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RESPONSE OF MAIZE HYBRIDS ON INCREASING PLANT DENSITY IN THE AGROCENOSIS IN THE NORTHERN STEPPE OF UKRAINE

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Topicality. *The plant density is an important agrotechnical technique in the agronomic design of an agrocenosis and managing the productivity of hybrids. Variations in plant density affect the growing conditions in the agrocenosis and lead to changes in the quantitative characteristics of plants. Therefore, the study of the effect of plant density on the formation of individual plant productivity and the response of hybrids to cultivation with different plant density in arid conditions of the Steppe becoming relevant and important scientific task.* ***Purpose.*** *The primary objective was studying the responses of maize hybrids to crowding stress, identifying hybrids resistant to growing in thickening of crops, determining the optimal plant density for each of the studied hybrids.* ***Materials and Methods.*** *Five mid-early maize hybrids were tested in the experiment: DB Khotyn, SY Rotango, SY Scorpius, SY Chorintos, Adevey. The studied plant density in agrocenoses before harvesting was 40,000, 60,000 and 80,000 plants/ha. The studies were carried out in accordance with generally accepted methods in crop production and animal husbandry.* ***Results.*** *SY Rotango hybrid had a strong susceptibility to crowding stress in agrocenoses with increased plants density. Increasing plant density did not enhance the yield of the SY Rotango hybrid. The plants density of 60,000 plants /ha ensured the formation of maximum yields for the hybrids DB Khotyn (7.43 t/ha), SY Scorpius (8.4 t/ha), SY Chorintos (8.54 t/ha). SY Chorintos hybrid had a parabolic nature of yield formation, i.e. yield increase up to a density of 60 thousand/ha and yield decrease with an increase in density to 80,000 plants /ha. The Adevey hybrid had a low susceptibility to the crowding stress and formed a maximum yield of 7.63 t/ha in crops with a plant density of 80 thousand/ha.* ***Conclusions.*** *In the arid conditions of the Steppe, plant density is one of the main methods for managing plant productivity and the yields of maize hybrids. The level of yields is determined by the peculiarities of the relationship between factors of the agrocenosis: plant density, number of ears per plant, grain weight per ear, yield. Maize hybrids of the same maturity group respond differently to growing conditions with different plant densities in agrocenoses. The SY Rotango hybrid, which has high susceptibility to the crowding stress, is not intended for cultivation in high-density agrocenoses. The Adevey hybrid is recommended for cultivation in agrocenoses with increased plant density in the arid conditions of the Northern Steppe of Ukraine.*

Key words: *maize, hybrid, plant density, quantitative trait, yield*

Introduction. Maize is an important grain and energy crop that plays a significant role in the grain balance of Ukraine. The successful strategy of maize breeding based on heterosis, the development of new hybrids, continuous genetic improvements in hybrids, the development and implementation of high-yielding cultivation technologies have contributed to the expansion of both the sown and geographical areas of this crop [1, 2].

Recent advances in breeding of maize hybrids and scientifically based cultivation technologies make it possible to obtain high grain yields in agrocenoses. However, in current agricultural production, the actual grain yield of maize hybrids averages about 65 % of the potential genetic yield under rainfed conditions [3, 4]. High yields in the conditions of an agricultural enterprise, while reducing the difference between the actual and potential yields of a maize hybrid, are achieved by using properly selected elements of varietal agricultural methods in growing technology. The indicator of grain yield is the product of grain weight per plant and number of plants per unit area, as a result, the actual yield can be improved by increasing the number of plants in the agrocenosis [5, 6].

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Management options for yields in agrocenoses, which reduce the difference between actual and potential yields and improve the efficiency of growing maize hybrids, are determined by the plant density. The yields of maize hybrids are determined by quantitative traits: the grain weight harvested per unit area and the average grain weight per plant. These yield traits have different manifestations depending on the growing conditions and the genotype of the hybrid. However, the greatest yield variation in maize hybrids is due to grain weight per plant. Understanding the processes of grain weight formation per plant is crucial for determining plant density in maize cultivation technology and increasing yields per unit area [7–9].

Plant density in the agrocenosis is one of the key factors in the cultivation technology of maize hybrids, determining the efficiency of plant growth and development, helping to maximise the genetic productivity of plants and ensure the most efficient utilisation of soil moisture and nutrient reserves. The number of plants per unit area in the agrocenosis is one of the elements of varietal agricultural methods that has a significant impact on the formation of quantitative traits of maize (the number of ear, the number of kernels per ear, the grain weight per ear), and as a result, has an important impact on the actual yield of maize hybrids. According to research, changes in plant density have a strong effect on maize hybrids, which have different responses to changing growing conditions. Studies have shown that increasing plant density has a positive, neutral and negative effect on the grain yield formation in maize hybrids [10–13].

Increasing the plant density within the limiting level leads to an increased grain yield of maize hybrids in the agrocenosis. When the limiting threshold of plant density is reached, the yield decreases depending on the physiological and biological properties of the genotype due to competition between plants in the agrocenosis. Increased competition between maize plants in agrocenoses for growth and development resources (light, moisture, and nutrients) results in a decrease in dry matter accumulation, disruption of biomass redistribution between the vegetative and generative parts of the plant, and a yield decrease [14–16].

Steadily increasing plant density rate, as a factor in yield formation, leads to crowding stress of the maize hybrids. Modern maize hybrids with high resistance to crowding stress ensure the high grain yields [17, 18].

However, during plant growth and development of the modern maize hybrids, the competition for resources between plants leads to high variability of morphological qualitative and quantitative traits, as well as to a decrease in the development rate. According to observations, increased plant density is accompanied by poorer root biomass, which leads to a lower ability of maize plants to consume moisture and nutrients from the soil, as well as a decrease in potential grain yield [19, 20].

Competition for resources among maize plants in the agrocenosis increases significantly from the flowering stage and to the beginning of physiological ripeness. During these stages of maize development, the growing conditions are crucial for the formation of grain weight per plant and grain weight per unit area. These quantitative traits, which have the dependence on the growing conditions at different plant densities and the crowding stress in the agrocenosis, determine the final yield of maize hybrids. By the end of the flowering stage, the maize plants accumulate about 50.0 % of the total dry matter in the process of yield formation. Therefore, the crowding stress during this period can negatively affect the accumulation rate of assimilates in the maize plants, as well as the formation of quantitative traits and yields. In addition, the genotype of maize hybrids plays an important role in the formation of quantitative traits and yields through the stability of its physiological properties, namely the response of maize plants to crowding stress [21–23].

Plant density can determine the level of formation of quantitative traits of productivity and yield of maize hybrids, which is a factor that controls the plant growth and development in the agrocenosis, as well as the response of the maize hybrids to crowding stress [24, 25].

The research was aimed to establish the optimal plant density of maize hybrids in the agrocenosis and their response to changes of growing conditions, as well as resistance to crowding stress in the arid conditions of the Northern Steppe of Ukraine.

Based on the operational requirements, the experiment was conducted to assess the resistance of maize the hybrids to crowding stress and to determine the optimal plant density in the agrocenosis for forming the maximum grain yield.

Materials and Methods. During 2021–2023, the studies were carried out in Komisarivka ALLC (Agricultural Limited Liability Company) of the Dnipropetrovsk region.

The soil cover of the experimental plots is represented by ordinary low-humus chernozems of medium thickness on loess. The humus content in the arable layer of 0–30 cm of full-profile chernozems varies from 3.8 to 4.1 %. In a soil layer of 0–40 cm, content of total nitrogen is 15–20 mg/kg (according to Kjeldahl), mobile phosphorus – 100–150 mg/kg, exchangeable potassium – 100–120 mg/kg of soil (according to Chirikov).

In the experiment, the registration plot area was 50.4 m^2. Each experimental variant had three repetitions. The predecessor of maize was winter wheat. After harvesting predecessor, the primary soil tillage included stubble breaking to a depth of 6–8 cm was carried with disk stubble plough. The second disking was carried out to a depth of 8–10 cm as the weeds grew. Ploughing to a depth of 27–30 cm was carried out in late September. The cultivation technology for maize hybrids was generally accepted for the Northern Steppe of Ukraine. The following mid-early maize hybrids were in the experiment: DB Khotyn (control), SY Rotango, SY Scorpius, SY Chorintos, and Adevey. The plant density of the maize hybrids before harvest was as follows: 40,000 plants/ha (control), 60,000 plants/ha and 80,000 plants/ha.

During the research, we used the measurement and calculation method for biometric analysis of plants; the weight method for determining grain moisture; the visual method for identifying the stages of plant growth and development; and the mathematical and statistical method for assessing the reliability of the results.

The experiments were carried out in accordance with generally accepted methods in plant production and agriculture [26, 27].

Mathematical and statistical calculations of the experimental results were carried out using the data analysis package Microsoft Office Excel and Statistica 6.

Results and Discussion. Comparison of research results showed that plant density has an impact on the grain yield of maize hybrids, and at the same time, maize plants have different resistance to crowding stress in the agrocenosis. In addition, plant density affected plant height in maize hybrids that clearly noted in the flowering stage. Depending on the resistance to crowding stress, the plant height of maize hybrids in the agrocenosis varied.

Plant density of 60,000 plants/ha did not affect the plant height of the DB Khotyn and SY Rotango hybrids. Only when the plant density increased to 80,000 plants/ha, their plant height increased to 192.5 cm and 195.3 cm, respectively (Table 1).

Table 1. Plant height of the maize hybrids at different plant densities in the flowering stage, cm (average for 2021–2023)

Hybrid	Plant height, cm		
	at plant density, plants/ha		
	40,000 (control)	60,000	80,000
DB Khotyn (control)	180.9	181.8	192.5
SY Rotango	182.3	183.9	195.3
SY Scorpius	187.6	209.8	220.5
SY Chorintos	203.2	224.6	234.4
Adevey	234.7	236.3	242.6
LSD_{05} plant density 9.8 hybrid 10.3			

SY Scorpius, SY Chorintos and Adevey hybrids were characterised by different responses to increasing the plant density, their plant height changed differently. At plant density of 60,000 plants/ha and 80,000 plants/ha, the plant height of the SY Scorpius hybrid increased by 22.2–32.9 cm, and of the SY Chorintos hybrid – by 21.4–31.2 cm, respectively, compared to the control. However, the Adevey hybrid was characterised by insignificant changes in plant height, when the plant density increased from 40,000 to 80,000 plants/ha in the agrocenosis. Thus, the plant height of the Adevey hybrid varied from 234.7 cm to 242.6 cm, depending on the different plant densities.

In addition, plant density affects the quantitative traits of maize hybrids. An increase in plant density leads to an upward change in morphological quantitative traits of maize plants. When crowding stress increases, quantitative traits of maize hybrids change as follows: the height of ear insertion increases, the number of ears per 100 plants decreases.

The DB Khotyn and SY Rotango hybrids, which had the lowest plant height at the control plant density, were characterised by a maximum increase in the ear insertion height by 11.3–26.3 % and 7.9–16.9 %, respectively, due to increasing the plant density to 80,000 plants/ha (Table 2).

The Adevey hybrid did not significantly change the ear insertion height (1.9–7.6 %) at the same plant height under different plant densities, however, a maximum value of ear insertion height was observed at a plant density of 80,000 plants/ha.

Table 2. Effect of plant density on the quantitative traits of maize hybrids, (average for 2021–2023)

Hybrid	Plant density, plants/ha					
	40,000 (control)		60,000		80,000	
	ear insertion height, cm	number of ears per 100 plants, pcs	ear insertion height, cm	number of ears per 100 plants, pcs	ear insertion height, cm	number of ears per 100 plants, pcs
DB Khotyn (control)	80	162	89	150	101	132
SY Rotango	89	168	96	160	104	150
SY Scorpius	99	167	105	159	107	149
SY Chorintos	103	170	108	161	115	151
Adevey	105	174	107	150	113	149

Under the crowding stress, all hybrids reduced the number of ears per plant. Increasing the number of plants in the agrocenosis from 40,000 to 80,000 plants/ha contributed to a decrease in the number of ears per 100 plants by 7.4–18.5 % (DB Khotyn), 4.8–10.7 % (SY Rotango), 4.8–10.8 % (SY Scorpius), 5.3–11.2 % (SY Chorintos), 13.8–14.4 % (Adevey). The Adevey hybrid significantly reduced the number of ears per 100 plants due to crowding stress. Thus, with increasing plant density, the Adevey hybrid had the lowest increase in the ear insertion height, and the highest decrease in the number of ears per 100 plants. In other words, the Adevey hybrid was most responsive to changes in plant density in terms of ear insertion height.

The maize hybrids had different susceptibility to changes in growing conditions that affected the formation of plant productivity elements. In our experiment, we identified and analysed individual productivity elements of maize hybrids to assess the effect of plant density on yield formation and the response of hybrids to crowding stress. The response to increasing plant density showed that productivity elements of maize hybrids change with increasing plant density. However, the general tendency of changes in productivity elements (grain weight per ear and 1,000 grain weight) was the same for all hybrids studied in the experiment. With increasing the plant density from 40,000 to 60,000 plants/ha, the grain weight per ear and the 1,000 grain weight of maize hybrids increased. The grain weight per ear increased within 123.2–127.1 g for all maize hybrids (Table 3).

In percentage terms, the Adevey hybrid had a maximum increase in grain weight per ear (71.9 %) at plant density of 60,000 plants/ha. However, the SY Chorintos hybrid formed the maximum grain weight per ear (325.3 g) at same plant density.

An increase in plant density from 60,000 to 80,000 plants/ha resulted in a decrease in the grain weight per ear and the 1,000 grain weight for all maize hybrids.

The resistance of all hybrids to crowding stress was determined by the decrease in grain weight per ear in the conditions of high plant density in the agrocenosis.

The maximum decrease in the grain weight per ear (14.6 %) under plant density of 80,000 plants/ha was observed in the Adevey

Table 3. Plant productivity elements of maize hybrids depending on plant density in agrocenoses, (average for 2021–2023)

Hybrid	Plant productivity elements					
	grain weight per ear, g	1,000 grain weight, g	grain weight per ear, g	1,000 grain weight, g	grain weight per ear, g	1,000 grain weight, g
	Plant density, plants/ha					
	40,000 (control)		60,000		80,000	
DB Khotyn (control)	188.7	303.5	312.2	311.3	269.5	270.1
SY Rotango	189.4	305.9	316.5	316.6	272.7	273.3
SY Scorpius	196.5	310.7	319.7	320.3	285.2	284.6
SY Chorin-tos	200.9	313.7	325.3	324.7	284.9	284.9
Adevey	186.4	312.1	320.5	312.3	273.6	274.4

hybrid, which was characterized by a maximum increase in the grain weight per ear due to increasing plant density from 40,000 to 60,000 plants/ha.

At plant density of 80,000 plants/ha, the minimum decrease in the grain weight per ear (10.8 %) was observed in the SY Scorpius hybrid. Also, the largest grain weight per ear was formed by the SY Scorpius and SY Chorintos hybrids (285.2 g and 284.9 g, respectively). The experimental results showed that the SY Scorpius hybrid had high resistance to crowding stress in agrocenoses. Compared to other maize hybrids, the SY Scorpius hybrid formed the highest grain weight per ear at plant density of 80,000 plants/ha.

The level of resistance of maize hybrids to crowding stress should be related to the efficiency of the genotype in the utilisation of solar radiation and soil moisture. Thus, the resistance to crowding stress was ensured by the interaction between such indicators as grain weight per ear, plant density, number of ears per plant and yield of maize hybrids. In addition, the above interaction determined the yield of hybrids.

It was proved that increasing the grain weight per ear and plant density from 40,000 to 60,000 plants/ha contributed to high grain yields of maize hybrids (7.43–8.55 t/ha) in the arid conditions of the Northern Steppe of Ukraine (Table 4).

Table 4. Yield of maize hybrids at different plant densities in agrocenoses, t/ha (average for 2021–2023)

Hybrid	Yield, t/ha		
	at plant density, plants/ha		
	40,000 (control)	60,000	80,000
DB Khotyn (control)	6.93	7.43	6.52
SY Rotango	7.99	8.14	7.38
SY Scorpius	7.45	8.54	8.47
SY Chorintos	7.35	8.55	8.24
Adevey	7.01	7.43	7.63
LSD_{05} plant density 0.16 hybrid 0.23			

The interaction between the factors of yield formation and the responce of maize hybrids to crowding stress had different effects on the grain yields.

Thus, the interaction between plant density and grain weight per ear provided the highest increase in yield of the SY Scorpius and SY Chorintos hybrids (14.6 and 16.3 %, respectively). At plants density of 60,000 plants/ha, these hybrids formed a maximum yield of 8.54 and 8.55 t/ha, respectively.

At plant density of 60,000 plants/ha in the agrocenosis, the SY Rotango hybrid reduced the number of ears per plant and simultaneously increased the grain weight per ear, while its grain yield increased slightly from 7.99 to 8.14 t/ha compared to the control plant density.

The Adevey hybrid formed the highest yield (7.63 t/ha) at plant density of 80,000 plants/ha, despite the decrease in grain weight per ear.

At a similar plant density in the agrocenosis, the SY Scorpius hybrid reduced the grain weight per ear and the number of ears per 100 plants and formed a grain yield of 8.47 t/ha, which was equal to the yield at a density of 60,000 plants/ha – 8.54 t/ha.

As a result, the plant density of 80,000 plants/ha and the interaction of factors affecting crop yields led to a decrease in grain yields of the DB Khotyn, SY Rotango, SY Chorinthos hybrids. These hybrids were identified as the most susceptible to the crowding stress.

It was found that the grain yield of maize hybrids under cultivation at different plant densities in the Northern Steppe of Ukraine is determined by the interaction between the factors of yield formation and the response of maize hybrids to the crowding stress in agrocenoses.

Conclusions. Plant density is an important component of maize cultivation technology, which has a significant effect on the structure and management of the agrocenosis, plant growth and development, productivity parameters, and hybrid yields.

All changes in the quantitative traits of individual plant productivity directly reflect the response of the maize hybrid to crop thickening. The grain yield of maize hybrids depends on the interaction of factors in the agrocenosis (number of plants in the agrocenosis, number of ears per plant, grain weight per ear, response of the maize hybrid to plant density).

Changes in the number of ears per plant and the grain weight per ear, as well as the genotype response to crowding stress, created a parabolic nature in the yield formation of the SY Chorinthos hybrid. The individual productivity of the DB Khotyn, SY Rotango, SY Scorpius, Adevey hybrids determined the linear nature of change in grain yields due to increasing the plant density.

The optimal plant density for the DB Khotyn hybrid was 40,000 plants/ha before harvesting.

The plant density of 60,000 plants/ha resulted in maximum grain yields of 8.14 t/ha for the SY Rotango hybrid, 8.54 t/ha for the SY Scorpius hybrid, and 8.55 t/ha for the SY Chorintos hybrid. At plant density of 80,000 plants/ha, the grain yield of the SY Scorpius hybrid slightly decreased to 8.47 t/ha, while the Adevey hybrid showed a maximum grain yield of 7.63 t/ha.

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Актуальність. У виробничих умовах гібриди не завжди формують високу врожайність. Густота стояння рослин є важливим агротехнічним прийомом в агротехнічному проектуванні агроценозу, який впливає на продуктивність рослин гібридів. Зміна густоти стояння рослин впливає на умови вирощування в агроценозі та викликає варіації кількісних ознак рослин. Тому вивчення впливу густоти посіву на формування продуктивності окремої рослини та реакції гібридів в умовах посушливого Степу України набуває актуальності та стає важливим науковим завданням. **Мета досліджень**. Основною метою було вивчення реакції гібридів кукурудзи на стрес скупченості рослин, виявлення гібридів, стійких до вирощування в посівах підвищеної густоти, визначення оптимальної густоти стояння посівів для кожного досліджуваного гібрида. **Матеріали та методи.** У досліді було випробувано 5 гібридів кукурудзи: ДБ Хотин, SY Rotango, SY Scorpius, SY Chorintos, Адевей. Гібриди відносяться до середньоранньої групи стиглості. Досліджувана густота рослин в агроценозах перед збиранням становила 40, 60, 80 тис./га. Дослідження проводили відповідно до загальноприйнятих методик у рослинництві та тваринництві. **Результати.** Гібрид SY Rotango мав сильну чутливість до стресу скупченості рослин в агроценозах із підвищеною густотою стояння рослин. Збільшення густоти рослин в посіві не призвело до підвищення врожайності гібриду SY Rotango. Густота рослин 60 тис./га забезпечила формування максимальної врожайності гібридів ДБ Хотин (7,43 т/га), SY Scorpius (8,54 т/га), SY Chorintos (8,54 т/га). Гібрид SY Chorintos мав параболічний характер формування врожаю: підвищення врожайності до густоти 60 тис./га та зниження врожайності при підвищеній густоті до 80 тис./га. Гібрид Адевей мав низьку чутливість до стресу скупченості рослин і формував максимальну врожайність 7,63 т/га в посівах із густотою стояння рослин 80 тис./га. **Висновки**. У посушливих умовах Степу щільність посівів є одним із основних методів управління продуктивністю рослин і врожайністю гібридів кукурудзи. Рівень формування врожайності визначається особливостями взаємозв’язку факторів агроценозу: густота рослин, кількість качанів на одній рослині, маса зерна одного качана, урожайність. Гібриди кукурудзи однієї групи стиглості по-різному реагують на умови вирощування в агроценозах з різною густотою стояння рослин. Гібрид SY Rotango, який має високу чутливість до стресу скупченості рослин, не призначений для вирощування в агроценозах з високою густотою посівів. Гібрид Адевей рекомендований для вирощування в агроценозах з підвищеною густотою стояння рослин в посушливих умовах північного Степу України.

Ключові слова: *кукурудза, гібрид, густота стояння рослин, кількісна ознака, урожайність*