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Effective hybrids of *Zea mays* L. under conditions of changes in the boundaries of agro-climatic zones under the influence of global warming

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Abstract. The studies were carried out in the European part of Russia in the steppe zone. The response of five *Zea mays* L. hybrids from different maturity groups to the spatial variability of regional conditions (climate, soil quality, agricultural technology) was studied. The obtained data are necessary for scientifically substantiated selection of agro-ameliorative measures and schemes for managing the production processes of agricultural plants in the context of changes in the boundaries of agro-climatic zones under the influence of global warming. It has been established that the limiting factor in the sustainable production of corn grain in areas with insufficient heat supply is the short duration of the growing season, therefore, earlier sowing dates for early ripening and cold-resistant hybrids are necessary. For areas with insufficient moisture supply, the conditions of moisture deficiency in the summer months reduce the yield of corn grain, so it is necessary to combine the early sowing of mid-season hybrids and the methods of moisture-saving technologies.

1. Introduction

For the European part of Russia, there is a shift of the boundaries of agro-climatic zones from south to north at a distance of 60-150 km, especially for the southern and central regions. This expands the possibilities of growing crops ecologically confined to semi-arid and semi-humid conditions, such as *Zea mays* L. (corn), which is the most important grain, grain fodder, fodder and industrial crop. Many researchers have noted significant climate changes over the past 40 years, which manifest themselves in a decrease in the global yield of a number of the most important (world) grain food crops [1-2]. On average, thanks to technological methods (new hybrids, agricultural technology, etc.), the increase in corn yield was 1178 kg/ha, but at the same time, the negative climatic impact on the yield of this crop was 90.3 kg/ha (about 8%). In general, such losses of agriculture on a global scale are compensated by



agrotechnological progress and the direct positive effect of an increase in the content of carbon dioxide in the atmosphere on crop yields [3].

The purpose of the study is to evaluate the growth processes of corn hybrids, taking into account the natural conditions of the southern and central regions of the European part of Russia.

2. Materials and methods

According to the length of the growing season, groups of corn hybrids are distinguished: ultra-early, mid-early, mid-ripening, mid-late, late-ripening, very late-ripening. According to the agro-climatic zones in the Russian Federation in the Central, Volga-Vyatka, Middle Volga, Ural regions, early-ripening corn hybrids are recommended for cultivation; Central Black Earth, Nizhnevolzhsky - early ripe and medium early; North Caucasian - early ripening, mid-early, mid-season and late-ripening. Successful cultivation of corn is possible if a hybrid with the correct FAO is selected (table 1, items in bold type for which long-term experiments have been carried out).

Table 1. Properties of corn hybrids grown in long-term experiments (2010-2015).

Ripeness group	Conditional indicator of precocity, FAO	Vegetation duration, days	Sum of active temperatures, °C	Number of leaves on the main stem in the VII-VIII stage of orthogenesis	Name of the hybrid	FAO number	* Approved for cultivation
Early	< 200	< 100	2100-2200	11-14	NK Falcon	190	5
					NK Gitago	200	5
					SI Phenomenon	220	---
					Delitop	210	5,6
Medium	201-300	100-115	2400	13-16	NK Cooler	220	5
					Nekta	230	5
					NK Novatop	240	5
Middle Late	301-400	115-130	2600	14-18	SI Lucius	340	6
Late	above 401	above 130	above 2800	16-20	NK Paco	440	6

Note: according to the State Register *5. Central Black Earth region - *Belgorod region, Voronezh region, Kursk region, Lipetsk region, Oryol region, Tambov region*; 6. North Caucasian region - the Republic of Adygea, the Republic of Dagestan, the Republic of Ingushetia, the Kabardino-Balkarian Republic, *the Krasnodar Territory, the Rostov Region*, the Republic of North Ossetia-Alania, the Stavropol Territory, the Chechen Republic, the Republic of Crimea

In the period 2010-2015. complex field studies were carried out on the cultivation of corn hybrids in different soil and climatic conditions and contrasting agricultural backgrounds. Experimental fields are located in the steppe zone. The soil is ordinary chernozem, southern chernozem and chestnut soil. The experimental scheme included productive hybrids Delitop (210-220), NK Gitago (FAO 200), SI Novatop (240), NK Lucius (340), SI Phenomenon (FAO 220). Seeding rate: 65 thousand/ha and 90 thousand/ha. The plot area was 10 ha. Repetition 4-fold. The duration of the growing season of corn is 90-150 days. The agrotechnology of cultivation and the system of protection of crops of field crops corresponded to the requirements adopted in this region. Long-term studies were carried out in the soil and climatic conditions of Belgorod, Voronezh, Krasnodar, Kursk, Lipetsk, Orel, Rostov, Tambov

regions, which made it possible to cover a wide range of soil and climatic conditions, as well as to study the reaction of corn hybrids in extremely dry conditions (low rainfall) and with a moisture deficit during the growing season (low moisture content in the soil).

The experimental data obtained were analyzed using the MS Excel program, Statistica 10.0. For data processing, correlation analysis (correlation coefficient, R , %) and analysis of variance (variation coefficient, K_v , %) were used at a given probability level (P_α).

3. Results and Discussion

Different phenophases of corn growth differ in their requirements for available moisture. The flowering phase of corn is especially sensitive to external conditions - two weeks before panicle flowering (or 10 days before heading) and two weeks after flowering (or 20 days after panicle heading). With strong deviations from the optimum of the water and thermal regime, a lag in the development of the plant, especially the cob (modified side shoots) from the development of the panicle, was noted. The gap between the flowering of the panicle and the cob increases to 2-3 days, which leads to a decrease in the efficiency of pollination, the number of grains in a row and in the cob, and in general to yield losses. Under semi-arid conditions on fields with irrigation, when 80% of the field water capacity (WC) is reached, the corn grain yield corresponds to the biological potential of the hybrid and is taken by us as 100%. On variants without irrigation, the level of corn grain yield at 60% PV is 47%, and with irrigation - 90%, i.e. the saved yield reaches 50% or more than 90 q/ha. Physiological ripeness (grain moisture 35-40%) occurs at 8 weeks or 50-57 days after pollination. The ratio of parts of the corn crop in the dry above-ground mass of the weight of the whole plant: leaves - about 30%, stems - 25%, rods - 10%, grain - 35%.

Results of field experiments for the period 2012-2015 showed that the grain yield for the entire set of tested hybrids ranged from 53.9 c/ha to 79.4 c/ha; and on average fluctuated, taking into account soil and climatic conditions, from 39.9 c/ha to 103.1 c/ha (figure 1).

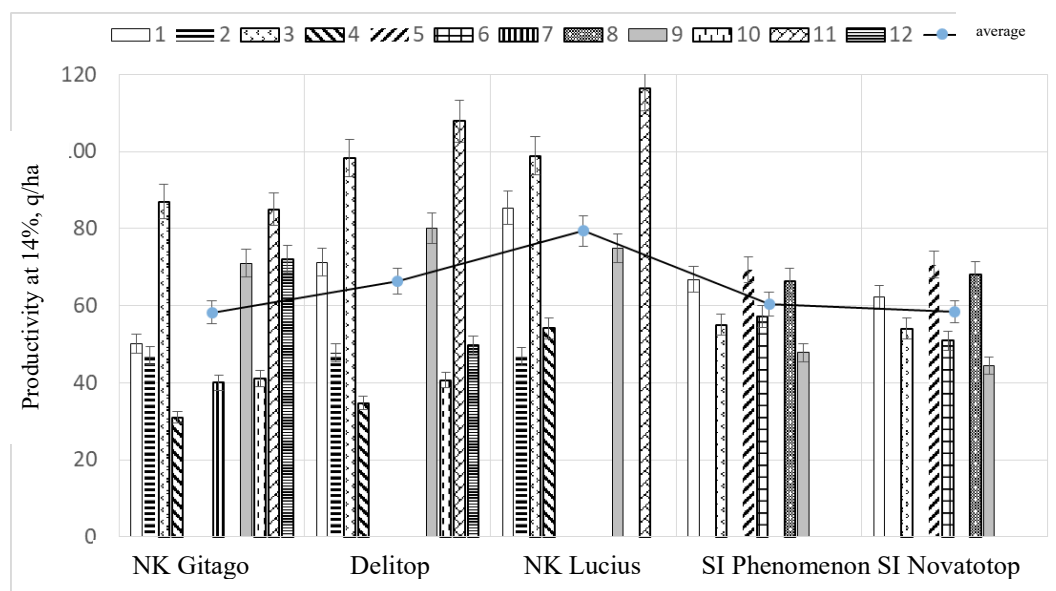


Figure 1. Distribution of the yield of corn hybrids depending on natural conditions (geographical location): 1 - Belgorod, 2 - Volgograd, 3 - Voronezh, 4 - Krasnodar, 5 - Kursk, 6 - Lipetsk, 7 - Orenburg, 8 - Orlovskaya, 9 - Rostov, 10 - Samara, 11 - Tambov, 12 - Ulyanovsk.

The influence of weather and soil conditions differed significantly in comparison with the genetic characteristics of hybrids. It has been established that the difference between the lower and upper yield limits for one hybrid in different soil and climatic conditions reaches 60% or 63.2 centners per hectare,

and the difference in the yield of different hybrids in one geographical location does not exceed 30% or 25.5 centners. / ha. The emphasis in long-term studies was placed on the analysis of the drought resistance of the studied hybrids. The experiments demonstrated that the yield of corn hybrids in environmental conditions with a minimum amount of precipitation varies and is determined by many factors, among which the influence of extreme weather conditions and soil properties, the duration of periods of drought and lack of soil moisture is significant.

A high result in terms of the yield of corn hybrids was observed for the Belgorod and Tambov regions, the lowest values for the Orenburg, Samara and Ulyanovsk regions. The best biological plasticity to the variability of soil and climatic conditions was demonstrated by the following maize hybrids - mid-late Lucius and mid-season SI Phenomenon. Analysis of the average yield values of the studied hybrids, taking into account the magnitude of variation, convincingly demonstrates the advantage of the hybrid SI Phenomenon (60.4 ± 7.7 c/ha), compared with other options - Delitop (66.3 ± 25.6 c/ha) and NK Lucius (79.4 ± 24.2 q/ha). According to our data, maize hybrids had a high index of resistance to water stress and effectively used the moisture reserves in the soil, forming the following sequence, taking into account the ripeness group: late (55%), medium (40%), and early (13%).

The data of multivariate statistical analysis showed that the sensitive phase of development of mid-ripening corn hybrids (number of days from sowing to flowering of 50% panicles) is significantly influenced by some factors ($P\alpha < 0.1$). It has been established that in the hybrid SI Phenomenon and SI Novatop, a decrease in soil quality ($R = -0.95$ - -0.87), an increase in sowing rates ($R = -0.89$ - -0.81), low soil temperature during sowing ($R = 0.84$ - 0.92). It should be noted that the SI Novatop hybrid was also less stress-tolerant to air heat ($R = 0.51$ - 0.63) and soil drought ($R = -0.64$ - -0.52).

With a moisture deficit, the yield of corn grain sharply decreased due to an increase in the number of poorly grained cobs, reaching 30-50% of the total number of cobs in the crop in very dry years. And in this case, it is promising to use mid-early corn hybrids that successfully tolerate drought, thanks to genetically fixed mechanisms:

- Reduction of water losses due to the closure of stomata;
- Inhibition of a further increase in the leaf surface, a decrease in the already existing leaf surface area due to premature drying;
- Temporary wilting (in some cases even deep) as a way to protect the crop from lethal dehydration, allowing for some time to retain the water necessary to maintain the viability of the plant;
- Defoliation of older leaves changes the redistribution of nutrients in favor of the stem or young leaves;
- Development of a powerful root system to maintain osmotic pressure and maintain a high level of water absorption;
- Synthesis of low molecular weight compounds of heat shock proteins;
- Synthesis and accumulation of osmotically active substances and assimilants in the cell sap of the stem and root system;
- The presence of a wax coating on the leaves and a special texture of corn kernels, which is characterized by the presence of a horn-like layer of endosperm (glassy part) from the periphery.

The result obtained for SI The phenomenon is explained by the genetic characteristics of the hybrid, which is characterized by a fairly high stress tolerance to moisture deficiency and responds positively to agrotechnological methods (influence on soil fertility, choice of sowing rate and depth, etc.). This makes it possible to obtain a consistently high yield of corn grain on different agricultural backgrounds both in optimal and extreme weather conditions in the years of observation.

Using the methods of mathematical statistics based on the main components, we studied the changes in the morphological characteristics of corn hybrids in space and time. The results obtained on

the spatial variability of the morphometric characteristics of corn and the spatial variability of geographical conditions were grouped into five main components (table 2). Confirmed earlier conclusions about the preservation of the genetic characteristics of hybrids in different soil and climatic conditions under optimal conditions of soil moisture (low value for leaves and stem $K_v = 16-26\%$) and a high response of plant height to stress factors - soil quality and weather conditions (K_v above 90%). There were no significant changes in morphometric characteristics at different sowing rates (65-90 thousand units/ha).

Table 2. Variability parameters of morphometric characteristics of corn hybrids under different environmental conditions.

No	Characteristic	Ky, %	Sign	R ($P\alpha < 0.10$)
1	habit	94±7	plant height	-0.35
			number of leaves	-0.34
2	sheet	26±4	ratio of width to length	-0.42
3	stem	16±3	volume	0.48
4	index A	8±2	plant density,	-0.50
			specific leaf surface area	-0.40
5	index B	8±3	plant density,	0.64
			specific leaf surface area	0.34

Note: *index A* is equal to the ratio of plant density and the height of their stems; *index B* equal to the product of plant density and the height of their stems

4. Conclusion

In our study, it was found that modern maize hybrids are characterized by high spatial variability depending on weather conditions and soil properties. The obtained data are necessary for scientifically substantiated selection of agro-ameliorative measures and schemes for managing the production processes of agricultural plants in the context of changes in the boundaries of agro-climatic zones under the influence of global warming. It has been established that the short duration of the growing season is the limiting factor in the formation of the corn grain yield in areas with insufficient heat supply. The condition for sustainable production of corn grain in this case is the earlier sowing of early ripening and cold-resistant hybrids, for example, for the Tambov, Belgorod, Voronezh, Kursk, Lipetsk and Oryol regions. For areas with insufficient moisture supply (Rostov, Volgograd oblast, etc.), the limiting factor is moisture deficit in the summer months. The condition for sustainable production of corn grain in this case is early sowing, moisture-saving technologies, etc.

According to long-term studies (2010-2015), the main components were identified for the European part of Russia, which reflect the change in the morphometric characteristics of corn depending on the spatial characteristics or geographical location of corn hybrid crops - plant size, number of leaves. It has been established that the length of a corn leaf will lag behind in growth rate from the growth rate of plant height. However, the effect of maize plant density on stem height is ambiguous.

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