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Effectiveness of urea-ammonia mixtures for ertilisation of maize (*zeamays l.*) mother plants under conditions of unstable moisture

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ABSTRACT

Studies in 2021-2023 under conditions of unstable moisture in the Central Forest-Steppe of Ukraine revealed a positive effect of urea-ammonia mixture (UAN) on the yield and sowing properties of seeds of maternal lines of maize hybrids of different maturity groups (P6/240, P5/320, P4/440). Based on the research results, it was found that the application of 80 l/ha of UAN in the V10 phase increased seed yield by 10.6-11.9% compared to the control. The highest level of seed yield of the maternal line of the early-ripening hybrid P6/240 (6.16 t/ha) by 22.5%, the mid-ripening hybrid P5/320 (6.20 t/ha) by 21.3%, the late-ripening hybrid P4/440 (6.80 t/ha) by 16.4% and its maximum increase compared to the control was observed in the variant with the introduction of urea-ammonia mixture (UAN) at a dose of 120 l/ha. The subsequent increase in the dose of UAN to 160 l/ha was not effective, as the level of seed yield decreased in the hybrid P5/320 by 0.5%, P6/240 - by 3.9%. Statistical processing of the experimental data using the method of analysis of variance confirms the significant influence of fertilisers on the formation of seed yields of maize hybrids, which account for 37%. According to the experimental data, the positive effect of applying different doses of liquid nitrogen fertilisers on the weight of 1000 seeds, depending on the genetic characteristics of the hybrids and the dose of fertilisers, was noted to be 3.4-21.8%.

1. INTRODUCTION

In today's environment, fertiliser use plays an important role in maximising yields and growing efficiency [1]. Fertilisation is an important and effective way to manage yields and provides crops with essential nutrients such as nitrogen, phosphorus and potassium, which are essential for plant growth and development [2]. A lack of any of these nutrients can lead to a reduction in plant structural elements and yield. Additionally, there are other methods of seed stimulation in pre-sowing treatment of crops [3], [4].

Nitrogen is a key element for the intensive growth and development of maize. Optimal doses of nitrogen fertiliser help plants develop quickly, improve cob formation and increase yields. The application of nitrogen fertilisers helps to intensify assimilation processes, which has a positive impact on the quantity and quality of the corn crop [5- 7]. The most appropriate doses of nitrogen fertilisers contribute to the maximum and efficient use of available resources, such as water and soil nutrients, by plants, which improves the conditions for their growth and development [8], [9]. The authors of [10] argue that nitrogen is essential for optimal growth, development and yield of maize, and its proper application is a key technological aspect. The use of nitrogen fertilisers is important for increasing corn yields. Studies [11], [12] have shown that nitrogen application increases grain yields and helps to increase protein and starch content. Maize yields in studies [13] almost doubled with nitrogen fertilisation. Mid-season nitrogen application for maize can be beneficial in different circumstances. This approach allows for additional support of plant nutrient requirements and provides optimal conditions for active growth and development of the crop [14]. The additional nitrogen helps plants to form more biomass and generative organs, which in turn leads to higher grain yields [15- 17]. In production, there are different ways of applying nitrogen fertiliser to maize that can be used depending on the conditions, available equipment and requirements of a particular field. Studies [18], [19] indicate that the choice of nitrogen fertiliser application method for maize may depend on various factors, such as the availability of special agricultural machinery, soil and climatic conditions, as well as field-specific characteristics and yield requirements. By considering these aspects, fertiliser use for maize can be optimised to maximise yields and production efficiency, while also taking into account economic and environmental benefits [20- 22].

Fertigation can be an effective way of applying nitrogen fertiliser to maize to help maximise yields and optimise nutrient use. Liquid fertilisers applied by fertigation dissolve quickly in water and are absorbed by plants through the roots. This allows you to instantly influence the growth and development of the crop and improve the realisation of its productive potential under irrigation conditions. This method is particularly effective for optimising the fertilisation system for crops such as maize, which may require different amounts of nitrogen at different stages of organogenesis [23- 25]. The use of liquid fertilisers allows for the combination of fertilisation and irrigation [26]. This helps to use water efficiently, as the fertiliser is delivered directly to the root zone of the plants during irrigation. The application of liquid fertilisers can help avoid nutrient losses due to evaporation or fixation in the soil, as they dissolve quickly in water and are available for plant uptake. The choice of liquid fertiliser is important. Using urea-ammonia mixture (UAN) can be an effective way to feed corn, allowing it to meet its nitrogen requirements and contribute to high yields [27], [28]. Studies [29] indicate that the application of UAN as a traditional fertiliser method increased grain yields by 1.8-2.4%, while the use of fertigation increased grain productivity by 6.6-7.6%. The use of UAN can help to ensure efficient nutrient uptake, as it provides nitrogen to the crop in a form that is easily available for plant uptake [30], [31]. Thus, applying urea-ammonia mixture to corn by fertigation is an effective and environmentally friendly way of plant nutrition that maximises yields and ensures high quality of the crop.

The aim of the research is to identify ways to increase the seed yield of maize hybrid maternal lines based on the analysis of the impact of liquid nitrogen fertilisation. Research objective: to investigate the effect of different doses of liquid nitrogen fertilisers (LNF) applied by fertigation on the yield of seed crops of maize hybrids.

2. MATERIALS AND METHODS

Experimental studies were conducted under conditions of unstable moisture in the Central Forest-Steppe of Ukraine. According to the agroclimatic zoning, the territory of the experimental plots belongs to the zone of

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insufficient moisture (Figure 1). The climate is continental with cold winters and hot summers. The sum of active temperatures is 22-50 °C. The average annual air temperature on the farm is 9 0C. The coldest period over the years of research is in January and amounts to minus 2,6 0C, and the warmest period is in August, 23,3 0C. The beginning of frost is noted in the first decade of October. The duration of the frost-free period is 175-180 days.

Dynamics of the average monthly rainfall during the corn growing season is presented in Figure 1. Dynamics of the average monthly air temperature over the years of research is presented in Figure 2.

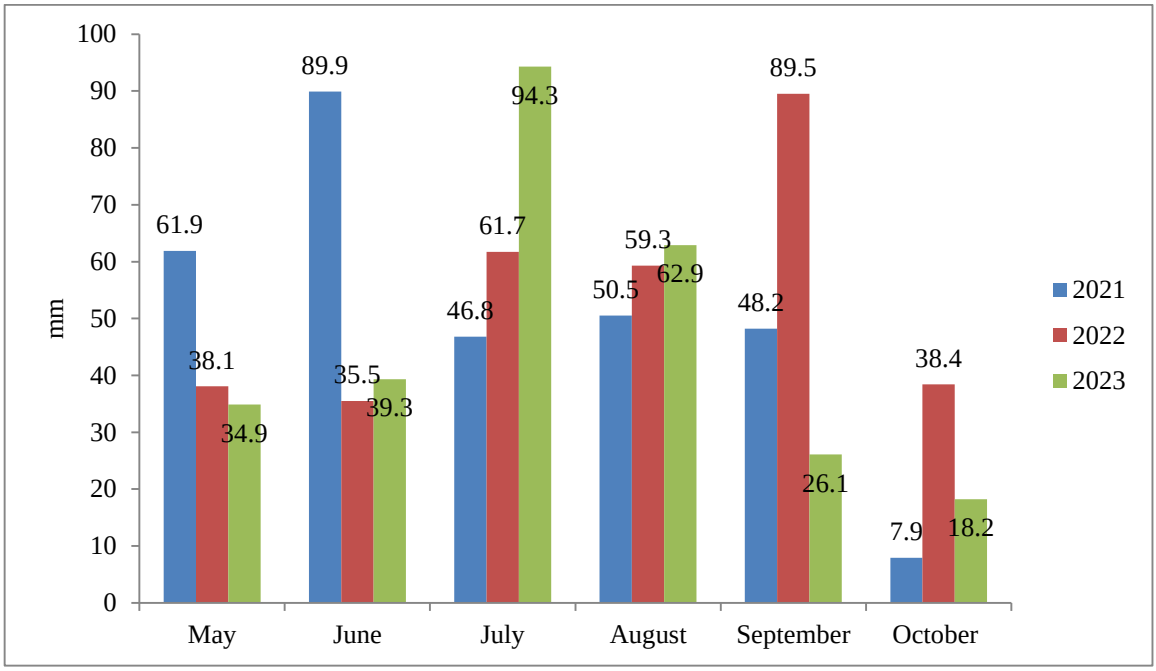

Figure 1. Dynamics of the average monthly rainfall during the corn growing season

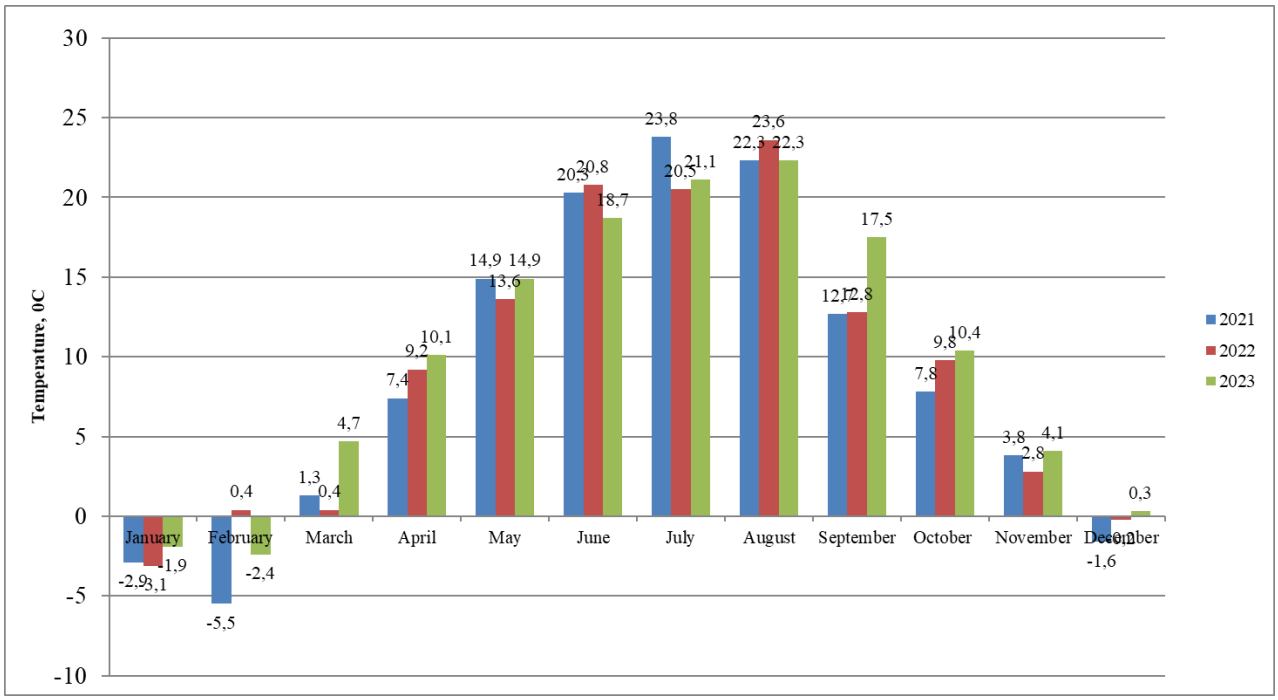

Figure 2. Dynamics of the average monthly air temperature over the years of research

The highest rainfall during the corn growing season was in 2022 - 322.4 mm. It is also worth noting that this year the highest monthly rainfall of 90 mm was recorded in September. Excessive moisture of precipitation this month had more negative than positive impact on corn crops, as it led to the extension of the harvesting period and worsening of the conditions for harvesting. Maize is a plant that requires moderate moisture supply throughout the entire period of growth and development, but some phases of development can be particularly critical in terms of water consumption. Analysing monthly data, we conclude that not only the total amount of precipitation during the growing season is important, but also its distribution by crop development stages. In 2021, at the initial stages of growth, the amount of precipitation was 90 mm, and during the critical phase of panicle ejection, it was only 46 mm. In 2022, the highest rainfall was in the V3-V12 phase - 61 mm, and in the VT phase - 59 mm, which is not enough for normal growth and development of corn. The best water supply during critical phases was recorded in 2023; the initial stages - 40 mm and the panicle ejection phase - 94 mm.

The soil is a typical low humus, heavy loamy black soil characterised by the following agrochemical parameters. The humus content in the topsoil (0-20 cm) varied between 3.8-4.2%. Humus reserves in the one-metre layer are 500-550 tonnes per hectare. The topsoil (0-20 cm) contained 9.8-10.2 mg of nitrate nitrogen, 24.3 mg of mobile phosphorus, and 264 mg/kg of exchangeable potassium. These indicators correspond to low nitrogen availability and medium phosphorus and potassium availability. The reserves of productive moisture in the one-metre soil layer at the time of sowing are within 135-140 mm. The soil has a high absorption capacity due to the high content of highly dispersed silt particles. The absorption capacity of the topsoil is 40 mg. equivalent/100g of soil. The soil density is 1.15-1.16 g/cm³. The soil reaction is close to neutral - pH 5.9-6.1.

The experimental design included: assessing the impact of weather conditions on seed yield in the years of research (2021-2023) (factor A); studying the productivity of maternal lines of hybrids of different maturity groups P4/440, P5/320, P6/240 (factor B); the impact of UAN application rates (urea-ammonia mixture, grade 32) - 80, 120, 160 l/ha (factor C). The sown and recorded area for each maize hybrid was 1.0 ha. The replication of the experimental variants was three times. The placement of the variants was randomised by the rate of UAN application. Sowing - the first decade of May, the predecessor is corn. A 16-row Kinze seeder was used for sowing.

UAN was applied by fertigation (through irrigation) at the V10 stage (10 leaves of maize). In addition to fertigation, watering was used at critical stages of corn development: V4 (4 leaf stage) - 20 mm, V8 (8 leaf stage) - 20 mm, VT (panicle ejection stage) - 45 mm.

Hybrids: P4/440 is a late-ripening (FAO 440), toothy grain type. It has excellent moisture return and drought resistance. Suitable for monoculture cultivation. Areas of application: grain, ethanol. Recommended for cultivation in the Forest-Steppe and Steppe zones. Late harvesting should be avoided. P5/320 is a mid-season variety (FAO 320). It has excellent drought tolerance and moisture retention. Resistance to smut diseases is 7/9. It is suitable for growing in monoculture and with minimum tillage technology. Recommended sowing dates are early and optimal (late April - first half of May). Recommended cultivation zone - Forest-Steppe, Steppe. P6/240 is an early ripe variety (FAO 240). The grain type is toothed. Areas of application - grain, ethanol, starch. Suitable for monoculture cultivation. Late harvesting is not recommended. Cultivation areas: Forest-steppe and Polissya. Apply insurance herbicides in accordance with the recommended stages of crop development.

Harvesting and moisture determination were carried out at the stage of full grain ripeness with an Ohbo

2460 combine harvester from each plot. Corn grain yield was converted to a standard moisture content of 14%. The weight of 1000 kernels were determined from two samples of 500 kernels each. Each sample was weighed to the nearest 0.1 g, converted to a weight of 1000 kernels, and the average weight was determined.

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 (LSD05).

3. RESULTS AND DISCUSSION

Fertilisation is considered the most effective way to manage yields. Research results show that the use of 80 l/ha of nitrogen fertilizers in the form of UAN allows to increase the seed yield of maize hybrid mother lines by 0.54-0.6 t/ha compared to the control (Table 1). An increase in the rate of UAN application to 120 l/ha contributed to an increase in seed yield by 0.96-1.13 t/ha compared to the control, and by 0.41-0.55 t/ha compared to 80 l/ha of UAN. The subsequent increase in the fertiliser dose by 40 l/ha or 33.3% was not effective, because in the variants with a rate of 160 l/ha of UAN, even a decrease in yield was observed, which was noted in the maternal forms of maize hybrids P5/320 and P6/240. These research results indicate that it is inexpedient to increase the dose of UAN to 160 l/ha under conditions of unstable moisture, because their application does not have a positive effect and is not implemented in the form of an additional seed yield of the mother lines.

Table 1. Seed yield depending on genetic characteristics and fertiliser, t/ha

Hybrid	Application rate, l/ha (application phase V10)	Years			Average for 2021-2023
		2021	2022	2023	
P4/440	Monitoring	5,95	5,64	5,94	5,84
	80	6,33	6,16	6,67	6,39
	120	6,84	6,55	7,01	6,80
	160	6,93	6,75	6,85	6,84
P5/320	Monitoring	5,27	4,68	5,39	5,11
	80	5,65	5,26	6,05	5,65
	120	6,17	5,88	6,53	6,20
	160	6,12	6,02	6,36	6,17
P6/240	Monitoring	5,19	4,63	5,28	5,03
	80	5,77	5,17	5,94	5,63
	120	6,16	5,96	6,35	6,16
	160	5,96	5,57	6,25	5,92
Average by year		6,03	5,69	6,22	-
LSD_{05}	Year (A)				0,05
LSD_{05}	Hybrid (B)				0,05
LSD_{05}	Application rate (C)				0,06
LSD_{05}	AB				0,09
LSD_{05}	AC				0,1
LSD_{05}	BC				0,12
LSD_{05}	ABC				0,18

As shown by the calculations of the research results, the seed yield of maternal lines can be significantly affected by the conditions of the years of cultivation (Figure 3). The most favourable weather conditions were in 2023, when the average seed yield was the highest (6.22 t/ha), and the difference compared to 2021 and 2022 was 0.19 and 0.53 t/ha or 3.2 and 9.3%, respectively.

The research results show that, on average, according to the maternal lines of hybrids, the lowest seed yield was naturally formed in the variant without mineral fertilisers - 5.47 t/ha (Figure 4). The highest increase in corn seed yield compared to the control was obtained in the variant with UAN application at a rate of 120 l/ha, where it was 0.92 t/ha or 16.8%. It should be noted that the application of UAN at a rate of 80 and 160 l/ha also contributed to a significant increase in seed yield compared to the control, respectively 0.45 and 0.87 t/ha or 8.2 and 15.9%. However, the level of seed yield of maize hybrids against the background of the above norms of UAN application was inferior to the best variant by 0.05-0.47 t/ha or 0.8-7.9%.

The results of the analysis of variance show that among the factors studied in the experiment, the greatest influence on seed yield was the application of mineral fertilisers - 37 % (Figure 5). The share of the influence of genetic characteristics of hybrids on the level of seed productivity of mother lines was 34%. In the presented experiment, the complex effect that characterised the conditions of the years of cultivation was 24 %. Thus, the main factors for the formation of seed yield of maize hybrids' maternal forms under conditions of unstable moisture are regulated, in particular, biological characteristics of maize biotypes and fertilisation system. It is worth noting the statistically significant interaction of the factors studied in the experiment. Despite its small share, which did not exceed three per cent, it was statistically significant.

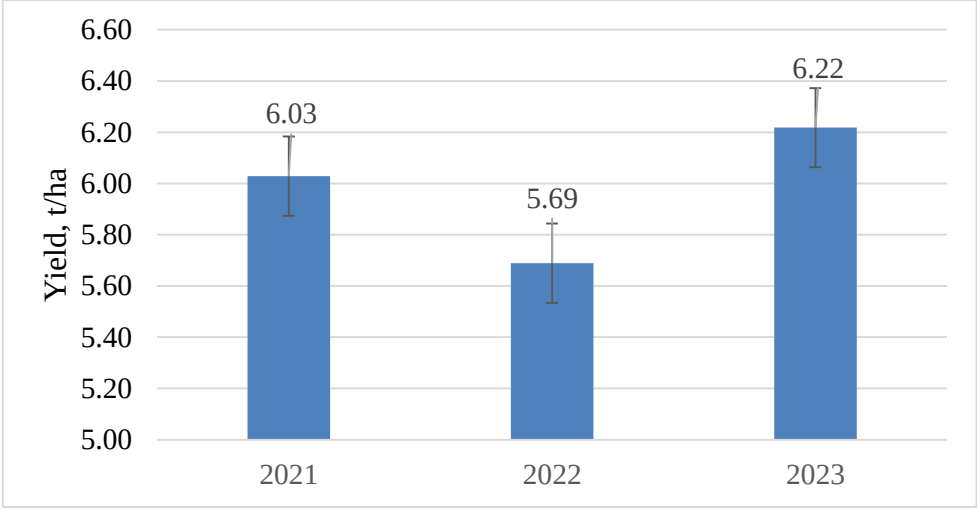

Figure 3. Influence of growing year conditions on the yield of maize hybrids

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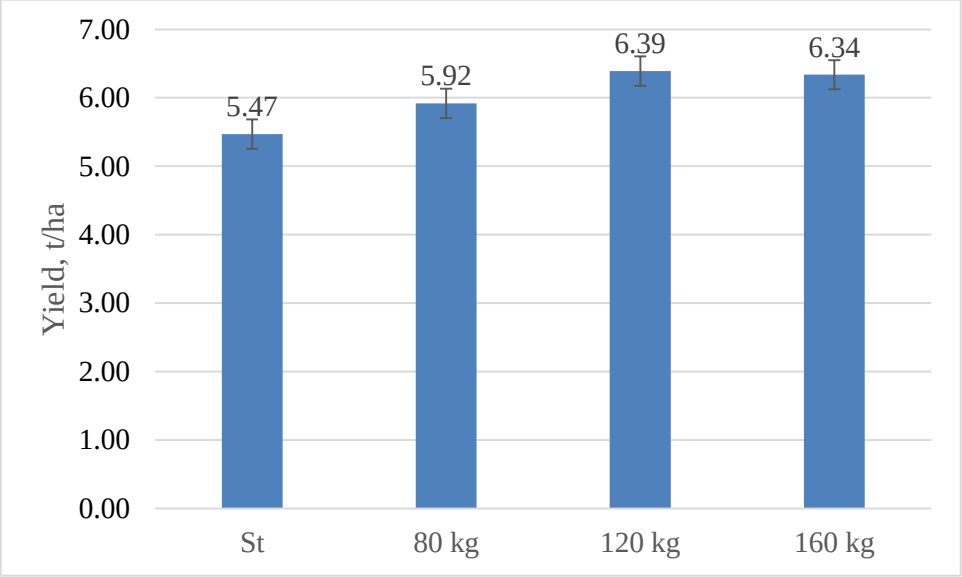

Figure 4. Effect of fertilisation on corn hybrid yields (average for 2021-2023)

An important indicator of seed characteristics that plays a significant role in the formation of its sowing qualities is the weight of 1000 seeds. According to the results of the research, the pattern of fertiliser application on the weight of 1000 seeds is similar to their effect on the formation of the yield. The use of 80 l/ha of UAN contributed to an increase in the above indicator, depending on the genetic characteristics of the hybrid, by 9-24 g compared to the control (Table 2). An increase in the rate of UAN application to 120 l/ha made it possible to increase the weight of 1000 seeds by 23-31 g. Further increase in fertiliser rates to 160 l/ha did not lead to a significant increase in this indicator, and sometimes had the opposite effect. Thus, it is important to establish the optimal rates of nitrogen fertiliser application in order to achieve the highest efficiency in terms of their impact on both the level of realisation of the productive potential of maize hybrid parent lines and the weight of 1000 seeds.

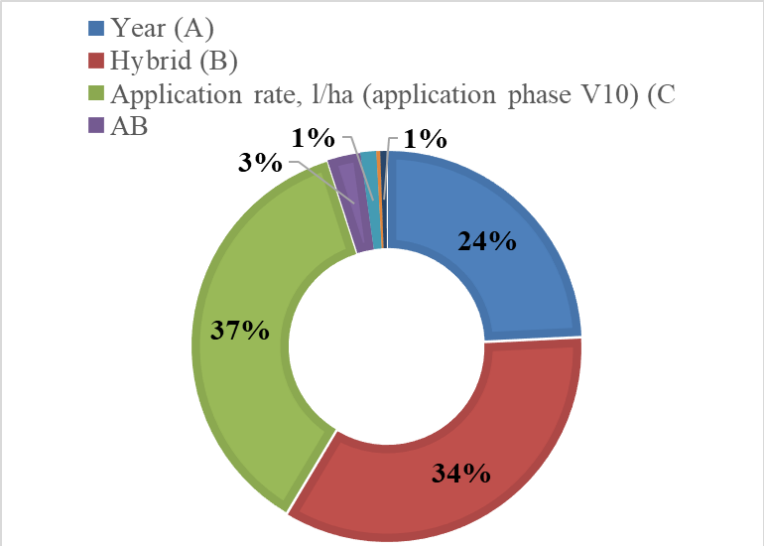

Figure 5. Share of influence of factors and their interactions on seed yield formation

Table 2. Weight of 1000 seeds depending on genetic characteristics and fertiliser, g

Hybrid	Application rate, l/ha	Years	Average

	(application phase V10)	2021	2022	2023	
P4/440	Monitoring	279	244	275	266
	80	283	253	289	275
	120	307	290	316	304
	160	308	291	311	303
P5/320	Monitoring	236	220	239	232
	80	244	235	289	256
	120	269	275	294	279
	160	266	289	290	281
P6/240	Monitoring	231	209	236	225
	80	243	217	270	243
	120	284	249	288	274
	160	279	243	280	267
Average		269	251	282	
LSD_{05}	Year (A)				1,33
LSD_{05}	Hybrid (B)				1,4
LSD_{05}	Application rate (C)				1,84
LSD_{05}	AB				2,3
LSD_{05}	AC				2,67
LSD_{05}	BC				2,79
LSD_{05}	ABC				4,6

As can be seen from Figure 3, there is an average direct correlation between fertiliser application rates and seed yield of the mother lines. A direct strong correlation was recorded between the weight of 1000 seeds and yield, which indicates the importance of taking this indicator into account as a possible parameter for characterising the yield potential of future seed material.

The use of multiple regression analysis allowed us to establish certain patterns for the formation of indicators of 1000 seeds weight and yield (Figure 6). A direct relationship between them and the fertiliser rate was observed only before the application of 120 l/ha, and then there was a tendency for an inverse relationship (Figure 7). The results of the research presented in Figure 4 indicate that under this fertilisation system there is a virtually linear effect of fertiliser rates on the formation of 1000 seeds and the level of yield, but further increase in nitrogen rates can lead to a significant decrease in both yield and quality of seed material.

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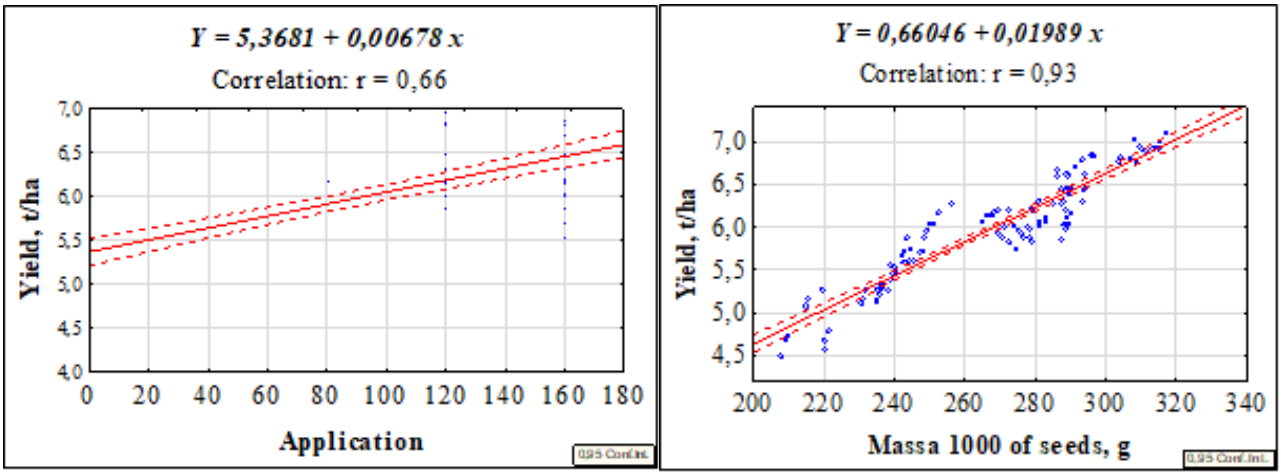

Figure 6. Regression equation of yield dependence on fertiliser rates and weight of 1000 seeds

$$Y=1,28+0,07x+0,02y-0,0002x^2-0,0008xy+0,0006y^2$$

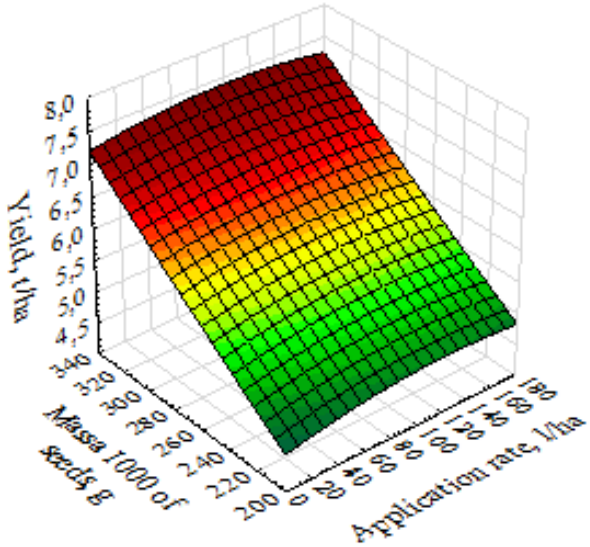

Figure 7. Multiple regression equation for weight of 1000 seeds and yield of mother forms depending on fertiliser

Modern fertilisation methods for maize include a variety of technologies and approaches aimed at maximising efficiency and ensuring precise and cost-effective nutrient application. Numerous scientific studies support the application of fertiliser through the irrigation system. This allows for precise dosing of fertilisers and their application directly to the area where the plant root system operates. This method allows for efficient use of fertilisers, avoids evaporation losses and ensures an even distribution of nutrients. In the study [18], nitrogen application increased grain yield by more than 57% compared to the control. The authors of [29] believe that optimising UAN application rates through fertigation will achieve better corn yields and environmental benefits. This point of view coincides with our results, because in all variants of the experiment, an increase in corn seed yield was observed during fertigation. Thus, on average, in 2021-2023, the application of 80 kg/ha of nitrogen fertilizers in the form of urea-ammonia mixture improved the conditions for the growth and development of corn and increased the seed yield of the maternal lines of hybrids P4/440, P5/320, P6/240 by 9.4, 10.6 and 11.9%, respectively, compared to the variant without fertilizers. The application of UAN at a dose of 120 l/ha was more effective in terms of its impact on the

formation of seed productivity of maize hybrid maternal lines, which contributed to an increase in yield by 16.4-22.5%. It should be noted that the hybrid P6/240 had the highest value of this indicator, and P4/440 had the lowest. The mother line P5/320 occupied an intermediate position, its yield on the above fertilisation background increased by 21.3% compared to the control. Increasing the dose of nitrogen fertiliser by another 40 l/ha was not effective. As a result of applying this dose of UAN, the seed yield of the mother line P4/440 increased by only 0.6% compared to the previous variant, and the seed productivity of the lines P5/320 and P6/240 even decreased by 0.5% and 3.9%, respectively. Studies have shown that, on average, by fertiliser variants and years of experimentation with varying degrees of favourable weather conditions, the maximum seed yield (6.47 t/ha) was formed by the late-ripening hybrid P4/440. According to this indicator, it was ahead of the early-ripening hybrid P6/240 and the mid-ripening hybrid P5/320, respectively, by 0.78 and 0.69 t/ha or 13.7 and 11.9%. It is important to note that the study observed a statistically significant interaction between fertiliser and year conditions in terms of the impact on the realisation of the genetic productivity potential of maize hybrid maternal lines. Even at relatively small values, not exceeding three per cent, this interaction was statistically confirmed.

Studies [16] show that late nitrogen application can increase the potential number and weight of grains, which is confirmed by our research results. Therefore, the use of 80 l/ha of UAN contributed to an increase in the weight of 1000 seeds, depending on the genetic characteristics of the mother lines of hybrids by 3.4-10.3%. It should be noted that the minimum value of the increase in the weight of 1000 seeds in the late-ripening hybrid P4/440, and the maximum - in the mid-ripening hybrid P5/320. It was found that the maximum increase in the weight of 1000 seeds was noted in the variant with the introduction of 120 l/ha of UAN, which in the maternal lines of the early-ripening hybrid P6/240 was 21.8 %, the mid-ripening P5/320 - 20.3 %, and the late-ripening P4/440 - 14.3 %. In the case of increasing the dose of UAN to 160 l/ha, the weight of 1000 seeds were close or even lower compared to the previous fertiliser variant.

There is a moderate direct correlation between fertiliser application rates and seed yield of maize parental lines, indicating that an increase in fertiliser application has a positive effect on seed yield. The direct strong correlation between the weight of 1000 seeds and yield indicates the importance of this indicator as one of the possible parameters for predicting the yield potential of seed material in the future. The authors of [13] believe that strategies to refine fertiliser recommendations should include information on soil types and soil properties. Also, research by [10] indicates that nitrogen recommendations need to be improved for economic and environmental reasons. This view reflects a different perspective on the issues related to maize seed production. Hence, it is worth considering this strategy in future research.

4. Conclusions

Thus, we have established the effectiveness of applying liquid mineral nitrogen fertilisers in the form of urea-ammonia mixture (UAN) by fertigation and their influence on seed yield and weight of 1000 seeds of maize hybrid mother lines of different maturity groups (P6/240, P5/320, P4/440). It was found that the introduction of different doses of UAN had a positive effect on the level of realisation of the genetic potential of the yield of maize hybrid maternal lines and improvement of seed quality. When 80 l/ha of UAN was applied in the V10 phase, the increase in seed yield was 10.6-11.9% compared to the control. The maximum increase in seed yield of hybrids P6/240 (by 22.5%), P5/320 (by 21.3%), P4/440 (by 16.4%) was obtained by applying urea-ammonia mixture (UAN) at a dose of 120 l/ha. Further increase in the rate of UAN application to 160 l/ha also contributed to an additional increase in seed yield compared to the variant without fertiliser, namely by 17.1-20.7%, but this dose of nitrogen fertiliser was not effective compared to the previous fertiliser variant, as it resulted in a decrease in seed yield, in particular, in the hybrid P5/320 by 0.5%, P6/240 - by 3.9%. It was found that fertiliser application had a positive effect on the weight of 1000

seeds, in particular, it increased it by 3.4-21.8%, depending on the genetic characteristics of the hybrids and the dose of fertiliser.

Thus, the best fertiliser options and method of applying urea-ammonia mixture (UAN) can be recommended for agricultural enterprises specialising in growing maize hybrid seeds in the unstable moisture conditions of the Central Forest-Steppe of Ukraine.

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