

# Ecological plasticity and adaptive potential of annual form of white sweet clover (*Melilotus albus* Medik)

*A V Kazarina*<sup>1\*</sup>, *L K Marunova*<sup>1</sup>, *E A Atakova*<sup>1</sup>, and *I S Abramenko*<sup>1</sup>

<sup>1</sup>Samara Federal Research Scientific Center RAS, Volga Scientific Research Institute of Selection and Seed-Growing named after P.N. Konstantinov, 76, street Shosseynaya, city Kinel, Samara Region, 446442, Russian Federation

**Abstract.** The ecological plasticity, stability, and adaptive potential of varieties and promising genetic lines of the annual form of white sweet clover were assessed. The studies were carried out in 2016-2020 in Volga Scientific Research Institute of Selection and Seed-Growing named after P.N. Konstantinov, Samara Federal Research Scientific Center, Russian Academy of Sciences. According to the parameters of ecological plasticity and stability, the studied varieties and genetic lines were differentiated into groups according to their response to the changes in environmental conditions. Most of studied varieties belonged to highly plastic genotypes; varieties Srednevolzhsky, Kinelsky, Zavolzhsy, and genetic line Hugh 0 were characterized by the highest stability under the conditions of the Samara Trans-Volga Region. Varieties Srednevolzhsky, Kinelsky, Zavolzhsy, and genetic lines Hugh 0, Hugh 40 and Indus 1 were highly resistant to unfavorable environmental factors. All the studied genetic lines and varieties are characterized by high selective value and thus may be used as a starting material for developing of new varieties of the annual form of white sweet clover.

## 1 Introduction

Annual form of white sweet clover (*Melilotus albus* Medik) is one of the most valuable forage, melliferous, medicinal, and phytomeliorative plants [1-2]. It is characterized by high ecological plasticity, resistance to environmental stress factors, and the ability to use agro-climatic resources economically and efficiently. Due to the deeply penetrating root system, sweet clover can grow in a wide range of edaphic conditions [3]. Practically, it has been proven as promising plant for hay, haylage, green fodder, and as a pasture plant [4-6]. White sweet clover is an excellent green manure crop and accumulator of the most important nutrients (nitrogen, phosphorus, and potassium) in the soil. High rate of decomposition of green mass and roots is its great advantage. Its meliorative effect in the soil is manifested due to the high content of calcium in the root residues, which it transports via its powerful root system from the deep layers to the soil surface [7].

---

\* Corresponding author: [Kazarinaav@bk.ru](mailto:Kazarinaav@bk.ru)

The forest-steppe of the Middle Volga Region is characterized by periodically recurring summer droughts; the latter are one of the limiting factors affecting greatly the stability of forage production. At the same time, the stability of field fodder production is preconditioned by the correct selection of drought-resistant crops and varieties capable of forming high and stable yields under any weather conditions [4].

At the present stage, developing of new high-tech varieties, which realize the soil and climatic potential of the region the most and are characterized by high ecological plasticity and resistance to stress factors of the environment, is the actual task of breeding the annual form of white sweet clover.

The study aims to analyze and to assess the parameters of ecological plasticity and adaptability of varieties and promising genetic lines of the annual form of white sweet clover bred in Volga Scientific Research Institute of Selection and Seed-Growing named after P.N. Konstantinov, Samara Federal Research Scientific Center, Russian Academy of Sciences (Volga NISS).

## **2 Materials and methods**

The annual form of white sweet clover, represented by varieties Kinelsky, Povolzhsky, Srednevolzhsky, and Zavolzhsky, included in the State Register of Breeding Achievements of the Russian Federation, and 9 promising genetic lines, recently developed in the Volga NISS, were the study objects. The Srednevolzhsky variety was set as the standard.

The study was carried out in the fields of selection and seed-growing crop rotation of the Laboratory of Introduction and Selection of Forage and Oilseeds in 2016-2020. The area of the plots was 25 m<sup>2</sup>, in four replicates for each variety/genetic line.

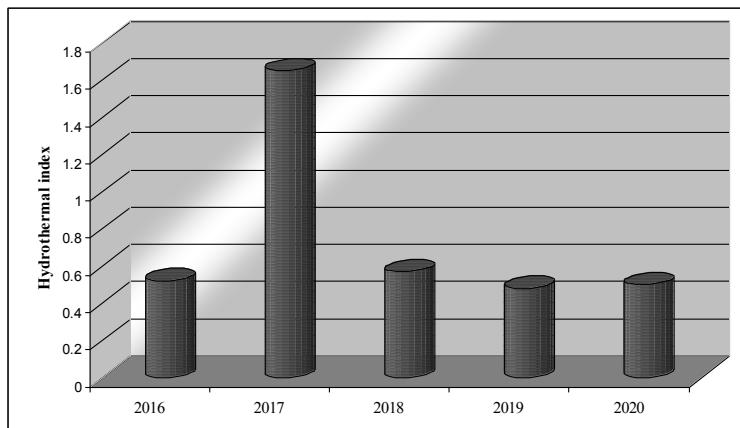
Biometric analysis was applied to assess the yield of varieties and genetic lines. Standard deviations were calculated using conventional methods. The parameters of ecological plasticity and indices of environmental conditions were calculated according to the method proposed by S.A. Eberhart and W.A. Russel [8]. Stress tolerance and genetic plasticity were calculated using the equation proposed by A.A. Rossielle and J. Hamblin [9]. Ultrastability ( $H_{om}$ ) was determined by the Khangildin method [10].

## **3 Results**

The temperature regime during the growing season in 2016 was characterized by extreme maximum. The amount of precipitation in May and July approached the mean multiyear values; in June and August, the precipitation was significantly lower than the mean multiyear average. The hydrothermal index (HTI) was 0.52 in May—July, i.e. during the formation of the green mass crop (Figure 1).

In 2017, the period of growth and development of sweet clover coincided with abundant rainfall, which had a positive effect on the forage productivity of plants. In May—July 2017, HTI reached 1.65. The growing season of 2018 was characterized by a precipitation deficiency in the first half of the growing season and a significant excess of average annual values in July. In general, HTI was 0.57 for the period from May to July.

During the period of green mass yield formation of the sweet clover in 2019 and 2020, HTI values were quite similar and amounted to 0.48 and 0.50, respectively; this characterized the conditions during these years as arid. However, the contrasting weather conditions of 2019 appeared to be more favorable conditions for the initial growth and development of sweet clover. In contrast, in 2020, the impact of environmental stress factors was observed throughout the entire growing season.



**Fig. 1.** Hydrothermal conditions of the growing seasons of 2016 – 2020.

The calculation of the index of the environment ( $I_j$ ) allows to differentiate the study years into favorable and unfavorable for the growth and development of the annual form of white sweet clover. The best conditions for growth and development were formed in years with a positive  $I_j$  value (+7.05 in 2017 and +3.81 in 2018), the worst, with a negative one (-1.31 in 2016, -4.45 in 2019, and -5.09 in 2020).

According to analysis of variance, environmental conditions and the interaction "genotype—environment" influenced significantly the yield of the studied varieties. Factor share evidenced that "year" is the leading factor affecting general phenotypic variation in yield, bringing 66.74% of total variation. The contribution of the "genotype" factor was 10.45%; the interaction of these factors contributed 20.39% to the overall variability of the yield of green mass. This indicated a fairly high ecological reliability of the studied genotypes.

During the entire study period, the yield of all varieties and promising genetic lines significantly exceeded that of Srednevolzhsky standard, except Kinelsky variety, which was similar to the standard (Table 1).

**Table 1.** Green mass yield and ecological plasticity of varieties and promising genetic lines of annual form of white sweet clover.

Variety	Yield, tons/hectare					Average	Plasticity, $b_i$
	2016	2017	2018	2019	2020		
Srednevolzhsky	26.12	25.00	30.37	22.22	22.07	25.16	1.42
Kinelsky	26.50	25.10	30.50	26.22	27.50	27.16	0.01
Povolzhsky	29.15	38.72	32.65	24.97	26.77	30.45	0.99
Zavolzhsky	30.37	39.07	33.70	29.25	24.75	31.43	0.96
Hugh 1	30.45	44.00	36.62	23.80	23.07	31.59	1.67
Hugh 40	30.57	37.37	38.65	23.55	26.67	31.36	1.16
Hugh 0	30.90	38.15	32.72	28.77	24.90	31.09	0.88
Kin 1	27.05	43.97	33.47	24.12	24.75	30.67	1.51
Ind 1	27.10	36.77	37.10	25.40	26.47	30.57	1.05
Zhel	28.27	37.40	33.97	25.57	25.57	30.16	1.00
C+1	29.05	37.62	32.62	25.20	24.72	29.84	1.01
D-138	29.50	39.95	37.27	27.32	23.65	31.54	1.28
D-142	30.37	41.62	32.32	28.23	25.42	31.59	1.09
HTI <sub>05</sub>	0.61	0.57	0.54	0.50	0.23		
Average	28.88	37.24	34.00	25.74	25.10		
$I_j$	-1.31	7.05	3.81	-4.45	-5.09		

In the years characterized by positive  $I_j$ , the genetic lines Hugh 1, Kin 1, D-138, D-142, Hugh 40, and Zavolzhsy variety were characterized by green mass yield of 36.65-44.00 tons per hectare. In unfavorable years (negative  $I_j$ ), the average yield of the entire set of varieties decreased by 24.3-32.6%, ranging from 22.07 to 29.25 tons per hectare. On average, over five years of study, the largest yield of forage mass was provided by the Hugh 1, D-142, and D-138 genetic lines and the Zavolzhsy variety (31.43-31.59 tons per hectare).

The reliability of differences between varieties and genetic lines of annual form of sweet clover in contrasting growing conditions allowed to assess their ecological plasticity and stability.

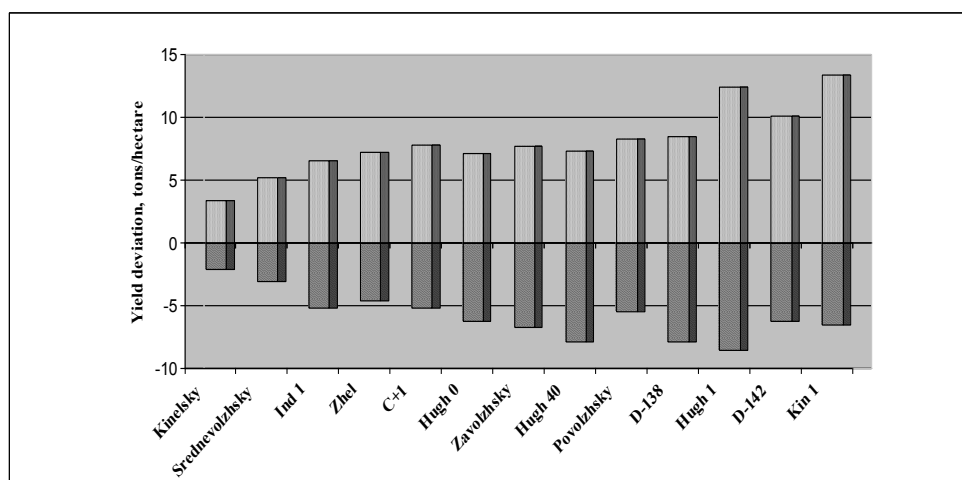
The linear regression coefficient ( $b_i$ ), characterizing ecological plasticity in our studies, ranged from 0.01 to 1.67. The varieties and genetic lines with  $b_i \geq 1$  belonged to intensive type. They demanded specific agricultural technology, but brought the greatest result in favorable conditions. In our studies, Srednevolzhsky variety, Hugh 1, Kin 1, and D-142 genetic lines were characterized by the greatest response to the changes in environmental conditions.

The Kinelsky variety might be classified as a neutral type (low ecological plasticity,  $b_i = 0.01$ ).

All the other varieties and genetic lines belonged to the group of highly plastic genotypes ( $b_i$  was equal to 1.0 or close to this value). The yield of these genetic lines and varieties depended on the changes in environmental conditions.

The yield of green mass of varieties and promising genetic lines of the annual form of white sweet clover deviated from the average over the study period, which testified to their stability (Figure 2).

In most of the analyzed varieties, the deviations from the average yield were not high in contrasting years, i.e. there was a stability of the varieties in regard to the soil and climatic conditions of the Samara Trans-Volga Region. Low fluctuations of this indicator were noted for the varieties Srednevolzhsky, Kinelsky, and Zavolzhsy and for genetic lines Ind 1, Zhel, C+1, and Hugh 0.



**Fig. 2.** Stability of yield of green mass of varieties and promising genetic lines of annual form of white sweet clover, 2016-2020.

The genetic lines Hugh 1 and Kin 1 were characterized by the largest range of deviations from the average yield; this indicated a highly pronounced response of these

types to the changes in growing conditions. For other varieties and genetic lines, the indicators of stability were close to average and varied from -5.48 to +13.3 tons per hectare.

The varieties and promising genetic lines of the annual form of white sweet clover bred in the Volga NIISS were analyzed according to the main statistical parameters characterizing the adaptive potential in terms of green mass yield.

The degree of genotype resistance to environmental stress factors was characterized by the difference between the minimum and maximum yield. The smaller the gap between the maximum and minimum yield, the higher the stress resistance of the variety and the wider the range of its adaptive capabilities, and the genotype resistance value had a negative sign.

In our experiments, Srednevolzhsky, Kinelsky, and Povolzhsky varieties and Hugh 40, Ind 1, and Zhel genetic lines were characterized by the greatest resistance to unfavorable environmental factors, in which the least decrease in yield was observed in contrasting growing conditions (Table 2).

The average yield under contrasting (stressful and non-stressful) conditions characterized genetic plasticity. The higher these values, the greater the degree of correspondence between the variety genotype and environmental factors. The maximum ratio between the genotype and environmental factors was noted in the genetic lines Hugh 40 (34.4), D-142 (33.5), Hugh 1 (33.5), and Povolzhsky variety (33.5).

Ultrastability was an important indicator characterizing the resistance of plants to the effects of unfavorable environmental factors, i.e. the ability of the genotype to minimize the effects of the interaction of stressful external conditions.

The ability of varieties to maintain low variability of productivity traits could be considered a criterion for their ultrastability. The relationship between ultrastability ( $H_{om}$ ) and the coefficient of variation ( $V_c$ ) allowed one to assess the stability of a trait under changing environmental conditions.

During the study period, varieties Kinelsky, Srednevolzhsky, and Zavolzhsky and genetic line Hugh 0 had the greatest stability. High variability ( $V_c = 27.06-28.05\%$ ) and low ultrastability ( $H_{om} = 5.90-5.38$ ) were characteristic of genetic lines Kin 1 and Hugh 1, which indicated instability and reduced adaptability of these types under the conditions prevailing during the study period.

**Table 2.** Evaluation of varieties and promising genetic lines of the annual form of white sweet clover in terms of adaptability, 2016-2020.

Variety	Stress resistance, $x_{lim} - x_{opt}$	Genetic plasticity, $(x_{opt} + x_{lim})/2$	Coefficient of variation, $V_c$ , %	Ultrastability, $H_{om}$	Selective value, $S_c$
Srednevolzhsky	-2.93	23.5	13.51	63.56	22.21
Kinelsky	-2.40	26.3	7.55	149.90	29.76
Povolzhsky	-11.95	33.5	28.05	5.38	16.56
Zavolzhsky	-14.32	32.0	20.95	13.99	22.38
Hugh 1	-20.93	33.5	15.79	14.89	20.29
Hugh 40	-10.70	34.4	27.06	5.90	17.26
Hugh 0	-13.25	31.6	19.14	15.51	22.01
Kin 1	-19.22	31.5	17.61	14.48	20.62
Ind 1	-10.30	31.2	18.10	12.78	19.61
Zhel	-11.83	32.8	17.86	14.26	21.05
C+1	-12.90	31.9	16.99	12.92	19.91
D-138	-16.30	31.8	21.72	8.91	18.67
D-142	-16.20	33.5	19.50	10.00	19.29

The selective value of a genotype was a complex indicator that took into account both yield and stability. Applying this indicator made it possible to predict the efficiency of using specific genotypes in the breeding process.

In our studies, all studied varieties and genetic lines were characterized by high breeding values (16.56-29.76) and thus could be recommended for practical use in breeding of the annual form of white sweet clover.

## 4 Discussion

In 2016-2020, the ecological plasticity and adaptability of varieties and promising genetic lines of annual form of white sweet clover (*Melilotus albus* Medik) have been assessed in the climatic conditions of Samara Trans-Volga Region. The peculiarities of the formation of the green mass yield in the years contrasting in hydrothermal conditions were described, the indicators of stress resistance, ultrastability, ecological plasticity, and breeding value of the studied varieties were calculated. The algorithm used for calculating the indicators of ecological plasticity and adaptability made it possible to assess objectively the ability of varieties to combine a relatively high yield with stability in various growing conditions in a best way.

## 5 Conclusion

Three groups of varieties and promising genetic lines of the annual form of white sweet clover are differentiated according to their response (yield and parameters of ecological plasticity) to the changes in environmental conditions. The genetic lines Hugh 1, D-142, and Kin 1, as well as Srednevolzhsky variety, are referred to the group of the intensive type, more demanding for agricultural technology. The Kinelsky variety is characterized by a low indicator of ecological plasticity; it is classified as a neutral type. The other varieties and genetic lines belong to the group of highly plastic genotypes, their productivity corresponded to the changes in environmental conditions. Varieties Srednevolzhsky, Kinelsky, and Zavolzhsy and genetic lines Ind 1, Zhel, C+1, and Hugh 0 are most stable in the climatic conditions of Samara Trans-Volga Region. Varieties Srednevolzhsky, Kinelsky, and Povolzhsky and genetic lines Hugh 40, Zhel, and Ind 1 have high resistance to unfavorable environmental factors. The maximum ratio between the genotype and environmental factors is observed for Povolzhsky variety and genetic lines D-142, Hugh 40, and Hugh 1. All studied varieties and genetic lines have a high breeding value and may be used as a starting material for developing new varieties of annual form of white sweet clover for the forest-steppe climatic conditions of the Middle Volga Region.

## References

1. J. De Dios Guerrero-Rodriguez, D.K. Revell, W.D. Bellotti, Anim. Feed Sci. Tech., **170**, 1-2, 97-104 (2011)
2. Zh.Sh. Zhumadilova, B. Mukhambetov, K.M. Abdieva, E.Zh. Shorabaev, A.K. Sadanov, Successes of modern natural science, **5**, 546-549 (2014)
3. K. Luo, M.Z.Z. Jahufer, F. Wu, H. Di, D. Zhand, X. Meng, J. Zhang, Y. Wang, Front Plant Sci, **7**, 972 (2016)
4. V.F. Kazarin, A.V. Kazarina, L.K. Marunova, Izvestiya Samarskogo nauchnogo tsentra RAN, **2**, **4**, 712-716 (2018)

5. V.F. Kazarin, A.V. Kazarina, Trudy Kubanskogo gosudarstvennogo agrarnogo universiteta, **3**, **54**, 156-161 (2015)
6. N.I. Dzyubenko, O.V. Duk, L.L. Malyshev, Yu.A. Prosvirin, I.A. Kosareva, Sel'skokhozyaystvennaya biologiya, **6**, **53**, 1294-1302 (2018)
7. A.A. Mushinsky, Izvestiya Orenburgskogo agrarnogo universiteta, **4**, 29-31 (2004)
8. S.A. Eberhart, W.A. Russel, Crop Sci., **1**, 36-40 (1966)
9. A.A. Rossielle, J. Hamblin, Crop Sci., **6**, 943-946 (1981)
10. V.V. Khangildin, S.V. Biryukov, Genetic and Cytological Aspects of Agricultural Plant Breeding: Collection of Scientific Tr./ VASHNIL, Vsesoyuz. Selection.-Genet. In-t (Odessa: VSGI) 67-76 (1984)