UDC 633.15: 631.81.095.337: 631.816.35 https://doi.org/10.31867/2523-4544/0341

EFFICIENCY OF MACRO- AND MICROELEMENTS IN FOLIAR FEEDING OF MAIZE

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Topicality. *For optimal development and yield formation, maize requires macronutrients, not only nitrogen, phosphorus and potassium, but also sulphur and magnesium, as well as microelements such as boron, manganese, copper and zinc. Even a small demand in these elements is essential for the plant growth and development.* ***Purpose.*** *Studying the effectiveness of the application of individual macro- and microelements for foliar feeding of maize, their effect on the formation of biometric parameters of the ear, yield attributes and grain yield in the Western Forest-Steppe of Ukraine.* ***Materials and Methods****. In a two-factor experiment, the impact of macronutrients (magnesium and sulphur) and microelements (boron, manganese, copper, zinc) in the form of highly concentrated liquid fertilisers used for foliar feeding in 5–6 and 8–9 leaf stages of maize for early-ripening hybrids DN Aton and mid-early hybrid DN Astra was studied.* ***Results.*** *It was established that foliar feeding with macro- and microelements had a positive effect on the formation of biometric parameters of the ear and yield attributes. In particular, in the early-ripening hybrid DN Aton, the grain weight per ear increased by 1.7–12.2 %, the 1000 grain weight – by 2.6–7.8 %, the grain yield per ear – by 0.5–2.2 % in the experimental variants compared to the control. These indicators increased by 2.2–15.4 %, 2.4–11.3 % and 1.2–2.9 %, respectively, in the mid-early hybrid DN Astra. Variation of the number of productive ears and yield attributes over the years of research definitely had an impact on the formation of grain yield of maize hybrids. Over the years of research, the average grain yield of the early-ripening hybrid DN Aton was 9.00–9.40 t/ha, and the mid-early hybrid DN Astra was 9.11–9.88 t/ha. All macro- and microelements used in the research provided a significant increase in grain yield compared to the control, namely DN Aton had an increase in yield of 0.29–0.72 t/ha or 3.2–8.0 % and DN Astra – 0.32–0.77 t/ha or 3.5–8.4 %.* ***Conclusions****. The macro- and microelements used for foliar feeding of maize have a positive effect on the formation of biometric parameters of the ear and yield attributes, as well as increase the number of productive ears and grain yield. Zinc has the greatest impact on the formation of the above indicators. Boron, magnesium and manganese were the least effective in maize crops.*

Key words*: maize, hybrid, macronutrients, micronutrients, feeding, biometric indicators, yield attributes, yield*

Introduction. In the development of maize (Zea mays L.) plants, there are two important critical stages in terms of macro- and microelements availability for their growth: the 3–5 and 7–8 leaf stages. In the initial period (before the formation of the first aboveground node), maize grows very slowly, its root system is poorly developed and unable to intensively absorb nutrients from the soil. Therefore, maize plants need to be provided with manganese, zinc and boron to stimulate the growth of the root system. Plant growth is intensive in the next critical stage of maize (7–8 leaves). Improving mineral nutrition during this period increases the grain content of the ears and improves grain quality. The demand for microelements such as zinc, manganese, boron, and copper also increases in this stage. [1].

The full absorption of essential nutrients (nitrogen, phosphorus and potassium) by plants is fundamentally impossible without micronutrients. Lack of micronutrients disrupts the metabolism and physiological processes in plants. Microelements contribute to the synthesis of a full range of enzymes in plants, which allow for more intensive consumption of energy, water and microelements. Only a balanced application of fertilisers containing microelements can ensure that the seeds are able to produce the maximum yield of the quality that is genetically inherent in them. Lack of microelements in available form in the soil leads to a decrease in the rate of processes responsible for plant development. Ultimately, it results in losses in yield and its

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grade, as well as unsatisfactory organoleptic properties [2].

Given that in most cases, soil reserves of available microelements are insufficient to provide plants with them in the required quantities, or for certain reasons they are not readily available to plant root systems, there is a need for the additional microelements application. The most effective is the introduction of microelements by foliar feeding with micronutrients in the form of chelates [3].

Liquid fertilisers are used for foliar feeding, the range of which is growing annually. Their effectiveness in crop cultivation technologies is quite high, regardless of the application method. This is substantiated by a number of scientific studies and is explained by the fact that the increase in yields and improvement of product quality significantly exceeds the increase in production costs per hectare of crops. In particular, the application of microfertilisers for foliar feeding of maize in the Western and Left-Bank Forest-Steppe of Ukraine contributes to more intensive growth and development of plants, improvement of biometric parameters and yield attributes, as well as higher yields and profitability [4–7].

The expediency of applying complex microfertilisers for foliar feeding of maize in the 4 and 8 leaf stages was established on dark grey podzolic soils of the Left-Bank Forest-Steppe, as well as the regularities of changes in the protein, starch and fat content in grain from the applied fertilisers were revealed [8].

The application of complex fertilisers based on microelements on ordinary low-humus chernozems in the Northern Steppe of Ukraine contributed to an increase in the leaf area, grain content of the ear and productivity of maize plants, but at the same time certain technological features regarding the spraying dates of crops were observed. Spraying of maize plants in the 6–8 leaf stage resulted in an increase in the lower ear insertion height, the number of ears per 100 plants and grain yield, but the impact on production profitability was insignificant [9–11].

Microfertilisers applied on irrigated dark chestnut soils of the Southern Ukraine had a positive effect on growth processes, ear insertion height and assimilation area in certain stages of development, duration of interstage periods and grain yield of maize hybrids of different maturity groups [12, 13].

Research conducted in different soil and climatic zones involved the study of complex liquid fertilisers containing several microelements. Scientists have conducted research on the effectiveness of individual microelements, in particular zinc. Zinc-containing fertilisers used in growing maize for grain increased plant height, leaf area, ear insertion height, structural elements, yield and grain quality. [10, 11, 14–17].

The research was aimed at studying the effectiveness of the use of individual macro- and microelements in the form of highly concentrated liquid fertilisers for foliar feeding of maize, their impact on the formation of biometric parameters of the maize ear, yield attributes and grain yield in the Western Forest-Steppe of Ukraine.

Materials and Methods. The research was carried out at the Khmelnytskyi State Agricultural Experimental Station of the Institute of Feed Research and Agriculture of Podillia of NAAS during 2021–2023. The soil of the experimental plot is podzolized medium loamy low humus chernozem slightly washed out on loess-like loam of brownish-pale colour, with a fine nutty structure. The soil is viscous in the wet condition. The soil is well saturated with soil matrix – 39.8–42.0 mg-eq. per 100 g of soil, with hydrolytic acidity of 1.8–2.7 mg-eq. per 100 g of soil. The humus content (according to Tyurin) is 3.2 %. The soil is medium well supplied with nutrient forms: easily hydrolysable nitrogen content is 14.4–16.6, mobile phosphorus is 11.0–12.0, and exchangeable potassium is 7.8–8.0 mg per 100 g of soil.

Technology of maize cultivation was generally accepted for the Western Forest-Steppe zone of Ukraine, except for the factors studied. After harvesting the predecessor (soybean), stubble was ploughed to a depth of 6–8 cm and the primary tillage (ploughing) was carried out to a depth of 25–27 cm. Spring tillage began with harrowing, followed by two cultivations: the first to a depth of 10–12 cm, and the second (pre-sowing) to the depth of seed placement. Mineral fertilisers $N_{48}P_{48}K_{48}$ were introduced under presowing cultivation. Sowing of the early-ripening hybrid DN Aton and the mid-early hybrid DN Astra was carried out with the SU-12 seeder at the optimal dates for the region (in the third ten-day period of April) with the planned pre-harvest plant density of 90,000 and 85,000 plants/ha, respectively. Feeding of maize plants was carried out in the 5–6 and 8–9 leaf stages according to the experimental design.

In the research, we used domestically produced formulations, namely highly concentrated liquid fertilisers: Chimic Bor (B – 150 g/l (in the form of boron-ethanolamine), N – 50 g/l); Oracul chelate magnesium (MgO – 82 g/l, N – 39 g/l, SO_3 – 165 g/l); Chimic Manganese (Mn – 60 g/l); Chimic Cu (65 g/l); Chimic S (SO_3 – 200 g/l; N – 100 g/l); Chimic Zinc (Zn – 85 g/l, N – 45 g/l, carbonic acid lots – 220 g/l).

Research methods: field trial was used to determine the response of maize plants to the studied factors; morphophysiological – to determine biometric parameters of plants; calculation and weighting – to establish parameters of plant structure and productivity; mathematical and statistical – to establish the reliability of the results of field experiments.

Results. According to scientific evidence, the productivity of maize hybrids is ensured by their biological properties to respond positively to weather factors in the cultivation area and the level of mineral nutrition. In our experiments, the sowing – seedling period was 8–10 days in 2021 under conditions of sufficient moisture supply, in 2022 it increased to 14–16 days, in 2023 the lack of precipitation and productive moisture in the topsoil resulted in its increase to 14–20 days. However, the intensive growth and development of maize plants in the early stages in 2021 under conditions of sufficient moisture supply was held back by rather low air and soil temperatures, their significant fluctuations in minimum and maximum values (Table 1).

Table 1. Weather conditions for the growing season 2021–2023

Year	Month						Growing season
	May	June	July	August	September	October	
Average daily air temperature, °C							
2021	15.8	22.0	25.2	20.7	13.8	7.9	17.6
2022	16.2	22.4	22.0	22.1	13.6	11.1	17.9
2023	17.2	20.6	22.4	23.9	19.0	11.8	19.2
Average for 1960–2020	13.6	18.4	19.3	18.6	13.4	7.4	15.1
Total precipitation, mm							
2021	188.6	58.2	349.2	166.5	71.2	0.7	834.4
2022	55.4	63.1	93.2	153.2	206.8	79.1	650.8
2023	9.9	126.2	295.4	45.4	9.2	74.4	560.5
Average for 1960–2020	70.1	107.4	129.9	89.8	62.4	46.6	506.2
Hydrothermal coefficient							
2021	3.84	0.88	4.48	2.59	2.72	0.28	2.46
2022	1.10	0.94	1.36	2.24	5.08	2.29	2.17
2023	0.19	2.04	4.25	0.61	0.16	2.00	1.55
Average for 1960–2020	1.61	1.93	2.16	1.58	1.56	2.03	1.81

The high amount of precipitation in July and August 2021 and 2023 contributed not only to the growth of vegetative mass, but also to the formation of ears and grain filling. In 2022, the intensive growth of vegetative mass and the formation of ears occurred under increased average daily air temperature and significantly lower precipitation compared to the average long-term data.

During the years of research, maize grain ripening occurred under rather different hydrothermal conditions. Thus, a decrease in the average daily air temperature in September in 2021 from 15.0 °C in the first ten-day period to 10.0 °C in the third ten-day period, against the background of a sufficiently high amount of precipitation, restrained grain ripening. Maize ripening occurred with a fairly high amount of precipitation and a gradual decrease in the average daily air temperature in September 2022. It is worth noting that rainfall in September was observed for 16 days, and in the period from 18 to 24 September it rained every day.

At the same time, the conditions for maize grain ripening were the most favourable in 2023 among all the years of research. The absence of precipitation in September with a significant rise in the average daily air temperature (+ 5.6 °C to the long-term average) significantly hastened the ripening of maize grain and contributed to a decrease in its moisture content.

The best conditions for emergence of seedlings were in 2021, the worst – in 2023. Hydrothermal conditions during the periods of growth and development of maize plants, formation of ears, grain filling in the years of research were generally favourable due to sufficient rainfall, but uneven distribution and rather high average daily air temperature. The best conditions for maize grain ripening were in 2023, and the worst were in 2022. The growing season of the early-ripening hybrid DN Aton was 120 days in 2023, and the mid-early hybrid DN Astra – 132 days, while in 2021 it was 114 and 134 days, and in 2022 – 128 and 137 days, respectively.

In 2021–2023, observations showed that foliar feeding with macro- and microelements affected the formation of biometric parameters of ears and yield attributes of maize hybrids. At the same time, they also varied over the years of research. In particular, the early-ripening hybrid DN Aton formed the smallest ear length (16.5–17.5 cm) in 2022, while the largest (18.4–19.8 cm) – in 2023. The number of grain rows per ear decreased from 16–18 in the first two years of research to 14 in 2023. The number of grains per row varied from 39 to 43 in 2021, and from 38 to 41 in the following two years. The highest grain weight per ear (160.1–184.8 g) and 1000 grain weight (301.0–316.3 g) were obtained in 2023, while the lowest values were in 2021 – 133.0–146.0 g and 189.7–209.3 g, respectively. In 2021 and 2022, the grain yield per ear was 80.0–82.9 % and 81.5–83.0 %, respectively, while in 2023 it increased to 83.7–85.8 %.

The mid-early hybrid DN Astra had the longest ear length of 19.7–22.6 cm in 2021, and the shortest (17.2–18.5 cm) in 2022. In the first two years of research, an average of 14 rows was formed on the ear, while in the third year of research their number decreased to 12 rows. The largest number of grains per row was 40–46 in 2021, while in the following years it decreased to 37–40 and 36–42, depending on the variant of foliar feeding. The highest grain weight per ear (143.9–167.5 g) and 1000 grain weight (310.0–340.6 g) were obtained in 2023, while the lowest grain weight per ear (127.3–149.3 g) was in 2022, and the lowest 1000-grain weight (234.6–260.9 g) was obtained in 2021. The grain yield per ear was the lowest (79.3–81.5 %) in 2022, and the highest (84.4–88.2 %) in 2023.

According to the results of 3-year studies, we conclude that foliar feeding with microelements in the 5–6 and 8–9 leaf stages increased the ear length of the early-ripening hybrid DN Aton by 0.3–1.1 cm or 1.7–6.2 %, and the ear length of the mid-early hybrid DN Astra by 0.5–2.0 cm or 2.8–11.0 % compared to the control (Table 2).

The number of grain rows per ear under foliar feeding with microelements in the early-ripening hybrid DN Aton was constant, while it increased by 2 rows in the mid-early hybrid DN Astra compared to the control. The number of grains per row was 38–42 in the early-ripening hybrid DN Aton and 38–43 in the mid-early hybrid DN Astra. Compared to the control, the grain weight per ear and 1000 grain weight also increased. In particular, the grain weight per ear in the early-ripening hybrid DN Aton increased from 144.6 g (in the control) to 147.1–162.3 g (with foliar feeding) or by 1.7–12.2 %, and the 1000 grain weight from 238.2 g to 244.5–256.9 g or by 2.6–7.8 %, respectively.

In the mid-early hybrid DN Astra, foliar feeding with microelements increased the grain weight per ear from 137.4 g (control) to 140.4–158.6 g (foliar feeding) or by 2.2–15.4 %. The 1000-grain weight increased from 268.0 g to 274.5–298.2 g, or by 2.4–11.3 %. The grain yield per ear increased by 0.5–2.2 % in the early-ripening hybrid DN Aton, and by 1.2–2.9 % in the mid-early hybrid DN Astra compared to the control.

Thus, the highest number of productive ears per 100 plants, grain weight per ear and 1000 grain weight in both maize hybrids was provided by zinc when used for two-time foliar feeding of crops in the form of a liquid highly concentrated fertiliser Chimic Zinc**.** In particular, the grain weight per ear increased by an average of 12.2 % in the early-ripening hybrid Aton, by 15.4 % in the mid-early hybrid DN

Table 2. Biometric characteristics of the ear and yield attributes, (2021–2023)

Foliar feeding (factor B)	Ear length, cm	Number of grain row, pcs.	Number of grain per row, pcs.	Grain weight per ear, g	Grain yield per ear, %	1000 grain weight, g
DN Aton (factor A)						
Control (no fertilisers)	17.6	16	38	144.6	81.7	238.2
Chimic Bor, 1.5 l/ha	17.9	16	39	147.1	82.2	244.5
Oracul Mg chelate, 2.0 l/ha	17.9	16	39	150.4	82.6	246.8
Chimic Manganese, 3.0 l/ha	18.2	16	39	152.8	82.7	251.1
Chimic Cu, 1.0 l/ha	18.2	16	40	156.1	83.1	253.2
Chimic S, 0 l/ha	18.6	16	40	158.4	83.6	255.2
Chimic Zinc, 1.5 l/ha	18.7	16	42	162.3	83.9	256.9
DN Astra						
Control (no fertilisers)	18.1	12	38	137.4	81.4	268.0
Chimic Bor, 1.5 l/ha	18.1	14	39	140.4	82.6	274.5
Oracul Mg chelate, 2.0 l/ha	18.6	14	39	144.0	83.0	277.5
Chimic Manganese, 3.0 l/ha	19.0	14	40	146.7	83.0	283.2
Chimic Cu, 1.0 l/ha	19.1	14	40	151.7	83.5	288.6
Chimic S, 0 l/ha	19.3	14	41	154.6	83.9	292.7
Chimic Zinc, 1.5 l/ha	20.1	14	43	158.6	84.3	298.2

Astra, the 1000 grain weight – by 7.8 and 11.3 %, the grain yield per ear – by 2.2 and 2.9 %, respectively.

Varying the number of productive ears and the yield attributes by years of research certainly influenced the formation of grain yields of maize hybrids. According to the results of records and calculations, the lowest grain yield of maize hybrids was formed in 2022, which was 8.76–9.46 t/ha for the early-ripening hybrid DN Aton, and 8.65–9.39 t/ha for the mid-early hybrid DN Astra. Both maize hybrids formed the highest yields of 9.37–10.08 t/ha and 9.28–10.05 t/ha, respectively, in 2023, depending on the variant of foliar feeding with macro- and microelements. It should be noted that the early-ripening hybrid DN Aton was inferior to the mid-early hybrid DN Astra in terms of grain yield only in 2021. In the next two years of research, the early-ripening hybrid DN Aton was superior in terms of yield to the mid-early hybrid DN Astra.

On average, over the years of research, the grain yield due to foliar feeding of early-ripening hybrid DN Aton was 9.0–9.40 t/ha, and the mid-early hybrid DN Astra – 9.11–9.88 t/ha. All macro- and microelements under study provided a significant increase in yield compared to the control, namely, when plants of the early-ripening hybrid DN Aton were fertilised, the increase was 0.29–0.72 t/ha or 3.2–8.0 %, and of the mid-early hybrid DN Astra – 0.32–0.77 t/ha or 3.5–8.4 % (Table 3).

Table 3. Grain yield of maize hybrids of early-ripening groups depending on foliar feeding with macro- and microelements

Foliar feeding (factor B)	Yield, t/ha				+ to control, %
	2021	2022	2023	average	
1	2	3	4	5	6
DN Aton (factor A)					
Control (no fertilisers)	8.87	8.76	9.37	9.00	-
Chimic Bor, 1.5 l/ha	9.20	9.03	9.64	9.29	3.2
Oracul Mg chelate, 2.0 l/ha	9.24	9.09	9.71	9.35	3.9
Chimic Manganese, 3.0 l/ha	9.29	9.13	9.74	9.39	4.3
Chimic Cu, 1.0 l/ha	9.39	9.22	9.87	9.49	5.4
Chimic S, 0 l/ha	9.47	9.33	9.96	9.58	6.4
Chimic Zinc, 1.5 l/ha	9.61	9.46	10.08	9.72	8.0

Table 3 continuation

1		2	3	4	5	6
DN Astra						
Control (no fertilisers)		9.39	8.65	9.28	9.11	-
Chimic Bor, 1.5 l/ha		9.76	8.93	9.60	9.43	3.5
Oracul Mg chelate, 2.0 l/ha		9.81	9.01	9.64	9.49	4.2
Chimic Manganese, 3.0 l/ha		9.86	9.04	9.66	9.52	4.5
Chimic Cu, 1.0 l/ha		9.96	9.14	9.77	9.62	5.6
Chimic S, 0 l/ha		10.07	9.23	9.88	9.73	6.8
Chimic Zinc, 1.5 l/ha		10.21	9.39	10.05	9.88	8.4
LSD_{05}	2021	A – 0.05		B – 0.10		AB – 0.14
	2022	A – 0.12		B – 0.17		AB – 0.24
	2023	A – 0.10		B – 0.15		AB – 0.22

According to the results of the mathematical processing, it was found that the increase in yields of both hybrids between variants of foliar feeding with individual macro- and microelements (factor B), namely magnesium, boron and manganese, was within the statistical error compared to the control.

Thus, among the macro- and microelements for foliar feeding, the least effective was boron in the form of liquid highly concentrated fertiliser Chimic Bor (1.5 l/ha), where the increase in grain yield in the early-ripening hybrid DN Aton was 0.29 t/ha or 3.2 %, and in the mid-early hybrid DN Astra – 0.32 t/ha or 3.5 %.

The greatest increase in yields of both maize hybrids under study was formed when using the microelement zinc for foliar feeding in the form of liquid highly concentrated fertiliser Chimic Zinc (1.5 l/ha) – 0.72 t/ha or 8.0 % and 0.77 t/ha or 8.4 %, respectively.

Conclusions. The application of macro- and microelements for foliar feeding in critical stages of maize development has a positive effect on the biometric parameters of the ear and the yield attributes and contributes to an increase in the number of productive ears and grain yield. Zinc is the most effective for increasing the values of the above indicators and forming them. After applying zinc in the form of liquid highly concentrated fertiliser Chimic Zinc for two-time foliar feeding of maize plants, the grain weight per ear increased by 12.2 % in the early-ripening hybrid DN Aton, and by 15.4 % in the mid-early hybrid DN Astra, the 1000 grain weight by 7.8 and 11.3 %, the grain yield per ear by 2.2 and 2.9 %, grain yield – by 0.72 t/ha or 8.0% and 0.77 t/ha or 8.4%, respectively. Boron was the least effective in maize crops in the form of a liquid highly concentrated fertiliser Chimic Bor.

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УДК 633.15: 631.81.095.337: 631.816.35

Молдован В. Г., Молдован Ж. А. Ефективність використання макро- та мікроелементів у позакореневому підживленні кукурудзи. *Зернові культури. 2024. 8 (2). 264–270.*

Хмельницька державна сільськогосподарська дослідна станція Інституту кормів та сільського господарства Поділля НААН, с. Самчики, Хмельницький район, Хмельницька область, 31182, Україна

Актуальність. Кукурудза для оптимального розвитку та формування врожаю потребує з макроелементів не лише азот, фосфор та калій, але й сірку та магній, з мікроелементів – бор, марганець, мідь та цинк. Потреба в цих елементах невелика, однак вони вкрай необхідні для росту та розвитку рослин. **Мета досліджень.** Вивчення ефективності використання окремих макро- та мікроелементів для позакореневого підживлення кукурудзи, їх впливу на формування біометричних показників качана, елементів структури та урожайності зерна в умовах Західного Лісостепу. **Матеріали і методи.** У двофакторному досліді вивчали гібриди кукурудзи ранньостиглий ДН Атон та середньоранній ДН Астра; макроелементи (магній та сірка), мікроелементи (бор, марганець, мідь, цинк) у вигляді висококонцентрованих рідких добрив, які застосовувалися для позакореневого підживлення кукурудзи у фази 5–6 та 8–9 листків. **Результати.** Встановлено, що позакореневі підживлення макро- та мікроелементами позитивно впливали на формування біометричних показників качана та елементів структури врожаю. Зокрема, у ранньостиглого гібрида ДН Атон, маса зерна з одного качана збільшувалася у варіантах досліду на 1,7–12,2 %, маса 1000 зернин – на 2,6–7,8 % , вихід зерна з качана – на 0,5–2,2 % порівняно з контролем. У середньораннього гібрида ДН Астра ці показники зростали на 2,2–15,4 %, 2,4–11,3 % та 1,2–2,9 % відповідно. Варіювання кількості продуктивних качанів і показників структури врожаю за роками досліджень, безумовно, впливало й на формування урожайності зерна гібридів кукурудзи. У середньому за роки досліджень, урожайність зерна у ранньостиглого гібрида ДН Атон становила 9,00–9,40 т/га, у середньораннього гібрида ДН Астра – 9,11–9,88 т/га. Усі макро- та мікроелементи, що використовували в дослідженнях, забезпечили істотний приріст урожайності порівняно з контролем, а саме при вирощуванні гібридів ДН Атон – 0,29–0,72 т/га або 3,2–8,0 % і ДН Астра – 0,32–0,77 т/га або 3,5–8,4 %. **Висновки.** Застосування макро- та мікроелементів для позакореневого підживлення кукурудзи позитивно впливає на формування біометричних показників качана та елементів структури врожаю, сприяє збільшенню кількості продуктивних качанів і підвищенню урожайності зерна. Найбільше впливає на формування вищевказаних показників цинк. Найменш ефективним було застосування на посівах кукурудзи бору, магнію та марганцю.

Ключові слова: *кукурудза, гібрид, макроелементи, мікроелементи, підживлення, біометричні показники, елементи структури, урожайність*