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FORMATION OF RESISTANCE OF ALFALFA PLANTS IN CONDITIONS OF DIFFERENT ECOLOGICAL GRADIENT FOR FODDER USE

Tyshchenko A. V. – Doctor of Agricultural Sciences, Senior Research
orcid.org/0000-0003-1918-6223
Institute of Climate-Smart Agriculture
of the National Academy of Agrarian Sciences of Ukraine
Tyshchenko O. D. – Candidate of Agricultural Sciences, Senior Research
orcid.org/0000-0002-8095-9195
Institute of Climate-Smart Agriculture
of the National Academy of Agrarian Sciences of Ukraine
PILIARSKA O. O. – Candidate of Agricultural Sciences, Senior Research
orcid.org/0000-0001-8649-0618
Institute of Climate-Smart Agriculture
of the National Academy of Agrarian Sciences of Ukraine

Introduction. Alfalfa is a perennial fodder crop grown all over the world and among fodder legumes is characterized by high productivity of fodder mass, its nutritional value with high protein content [3, 25, 33], as well as due to the root system helps increase soil fertility [14], protects soil from wind and water erosion [1, 35, 41]. In addition, the fixation of atmospheric nitrogen makes it an indispensable precursor for other crops [19, 32, 38, 40].

Alfalfa grows in a wide range of climatic conditions, from the equator and almost to the Arctic polar circles [5, 24, 39]. According to numerous forecasts, global climate change will lead to higher temperatures, changes in the geographical structure of precipitation and in the future to an increase in the frequency of extreme weather events [7, 10, 27, 55], which is already observed in southern Ukraine. Abiotic stresses are the main factors that reduce crop productivity. Drought is the most significant, as it limits the ability of agricultural plants, reducing their productivity in arid and semi-arid areas [8, 12, 17, 52, 57]. The intensity and severity of the drought can affect sensitive and strategic sectors, such as agriculture, which can threaten food security [15, 54]. The detrimental effects of abiotic stress are a serious limitation for growing this crop [26, 29, 51, 56]. But due to its strong and branched root system it is considered a culture with high drought resistance and wide adaptability to drought conditions [16, 21, 28, 53]. However, like any other crop, it reacts negatively to drought and, in order to adapt and survive under stress, it undergoes morphological, physiological, biochemical or molecular changes, which must be taken into account when creating drought-resistant varieties while increasing yields and product quality [9, 11, 13].

One of the main tasks facing alfalfa breeders is to create an optimal variety that can stably realize its potential and respond to changing growing conditions. In this regard, there is a need for a comprehensive assessment of breeding material for adaptive traits and yields in specific conditions [20, 31, 34, 36, 37, 49, 50].

The parameters of indicators of alfalfa forage were determined: stress resistance, selection value, genetic flexibility, homeostatic, general and specific ability and coefficients of adaptability, regression, stability in favorable (irrigation) and stressful (natural moisture) growing conditions.

The aim of the work is to study the adaptive potential of alfalfa genotypes of different ecological and geographical origin in the southern steppe of Ukraine and the selection of extensive, intensive and plastic.

Materials and methods. The response of alfalfa breeding samples to different growing conditions was studied at the Institute of Irrigated Agriculture, Kherson, Ukraine (46°44'33»N; 32°42'28»E; 50 m above sea level) during 2017–2020. The research was conducted under different humidification conditions: with and without irrigation (natural moisture). Under conditions of natural moisture, the yield strongly depended on the amount of precipitation during the growing season. Average temperatures and precipitation for all experimental seasons are shown in Table 1 together with long-term averages (1961–2015).

The study included 24 samples of alfalfa, of different ecological and geographical origin, which were tested in areas with an area of 25 m^2 in three replicates by randomized replicates (blocks), sowing rate was adjusted to 10 million viable seeds per hectare. The research was conducted according to the generally accepted method. The studied samples were sown in the third decade of March.

Statistical analysis. Analysis of the resistance of alfalfa genotypes to stress was performed using the index of environmental conditions (I_j), regression coefficient (b_i), predicted ecological stability, plasticity of the variety with different eco-gradient (S^2_{di}), determined by the method of Eberhart and Russell [6], indicators of stress resistance ($Y_{min} - Y$) and genetic flexibility (*Gf*) – by equations Rosielle and Hamblin [18] in the statement of Goncharenko, homeostatic parameters (*Hom*) and selection value (*Sc*) – according to Hangildin etc., coefficient of adaptability (CA) – by the method of Zhivotkov etc. [22], total adaptive capacity (TACi), variants of specific adaptive capacity (σ^2_{SACi}), relative stability of the genotype (s_{gi}), selection value of genotype (SVGi), nonlinearity coefficients (l_{gi}) and compensation-destabilization (C_{gi}), determined by Kilchevsky etc. [23].

A correlation analysis between forage yield and adaptability parameters was performed to determine extensive, intensive and plastic genotypes. Principal

Table 1

Weather conditions for conducting research (2017–2020)

	1961–2015		2017		2018		2019		2020	
	T **(°C)**	***P*** **(mm)**	***T*** **(°C)**	***P*** **(mm)**	***T*** **(°C)**	***P*** **(mm)**	***T*** **(°C)**	***P*** **(mm)**	***T*** **(°C)**	***P*** **(mm)**
March	2.3	26.0	7.0	5.2	1.5	61.0	5.9	7.3	7.6	6.2
April	10.0	33.0	9.3	87.9	14.1	1.6	10.5	56.0	9.8	2.8
May	16.0	42.0	16.3	25.6	19.5	35.7	18.0	72.8	14.7	29.3
June	19.9	45.0	22.0	10.3	22.9	23.1	23.8	92.6	22.7	45.1
July	21.9	49.0	23.4	39.8	24.2	90.8	23.2	48.7	24.7	59.0
August	21.3	37.8	25.4	4.8	25.5	0.0	23.4	22.1	23.8	25.3
September	16.4	40.0	19.9	0.7	18.7	42.8	18.1	12.1	20.8	25.0
October	10.2	28.0	11.3	12.0	13.5	9.6	11.6	10.4	15.5	21.5

Table 2

Homeostatic, ecological plasticity and adaptability of alfalfa populations on the basis of green mass yield in the amount of 2 years (2017–2020)

Variety, population	**Marking**	**Green mass yield, kg m^{-2}**		**Adaptability parameters**						
		$Y_{min} - Y_{max}$	***Ymean***	$Y_{min} - Y_{max}$, kg m^{-2}	***Sc***	***Gf***	b_i	S^2_{di}	***CA***	***Hom***
Unitro, standard	G1	5.03–22.83	13.46	–17.80	2.96	13.93	1.02	0.50	100.0	1.85
Elehiya	G2	3.99–23.21	14.07	–19.22	2.42	13.60	1.18	2.09	104.6	1.87
Prymorka	G3	4.05–22.82	12.71	–18.77	2.26	13.44	1.04	0.84	94.5	1.56
M.g. / P.p.	G4	4.85–24.43	14.20	–19.58	2.82	14.64	1.01	2.09	105.6	1.87
Sin(c). / Prymorka	G5	2.78–24.79	13.96	–22.01	1.57	13.79	1.15	1.97	103.8	1.61
LR / H	G6	5.28–23.69	14.09	–18.41	3.14	14.49	0.97	1.10	104.7	1.96
Prymorka / Sin(c).	G7	4.78–22.33	13.21	–17.55	2.83	13.56	0.93	0.64	98.2	1.80
A.-H. d. № 114	G8	3.05–22.34	12.84	–19.29	1.75	12.70	1.10	2.77	95.5	1.55
A.-H.d. № 15	G9	3.98–21.62	13.32	–17.64	2.45	12.80	1.04	2.90	99.0	1.83
A.-H. d. № 38	G10	4.86–21.22	13.38	–16.36	3.06	13.04	0.98	1.24	99.5	1.99
Selection by root system	G11	2.75–20.89	12.29	–18.14	1.62	11.82	0.96	1.63	91.4	1.51
Ram. d.	G12	5.57–22.48	13.82	–16.91	3.42	14.03	0.91	0.14	102.7	2.05
(Emeraude / T.)²	G13	5.16–23.30	13.61	–18.14	3.01	14.23	1.00	0.13	101.1	1.85
T. / Emeraude	G14	4.23–23.00	13.40	–18.77	2.47	13.62	1.03	0.97	99.6	1.74
M.g. / CP-11	G15	5.70–23.83	14.37	–18.13	3.44	14.77	1.01	0.09	106.8	2.07
Zymostiyka / M.K.	G16	3.83–21.52	13.19	–17.69	2.35	12.68	0.92	1.59	98.0	1.78
M.agr. / C.	G17	6.32–23.18	13.91	–16.86	3.79	14.75	0.94	0.67	103.4	2.08
A.r. d.	G18	5.57–21.40	13.01	–15.83	3.39	13.49	0.90	1.84	96.7	1.94
M.g. / M.agr.	G19	5.01–20.47	12.78	–15.46	3.13	12.74	0.86	0.13	95.0	1.92
M.g. d.	G20	4.65–21.45	12.90	–16.80	2.80	13.05	0.95	0.14	95.9	1.80
FHNV²	G21	6.61–23.13	13.63	–16.52	3.90	14.87	0.97	1.54	101.3	2.04
V.11/P. d.	G22	5.59–25.32	13.94	–19.73	3.08	15.46	1.09	1.66	103.6	1.79
G. / CP-11	G23	4.90–23.08	13.53	–18.18	2.87	13.99	1.04	0.69	100.5	1.83
Sybir. 8, d.	G24	5.43–21.57	13.28	–16.14	3.34	13.50	0.96	0.39	98.7	1.98
V, %			3.95	–8.22	22.03	6.29	7.81	73.24	3.95	8.85
$S\dot{x}_{absolute}$			0.11	0.30	0.13	0.18	0.02	0.17	0.81	0.03
$S\dot{x}_{relative}$			0.81	–1.68	4.50	1.28	1.59	14.95	0.81	1.81
$LSD_{0.01}$			0.34	0.95	0.40	0.56	0.05	0.55	2.56	0.11
$LSD_{0.05}$			0.25	0.69	0.29	0.40	0.04	0.40	1.85	0.08

component analysis (PCA) was performed on the basis of observations. Both correlation and PCA were performed using Microsoft ® Excel 2013/XLSTAT © -Pro (v.2015.6.01.23953, 2015, Addinsoft, Inc., Brooklyn, New York, USA).

Research results and their discussion. Over the years, the conditions for plant growth and development under irrigation have been more favorable than without it. The best conditions for irrigation were for sowing in 2017 (the first year of life with grass 2017, the second – 2018), where the index of environmental conditions (I_j) was + 9.21. Conditions for alfalfa crops in 2018 and 2019 were worse, the index of environmental conditions (I_j) was +3.73 and +5.04, respectively. In the conditions of natural moisture, the most favorable conditions were for sowing in 2017 with the index of environmental conditions − 3.93, while for crops in 2018 and 2019 they were worse and the index was − 5.34 and − 8.70, respectively.

According to the average yield of green mass (a total of two years) 8 populations significantly exceeded the standard *Unitro* (13.46 kg · m^{-2}), *Elehiya* (14.07 kg · m^{-2}), *M.g./P.p.* (14.20 kg · m^{-2}), *Sin(c)./Prymorka* (13.96 kg · m^{-2}), *LR/H* (14.09 kg · m^{-2}), *Ram. d.* (13.82 kg · m^{-2}), *M.g./CP-11* (14.37 kg · m^{-2}), *M.agr./C.* (13.91 kg · m^{-2}) and *V.11/P. d.* (13.94 kg · m^{-2}) (Table 2).

According to the level of stability of breeding samples of alfalfa (Ymin-Ymax) were identified populations: *M.g./M. agr.* – –15.46, *A.r. d.* – –15.83, *Sybir. 8, d.* – –16.14 and *A.-H. d. № 38* – –16.36 kg · m^{-2}, but none of them exceeded the yield standard.

Selection value (Sc) shows the stability of populations and is defined as the product of the average yield and the ratio between the minimum and maximum yield over the years of research. By high indicators of selection value (Sc) the populations were characterized: *FHNV*^{2} – 3.90, *M.agr./C.*> – 3.79, *M.g./CP-11* – 3.44 and *Ram. d.* – 3.42, but only populations *FHNV*^{2}, *M.agr./C.* and *Ram. d.* had a high rate of resistance to stress (Ymin-Ymax) was equal to –16.52; –16.86; –16.91, respectively), whereas in *M.g./CP-11* – –18.13.

The characteristics of the samples in relation to stress are supplemented by the indicator of genetic flexibility (Gf), which reflects the average yield of varieties in contrasting (optimal and limiting) conditions. High values of this indicator indicate a high degree of correspondence between population genotype and environmental factors. According to our calculations, alfalfa populations *V.11/P. d.* (15.46), *FHNV*^{2} (14.87), *M.g./CP-11* (14.77), *M.agr./C.* (14.75) і *M.g./P.p.* (14.64) stood out, that were able to form in contrast conditions a high yield of green mass in contrast to other genotypes.

Coefficient of adaptability (CA) reflects the ratio of the average yield of the sample to the yield of the average population. High adaptability of the variety provides stable yields in different environmental conditions, so an important characteristic of the genotype is its ability to stably realize its potential. Populations were characterized by high rates: *M.g./CP-11* – 106.8, *M.g./P.p.* – 105.6, *LR/H* – 104.7 and *Elehiya* – 104.6.

The regression coefficient (b_i) is a criterion for assessing the level of ecological plasticity and detects the response of the genotype to changes in environmental conditions. Analysis of the experimental material showed that the studied populations of alfalfa can be divided into three groups: intensive type ($b_i > 1$), stable ($b_i < 1$) and adapted to different conditions ($b_i = 1$). Genotypes with $b_i > 1$ are more sensitive to changes in growing conditions, i.e. such genotypes are demanding, for example, to the level of agricultural technology, mineral nutrition, etc. According to the regression coefficient (b_i), the best populations of the intensive type ($b_i > 1$) were *Elehiya*, in which it was 1.18, *Sin(c)./Prymorka* – 1.15, *A.-H.d.* № 114 – 1.10 and *V.11/P. d.* – 1.09. According to our data, the most stable (adaptive to different conditions) populations, i.e. those that are less responsive to changes in growing conditions, were: *M.g./M agr.* – 0.86, *A.r. d.* – 0.90, *Ram. d.* – 0.91, *Zymostiyka/M.K.* – 0.92 and *Prymorka/Sin(c).* – 0.93. Population (*Emeraude/T.*)^2 in which the regression coefficient $b_i = 1$ is well adapted to different environmental conditions.

In the analysis of breeding numbers by the coefficient of predicted stability S^2_{di} were identified the most stable, i.e. with S^2_{di} indicators tending to zero, populations: *M.g./CP-11* – 0.09, *M.g./M.agr.* and (*Emeraude/T.*)^2 – 0.13, *Ram. d.* and *M.g. d.* – 0.14.

An indicator of plant resistance to adverse environmental factors is homeostatic (Hom), i.e. plants are able to develop normally under adverse external conditions due to the manifestation of homeostasis. Hangildin V. V. linked the manifestation of high homeostatic (Hom) with the ability of plants to minimize the effects of adverse environmental conditions. Genotypes were characterized by high values of homeostaticity: *M.agr./C.* – 2.08, *M.g./CP-11* – 2.07, *Ram. d.* – 2.05 and *FHNV*^{2} – 2.04.

According to Kilchevsky etc. under adaptive ability understand the property of the population to maintain its characteristic value of the phenotypic manifestation of the trait There are total and specific adaptability [23]. Total adaptive capacity (TACi) is characterized by the average value of the trait under different conditions. The greatest effects of total adaptability (TACi) were observed in breeding samples: *M.g./CP-11* with an index 0.92, *M.g./P.p.* – 0.75, *LR/H* – 0.63 and *Elehiya* – 0.61. Populations were characterized by the lowest values of this trait: *Selection by root system*, in which it was equal to –1.16, *Prymorka* – –0.74 and *M.g./M.agr.* – –0.68 (Table 3).

The stability of the genotype response by productivity is determined by the value of the parameter σ^2_{SACi}. The variance parameter (σ^2_{SACi}) characterizes the specific adaptive ability, i.e. in favorable environmental conditions, a population with a high value of this indicator forms a relatively high yield. The most stable selection numbers are set: *M.g./M. agr.* ($\sigma^2_{SACi} = 36.18$), *Ram. d.* ($\sigma^2_{SACi} = 40.75$) and *A.r. d.* ($\sigma^2_{SACi} = 41.26$), but only in the *Ram. d.* population is the effect of general adaptability positive. Genotypes: *Elehiya*, *Sin(c)./Prymorka*, *A.-H. d. № 114* with values σ^2_{SACi} = 70.01, 65.65 and 61.48 are unstable.

The parameter of relative stability of the genotype (s_{gi}) is not related to the overall adaptive capacity and is relative. Many researchers point to the hereditary nature of this indicator, which allows the use of genotypes in breeding for stability. The lowest indicator of the relative stability of the genotype (s_{gi}) was characterized by populations: *Ram. d.* – 46.16, *M.g./M.agr.* – 47.09 and *M.agr./C.* – 47.61, which according to this indicator were the most stable.

The selection value of the genotype (SVGi) is used for simultaneous selection for the general adaptive ability and stability. The high selection value of the genotype (SVGi) characterized by genotypes: *Ram. d.*, *M.g./CP-11*, *M.agr./C.* and *LR/H* with values: 7.73; 7.63; 7.59; 7.55,

Table 3

Parameters of adaptive properties of alfalfa samples of the first and second years of life on the basis of green mass yield (2017–2020)

Variety, population	marking	Green mass yield, kg · m^{-2}		Adaptability parameters						
		$Y_{min} - Y_{max}$	Y_{mean}	TACi	$\sigma^2_{(G\times E)gi}$	σ^2_{SACi}	s_{gi}	SVGi	C_{gi}	l_{gi}
Unitro, standard	G1	5.03–22.83	13.46	0.00	0.37	51.57	53.37	6.60	1.06	0.0072
Elehiya	G2	3.99–23.21	14.07	0.61	3.27	70.01	59.49	6.08	1.44	0.0467
Prymorka	G3	4.05–22.82	12.71	-0.74	0.71	53.72	57.67	5.71	1.10	0.0132
M.g./P.p.	G4	4.85–24.43	14.20	0.75	1.61	51.33	50.46	7.36	1.05	0.0314
Sin(c)./Prymorka	G5	2.78–24.79	13.96	0.50	2.57	65.65	58.05	6.22	1.35	0.0391
LR/H	G6	5.28–23.69	14.09	0.63	0.86	46.90	48.61	7.55	0.96	0.0182
Prymorka / Sin(c).	G7	4.78–22.33	13.21	–0.25	0.70	42.56	49.40	6.98	0.87	0.0164
A.-H. d. № 114	G8	3.05–22.34	12.84	–0.61	2.67	61.48	61.05	5.36	1.26	0.0435
A.-H.d. № 15	G9	3.98–21.62	13.32	–0.13	2.34	55.23	55.79	6.23	1.13	0.0425
A.-H. d. № 38	G10	4.86–21.22	13.38	–0.07	0.95	47.89	51.73	6.77	0.98	0.0198
Selection by root system	G11	2.75–20.89	12.29	–1.16	1.31	46.65	55.57	5.77	0.96	0.0280
Ram. d.	G12	5.57–22.48	13.82	0.37	0.41	40.75	46.19	7.73	0.84	0.0101
(*Emeraude/T.*)^2	G13	5.16–23.30	13.61	0.15	0.05	49.03	51.47	6.92	1.01	0.0009
T./Emeraude	G14	4.23–23.00	13.40	–0.05	0.77	52.67	54.15	6.48	1.08	0.0145
M.g./CP-11	G15	5.70–23.83	14.37	0.92	0.02	49.82	49.12	7.63	1.02	0.0003
Zymostiyka / M.K.	G16	3.83–21.52	13.19	–0.27	1.49	42.87	49.66	6.94	0.88	0.0347
M.agr. / C.	G17	6.32–23.18	13.91	0.45	0.64	43.83	47.61	7.59	0.90	0.0146
A.r. d.	G18	5.57–21.40	13.01	–0.44	1.86	41.26	49.36	6.88	0.85	0.0452
M.g. / M.agr.	G19	5.01–20.47	12.78	–0.68	0.98	36.18	47.09	7.03	0.74	0.0272
M.g. d.	G20	4.65–21.45	12.90	–0.55	0.20	43.62	51.20	6.60	0.90	0.0046
FHNV^2	G21	6.61–23.13	13.63	0.18	1.21	47.26	50.44	7.07	0.97	0.0256
V.11 / P. d.	G22	5.59–25.32	13.94	0.49	1.67	59.30	55.24	6.59	1.22	0.0282
G. / CP-11	G23	4.90–23.08	13.53	0.07	0.57	53.35	54.01	6.55	1.10	0.0107
Sybir. 8, d.	G24	5.43–21.57	13.28	–0.18	0.34	45.00	50.53	6.87	0.92	0.0075
V, %			3.95	–	128.77	16.47	7.78	9.30	16.46	119.265
$S\dot{x}_{absolute}$			0.11	0.11	0.18	1.66	0.83	0.13	0.03	0.003
$S\dot{x}_{relative}$			0.81	–	26.29	3.36	1.59	1.90	3.36	24.345
$LSD_{0.01}$			0.34	0.34	0.57	5.27	2.62	0.40	0.11	0.009
$LSD_{0.05}$			0.25	0.24	0.41	3.80	1.89	0.29	0.08	0.007

respectively. Populations of this type can give maximum yields even under adverse conditions.

All breeding numbers had a linear response to environmental conditions (l_{gi} = 0.0009–0.0467). According to the compensation-destabilization coefficient, the genotypes were divided equally (12 each) with a variation of 0.74–1.44, which indicates both compensatory and destabilizing effects. The lowest compensation effect (C_{gi}) 0.74–0.85 observed in populations: *M.g./M.agr*, *Ram. d* and *A.r. d.*, and in genotypes: *Elehiya*, *Sin(c)./Prymorka* the highest destabilizing effect with the coefficient was observed C_{gi} = 1.44 and 1.35, respectively.

Correlation dependences between forage yield under different moisture conditions and parameters of adaptive traits were also analyzed to identify the most suitable identifiers of adaptability, which allow to isolate valuable breeding samples.

Coefficient of adaptability (CA) and the total adaptive capacity (TACi) had a high dependence (r = 0.775) with maximum productivity and medium (r = 0.427 and 0.428, respectively) with minimum (Table 4). A number of researchers [2, 46] studying the adaptability of different cultures believed that these indicators can identify a stable genotype. However, in our studies, the largest values of these indicators were characterized by populations, both stable and intensive.

The regression coefficient (b_i) had a mean dependence ($r = 0.601$) with a maximum yield and a negative ($r = -0.446$) with a minimum. S. A. Eberhart, W. A. Russell gradation was presented: $b_i > 1$ – varieties of intensive type, $b_i < 1$ – stable and $b_i = 1$ – plastic. Our research and the research of a number of authors [4, 30, 44, 45] confirm this pattern. The variance of specific adaptive capacity (σ^2_{SACi}) was characterized by the mean dependence ($r = 0.570$) with the maximum yield and the mean negative ($r = -0.475$) with the minimum. A number of authors [46] believe that the smaller the value of the specific adaptive capacity, the more stable the variety. This is confirmed by our research, but if the value (σ^2_{SACi}) of variance tends to the maximum, then such varieties should be considered – intensive type.

Table 4

Matrix of correlations between maximum and minimum yields of alfalfa populations and homeostatic, ecological plasticity and adaptability parameters (2017–2020)

	Y_{min}	Y_{max}	Y_{mean}	$Y_{min} - Y_{max}$	*Sc*	*Gf*	b_i	S^2_{di}	*CA*	*Hom*	*TACi*	$\sigma^2_{(G\times E)gi}$	σ^2_{SACi}	s_{gi}	*SVGi*	C_{gi}	I_{gi}
Y_{min}	**1.000**	0.159	0.427	0.552	0.988	0.701	–0.446	–0.490	0.427	0.863	0.428	–0.527	–0.475	–0.707	0.769	–0.474	–0.451
Y_{max}	0.159	**1.000**	0.775	–0.735	0.046	0.816	0.601	0.116	0.775	0.020	0.775	0.116	0.570	0.206	0.159	0.570	–0.055
Y_{mean}	0.427	0.775	**1.000**	–0.360	0.395	0.810	0.343	–0.025	1.000	0.551	1.000	0.024	0.319	–0.185	0.575	0.318	–0.108
$Y_{min} - Y_{max}$	0.552	–0.735	–0.360	**1.000**	0.640	–0.207	–0.815	–0.434	–0.361	0.577	–0.361	–0.460	–0.807	–0.660	0.394	–0.808	–0.263
Sc	0.988	0.046	0.395	0.640	**1.000**	0.613	–0.514	–0.504	0.394	0.915	0.395	–0.526	–0.538	–0.759	0.797	–0.537	–0.435
Gf	0.701	0.816	0.810	–0.207	0.613	**1.000**	0.172	–0.203	0.810	0.520	0.811	–0.224	0.132	–0.266	0.566	0.134	–0.304
b_i	–0.446	0.601	0.343	–0.815	–0.514	0.172	**1.000**	0.503	0.344	–0.426	0.344	0.573	0.995	0.855	–0.569	0.995	0.315
S^2_{di}	–0.490	0.116	–0.025	–0.434	–0.504	–0.203	0.503	**1.000**	–0.024	–0.404	–0.023	0.897	0.574	0.607	–0.514	0.570	0.887
CA	0.427	0.775	1.000	–0.361	0.394	0.810	0.344	–0.024	**1.000**	0.551	1.000	0.025	0.320	–0.184	0.574	0.319	–0.107
Hom	0.863	0.020	0.551	0.577	0.915	0.520	–0.426	–0.404	0.551	**1.000**	0.551	–0.376	–0.439	–0.749	0.852	–0.440	–0.315
TACi	0.428	0.775	1.000	–0.361	0.395	0.811	0.344	–0.023	1.000	0.551	**1.000**	0.025	0.320	–0.183	0.574	0.319	–0.107
$\sigma^2_{(G\times E)gi}$	–0.527	0.116	0.024	–0.460	–0.526	–0.224	0.573	0.897	0.025	–0.376	0.025	**1.000**	0.649	0.627	–0.520	0.647	0.951
σ^2_{SACi}	–0.475	0.570	0.319	–0.807	–0.538	0.132	0.995	0.574	0.320	–0.439	0.320	0.649	**1.000**	0.869	–0.591	1.000	0.404
s_{gi}	–0.707	0.206	–0.185	–0.660	–0.759	–0.266	0.855	0.607	–0.184	–0.749	–0.183	0.627	0.869	**1.000**	–0.910	0.869	0.441
SVGi	0.769	0.159	0.575	0.394	0.797	0.566	–0.569	–0.514	0.574	0.852	0.574	–0.520	–0.591	–0.910	**1.000**	–0.592	–0.421
C_{gi}	–0.474	0.570	0.318	–0.808	–0.537	0.134	0.995	0.570	0.319	–0.440	0.319	0.647	1.000	0.869	–0.592	**1.000**	0.403
I_{gi}	–0.451	–0.055	–0.108	–0.263	–0.435	–0.304	0.315	0.887	–0.107	–0.315	–0.107	0.951	0.404	0.441	–0.421	0.403	**1.000**

* – *Confidence interval (%): 95*

Selection value of the variety (*Sc*), homeostatic (Hom) and the selection value of the genotype (*SVGi*) ($r = 0.020–0.159$) with maximum yield and high (r = 0.769–0.988) with minimum. A number of authors [42, 43, 47, 48] believe that the higher their performance, the more stable the variety, which was confirmed by our research.

The relative stability of the genotype (s_{gi}) had a high negative correlation ($r = -0.707$) with the minimum yield and low ($r = 0.206$) with the maximum, i.e. the smaller the value of the relative stability of the genotype in the variety, the greater its productivity under limiting moisture conditions.

Coefficient of compensation (C_{gi}) had a medium correlation (r = 0.570) with maximum yield, and with minimum – average negative ($r = -0.474$). That is, when selecting varieties of intensive type, preference should be given to varieties with a destabilizing effect ($C_{gi} > 1$), and stable – with a compensating effect ($C_{gi} < 1$).

Analyzing the data obtained on alfalfa grass for two years in terms of homeostatic and adaptive indicators, the most stable population was *Ram. d.*, which exceeded the standard in terms of yield. It was highly homeostatic (*Hom* = 2.05), selection value of the variety (*Sc* = 3.42), coefficient of adaptability (*CA* = 102.7), the regression coefficient was less than one ($b_i = 0.91$) and the stability rate tended to zero ($S^2_{di} = 0.14$).

The most unstable were populations: *Elehiya* and *Sin(c)./Prymorka* with the highest rates of specific adaptive capacity (σ^2_{SACi} = 70.01 and 65.65, respectively), relative stability of the genotype (s_{gi} = 59.49 and 58.05, respectively) and low selection value of genotype (*SVGi* = 6.08 and 6.22, respectively) and were characterized by a destabilizing effect.

Selection numbers *Elehiya* and *Sin(c)./Prymorka* by indicators were distinguished as populations of intensive type, i.e. the regression coefficient was greater than one (b_i = 1.18 and 1.15, respectively), the predicted stability indicator tended to a maximum (S^2_{di} = 2.9 and 1.97, respectively), they were also characterized by low homeostatic values (*Hom* = 1.87 and 1.61, respectively) and low stress resistance ($Y_{min} - Y_{max}$) – –19.22 and –22.01, respectively).

The population (*Emeraude/T.*)^2 was isolated as a genotype that is well adapted to different conditions of the growing environment, had a regression coefficient b_i = 1. Although in *M.g./P.p.*, *LR/H* and *M.g./CP-11*, the regression coefficient was not equal to one, but was close (1.01, 0.97 and 1.01, respectively), however, these populations felt well under different humidity conditions and exceeded the yield standard. Therefore, they can also be attributed to plastic samples.

Characterizing the population on several grounds, we can say that the parameters of adaptability (σ^2_{SACi}) were identified as the most stable populations of *Ram. d.* and *M.g./M.agr.*, But only the first of them significantly exceeded the standard of yield. The populations had low variance of specific adaptability (σ^2_{SACi} = 40.75 and 36.18, respectively), relative stability of the genotype (s_{gi} = 46.19 and 47.09, respectively) and were characterized by high values of the selection value of the genotype *SVGi* = 7.73 and 7.03, respectively.

According to the results of GGE biplot analysis, the population of G5 is *Sin(c)./Prymorka* stood out as an intensive type, located on the border of the second and third quarters. It includes populations G4 – *M.g./P.p.* and G22 – *V.11/ P. d.*, which are in the same quarter with the vector of maximum yield, but are characterized by higher minimum yields, i.e., such plastic-intensive (Fig. 1).

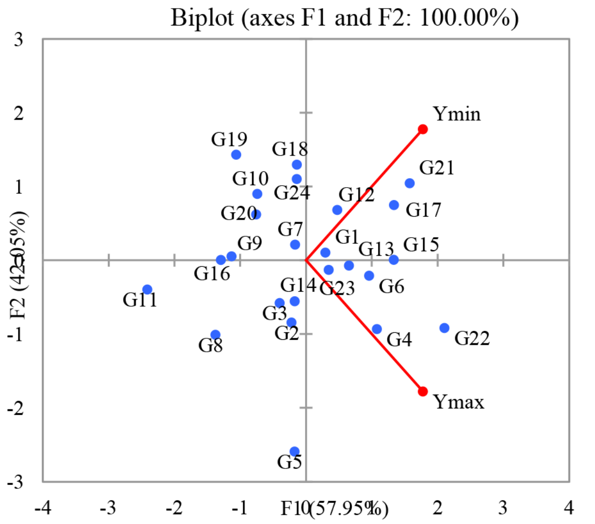

Fig. 2. Genotype-environmental interaction of alfalfa varieties and environments (biplot analysis method). The lines show the eigenvectors of the leading factor loads for environments:

● – humidification conditions; ● – genotypes

Populations G18 – *A.r. d.* and G19 – *M.g./M.agr.*, which are in the top IV quarters and less responsive to drought than others can be considered the most stable. These include populations G12 – *Ram. d.*, G17 – *M.agr./C.* and G21 – *FHNV*^{2}, which are in the same quarter with the vector of minimum yield, but are characterized by higher minimum and maximum yield, i.e., somewhat plastic-stable.

Populations G6 – *LR/H* and G15 – *M.g./CP-11*, located in the middle between the yield vectors, have signs of plastic genotypes that are well adapted to different growing conditions.

Conclusions. The most suitable adaptability identifiers are highlighted: regression coefficient (b_i), predicted ecological stability, plasticity of the variety with different eco-gradient (S^2_{di}), homeostatic (*Hom*), selection value (*Sc*), variants of specific adaptive capacity (σ^2_{SACi}), relative stability of the genotype (s_{gi}), selection value of genotype (*SVGi*), compensation-destabilization coefficient (C_{gi}), which made it possible to isolate valuable breeding specimens.

According to the selected parameters of adaptability and biplot analysis, alfalfa genotypes can be divided into:

– populations *Ram. d.* and *M.g./M.agr.* are the most stable and less responsive to deteriorating humidification conditions;

– populations *Elehiya* and *Sin(c)./Prymorka* respond well to improving moisture conditions, but have a sharp decrease in yield under worse conditions, it is recommended to grow them under irrigation;

– populations *M.g./P.p.*, *LR/H* and *M.g./CP-11* – plastic (form a high yield under different growing conditions), recommended for both irrigation and natural moisture.

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Tyshchenko A. V., Tyshchenko O. D., Piliarska O. O. Formation of resistance of alfalfa plants in conditions of different ecological gradient for fodder use

Alfalfa is a perennial fodder crop grown all over the world and among fodder legumes is characterized by high productivity of fodder mass, its nutritional value with high protein content, as well as due to the root system helps increase soil fertility, protects soil from wind and water erosion. **The aim** of the study was to study the ecological plasticity and stability of alfalfa genotypes against the background of arid conditions of the southern Steppe of Ukraine. **Materials and methods of research.** The research was conducted during 2017–2020 at the Institute of Irrigated Agriculture of the NAAS, Kherson region, Ukraine. The material for the study was 24 populations and varieties of alfalfa, which were sown under conditions of optimal (irrigation) and stressful (without irrigation) moisture. **Research results and their discussion.** During the research, the best conditions for irrigation were during the 2017 sowing, where the environmental conditions index (I_j) was +9.21. Conditions for alfalfa sowing in 2018 and 2019 were worse, the environmental conditions index (I_j) was +3.73 and +5.04, respectively. Under natural moisture conditions, the most favorable conditions were during the 2017 sowing with an environmental conditions index of 3.93, while for the 2018 and 2019 sowings they were worse – –5.34 and –8.70, respectively. The minimum yield of the populations ranged from 2.75 kg · m^{-2} to 6.61 kg · m^{-2}, and the maximum – from 20.47 to 25.32 kg · m^{-2}. **Conclusions.** According to the results of the assessment, the following populations were identified: the populations *Ram. d*. and *M.g. / M.agr*. are the most stable and least sensitive to deterioration of moisture conditions; the populations *Elehiya* and *Sin(c). / Prymorka* respond well to improved moisture conditions, but have a sharp decrease in yield under worse conditions, it is recommended to grow them under irrigation; the populations *M.g. / P.p.*, *LR / H* and *M.g. / CP-11* – plastic (form a high yield under various growing conditions), recommended for both irrigation and natural moisture.

Key words: alfalfa, population, variety, irrigation, genotype, plasticity, yield.

Тищенко А. В., Тищенко О. Д., Пілярська О. О. Формування стійкості рослин люцерни в умовах різного екологічного градієнта для кормового використання

Люцерна – багаторічна кормова культура, яку вирощують у всьому світі, і серед кормових бобових культур характеризується високою продуктивністю кормової маси, поживною цінністю з високим вмістом білка, а також завдяки кореневій системі сприяє підвищенню родючості ґрунту, захищає ґрунт від вітрової та водної ерозії. **Метою** дослідження було вивчення екологічної пластичності та стабільності генотипів люцерни на фоні посушливих умов південного Степу України. **Матеріали і методи досліджень.** Дослідження проводилися протягом 2017–2020 років в Інституті зрошуваного землеробства НААН, Херсонська область, Україна. Матеріалом для дослідження слугували 24 популяції та сорти люцерни, які висівали за умов оптимального (зрошення) та стресового (без зрошення) зволоження. **Результати дослідження та їх обговорення.** На протязі досліджень найкращі умови для зрошення були за сівби 2017 року, де індекс умов середовища (Ij) становив +9,21. Умови для посівів люцерни у 2018 та 2019 роках були гіршими, індекс умов середовища (I_j) становив +3,73 та +5,04 відповідно. В умовах природного зволоження найсприятливіші умови були за сівби 2017 року з індексом умов середовища – 3,93, тоді як для посівів 2018 та 2019 років вони були гіршими – –5,34 та –8,70 відповідно. Мінімальна врожайність популяцій коливалася від 2,75 кг/м^2 до 6,61 кг/м^2, а максимальна – від 20,47 до 25,32 кг/м^2. **Висновки.** За результатами оцінки були виділені популяції: популяції *Ram. d*. та *M.g. / M agr.* є найбільш стабільними та найменш чутливими до погіршення умов зволоження; популяції *Елегія* та *Сін(с). / Приморка* добре реагують на покращення умов зволоження, але мають різке зниження врожайності за гірших умов, рекомендується вирощувати їх на зрошенні; популяції *M.g. / П.п.*, *LR / H* та *M.g. / ЦП-11* – пластичні (формують високий урожай за різних умов вирощування), рекомендовані як для зрошення, так і для природного зволоження.

Ключові слова: люцерна, популяція, сорт, зрошення, генотип, пластичність, врожайність.

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