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Changes in the photosynthetic activity and grain yield of corn hybrids at different plant densities and the effect of microbiological fertilizers in the lower Volga region

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Abstract

The article deals with the influence of plant density and the use of Extrasol, microbiological fertilizer, on photosynthetic activity and productivity of corn hybrids of different ripeness groups in the Lower Volga region. The results indicate that an increase in plant density up to 65,000 plants/ha contributes to an increase in the studied parameters. The leaf area of Ross 197 MB, Ross 299 MB, and STK 175 corn hybrids with thickening was 35,220.9 m^2/ha, 40,168.4 m^2/ha and 44,540.1 m^2/ha, respectively; the photosynthetic potential of Ross 197 MV - 2.1 million m^2/ha per day, Ross 299 MV - 2.10 million m^2/ha per day, and STK 175 - 2.27 million m^2/ha per day; grain yield for Ross 197 MV is 6.90 t/ha, for Ross 299 MV – 6.37 t/ha, for STK 175 – 7.81 t/ha. The use of Extrasol promoted an increase in the leaf area by 1630.6-2257.9 m^2/ha and the photosynthetic potential of hybrids by 0.27-0.97 million m^2/ha per day.

Keywords: corn, hybrid, leaf surface area, photosynthetic potential, yield, plant density, microbiological fertilizer

Introduction

Corn is one of the most widespread crops in world agriculture. The agricultural mainstreaming of corn hybrids with distinctive morphological and biological characteristics makes it necessary to study some elements of technology that affect the characteristics of photosynthetic activity of plants and the formation of grain yield.

The plant density is one of the significant factors in the formation of the corn yield. As the sowing density increases, the yield of both the total above-ground mass and grain increases. The use of lines with a positive reaction to thickening makes it possible to obtain hybrids that provide an increase in grain yield at a higher plant density in comparison with the standard [1, 2]. Tall, powerfully developed corn hybrids form a higher yield with less plant density than undersized and more early maturing [3]. An increase in yield with the growing number of plants per unit area is observed only up to a certain limit, after which the yield decreases [4]. An important parameter of corn sowing is the leaf area [5, 6, 7]. It has been experimentally established that 87% of the total phyto area of corn plants falls on the share of leaves [8]. The size of leaves and their number play an important role in the photosynthetic activity of corn plants [5]. Photosynthetic activity of corn crops continues throughout the growing season [9]. Under unlimited nutrition and moisture supply, varieties of grain crops with erectoid leaf arrangement have an advantage. Moreover, early maturing forms have a lower specific surface density, shorter leaf length and width. Late-ripening varieties are characterized by long-lived leaves with large linear parameters [10, 11, 12, 13, 14, 15]. Corn refers to the C4 -plants group, characterized by a high photosynthetic intensity productivity, effective use of water under increased insolation and temperature [16, 17, 18, 19].

The photosynthetic yield and the yield of hybrids of corn and other agricultural crops depends on many factors, including the duration of the growing season [10, 14, 9], the set of agricultural techniques [20, 21], the level of mineral nutrition [21, 14, 15], etc. Currently, the level of farming culture is not limited to these factors. Against the background of the increasing anthropogenic load on agrocenoses, the practically unlimited use of agrochemicals, the use of environmentally friendly microbiological fertilizers, which contribute to an increase in the rate of circulation of nutrients, becomes especially relevant [22].

In the market of agrochemical services, microbiological products occupy a very significant place due to a number of their advantages: they reduce the activity of phytopathogens; participate in the microbiological transformation of heavy metals [22]; improve plant root nutrition by fixing atmospheric nitrogen and producing physiologically active substances [23]; they increase the content of basic nutrients in the soil [24, 25], therefore increasing the yield and improving the quality of the products obtained. Th objective of the research is to determine the effect of plant density and the use of Extrasol microbiological fertilizer on the photosynthetic activity of corn hybrids and grain yield.

Material and Methods

The experimental part was carried out at the experimental field of the Federal State Budgetary Scientific Institution

RosNIISK "Rossorgo" in 2014-2017. The field experiment was launched according to a three-factor scheme by split plots with the following factors: factor A - corn hybrids: A_1 - Ross 197 MV (early maturing), A_2 - Ross 299 MV (mid-early), A3 - STK 175 (mid-late); factor B - plant density: B_1 - 45.0 (recommended); B_2 - 55.0; B3 - 65.0 thousand plants/ha, respectively; factor C - Extrasol-treated variants: C_1 - untreated (control), C_2 - treated seed material, C3 - treated seeds and vegetative plants in the phase of 4-5 leaves. Each plot area - 15.4 m^2. The experiment was conducted in triplicate. The predecessor was summer fallow. In the experiments, a zonal corn farming technique was used; sowing was carried out in the optimal agronomic terms. The plant density was formed manually in the phase of 2–3 leaves. The soils of the experimental field are southern chernozem. The thickness of the arable horizon is 21-24 cm, the humus content in the soil is 5.1% in the layer up to 15 cm, and less than 2.9% in the 30-40 cm layer; the phosphorus content in soil is low, potassium and nitrogen - high, pH of the water extract is 6.7 - 6.9. Weather conditions during the experiment differed in temperature regime and moisture supply: the hydrothermal coefficient for the growing season of corn (May – September) was: 2014 - 0.48; 2015 - 0.52; 2016 - 0.73, 2017 - 0.92. Experimental studies were carried out in accordance with the provisions of the recommendations for field experiments with corn [26]. The leaf area was determined by the method of carvings [27]. Statistical processing of research results was carried out according to B.A. Dospekhov's method [28].

We used Extrasol as a microbiological fertilizer developed by the All-Russian Research Institute of Agricultural Microbiology of the Russian Academy of Agricultural Sciences (Bisolbi-Inter, LLC). The product consists of rhizosphere nitrogen-fixing bacteria *Bacillus subtilis*, strain Ch-13. Ingredients: vegetative cells <10%, spore culture >90% (of the total number of cells) and products of bacterial metabolism: antibiotics, enzymes, phytohormones, vitamins, etc. Seeds were treated with a solution of Extrosol (liquid form), 1 liter of the product per 1 ton of seeds. Vegetative plants were treated at the rate of 2 l/ha of the drug with the spray material flow rate of 300 l/ha (0.3 L per 10 m^2) [28].

Results and Discussion

Observations over the growth and development of corn plants revealed that the leaf surface area of the early maturing hybrid Ross 197 MB at the recommended plant density (45,000 plants/ha) and without the use of microbiological fertilizer was 25404.8 m^2/ha (Table 1). With an increase in the plant density by 10,000 plants/ha, the leaf surface area increased on average over the years of research by 7718.5 m^2/ha, or 28.0%. An increase in the number of plants from 45,000 to 65,000 plants/ha provides an increase in leaf area by 9818.1 m^2/ha or 38.6%.

After seeds inoculation with Extrasol, the increase in the leaf surface area of the Ross 197 MV hybrid was 1311.7 m^2/ha (5.2%) at a density of 45,000 plants/ha, 2520.2 m^2/ha (7.7%) for 55,000 plants/ha and 549.3 m^2/ha (1.5%) for 65,000 plants/ha. The increase in leaf surface is somewhat more noticeable with the double application of Extrasol: 2217.9 m2/ha (8.7%) at a density of 45,000 plants/ha; 3434.0 m^2/ha (10.5%) - 55,000 plants/ha; 884.8 m^2/ha (2.5%) - 65,000 plants/ha.

The intensity of the formation of the leaf area of the medium early hybrid Ross 299 MV in the control variant averaged 33,718.9 m^2/ha over the years of research. With an increase in seeding density to 55,000 and 65,000 plants/ha, an increase in leaf area was observed by 1919.3 m^2/ha (5.7%) and 6449.5 m^2/ha (19.1%), respectively. Treatment of seeds with Extrasol allowed to increase the leaf area by 1647.0-2053.6 m^2/ha, or 4.6-5.6%. In the case of C_3 treatment, the leaf area increased by 7.1-10.7%.

In the control variant and at a plant density of 45,000 plants/ha, the leaf area of the medium late hybrid STK 175 was 39,635 m^2/ha. An increase in plant density to 55,000 plants/ha and 65,000 plants/ha led to an increase in leaf area by 3465.1 m^2/ha (8.7%) and 4904.5 m^2/ha (12.4%), respectively. C_2 and C_4 showed an increase in the leaf area by 2.3-5.62% and 1.67-6.85%, respectively, depending on the plant density.

It should be noted that the greatest effect of seed treatment with Extrasol is provided at a density of 45,000 plants/ha in Ross 299 MB and STK 175 and at a density of 55,000 plants/ha in Ross 197 MB. Two-fold application of microbiological fertilizer is more expedient at a density of 55,000 plants/ha in Ross 197 MV and Ross 299 MV and at a density of 45,000 plants/ha in the late-ripening hybrid STK 175. The largest leaf area according to factor A was in STK 175 and amounted to 43,465.8 m^2/ha. Ross 299 MB and Ross 197 MB showed lower values - 37671.3 and 32263.2 m^2/ha, respectively. Significant differences were found between the values of the trait according to factor B. The maximum leaf area by plants is formed at a density of 65,000 plants/ha - 40,928.8 m^2/ha.

Application of microbiological fertilizer (factor C) also influenced the formation of leaf area. Treatment of seeds and vegetative plants in the phase of 3-5 leaves provided a higher leaf area - 38920.4 m^2/ha.

Table 1: Leaf surface area of corn hybrids in the flowering phase (m^2/ha), 2014-2017

Hybrids (A)	Treatment variant (C)	Plant density, thousand ha (B)			Average factor A	Average factor C
		45	55	65		
Ross 197 MV	C_1	25,404.8	32,523.0	35,222.9	32,263.2 a	C_1= 36,662.5a C_2 = 38,293.1 b C_3 = 38,920.4 b
	C_2	26,715.7	35,043.2	35,772.2		
	C_3	27,622.7	35,957.0	36,107.7		
Ross 299 MV	C_1	33,718.9	35,638.2	40,168.4	37,671.3 b	
	C_2	35,622.2	37,285.9	42,222.0		
	C_3	36,114.3	39,484.3	43,069.1		
STK 175	C_1	39,635.6	43,110.7	44,540.1	43,465.8 c	
	C_2	41,864.4	44,141.5	45,970.9		
	C_3	42,351.0	44,291.6	45,286.4		
Average factor B		34,338.8a	38,608.4b	40,928.8b		
F_{fact}. Factor A – 17.7*, HCP_{05} factor A – 3454.4 F_{fact}. Factor B – 38.9* HCP_{05} factor B – 3433.4 $F_{fact.}$ Factor C – 15.1*, HCP_{05} factor C – 1359.4 F_{fact}. interrel. BC – 3.3*, HCP_{05} interrel. BC – 3932.9						

The studied methods had different effects on the photosynthetic potential of corn crops. During the years of research, the photosynthetic potential of the early maturing hybrid Ross 197 MV at the recommended plant density was 1.46 million m^2/ha day. With thickening, the photosynthetic potential increased: by 0.08 million m^2/ha day (5.5%) at 55,000 plants/ha and by 0.75 million m^2/ha per day (51.3%) at 65,000 plants/ha. Treatment of seed material with Extrasol contributed to an increase in the photosynthetic potential by 0.03-0.07 million m^2/ha per day at a plant density of 45,000 and 55,000 thousand plants/ha. A similar trend is observed with treatment variant C_3.

The photosynthetic potential of Ross 299 MB and STK 175 at a density of 45,000 plants/ha was 1.76 and 2.08 million m^2 per day, respectively. With an increase in plant density to 55,000 and 65,000 plants/ha, the value of the photosynthetic potential of Ross 299 MV sowing increased by 0.25 and 0.34 million m^2/ha day, or 14.2 and 19.3%, respectively. The effectiveness of pre-sowing seed treatment with Extrasol was revealed at all studied densities, the increase in the trait was 0.08-0.17 million m^2/ha per day. During the treatment of seeds and subsequent spraying of plants in the phase of 4-5 leaves, the positive dynamics of the formation of the leaf surface was revealed at 55,000 and 65,000 plants/ha. In medium-late hybrid crops, the greatest increase in the photosynthetic potential was revealed with an increase in the stand density to 65,000 plants/ha - 2.78 million m^2/ha per day versus 2.08 million m^2/ha per day at 45,000 plants/ha. Extrasol, both with a single (C_2) and double (C_3) application, provided an increase in the photosynthetic potential at 45,000 and 55,000 plants/ha.

On average, over the years of research, the highest photosynthetic potential in the crops of Ross 299 MV was revealed at a density of 65,000 plants/ha using the treatment variant C_3. In the crops of the STK 175 hybrid, the maximum photosynthetic potential was revealed for seeds inoculation at a density of 65,000 plants/ha - 2.81 million m^2/ha per day.

The range of variation of the private averages for factor A was within 1.75-2.72 million m^2 per day; for factor B – 1.82-2.36 million m^2 per day. A low influence on the variability of the trait of the studied factors was revealed: factor A (hybrid) - 14.7%, B (plant density) - 9.6%.

The use of Extrasol microbiological fertilizer provided a slight increase in the photosynthetic potential, however, no significant differences were found in the variants.

Table 2: Photosynthetic potential (million m^2/ha per day), 2014-2017

Hybrids (A)	**Treatment variant (C)**	**Plant density, thousand ha (B)**			**Average factor A**
		45	**55**	**65**	
Ross 197 MV	c1	1.46	1.54	2.21	1.75 a
	c2	1.49	1.61	2.08	
	c3	1.54	1.67	2.21	
Ross 299 MV	c1	1.76	2.01	2.10	2.02 b
	c2	1.84	2.09	2.21	
	c3	1.76	2.18	2.27	
STK 175	c1	2.08	2.12	2.78	2.72 c
	c2	2.15	2.27	2.81	
	c3	2.22	2.34	2.57	
Average factor B		1.82 a	1.98ав	2.36 в	
	F_{fact}. Factor A – 39.434*, HCP_{05} factor A – 0.194 F_{fact}. factor B – 4,129* HCP_{05} factor B – 0.381				

The experiment revealed that the studied corn hybrids differed in yield depending on their planting density in the area. The average grain yield of Ross 197 MB for four years at a lower density and without the use of Extrasol was 6.01 t/ha. An increase in plant density by 10,000 plants/ha contributed to an increase in yield by 0.68 t/ha or 11.3%, and an increase by 20,000 thousand plants/ha by 0.89 t/ha or 14.8%. The grain yield of Ross 299 MB at a density of 45,000 plants/ha was 6.03 t/ha. Cultivation of a hybrid with a density of 55,000 plants/ha and 65,000 plants/ha without treatment with Extrasol provided an increase in yield of 0.23 t/ha (3.8%) and 0.34 t/ha (5.43%), respectively. Seed treatment with microbiological fertilizer provided an increase in the yield by 0.10-0.24 t/ha, depending on the plant density. Double application (treatment of seeds and vegetative plants in the phase of 4-5 leaves) of Extrasol provided yield increase by 0.31-0.62 t/ha in comparison with C_1. The highest grain yield was found with a combination of high density and the variant C_3 - 6.99 t/ha.

The grain yield of the late-ripening hybrid STK 175 varied within significant limits according to the experimental variants. The maximum indicator was set at a density of 65,000 plants/ha without the use of microbiological fertilizers - 7.81 t/ha. The increase relative to the recommended density was 1.85 t/ha (37.14%) at a density of 55,000 plants/ha and 2.83 t/ha at a density of 65,000 plants/ha. Extrasol-treated variants showed the yield increased by 0.49-0.97 t/ha as it thickened. C_2 at a density of 45,000 plants/ha showed an increase in yield by 0.22 t/ha (4.4%) 0.61.

Table 3: Grain yield of corn hybrids (t/ha), 2014-2017

Hybrids (A)	**Treatment variant (C)**	**Plant density, thousand ha (B)**			**Average factor C**
		45	**55**	**65**	
Ross 197 MV	c1	6.01	6.69	6.90	C_1 =6.43b
	c2	5.60	6.23	7.37	C_2 = 6.39b

	c3	5.66	6.26	6.19	C_3 =6.09a
Ross 299 MV	c1	6.03	6.26	6.37	
	c2	6.26	6.47	6.47	
	c3	6.34	6.65	6.99	
STK 175	c1	4.98	6.83	7.81	
	c2	5.20	6.80	7.17	
	c3	4.52	6.22	6.01	
Average factor B		5.62a	6.49b	6.80b	
	F_{fact}. Factor B – 12.174* HCP_{05} factor B – 0.60 $F_{fact.}$ Factor C – 10.062*, HCP_{05} factor C – 0.20 F_{fact}. interrel. BC – 3.666*, HCP_{05} interrel. BC – 0.66				

The interval of variation of private averages for factor B was 5.62-6.80 t/ha, for factor C – 6.09-6.43 t/ha. The influence of factors on the variability of "grain yield" is distributed as follows: factor B - 16.9%, factor C - 14.9%. The combined contribution of these factors (BC) was 12.10%.

Conclusion

1. The leaf area of corn hybrids differing in the duration of the growing season significantly differed in factors A, B, C. The highest leaf area in terms of factor A on average over the years of research was found in the mid-late hybrid STK 175 and amounted to 43,565.8 m^2/ha. It was found that the maximum leaf area of the hybrids was formed at a density of 65,000 plants/ha (factor B) - 40,928.8 m^2/ha, as well as when processing seeds and vegetative plants with Extrasol microbiological fertilizer (factor C) - 38,920.4 m^2/ha.
2. The interval of variation of the photosynthetic potential for factor A was 1.75-2.72 million m^2 per day. The highest photosynthetic potential was recorded in STK 175. The cultivation of corn hybrids with a density of 65,000 plants/ha (factor B) provided a higher rate of photosynthetic potential - 2.36 million m^2 per day. The influence of the studied factors on the variability of the trait was: factor A (hybrid) - 14.7%, B (plant density) - 9.6%.
3. The grain yield for factor B was in the range of 5.62-6.80 t/ha. The highest value was found for cultivation with a density of 65,000 plants/ha. The interval of comparison of partial averages for factor C was 6.09-6.43 t/ha. The influence of factors on the variability of "grain yield" is distributed as follows: factor B - 16.9%, factor C - 14.9%. The combined contribution of these factors (BC) was 12.10%.

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