medium grade		**6.49–7.73**	**7.18**	**0.00**	**0.23**	**0.40**	**7.6**	**3.57**	**2.67**	**1.386**
V, %			6.33		163.75	146.69	56.47	33.46	148.87	203.06
$S\dot{x}_{absolute}$			0.11	0.11	0.09	0.14	1.01	0.31	0.92	0.67
$S\dot{x}_{reletive}$			1.49		38.60	34.58	13.31	7.89	34.62	47.86
LSD_{01}			0.34	0.34	0.28	0.44	3.19	0.98	2.93	2.12
LSD_{05}			0.25	0.25	0.20	0.32	2.30	0.71	2.12	1.53

the destabilization effect. When selecting stable varieties, preference should be given to varieties with K_{gi} < 1.

The *Harantiia odes'ka* variety was characterized by a high selection value of the genotype (SVG_i) with a value of 6.55. Varieties of this type are the most valuable and can give maximum yields even under adverse conditions.

According to the parameters of adaptability, the *Harantiia odes'ka* variety was selected as the most stable, while the *Schedrist' odes'ka* was selected as an intensive type variety.

There is an average positive correlation r = 0.300 between the maximum and minimum yields. Both yield levels of winter wheat varieties were characterized by a high positive correlation (r = 0.791–0.820) with genetic flexibility (*Gf*). The maximum yield was characterized by a high positive dependence (r = 0.930–0.931) on the average yield (*Ymean*), adaptability coefficient (*CA*) and general adaptive capacity (GAC_i), on the other hand, the minimum yield with these parameters had an average positive dependence r = 0.543–0.545 (Table 4).

The minimum yield was characterized by an average negative correlation (r = -0.527– -0.623) with the level of resistance to stress conditions (*RS*), regression coefficient (b_i), variance of deviation from the regression line (s^2_{di}), a sign of stability of the genotype response (σ^2_{SACi}) and compensation coefficient (K_{gi}), instead, the maximum yield had an average positive relationship (r = 0.340–0.559) with these parameters. The relative stability of the genotype (s_{gi}) was characterized by a high negative correlation (r = -0.709) with the minimum productivity and a medium positive correlation (r = 0.443) with the maximum. This suggests that the lower the value of these parameters, the more stable the variety, and, conversely, the higher the value, the more unstable the variety is, that is, it belongs to the intensive type.

The selection value of the genotype (SVG_i) had a medium positive relationship (r = 0.643) with the minimum yield and a low negative (r = -0.122) with the maximum. The breeding value of the variety (*Sc*) was characterized by a high positive correlation (r = 0.840) with the minimum yield and average (r = 0.551) with the maximum yield, which suggests that the higher the values of these parameters, the more stable the variety.

The homeostatic index (*Hom*) had a low correlation with the productivity of both levels (r = 0.091–0.293).

According to the results of the GGE biplot analysis, winter wheat varieties *Koshova* (G5), *Khersons'ka bezosta* (G9), *Harantiia odes'ka* (G11) and *Lira odes'ka* (G13),

Table 4

Matrix of correlations between the maximum and minimum yield of winter wheat varieties and homeostaticity, ecological plasticity and adaptability parameters (2017, 2019)

	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	0.300	0.543	-0.623	0.840	0.820	-0.527	-0.549	0.543	0.293	0.545	-0.661	-0.611	-0.709	0.643	-0.612	0.178
Ymax	0.300	1.000	0.931	0.559	0.551	0.791	0.543	0.340	0.930	0.091	0.930	0.231	0.506	0.443	-0.122	0.505	-0.303
Ymean	0.543	0.931	1.000	0.291	0.730	0.906	0.347	0.118	1.000	0.124	1.000	0.046	0.299	0.159	0.203	0.297	-0.162
RS	-0.623	0.559	0.291	1.000	-0.278	-0.064	0.903	0.756	0.290	-0.180	0.288	0.764	0.946	0.979	-0.659	0.946	-0.403
Sc	0.840	0.551	0.730	-0.278	1.000	0.869	-0.261	-0.204	0.730	0.527	0.732	-0.316	-0.235	-0.339	0.421	-0.237	0.069
Gf	0.820	0.791	0.906	-0.064	0.869	1.000	-0.012	-0.148	0.906	0.243	0.907	-0.285	-0.088	-0.189	0.340	-0.089	-0.068
b_i	-0.527	0.543	0.347	0.903	-0.261	-0.012	1.000	0.461	0.346	-0.449	0.344	0.574	0.857	0.841	-0.475	0.858	-0.371
s^2_{di}	-0.549	0.340	0.118	0.756	-0.204	-0.148	0.461	1.000	0.118	0.192	0.117	0.884	0.815	0.796	-0.440	0.815	-0.146
CA	0.543	0.930	1.000	0.290	0.730	0.906	0.346	0.118	1.000	0.123	1.000	0.045	0.298	0.158	0.205	0.296	-0.161
Hom	0.293	0.091	0.124	-0.180	0.527	0.243	-0.449	0.192	0.123	1.000	0.125	0.001	-0.114	-0.081	-0.023	-0.114	0.094
GAC_i	0.545	0.930	1.000	0.288	0.732	0.907	0.344	0.117	1.000	0.125	1.000	0.042	0.295	0.156	0.204	0.293	-0.161
$\sigma^2_{(G\times E)gi}$	-0.661	0.231	0.046	0.764	-0.316	-0.285	0.574	0.884	0.045	0.001	0.042	1.000	0.887	0.801	-0.330	0.886	0.007
σ^2_{SACi}	-0.611	0.506	0.299	0.946	-0.235	-0.088	0.857	0.815	0.298	-0.114	0.295	0.887	1.000	0.934	-0.446	1.000	-0.206
s_{gi}	-0.709	0.443	0.159	0.979	-0.339	-0.189	0.841	0.796	0.158	-0.081	0.156	0.801	0.934	1.000	-0.726	0.935	-0.426
SVG_i	0.643	-0.122	0.203	-0.659	0.421	0.340	-0.475	-0.440	0.205	-0.023	0.204	-0.330	-0.446	-0.726	1.000	-0.448	0.556
K_{gi}	-0.612	0.505	0.297	0.946	-0.237	-0.089	0.858	0.815	0.296	-0.114	0.293	0.886	1.000	0.935	-0.448	1.000	-0.208
l_{gi}	0.178	-0.303	-0.162	-0.403	0.069	-0.068	-0.371	-0.146	-0.161	0.094	-0.161	0.007	-0.206	-0.426	0.556	-0.208	1.000

** – Confidence interval (%): 95.*

which are in the same quarter with the minimum yield vector (*Ymin*), are characterized by the smallest decrease in yield at deterioration of growing conditions and the highest yield under adverse conditions, that is, it is the most stable variety (Fig. 1).

The variety *Burhunka* (G5) is in one quarter of the maximum yield vector (*Ymax*) and is the closest to its peak, characterized by one of the largest reductions in yield when growing conditions worsen, that is, this variety can be classified as an intensive type. This type includes the variety *Schedrist' odes'ka* (G18), located in the III quarter, as close as possible to the ordinate axis and far from the center.

Winter wheat varieties *Anatoliia* (G1), *Askaniis'ka* (G10) and *Tradytsiia odes'ka* (G17), located on the abscissa axis, between the vectors of minimum yield (*Ymin*) and maximum yield (*Ymax*), are characterized by relatively high yields under both (worst and best conditions) of moisture, that is, they belong to the plastic type. However, none of them corresponds to this type according to the regression coefficient ($bi = 1$) – 1.19, 1.33 and 0.16, respectively.

Winter wheat varieties *Ledia* (G7) and *Rosynka* (G8) are in the IV quarter characterized by a small yield loss when conditions worsen, but they formed the lowest yield under both conditions.

Cluster analysis makes it possible to identify winter wheat varieties based on genetically determined adaptability to the relevant conditions. On the dendrogram, the numbers of the objects being merged and the distance at which the merger took place are indicated (Fig. 2).

The closest in terms of yield and adaptability parameters were the varieties that formed two subclusters: G1 – *Anatoliia* and G10 – *Askaniis'ka* at a distance of 30 and G3 – *Konka* and G5 – *Koshova* at a distance of 51 were further grouped into 1 cluster. In general, four clusters were formed: in the first cluster, at a distance of 5720, ten varieties that are more directed to the intensive type were united, in the third cluster, at a distance of 20857, six varieties that were more directed to the stable type were united. Genetic divergence was shown by varieties G8 – *Rosynka* to stability, forming cluster 2, and G17 – *Schedrist' odes'ka* to intensity, forming cluster 4 (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.

Cluster 1 included six varieties more directed to the intensive type, compared to the agglomerative hierarchical cluster analysis, the exceptions are the varieties G3 – *Konka*, G5 – *Koshova*, G12 – *Zysk* and G18 – *Schedrist' odes'ka*, which entered and formed the second cluster, as varieties of the intensive type. The smallest distance to the center of the first cluster was observed in the G1 – *Anatoliia* variety at the level of 1.058, whereas the largest 18.278 was observed in the G2 – *Burhunka* variety. The smallest distance to the center of the second cluster was observed in the G5 – *Koshova* variety at the level of 37.450, while the largest was 54.734 in the G3 – *Konka* variety (Table 5).

Cluster 3 included two varieties: G8 – *Rosynka*, transferred from cluster 2, and G17 – *Tradytsiia odes'ka*, transferred from cluster 4, with the same distance to the center of 484.880.

The fourth cluster includes six varieties that are more oriented to the stable type, with the smallest distance of 26.438 to the center of the cluster in the selection sample G11 – *Harantiia odes'ka*, and the largest – 90.075 in G13 – *Lira odes'ka*.

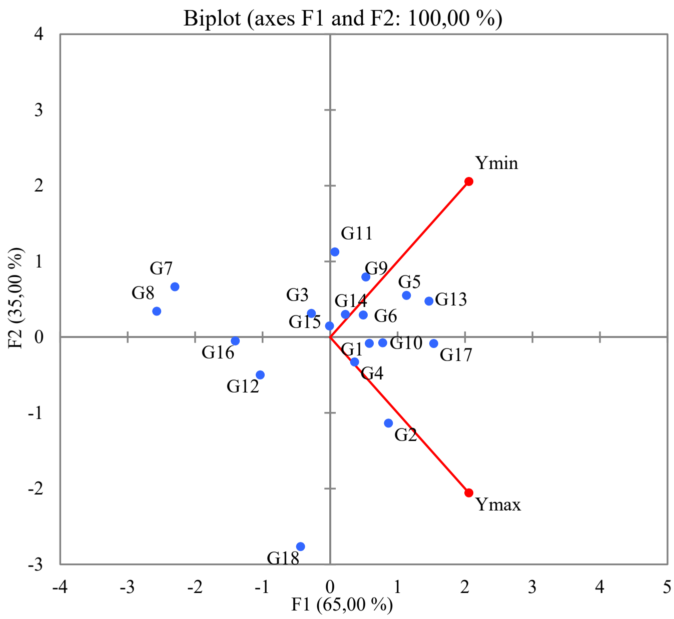
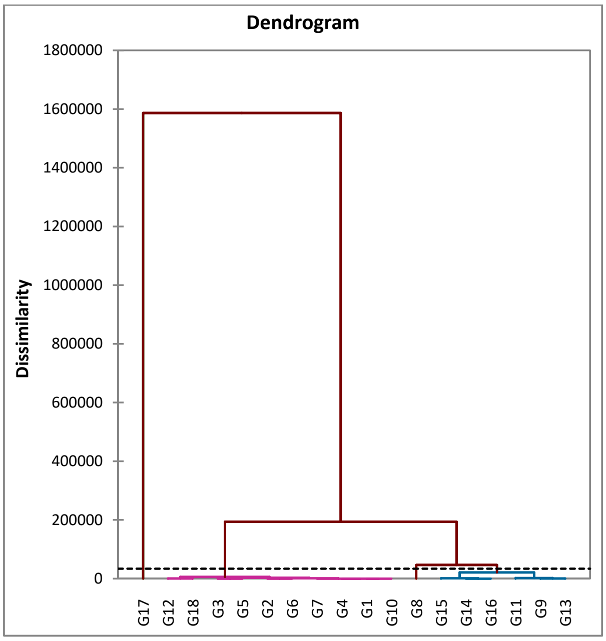


Fig. 1. Genotype-environment interaction of winter wheat varieties and environments (biplot analysis method). The lines show the eigenvectors of the leading factor loads for the environments:
● – yield level; ● – varieties



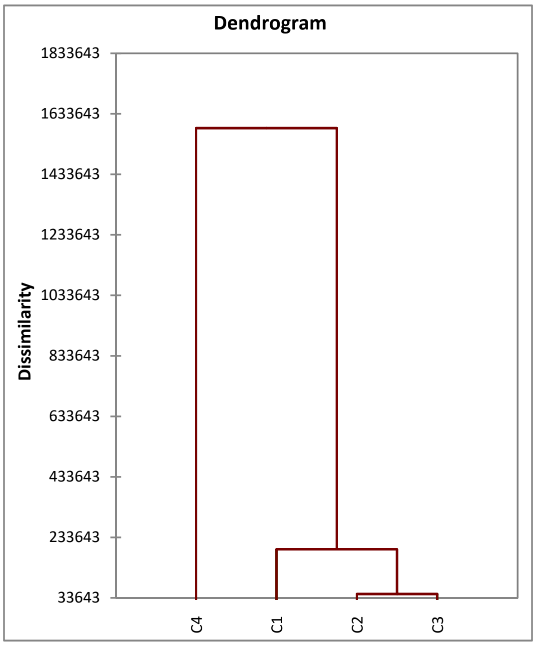


Fig. 2. Dendrogram of clustering of eighteen varieties of winter wheat according to adaptability to environmental conditions

Table 5

Clustering of eighteen varieties of winter wheat according to adaptability to environmental conditions 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
1	2	3	4	5
Anatoliia	G1	1	1.058	1
Burhunka	G2	1	18.278	1
Konka	G3	2	54.734	1
Kokhana	G4	1	17.093	1
Koshova	G5	2	37.450	1

Continuation of table 5

1	2	3	4	5
Mariia	G6	1	13.657	1
Ledia	G7	1	14.428	1
Rosynka	G8	3	484.880	2
Khersons'ka bezosta	G9	4	62.200	3
Askaniis'ka	G10	1	7.404	1
Harantiia odes'ka	G11	4	26.438	3
Zysk	G12	2	40.369	1
Lira odes'ka	G13	4	90.075	3
Mudrist' odes'ka	G14	4	37.934	3
Nyva odes'ka	G15	4	86.077	3
Pylypivka	G16	4	53.630	3
Tradytsiia odes'ka	G17	3	484.880	4
Schedrist' odes'ka	G18	2	53.593	1

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

According to the parameters of adaptability, the varieties *Koshova*, *Khersons'ka bezosta*, *Harantiia odes'ka* and *Lira odes'ka* were selected as the most stable, while *Schedrist' odes'ka* and *Burhunka* were selected as intensive type varieties.

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Тищенко А.В., Коновалова В.М., Базалій Г.Г., Фундират К.С., Тищенко О.Д., Резніченко Н.Д., Коновалов В.О. Екологічна пластичність та стабільність сортів пшениці озимої в умовах Південного Степу України (ч. 1 – роки з достатнім зволоженням)

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 дозволили виділити сорти озимої пшениці з найвищою урожайністю за максимальною продуктивністю – *Бургунка* – 8,46 т/га, *Традиція одеська* – 8,32 та *Щедрість одеська* – 8,58 т/га, за мінімальною продуктивністю – *Кошова* – 7,14 т/га, *Херсонська безоста* – 7,00, *Ліра одеська* – 7,24 т/га та *Традиція одеська* – 7,05 т/га. За параметрами адаптивності, як найбільш стабільний, був виділений сорт *Гарантія одеська*, натомість *Щедрість одеська* був виділений як сорт інтенсивного типу. 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}), коефіцієнт компенсації (K_{gi}), відносна стабільність генотипу (s_{gi}), селекційна цінність генотипу (*СЦГі*), селекційна цінність сорту (*Sc*) за якими найбільш чітко можна охарактеризувати тип сорту. **Висновки.** Виділені параметри адаптивності за ними та біплот-аналізом, як найбільш стабільний, були виділені сорти *Кошова*, *Херсонська безоста*, *Гарантія одеська* та *Ліра одеська*, натомість *Щедрість одеська* та *Бургунка* виділені як сорти інтенсивного типу.

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

Tyshchenko A.V., Konovalova V.M., Bazalii H.H., 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 1 – years with sufficient moisture)

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 made it possible to single out the varieties of winter wheat with the highest productivity in terms of maximum productivity – *Burhunka* – 8.46 t/ha, *Tradytsiia odes’ka* – 8.32 and *Schedrist’ odes’ka* – 8.58 t/ha, in terms of minimum productivity – *Koshova* – 7.14 t/ha, *Khersons’ka bezosta* – 7.00, *Lira odes’ka* – 7.24 t/ha and *Tradytsiia odes’ka* – 7.05 t/ha. According to the parameters of adaptability, the *Harantiia odes’ka* variety was selected as the most stable, while the *Schedrist’ odes’ka* was selected as an intensive type variety. 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 reaction (σ^2_{SACi}), the compensation coefficient (K_{gi}), the relative stability of the genotype (s_{gi}) , the selection value of the genotype (*SVGi*), the selection value of the variety (*Sc*) by which the type of variety can be most clearly characterized. **Conclusions.** According to them and the biplot analysis, the isolated parameters of adaptability were selected as the most stable varieties *Koshova*, *Khersons’ka bezosta*, *Harantiia odes’ka* and *Lira odes’ka*, instead *Schedrist’ odes’ka* and *Burhunka* were selected as intensive type varieties.

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