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The influence of irrigation and seeding rates on the yield of female components lines of corn in conditions of unstable moisture in Ukraine

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Abstract. In regions with insufficient rainfall or different climates, the use of irrigation systems is an important element of corn growing technology. The variation in corn yield on non-irrigated lands is 533% and 200% greater than on irrigated lands. Corn yield also depends heavily on sowing density. The optimal plant density is an unstable value. Field studies were conducted in conditions of unstable moisture in the central part of the Forest-Steppe of Ukraine, which according to agro-climatic zoning belongs to the zone of unstable moisture. The experimental design included: assessment of the characteristics of weather conditions during the years of research (2021–2023) and their impact on seed yield (factor A); determination of seed productivity of female components linesof hybrids of different maturity groups P4/440, P5/320, P6/240 (factor B); the impact of growing hybrids with and without irrigation (factor C); the effect of different seeding rates on seed yield (60, 70, 80, 90 thousand seeds per ha^{-1}) (factor D). The test results show that during the change in corn productivity depending on genetic properties, seeding rate and irrigation, the late-ripening hybrid P4/440 was characterized by the highest grain yield when grown under irrigation, with a seeding rate of 90 thousand similar seeds per ha^{-1} a decrease in the seeding rate from 90 to 80, 70, 60 seeding rate thousand seeds ha^{-1} was accompanied by a decrease in the yield of seeds of female components lines: in the early-ripening hybrid P6/240 - by 0.31, 0.63 and 1.10 t ha^{-1} or 5.7, 11.5 and 20.1%, in the mid-ripening hybrid P5/320 - by 0.59, 1.08 and 1.42 t ha^{-1} or 9.8, 17.9 and 23.5%, in the late-ripening hybrid P4/440 - by 0.39, 0.74 and 1.28 t ha^{-1} or 6.0, 11.4, 19.8%. The greatest influence on the formation of yield is the irrigation factor - 53%. Genetic properties influenced 28%. gradual increase in the yield of seeds of female components lines of culture when increasing the seeding rate from 60 to 70 thousand seeds ha^{-1} (by 0.01 t ha^{-1}) and reaching a maximum at a rate of 80 thousand seeds ha^{-1} (by 0.05 t ha^{-1}). But with an increase in the seeding rate to 90 thousand ha^{-1}, the seed yield sharply decreased by 0.13 t ha^{-1}. The highest yield in variants without irrigation was observed when using the minimum seeding rate - 60 thousand seeds ha^{-1}. A gradual increase in the seeding rate without irrigation led to a negative result, in particular, a decrease in the average yield for corn hybrids by 0.07–0.31 t ha^{-1} or 1.8–7.9%. Hybrids reacted differently to the seeding rate and cultivation on rainfed and irrigated land. Early ripening hybrid P6/240, mid-ripening P5/320 and late-ripening P4/440 hybrids formed the highest seed yield when grown under irrigation with a seeding rate of 90 thousand seeds ha^{-1}. When grown without irrigation, the best conditions for the formation of plant components and high yield were noted at the lowest seeding rate of 60 thousand seeds ha^{-1}. The minimum seeding rate ensured the production of seeds with a high mass of 1,000 seeds.

Key words: corn, hybrid, female components lines, irrigation, seeding rate.

INTRODUCTION

Due to climate change in Ukraine, irrigation systems are being widely developed and implemented at the state and regional levels with the participation of international foundations, which is especially important for seed production.

The problem of food security has become critical. Trends in global climate change are increasing the need to find new suppliers of food. Therefore, the development of corn production for grain, along with other crops, is a strategic component of solving the global food problem and a guarantee of financial stability of supplier countries (Vasylishyn et al., 2022).

Military operations in Ukraine have negatively affected the functioning of food systems. Integrated supply chains for agricultural products and food products have been disrupted. Active hostilities are currently taking place in those regions where most grain crops are grown. This has led to a decrease in yields, harvests and grain exports. The export of Ukrainian products to foreign markets has been significantly complicated due to the blockade of Ukrainian ports, which has negatively affected countries that depend on food imports. The consequences have led to serious threats to global food security, namely: a further increase in world food prices; a global jump in inflation, which will primarily affect countries with underdeveloped unstable economies in the Middle East and North Africa (Onegina & Antoshchenkova, 2022).

Corn cultivation is one of the most important aspects of agricultural production, ensuring not only the food security of the state, but also used in animal husbandry and for the production of biofuels. Thanks to technological and scientific achievements in recent years, corn cultivation has become more productive and resistant to various stress factors. A scientifically sound approach to the development and implementation of corn cultivation technology can increase crop yield, ensure its stability, and reduce the impact of negative factors on plant growth and development. In regions with insufficient rainfall or different climates, the use of irrigation systems is an important element of corn cultivation technology (Zhu & Burney, 2022; Juraev et al., 2021). Many years of research have shown that a 30% decrease in precipitation can reduce average yields by 10% (Rohit et al., 2021). Maize yield variability in dryland is 533% and 200% greater than in irrigated areas (Irmak et al., 2022). Severe water stress can significantly limit the growth and development of maize in the field and has a potentially negative impact on its yield (Libing et al., 2019; Bharathi et al., 2021).

Careful monitoring and management of water supply can help reduce the effects of water stress on maize (Zhu & Burney, 2022). Irrigation allows plants to be provided with the necessary amount of moisture during critical phases for maize and ensure optimal growth and development (Grafton et al., 2018; Lubajo & Karuku, 2022).

Maize yield can vary depending on the level of irrigation at different stages of its development. Studies indicate that insufficient irrigation during the initial stages of growth can lead to underdevelopment of the root system and low yield. During this period, roots and leaves are actively formed, so plants need sufficient moisture to optimally ensure the passage of these important stages in the organogenesis of the crop (Huihui et al., 2019).

It is important to ensure sufficient moisture levels during reproductive development, since during this period plants form generative organs (panicle, ear). Pollination of stamen filaments occurs, the formation and filling of the grain. Insufficient irrigation at this stage can lead to uneven placement of grains on the ear and a decrease in the number of grains per plant (Comas et al., 2019).

During grain ripening, plants require less moisture, but it is necessary to ensure a sufficient level of irrigation to form high-quality grain. Insufficient irrigation at this stage can lead to a low amount of moisture in the grain, which can worsen its quality indicators (1000-grain weight, protein and starch content) and reduce yield (Zou et al., 2021).

In general, corn requires different irrigation at different stages of its growth and development, which contributes to the optimal provision of physiological needs of plants for moisture during the growing season and the formation of stable yields (Afshin et al., 2019; Marilyn & Victor, 2022). The maximum realization of the genetic potential of corn hybrids productivity, improvement of biometric and economic characteristics of cobs and quality indicators of grain is achieved by timely irrigation and providing the plant with the necessary amount of moisture (Yue-e et al., 2021; Huifang et al., 2019).

Corn yield is highly dependent on planting density. The optimal plant density is an unstable value. It can vary depending on various factors, including: climatic conditions, soil type and fertility level, maturity group, and biological characteristics of corn hybrids (Ronald et al., 2021). Increasing corn density in irrigated areas can be an important way to increase the efficiency of plant nutrition, which affects the increase in yield and improve the economic performance of crop cultivation (Hernández et al., 2020; Ning et al., 2019). Some corn hybrids may be more adapted to high plant density and are able to compensate for yield losses due to increased intraspecific competition (Gonzalez et al., 2018; Kamara et al., 2021; Li et al., 2018). In such cases, increasing plant density may not affect yield (Abd El-Aty et al., 2019).

In arid regions, the impact of planting density on maize yield can be important, as water availability is limited and the level of water use efficiency can have critical consequences (Dhaliwal & Williams, 2019; Mylonas et al., 2020). Increased planting density can cause competition for water between plants. If water resources are limited, this can lead to stress for each plant and reduce its yield (Winans et al., 2021; Jiang et al., 2018). Therefore, some scientists believe that in arid conditions with insufficient water, it would be advisable to reduce planting density (Haarhoff & Swanepoel, 2018; Fernando et al., 2020). This will help improve crop moisture supply, their optimal growth and development, and reduce plant competition for water (Anna et al., 2019).

So far, domestic breeders have created a number of corn hybrids that differ among themselves in morphological features, biological features, indicators of yield and grain quality, and have a high level of adaptive potential to adverse environmental conditions (Tryhub et al., 2020).

Studies show that growing corn with optimal plant density is an important aspect for achieving maximum yield and crop quality (He et al., 2022; Ye et al., 2023). The optimal plant density is established taking into account the bioclimatic potential the purpose of growing corn.

The purpose of our research was to determine the components of seed yield formation of female components linesof corn hybrids at different sowing rates and growing crops with and without irrigation.

Research objectives: to investigate the influence of irrigation and different seeding rates on the yield of female components linesof corn hybrids.

MATERIALS AND METHODS

Field studies were conducted in the central part of the Forest-Steppe of Ukraine. According to agroclimatic zoning, the territory of the research plots belongs to the zone of unstable moisture. The climate is continental, with cold winters and hot summers. The number of active temperatures is 2,250 °C. The average annual air temperature in this area is 9 °C. The coldest period during the years of research is observed in January and is -2.6 °C, and the warmest is in August (23.3 °C). The onset of frosts was noted in the first decade of October. The duration of the frost-free period is 175–180 days.

In conditions of unstable moisture, the amount and distribution of precipitation are the main factors that determine the level of efficiency of growing agricultural crops, including corn. Abnormal weather conditions, in particular, a deficit of precipitation and their uneven distribution, can significantly affect the growth and development of plants (Fig. 1).

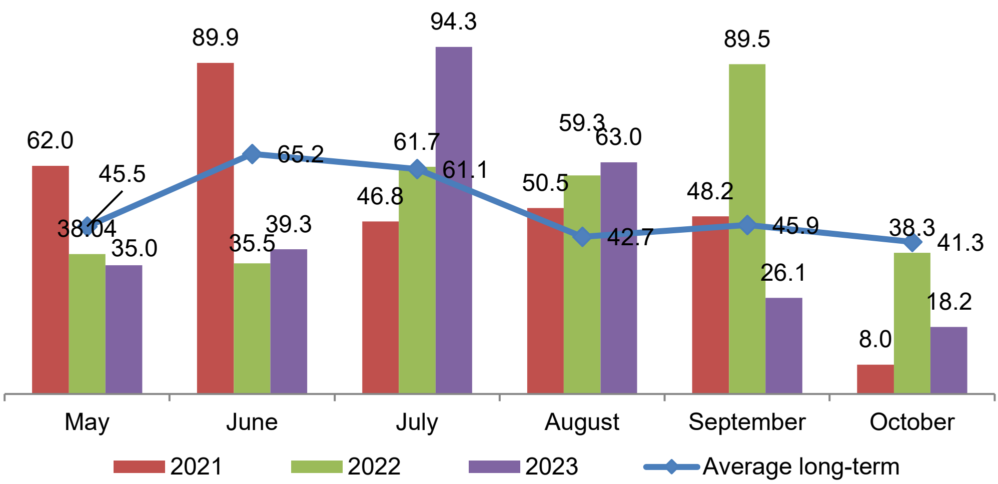

Figure 1. Distribution of precipitation during the corn growing season (average for 2021–2023).

In 2021, the total amount of precipitation in May and June exceeded the multi-year average by 41.2 mm or 37.2%. However, in July, there was a decrease in the amount of precipitation, compared to the multi-year average, by 14.3 mm or 23.4%. In the following months, the amount of precipitation was close to the multi-year average. In October, the amount of precipitation was 8 mm or 19.3% of the multi-year average, but this did not significantly affect the formation of yields at the final stage of the corn growing season. The amount of precipitation for May-October 2022 was 322.3 mm, which is 20.6 mm or 6.8% more than the multi-year average. This indicates sufficient moisture supply for corn crops during the growing season. But the uneven distribution of precipitation caused a moisture deficit in May and especially in June, which caused a temporary slowdown in the growth processes of the crop.

During the 2023 growing season, the total amount of atmospheric precipitation was lower than the long-term average by 25.8 mm or 8.6%. Their uneven distribution was noted, during which a precipitation deficit of 79.3 mm or 40.1% was observed in May-October, and an excess of 53.5 mm or 51.5% was observed in July-August.

The results obtained indicate significant fluctuations in the distribution of precipitation between years. Such variations can affect the growth of corn, which requires the adaptation of growing technologies to specific weather conditions each year, the use of different approaches to managing agrotechnical measures, taking into account the variability of climatic conditions.

Temperature is one of the key factors affecting the processes of plant growth and development. Optimal temperature conditions ensure efficient corn growth, while deviations from the norm can lead to stressful conditions and reduced yields. Analysis of the temperature regime indicates the presence of significant temperature fluctuations during the growing season of corn in different years, compared with the average multi-year indicators (Fig. 2).

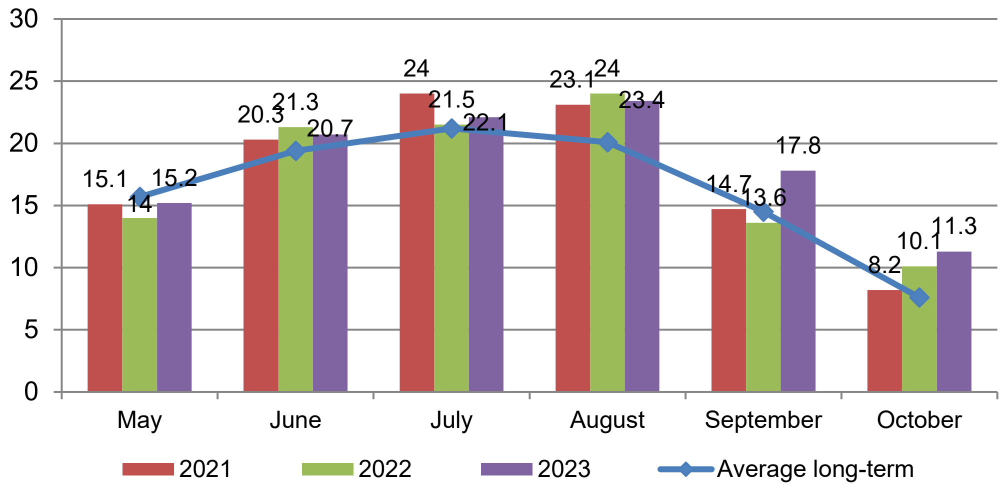

Figure 2. Temperature distribution during the corn growing season (average for 2021–2023).

A stable excess of the average monthly air temperature, compared to the average multi-year values, was observed during June-July in all years of research. But the largest deviations were observed in August-September 2023 and August 2022, when the average monthly temperature exceeded the average values, respectively, by 3.3 °C and

3.9 °C. The air temperature in many months was close to the average multi-year. The data obtained indicate the importance of taking into account the temperature regime for optimizing agrotechnical measures in corn cultivation and adapting to changing climatic conditions.

The main type of soil in the experimental area is typical low-humus chernozem, which by mechanical composition belongs to heavy loams. It is characterized by the following agrochemical indicators: in the arable soil layer (0–20 cm) the humus content is 3.8–4.2%; nitrate nitrogen contains 9.8–10.2 mg, mobile phosphorus – 24.3 mg, exchangeable potassium – 264 mg kg^{-1} of soil. The content of nutrients in the arable soil layer is equal to low nitrogen supply and medium – phosphorus and potassium. The reserves of available moisture in the meter layer of soil at the time of sowing were within the average long-term value and amounted to 135–140 mm.

The arable soil layer of the experimental plot is characterized by a high absorption capacity (40 mg. equiv./100 g of soil), which is due to the high content of highly dispersed silty particles. The soil density varies from 1.15 g cm^{-3} at the time of sowing to 1.36 g cm^{-3} before harvesting. The reaction of the soil solution is close to neutral – pH 5.9–6.1.

The experimental plan included: conducting an assessment of weather and climatic conditions over the years of research (2021–2023) and their impact on seed yield (factor A) - irrigation was carried out by sprinkling. The irrigation source was a well with water mineralization of 0.78–1.12 g dm^{-3}. Water consumption rate – 450 m^{-3} ha.; determination of seed productivity of female components linesof hybrids of different maturity groups P4/440, P5/320, P6/240 (factor B); the impact of growing hybrids with and without irrigation (factor C); the impact of different seeding rates on seed yield (60, 70, 80, 90 thousand seeds ha^{-1}) (factor D). The plot area for each corn hybrid was 120 m^2. The repetition of the experimental variants was threefold. The placement of variants was randomized according to the seed sowing rate. Corn was sown in the first decade of May. Corn in the experiment was placed after corn. Sowing was carried out using the Precision Planting system. As the seeder moves to a zone with higher or lower density, the system automatically adjusts the seeding rate according to the set scheme.

Irrigation was carried out in critical phases of corn development: V4 (phase 4 leaves) – 20 mm, V8 (phase 8 leaves) – 20 mm, VT (phase of panicle ejection) – 45 mm.

The harvest and moisture content were recorded in the phase of full grain maturity using an OXBO 2460 combine harvester from each experimental site. The yield of corn grain was converted to a standard moisture content of 14%. The mass of 1,000 grains was determined using generally accepted methods (Yeshchenko et al., 2005).

Data analysis was performed using descriptive statistics, regression, and analysis of variance (ANOVA) in the STATISTICA 10.0 software. Experimental data were evaluated using analysis of variance (ANOVA) to calculate the least significant difference (LSD_{05}).

RESULTS AND DISCUSSION

The results of the research indicate a significant influence of all the studied factors and their interaction on the formation of the yield of female components linesof corn.

The results of the tests indicate that during the change in corn productivity depending on genetic properties, seed sowing rate and irrigation, the late-ripening hybrid P4/440 was characterized by the highest grain yield when grown under irrigation, with a sowing rate of 90 thousand seeds per hectare (Table 1).

The same seeding rate is the most effective for hybrids P6/240 and P5/320 when grown under irrigation. Studies show that reducing the seeding rate from 90 to 80, 70, 60 thousand seeds per 1 ha was accompanied by a decrease in the yield of seeds of the female components lines: in the early-ripening hybrid P6/240 - by 0.31, 0.63 and 1.10 t ha^{-1} or 5.7, 11.5 and 20.1%, in the mid-ripening hybrid P5/320 - by 0.59, 1.08 and 1.42 t ha^{-1} or 9.8, 17.9 and 23.5%, in the late-ripening hybrid P4/440 - by 0.39, 0.74 and 1.28 t ha^{-1} or 6.0, 11.4, 19.8%. Despite the fact that most modern hybrids have a wide range of optimum plant density due to good compensatory ability (formation of a larger number of grains in a row, a greater mass of 1,000 grains, formation of a second ear). But under irrigation conditions, this biological feature of corn does not compensate for the crop failure caused by insufficient plant density per unit area.

Table 1. Yield of female components lines (♀) of hybrids depending on irrigation and sowing rate (average for 2021–2023)

♀ hybrid	Seeding rate, thousand seeds ha^{-1}	Average productivity, t ha^{-1}		
		control (no irrigation)	irrigation growth	growth
P4/440	60	5.02	5.20	0.18
	70	4.72	5.74	1.02
	80	4.26	6.09	1.83
	90	3.15	6.48	3.33
P5/320	60	4.44	4.62	0.18
	70	4.16	4.96	0.8
	80	3.81	5.45	1.64
	90	3.37	6.04	2.67
P6/240	60	3.96	4.37	0.41
	70	3.74	4.84	1.1
	80	3.34	5.16	1.82
	90	2.96	5.47	2.51
LSD_{05}				
Year (A)		0.33		
♀ hybrid (B)		0.36		
Irrigation (C)		0.27		
Seeding rate, ha^{-1} (D)		0.37		
AB		0.57		
AC		0.46		
BC		0.49		
AD		0.66		
BD		0.72		
CD		0.54		
ABC		0.8		
ABD		1.14		
ACD		0.93		
BCD		0.98		
ABCD		1.61		

The reaction of corn hybrids to different seed sowing rates when grown without irrigation was the opposite. Studies show that hybrids P6/240, P5/320 and P4/440 formed the maximum seed yield when sowing at the lowest rate - 60 thousand seeds ha^{-1}. At the same time, the seed yield exceeded the experimental variants with a seeding rate of 70, 80 and 90 thousand seeds ha^{-1} in the hybrid P6/240 – by 0.22, 0.62 and 1.0 t ha^{-1} or 5.6, 15.7 and 25.3%, in the hybrid P5/320 – by 0.28, 0.63 and 1.07 t ha^{-1} or 6.3 14.2 and 24.1%, in the hybrid P4/440 – by 0.30, 0.76, 1.87 t ha^{-1} or 6.0, 15.1 and 37.3%. This indicates that in the conditions of the unstable moisture zone of Ukraine, the main limiting factor for high crop productivity is the reserves of available moisture in the soil during the crop growing period.

It should be noted that corn hybrids reacted differently to an increase or decrease in the seeding rate against the background of irrigation or without irrigation. Experimental data show that with an increase in the seeding rate from 60 to 70 and 80 thousand seeds ha^{-1} in the variant without irrigation, the numerical value of the decrease in the seed yield of the mother forms of corn hybrids was almost the same. But with an increase in the seeding rate to 90 thousand seeds ha^{-1}, the late-ripening hybrid P4/440 stood out with the most negative reaction to the thickening of the sowing and the maximum decrease in yield. This indicates a deficit of available moisture in the soil to meet the physiological needs of hybrids with a longer vegetation period.

When growing corn in the variant with irrigation, with a decrease in the seeding rate from 90 to 80, 70, 60 thousand seeds ha^{-1} in the experiment, the value of the seed yield shortfall was close to the early-ripening hybrid P6/240 and the late-ripening P4/440. In the mid-ripening hybrid P5/320, the yield reduction was significantly greater compared to the early-ripening and late-ripening hybrids, respectively, at the sowing rate of 80 thousand seeds ha^{-1} - by 0.20 and 0.28 t ha^{-1}, 70 thousand seeds ha^{-1} - by 0.34 and 0.45 t ha^{-1}, 60 thousand seeds ha^{-1} - by 0.14 and 0.32 t ha^{-1}.

The grouping of the factors showed that the P4/440 hybrid with irrigation formed a yield of 0.8 t ha^{-1} more than without irrigation (Fig. 3). The difference between the irrigation and non-irrigation options with the P5/320 hybrid was 1.44 t ha^{-1}, and P6/240 - 1.58 t ha^{-1}.

Grouping of the effects of factors showed that the increase in yield under irrigation compared to the control was: in the hybrid P4/440 – 37.1%, P5/320 – 33.4%, P6/240 – 41.7% (Fig. 3).

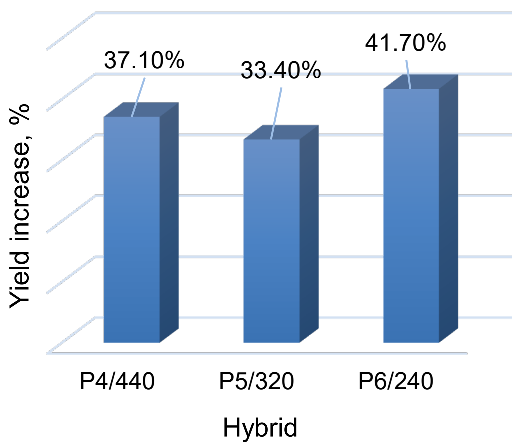

Figure 3. Increase in seed yield of the studied hybrids under irrigation, average for 2021–2023.

Thus, for effective management of the yield of female components lines, it is first necessary to take into account their genetic properties, that is, the ability of hybrids to maximize the bioclimatic potential of the region, the resource content of technologies and their transformation into a crop yield. It is genetic features that should become the basic element in determining the strategy for the formation of yield. Irrigation of crops with a value of 95 mm turned out to be effective for the formation of the yield of seeds of female components linesand has prospects for further research in order to clarify irrigation norms.

According to the results of variance analysis, it was found that the irrigation factor has the greatest influence on the formation of yield - 53%. Genetic properties influenced 28%. It was characteristic that the conditions of the growing years, which have a dominant influence when growing corn without irrigation, in this experiment influenced only 12%. This indicates a significant possibility of managing the production processes of agrocenoses of seed crops. It should be noted that the interaction of the factors studied in the experiment, although it had a less pronounced effect, was statistically significant at a high level of significance ($p \leq 0.01$).

Therefore, in conditions of moisture deficiency, this indicator requires clarification to develop methods for effective management of the yield of female components linesof corn hybrids. For this, it is advisable to also determine reliable indicators - economically valuable traits that are directly related to yield.

Studies show that seed sowing rates also have a significant impact on the formation of the yield of female components lines. The use of irrigation has a noticeable and visual effect, this was also confirmed by the results of mathematical processing of the experimental results.

A steady trend towards an increase in yield is observed in the variants with irrigation (Fig. 4).

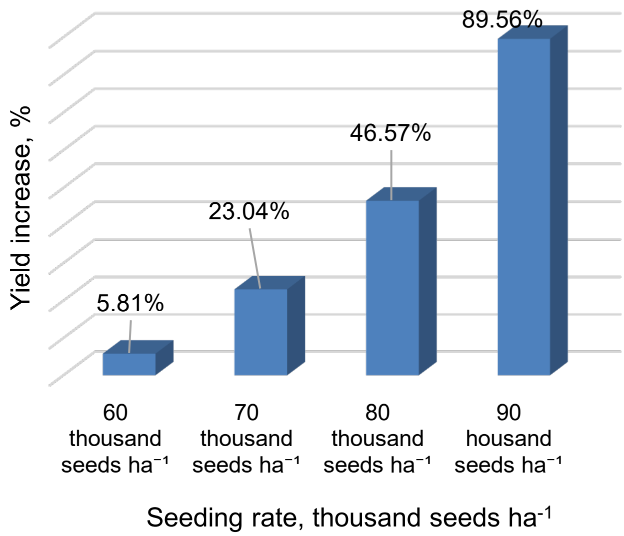

Figure 4. Increase in corn seed yield depending on irrigation at different seeding rates, average for 2021–2023.

The increase in corn seed yield under irrigation compared to the control depending on the seeding rate was: 60 thousand ha^{-1} - 5.81%, 70 thousand ha^{-1} - 23.04%, 80 thousand ha^{-1} - 46.57%, 90 thousand ha^{-1} - 89.56%.

Thus, on average, for the tested corn hybrids, when grown under irrigation, a gradual increase in the yield of seeds of the mother crop forms was noted when the seeding rate was increased from 60 to 70 thousand seeds ha^{-1} (by 0.01 t ha^{-1}) and reached a maximum at a rate of 80 thousand seeds ha^{-1} (by 0.05 t ha^{-1}). But when the seeding rate was increased to 90 thousand ha^{-1}, the seed yield sharply decreased by 0.13 t ha^{-1}.

The highest yield on variants without irrigation was observed when using the minimum seeding rate of 60 thousand seeds ha^{-1}. A gradual increase in the seeding rate without irrigation led to a negative result, in particular, a decrease in the yield on average for corn hybrids by 0.07–0.31 t ha^{-1} or 1.8–7.9%. This indicates that in the conditions of unstable moisture in the central part of the Forest-Steppe of Ukraine, effective cultivation of corn seed crops requires optimization of the plant life factor, which is at a minimum (available moisture reserves).

One of the most important indicators of the formation of the yield of corn seed crops is the mass of 1,000 seeds. This indicator characterizes the fullness of the seed, nutrient reserves and significantly determines its sowing qualities and the value of the seed batch as a whole. The obtained research results indicate similar patterns of influence of the studied factors on the mass of 1,000 seeds, as on seed yield (Table 2).

Table 2. Weight of 1,000 grains of female components lines (♀) depending on irrigation and seeding rate (average for 2021–2023)

♀ hybrid	Seeding rate, thousand seeds ha^{-1}	Weight of 1,000 seeds, g		
		control (no irrigation)	irrigation growth	growt
P4/440	60	283.9	318.2	34.3
	70	276.7	314.9	38.2
	80	270.1	307.0	36.9
	90	265.2	299.8	34.6
P5/320	60	242.7	277.7	35.0
	70	234.8	272.6	37.8
	80	223.9	264.3	40.4
	90	216.9	258.0	41.1
P6/240	60	249.0	280.9	31.9
	70	240.1	275.1	35.0
	80	229.6	271.2	41.6
	90	224.5	267.3	42.8
LSD_{05}				
Year (A)		0.03		
♀ hybrid (B)		0.04		
Irrigation (C)		0.03		
Seeding rate, thousand ha^{-1} (D)		0.04		
AB		0.06		
AC		0.05		
BC		0.05		
AD		0.07		
BD		0.08		
CD		0.06		
ABC		0.08		
ABD		0.12		
ACD		0.1		
BCD		0.11		
ABCD		0.17		

The results of the studies show that the mass of 1,000 seeds was significantly higher in the variants where irrigation was used. In the late-ripening hybrid P4/440, the mass of 1,000 seeds against the background of irrigation was, depending on the seeding rate, from 299.8 to 318.2 g or was higher, compared to growing without irrigation, by 34.3–38.2 g. In the mid-ripening hybrid P5/320, the difference in this indicator was in the range of 35.0–40.4 g, which confirms the importance of irrigation for obtaining high-quality seeds with a large mass, and, therefore, a fairly high potential. A similar pattern was also observed in the early-ripening hybrid P6/240.

The importance of the mass of 1,000 seeds as an indicator is confirmed by its close direct relationship with seed yield – $r = 0.80$ (Fig. 5).

But this indicator is, albeit weakly, but statistically significantly inversely correlated with the seeding rate ($r = –0.24$). It is obvious that the mass of 1,000 seeds turned out to be an important indicator for determining the yield of female components linesand requires further research into its influence on the formation of seed yield of first-generation hybrids.

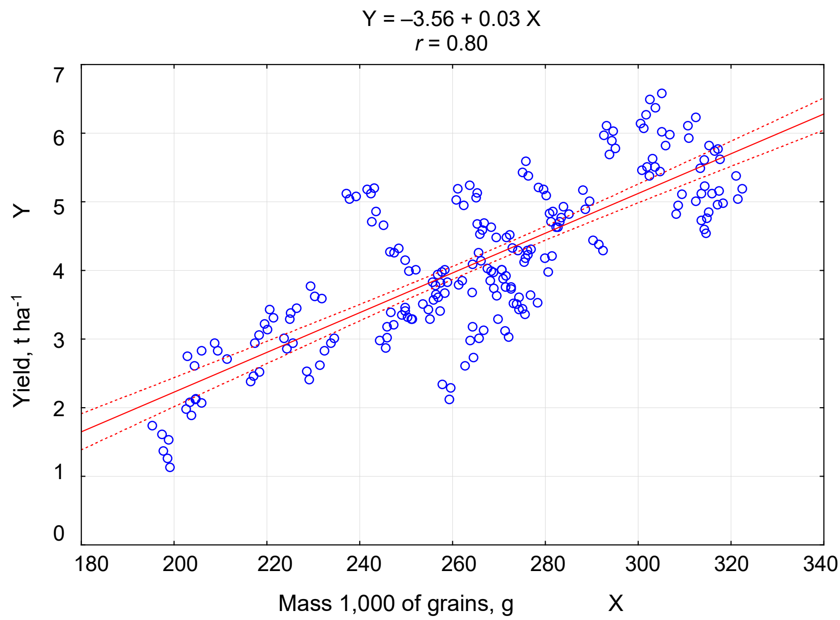

Figure 5. Dependence of seed yield on the mass of 1,000 grains.

But this indicator is in a weak, but statistically significant inverse correlation with the seeding rate (r = –0.24) (Fig. 6).

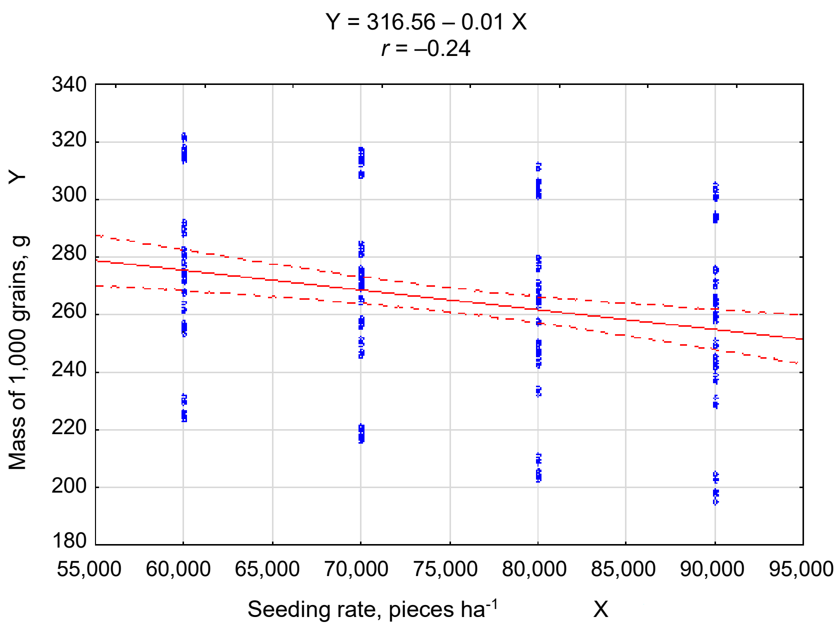

Figure 6. Dependence of seed yield on the mass of 1,000 grains.

Data analysis by the multiple regression method made it possible to establish an equation of the quadratic dependence of the yield of seed crops of female components linesof hybrids on the seeding rate and the mass of 1,000 seeds.

DISCUSSION

Water is one of the important natural resources necessary for plant life, and the increase in its scarcity prompts the search for ways to effectively use moisture and manage the water regime (Brar et al., 2016; Djaman et al., 2022). Maize plants are quite sensitive to water shortages, since their root system is not sufficiently branched and does not penetrate deeply into the soil. It was found that in the panicle ejection phase (VT), 94% of the total root length was located from the soil surface to a depth of 60 cm and 85% in the soil layer up to 30 cm. This distribution of the bulk of corn roots can lead to sharp fluctuations in corn yield in years with a deficit of soil moisture due to frequent drought. The results of our research also indicate the dominant influence of weather conditions, in particular the deficit of precipitation moisture in the panicle ejection phase (VT) and stigma yield (R1) on the level of seed yield when growing corn without irrigation.

According to the experiment, it was found that on average for 2021–2023, both the early-ripening hybrid P6/240, and the mid-ripening P5/320 and late-ripening P4/440 hybrids formed the highest seed yield when grown under irrigation with a sowing rate of 90 thousand seeds ha^{-1}. Sowing corn hybrids with a rate of 60, 70, 80 thousand seeds ha^{-1} against the background of irrigation turned out to be ineffective. Increasing plant density is accompanied by an increase in grain yield of corn hybrids by achieving the optimal number of plants per unit area (Assefa et al., 2016). It has been studied that higher corn plant density contributes to higher grain yield. When testing corn hybrids ZP 500, NS 5010 and AS 534 in Serbia at densities from 50,125, to 59,523, 69,686 and 79,365 plants ha^{-1} during three consecutive growing seasons (2016–2018), it was found that they formed the highest grain yield at the maximum plant density (79,365 plants ha^{-1}) (Mandi´c et al., 2024).

Studies show that when growing female components linesof corn hybrids without irrigation, high plant density per unit area led to a decrease in seed yield. The highest seed yield of corn hybrids was formed at the lowest seeding rate, in particular 60 thousand seeds ha^{-1}. Increasing the crop density also has its limitations, since exceeding the optimal plant density leads to increased competition for water, nutrients and light, worsening conditions for pollination and the formation of crop structure elements, in particular, a decrease in the number of grains per ear, the weight of 1,000 grains (Berzsenyi & Tokatlidis, 2012; Cerrudo et al., 2020). Therefore, to obtain high corn yields, the plant density must be optimal, since thinned and thickened crops reduce this indicator (Shakalii et al., 2024). One of the most important factors in the quality of seed material is the weight of 1,000 seeds, because well-filled seeds have greater germination energy, a higher percentage of germination and, accordingly, give a good start to plants from the very beginning. In field crops, the dependence of the level of plant yield on the mass of 1,000 seeds was noted (Bahan et al., 2024). The conducted studies revealed that when growing corn hybrids both against the background of irrigation and in the variant without irrigation, the mass of 1,000 seeds increased from the maximum to the minimum seeding rate. A similar pattern is evidenced by the results of the studies of Zhang et al.

(2015) and Jia et al. (2018). Correlation analysis indicates a direct close relationship between the yield of corn hybrid seeds and the mass of 1,000 seeds. This indicates a direct positive effect of the thousand-seed weight indicator on grain yield. The results of the studies of Chen et al. (2017) and Jahangirlou et al. (2021) also showed that these traits determine grain yield.

According to the research conducted by Shatkovsky (Shatkovsky et al., 2020), it was found that irrigation in combination with other agrotechnical measures is a determining factor in the activation of growth processes and the formation of corn yield. The highest yield indicators were achieved when irrigation was used. The lowest corn yield indicators were recorded with natural moisture, which indicates high risks and limited feasibility of growing this crop without additional irrigation.

Fomichev (2019) considers modern irrigation methods as a key factor in the intensification of grain corn growing technologies. The obtained research results confirm that the method of irrigation significantly affects the formation of the main biometric indicators, crop structure and productivity of this crop.

CONCLUSION

Determination of the optimal seeding rate for female components linesof corn hybrids of different maturity groups should be carried out comprehensively, taking into account the bioclimatic potential of the growing area, genetic characteristics and agrotechnical factors. According to the results of the research, it was found that in conditions of unstable moisture in the central part of the Forest-Steppe of Ukraine, one of the decisive factors in the formation of elements of the crop structure and a prerequisite for high corn grain yield is the level of plant provision with available moisture during the growing season. Moisture deficiency limits the formation of high seed yield and 1,000-seed weight.

Hybrids reacted differently to the seeding rate and cultivation under rainfed and irrigation. Early-ripening hybrid P6/240, mid-ripening P5/320 and late-ripening P4/440 hybrids formed the highest seed yield when grown under irrigation with a seeding rate of 90 thousand seeds ha^{-1}. When grown without irrigation, the best conditions for the formation of plant components and high yield were noted at the lowest seeding rate - 60 thousand seeds ha^{-1}. The minimum seeding rate ensured the production of seeds with a high mass of 1,000 seeds.

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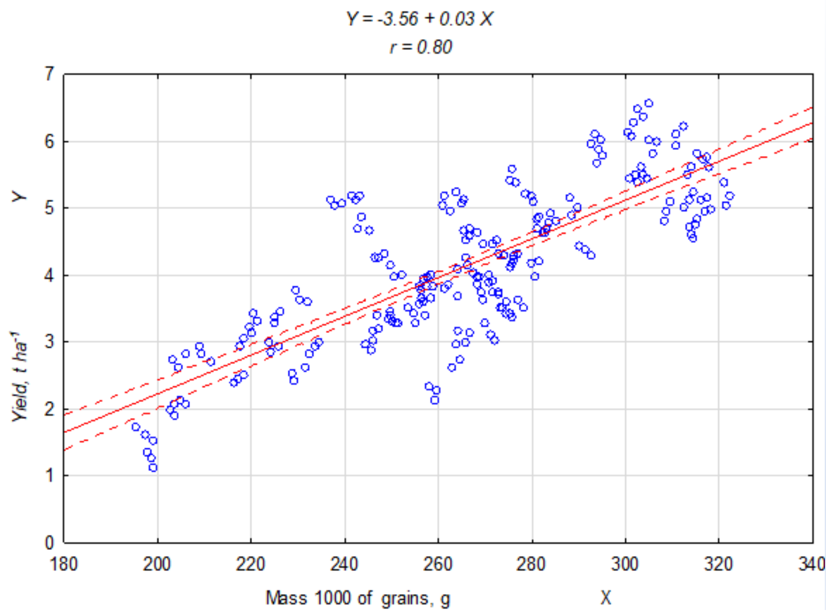

Y = -3.56 + 0.03 X
r = 0.80
Y
Yield, t ha-1
Mass 1000 of grains, g
X
0
1
2
3
4
5
6
7
180
200
220
240
260
280
300
320
340