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MODELS OF QUANTITATIVE ASSESSMENT OF THE INFLUENCE OF ELEMENTS OF TECHNOLOGY ON SEED YIELD OF PARENTAL COMPONENTS OF MAIZE HYBRIDS UNDER IRRIGATION CONDITIONS

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Abstract

The results of research on establishing the correlation-regression dependence of the assimilation surface area of plant leaves of inbred lines-parental components of corn hybrids of different FAO groups and seed yield depending on the density of plants and treatment with the drug Retengo® are highlighted. The research is based on a comparative assessment of three parent lines of different FAO groups: DK247 (FAO 290), DK205710 (FAO 380), DK445 (FAO 420). The effectiveness of the application of the fungicide with growth-stimulating action Retengo® at different plant densities was determined. The yield calculation showed that the realization of the seed yield potential for each inbred line depends on the genotype, in accordance with the established individual parameters of the optimum leaf surface and phytocenosis density in the crop. The use of the fungicide with growth-stimulating action Retengo® strengthens the correlation of the area of leaves of plants of lines and the yield of seeds.

Key words: *maize, lines - parental components, plant density, fungicide, leaf area, seed yield.*

INTRODUCTION

In recent decades, the yield of corn hybrids has increased significantly due to the use of new genotypes and innovative agricultural technologies (Assefa et al., 2018; Kaminskiy & Asanishvili, 2020).

The creation and introduction into production of innovative corn hybrids of various FAO groups, characterized by a high effect of heterosis and high potential yield, depends on the genetic potential of the parent lines included in the pedigree of these hybrids. An important issue is increasing the seed production of parental components of promising corn hybrids for their accelerated introduction into production. However, the realization of the genetic potential of parental components is carried out to the full extent only under conditions of application of optimal measures of agricultural technology (Abelmasov & Bebeh, 2018).

The formation of the crop depends on the intensity of photosynthesis, since the processes of accumulation of organic matter are closely related to the activity of the leaves and their ability to accumulate solar light energy. According to the modern theoretical understanding of the functioning mechanisms and interrelationships of the donor-acceptor system in a plant, it is possible to ensure an intensive production process by modifying the morpho-physiological features of the culture, forming a powerful photosynthesizing surface, and extending the life of the photosynthetic apparatus. The intensity of biomass accumulation is determined by the optimal content and ratio of photosynthesis pigments (carotene, xanthophyll, pheophytin a, pheophytin b, chlorophyll a, chlorophyll b), which depend not only on the direction of photosynthesis, but also on the speed and nature of plant metabolism (anatomical and

morphological changes) (Milas et al., 2018; Odabas et al., 2013).
The formation of the corn grain mainly occurs due to the photosynthesis of the upper leaves. Higher productivity is ensured by hybrids in which the leaves of the middle and lower tiers intensively use the weakened insolation, and the upper ones are better adapted to the intensive supply of PAR. The maximum size of the leaf area is reached on the 70th day after the emergence of seedlings, which coincides with the phase of "ejection - flowering of the panicle". After that, there is a gradual decrease in the area of the leaf surface and reaches zero on the 130th day of vegetation (Su et al., 2018). The increase in leaf surface occurs unevenly during the growing season and is largely determined by the amount of nutrients in the soil, including trace elements (copper, zinc, etc.) (Yunusov et al., 2020).
The loss of 25% of leaves by plants at all stages of development, except for the period of "dropping the panicle - milk ripeness", leads to a decrease in the yield of corn grain by 10% (Boedhram et al., 2001).
Inbred lines - parent components of corn hybrids, as a product of long-term forced self-pollination, are more demanding on growing conditions, differ in increased sensitivity to the influence of adverse factors, and have a smaller plant habit compared to hybrids. The genotypic features of the line affect the phenotypic manifestation of traits; therefore, it is necessary to take into account the biological features of the parental components and technological recommendations for growing hybridization plots. In this regard, scientific developments on the optimization of technological techniques for growing seeds of inbred lines of corn, parental components of promising hybrids, are becoming of urgent importance (Dziubetskyi et al., 2020).
Plant density plays an important role in the complex of agrotechnical measures of corn cultivation, which depend on the yield and its quality. A significant harvest can be obtained due to high individual productivity and the maximum permissible stem density in a specific growing area (Youngerman et al., 2018; Bahan, 2022).
The density of plants is one of the main factors that determines the efficiency of using fertility, temperature and water regimes of the soil, solar energy and other components of the vital activity of the agrocenosis. Optimizing the conditions for growing agricultural crops allows to increase the productivity of both a single plant and the crop as a whole (García-Martínez et al., 2020; Sarlangue et al., 2007; Liu Y. et al., 2021).
Since the formed corn seed is a product of the photosynthetic activity of the plant, it is important to determine the optimal area of the assimilation surface of the leaves, which is the basis of photosynthesis. Leaf area is closely related to seeding density. Thus, it is possible to state that the density of plants in the field is the main condition that determines the area of plant leaves, according to existing growing conditions. The optimal density of the phytocenosis ensures the appropriate intensity of photosynthesis and, therefore, the final yield of one plant and the entire crop yield (Shapiro & Wortmann, 2006). On the other hand, in sowing, there is competition between plants for obtaining space, light, water, mineral nutrition and carbon dioxide, which affects the individual productivity of the plant and the sowing as a whole (Attia et al., 2021).
Considering the above, we can assert the importance of determining the optimal seeding density for each genotype. Plant density depends on growing conditions (duration of the vegetation period, sum of effective temperatures, availability of moisture, nutrients, etc.) and the genotype of the plant (Kharchenko et al, 2019; Ren et al., 2021; Sher et al., 2017).
The use of growth regulators is one of the promising directions in agricultural production. The use of regulators is especially important for crops of self-pollinated lines of corn, which, due to morphological and biological features, differ in low germination energy, weak initial growth, sensitivity to damage by pests, phytoinfections, etc. (Ivanyshyn, 2020; Vozhehova et al., 2022).
Fungicides have a positive effect on plants due to the reduction of fungal diseases of corn, such as *Ustilago zeae* (Beckm.), *Pseudomonas hoici Kendr.* and *Erwinia dissalvens* (Burkh.), *Helminthosporium turcicum* (Pass.). In addition, treatment with fungicidal drugs with a re-regulating effect increases the stress resistance of plants to adverse biotic and abiotic conditions (Vozhehova et al., 2021; Marchenko, 2019).
However, for new inbred lines-parental components of hybrids, there are no

recommendations on the optimization of technology elements; therefore research is needed on the influence of plant density and re-regulating drugs on the area of the assimilation surface and the yield of parental lines under drip irrigation conditions.

MATERIALS AND METHODS

The purpose of the research was to determine the dynamics of the area of the assimilation surface of plant leaves and to record the yield of seeds of inbred lines-parental components of hybrids of corn of different FAO groups, depending on the density of plants and treatment with the drug Retengo®.

The response of corn hybrids to different cultivation conditions was studied at the Institute of Irrigated Agriculture, Kherson, Ukraine (46°44'33" N; 32°42'28" E; 50 m above sea level) (location A) during 2018-2020. A three-factor experiment (factor A - parent lines, B - treatment of plants with Retengo®, C - density of plants in sowing) was established by the method of randomized split blocks. The sown area of the plots was 50.0 m^2, the accounting area was 30.0 m^2. The research was carried out in quadruplicate.

The material for the research was the parental components of different maturity groups: DK445 (Mixed germplasm, FAO 420) - parent component of hybrids Arabat, Vira, Hileya; DK205710 (Iodent germplasm, FAO 380) - the parent component of the Kakhovsky hybrid; DK247 (Mixed germplasm, FAO 290) - parent component of hybrids Skadovs′kyy, Oleshkivs′kyy (the lines belong to the Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine and were used in joint breeding programs with the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine). The plant density of the parent components was 60,000, 70,000, 80,000, 90,000, 100,000 plants ha^{-1}. The treatment of the parent components of corn was carried out with the drug Retengo® - a fungicide with a re-regulating effect from the AgCelence® group of drugs, which is included in the State Register of pesticides and agrochemicals approved for use in Ukraine. Plants were treated with Retengo® in the 7-8 leaf phase (BBCH 16-19).

The area of the leaf surface was determined by the linear method with subsequent calculation according to the formula: $S = k * l * n$, where S - leaf area, cm^2; k - average correction factor, is equal to 0,75; l - leaf length, cm; n - the width of the leaf at its widest point, cm.

Agricultural cultivation techniques and research methods are generally accepted for irrigation conditions in addition to the studied factors. Surface drip irrigation was used, the level of pre-irrigation soil moisture being 80% of the lowest moisture content in the 0–50 cm soil layer (Vozhehova et al., 2014).

Mathematical processing of research results was carried out by the method of dispersion analysis using the Agrostat computer program package (Ushkarenko et al., 2009)

RESULTS AND DISCUSSIONS

Currently, there are many models for predicting the yield of agricultural crops, in particular corn (Kharchenko et al., 2019).

Researchers believe that early-ripening hybrids of corn and low-growing plants better withstand the thickening of plants, and increase the yield on the sowing area. Later-ripening plants are better grown in sparse crops, where they simultaneously increase the biometric indicators of the plant and the yield of one plant. This response of hybrids to seeding density can be predicted using cluster analysis and cluster diagram (Palamarchuk et al., 2021).

For the optimal passage of the photosynthesis process, corn crops must have a certain area of the leaf surface, which acts as a means of accumulating plastic substances for the formation of the seed crop of parent components. In conditions of irrigation, the intensity of physiological processes of corn increases - the area and productivity of the leaf apparatus of plants increases (Marchenko et al., 2020).

During the determination of the area of the leaf apparatus of corn in the section of the development phases, a positive dynamic of its increase until the flowering phase and a decrease of the indicator during the phase of milk ripeness of the grain were established. In the phase of 15 leaves (BBCH 37-39), a difference in the indicator in the cross section of the line is noted. Thus, the DK 445 line was leafier and provided an indicator value within the range of 0.344-0.395 m^2/plant, while the DK 247 line had a leaf area value from 0.262 to 0.316 m^2/plant (Table1).

Table 1. The area of the assimilation surface of one plant of lines–parental components of corn hybrids depending on the factors of the experiment (average for 2018-2020), m^2/plant

The line is the parent component (Factor A)	Drug treatment (Factor B)	Density, plants ha^{-1} (Factor C)					Average by factor	
		60,000	70,000	80,000	90,000	100,000	A	B
in the phase of 15 leaves (BBCH 37-39)								
DK 247 (FAO 290)	no processing, control	0.291	0.282	0.273	0.268	0.262	0.285	0.274
	Retengo®	0.316	0.305	0.291	0,289	0.287		0.296
DK 205710 (FAO 380)	no processing, control	0.343	0.332	0.322	0.321	0.315	0.329	0.319
	Retengo®	0.362	0.351	0.342	0.337	0.329		0.340
DK 445 (FAO 420)	no processing, control	0.373	0.362	0.353	0.351	0.344	0.362	0.349
	Retengo®	0.395	0.384	0.372	0.374	0.365		0.374
Average by factor C		**0.347**	**0.336**	**0.326**	**0.323**	**0.317**		
LSD_{05}		0.034	0.034	0.034	0.035	0.034		
in the flowering phase (BBCH 63-67)								
DK 247 (FAO 290)	no processing, control	0.382	0.371	0.362	0.351	0.319	0.376	0.357
	Retengo®	0.423	0.412	0.401	0.382	0.359		0.395
DK 205710 (FAO 380)	no processing, control	0.434	0.423	0.411	0.401	0.378	0.426	0.409
	Retengo®	0.472	0.461	0.452	0.427	0.402		0.443
DK 445 (FAO 420)	no processing, control	0.484	0.473	0.454	0.435	0.413	0.462	0.452
	Retengo®	0.505	0.495	0.471	0.453	0.432		0.471
Average by factor C		**0.450**	**0.439**	**0.425**	**0.408**	**0.384**		
LSD_{05}		0.040	0.041	0.037	0.034	0.037		
in the phase of milky seed maturity (BBCH 83-85)								
DK 247 (FAO 290)	no processing, control	0.341	0.330	0.323	0.311	0.282	0.337	0.317
	Retengo®	0.383	0.372	0.361	0.342	0.324		0.356
DK 205710 (FAO 380)	no processing, control	0.394	0.383	0.371	0.351	0.331	0.385	0.366
	Retengo®	0.431	0.422	0.403	0.392	0.367		0.403
DK 445 (FAO 420)	no processing, control	0.444	0.433	0.414	0.398	0.381	0.422	0.414
	Retengo®	0.465	0.454	0.432	0.404	0.395		0.430
Average by factor C		**0.410**	**0.399**	**0.384**	**0.366**	**0.347**		
LSD_{05}		0.041	0.041	0.036	0.033	0.038		
LSD_{05}		0.042	0.042	0.039	0.036	0.033		

Until the phase of 15 leaves (BBCH 37-39) the density of plants did not significantly affect the size of the leaf surface area of one plant, and after this period (in the second half of the growing season), a clear pattern of a decrease in the leaf surface of a plant with an increase in plant density was noted. Thus, thickening from 60,000 plants ha^{-1} to 100,000 plants ha^{-1} contributed to the reduction of leaf area: in the 15-leaf phase by 7.6-9.9%, and in the flowering phase by 14.2-17.3%. In the flowering phase (BBCH 63-67) the area of the corn assimilation apparatus reached its maximum. The genotype of the FAO group of parental component lines had the greatest influence on the indicators of the area of the assimilation surface. In the flowering phase, the largest plant leaf area was in the mid-late line DK 445 (FAO 420), and the average factor A (parental line) was 0.462 m^2/plant. A smaller area of the plant assimilation surface was formed by the mid-ripe line DK

205710 (FAO 380) - 0.426 m^2/plant, and the mid-early line DK247 - 0.376 m^2/plant.

In the phase of milk ripeness (BBCH 83-85) the area of the leaves of the corn line decreased because the growth processes stopped, the generative period began, during the origin of which nutrients are redistributed, the drying of the lower leaves was noted. Thus, in the phase of milk ripeness, the values were lower than in the flowering phase by 0.039-0.041 m^2/plant.

The genotype of the line influenced the leaf area of the parental components of the corn hybrids. The maximum value of this indicator, on average according to factor A, was 0.422 m^2/plant in the mid-late line DK 445, the minimum value was in the mid-early line DK247 (0.337 m^2/plant). Plant density also has a significant effect on the "plant leaf area" feature. The maximum assimilation surface area, on average over the years of research (0.347-0.450 m^2/plant), was shown by plants at a density of 60,000 plants ha^{-1}, and all parent lines, regardless of genotype, showed maximum leaf area at this density. The minimum indicators of the area of the assimilation surface of the leaves were observed at a density of 100,000 plants ha^{-1} - 0.317-0.384 m^2/plant.

Treatment of plants with the drug Retengo® increased the area of the assimilation surface by 0.016–0.039 m^2/plant or by 3.8–12.3%, compared to the untreated control.

According to Li et al. (2015) yield of corn grain and dry matter when growing corn hybrids under drip irrigation depended on plant density. The optimal seeding density is set ≤ 4.7 plants/m^2. With an increase in density to 8.3 plants/m^2, the relationship with the productivity index was not established, but the yield of grain and dry matter decreased. As the density increased to 10.7 or more plants/m^2, the productivity index decreased.

Using the Bayesian computational methods, Lacasa et al. (2021) significant relationships were established between the yield of agricultural crops and the density of sowing. Using linear regression to determine the response to changes in corn planting density, Assefa et al. (2018) reported that the share of the effect of plant density on corn yield ranged from 8.5 to 17%.

Sun et al. (2016), using the APSIM model, which takes into account the variability of weather factors, according to data from an 11-year field experiment, confirmed that plant density is one of the most important factors affecting corn yield. At the same time, the density of plants correlates with the optimal time of sowing.

In our studies, the seed yield varied depending on the line and the density of the cenosis. Thus, the medium-early DK 247 line showed the maximum seed yield at a density of 90,000 plants ha^{-1} and treatment with Retengo®– 4.94 t ha^{-1}. The medium-ripe line DK 205710 showed the maximum seed yield at a density of 80,000 plants ha^{-1} and treatment with Retengo®– 5.61 t ha^{-1}.

The highest seed yield was shown by the mid-late line DK 445, which is the parent form of the Arabat, Hileya, Vira hybrid at a density of 70,000 plants ha^{-1} and treatment in the 7–8 leaf phase with the re-regulating fungicide Retengo® - 7.08 t ha^{-1} (Figure 1).

Effective seed production of corn lines and hybrids involves accelerated reproduction of parental components and obtaining seeds with high sowing qualities. In order to improve the methods of selection for the productivity of corn lines under irrigation conditions, an important issue is to find out the specifics of the relationship between seed yield and the area of the assimilation surface of the plant. These two key indicators may have been antagonistic.

The area of the assimilation surface increases on thinned crops and, at the same time, seed yield may decrease. Therefore, correlation-regression modeling of the variation of these features was carried out. Analyzing the obtained data, it is possible to conclude that the high leaf surface area of the parent components does not always indicate a high seed yield.

A high negative correlation between the area of the assimilation surface and yield was found in the mid-early line-parental component DK 247 ($r = -0.771$). The use of the drug Retengo® weakened the negative correlation and, at a certain interval, the increase in the area of the leaf surface (from 0.372 to 0.381 m^2/plant) and productivity went in parallel (Figure 2).

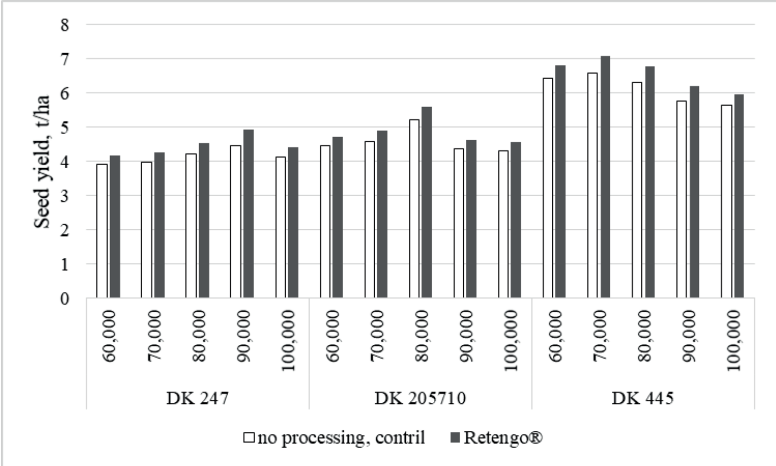

Figure 1. Seed yield of parent lines of corn hybrids depending on plant density and treatment with Retengo®, t ha^{-1} (average for 2018-2020)

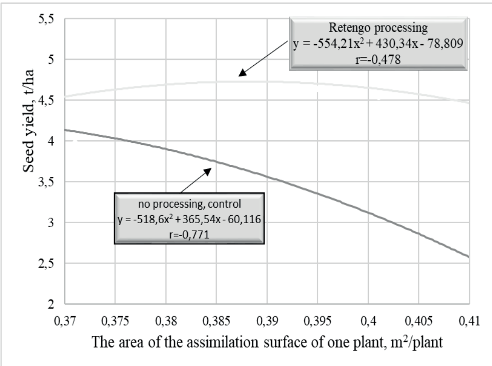

Figure 2. Correlation-regression model of the dependence of seed yield and the area of the assimilation surface of one plant of the mid-early line DK 247 (average for 2018-2020)

An increase in the assimilation surface over 0.38 m^2/plant was accompanied by a drop in productivity. It was found that without the use of Retengo®, an increase in the area of the assimilation surface of one plant leads to a significant drop in productivity.

In the mid-late line DK 445, the increase in the area of the assimilation surface was accompanied by an increase in yield (Figure 3). Such changes take place in parallel under the action of Retengo® and on the control version. However, the growth of the area of the assimilation surface is limited to an area of 0.473-0.495 m^2/plant, this level of plant leaf area corresponds to a density of 70,000 plants ha^{-1}.

Therefore, it is possible to conclude that the main factor for obtaining a high yield of quality seeds in the DK445 line is the density of 70,000 plants ha^{-1} and the use of Retengo®.

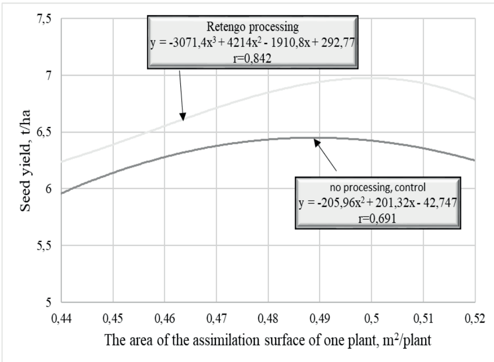

Figure 3. Correlation-regression model of the dependence of seed yield and the area of the assimilation surface of one plant of the mid-late line DK445 (average for 2018-2020)

The increase in productivity and the area of the assimilation surface in the lines of the parent components was due to a decrease in the incidence of fungal diseases of corn, such as *Ustilago zeae* (Beckm.), *Pseudomonas hoici* Kendr. and *Erwinia dissalvens* (Burkh.), *Helminthosporium turcicum* (Pass.). In addition, this drug has a re-regulating effect in the direction of increasing stress resistance to biotic and abiotic conditions.

CONCLUSIONS

It was established that in the flowering phase the area of the assimilation surface of the leaves of corn plants reached its maximum, its values ranged from 0.319 to 0.505 m^2/plant. Treatment of plants with the drug Retengo® increased the area of the assimilation surface by 0.016-0.039 m^2/plant or by 3.8-12.3%, compared to the untreated control.

An increase in plant density from 60,000 plants ha^{-1} to 100,000 plants ha^{-1} contributed to a decrease in leaf area: in the 15-leaf phase by 7.6-9.9%, and in the flowering phase by 14.2-17.3%.

The calculation of seed yield showed that the maximum values of the inbred mid-late line DK 445 (FAO 420) were formed on the variant at a density of 70,000 plants ha^{-1} and for treatment with the fungicide Retengo® – 7.08 t ha^{-1}. The mid-germination DK 247 line showed the maximum seed yield at a density of 90,000 plants ha^{-1} after treatment with the drug Retengo ® – 4.94 t ha^{-1}. The medium-ripe line DK 205710 showed the maximum seed yield at a density of 80,000plants ha^{-1} and application of Retengo® – 5.61 t ha^{-1}. The maximum values of seed productivity were formed by those variants in which the optimal area of the leaf apparatus of plants was observed.

Under the conditions of the optimal irrigation regime, parent lines of corn hybrids of different FAO groups form seeds with high sowing qualities at different plant densities – from 60,000 to 100,000 plants ha^{-1}. The density of the cenosis is of decisive importance for the formation of seed yield, and for each line-parental component there is an optimum density of plants. The correlation of seed yield and the area of the assimilation surface can be positive (r = 0.691 - 0.842) and negative (r = -0.478 - –0.771) depending on the norm of the reaction of the genotype, but this dependence is not linear and each line has its own optimum a combination of these indicators.

Treatment with the drug Retengo® changed the correlations of seed yield and the assimilation surface area of plants in the direction of increasing the positive dependence of these characteristics.

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