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EFFECTIVENESS OF ZINC IN FOLIAR FEEDING MAIZE IN THE WESTERN FOREST-STEPPE OF UKRAINE

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Topicality. *Maize requires not only macronutrients such as nitrogen, phosphorus and potassium, but also micronutrients such as Cu, Mo, Mn, Co, Zn, B, etc. for optimal development. In maize cultivation technologies, the effectiveness of micronutrient fertilisers is quite high, regardless of the application method (pre-sowing seed treatment or foliar feeding). Among the micronutrients, zinc is especially important in plant life, as its deficiency leads to a growth slowdown due to reduced internodes, reduced ear grain content or lack of ear setting.* ***Purpose.*** *To study the effectiveness of applying zinc in the form of a highly concentrated liquid fertiliser for foliar feeding maize and its impact on plant growth and development, leaf area formation, individual productivity, and grain yield in the Western Forest-Steppe.* ***Materials and Methods****. In a two-factor experiment, early-ripening DN Aton and mid-early DN Astra maize hybrids were studied; highly concentrated liquid zinc fertilizer Chimic Zinc was applied to spray crops in the 5–6 and 8–9 leaf stages.* ***Results****. It was established that the linear dimensions of plants are determined by the genetic characteristics of hybrids and significantly depend on their maturity group and mineral nutrition. In particular, the plant height of the early-ripening hybrid DN Aton in the tasseling stage was 200.0 cm and of the mid-early hybrid DN Astra – 210.7 cm in the control, while it increased to 225.1 and 238.3 cm, respectively, due to two-time zinc feeding. The leaf surface area of the early-ripening hybrid DN Aton increased from 31.57 to 34.67 thousand m^2/ha, in the mid-early hybrid DN Astra – from 33.59 to 36.99 thousand m^2/ha. Variation in the number of productive ears and yield structure indicators by experimental variants certainly influenced the formation of grain yield. Maize yield increased by 0.72 t/ha (8.2 %) in the early ripening hybrid DN Aton and by 0.78 t/ha (8.6 %) in the mid-early hybrid DN Astra compared to the control due to the zinc application for foliar feeding of maize in the 5–6 and 8–9 leaf stages.* ***Conclusions.*** *Foliar feeding maize in stages of 5–6 and 8–9 leaves with highly concentrated liquid zinc fertilizer Chimic Zinc has a positive effect on the plant growth and development, the formation of leaf surface area and photosynthetic potential, increases in the number of productive ears per 100 plants, improves indicators of yield structure elements, which contributes to higher grain yield.*

Key words: *maize, hybrid, development stage, feeding, leaf surface area, individual productivity, yield*

Introduction. Fertilizers are one of the most effective means of controlling the maize (Zea mays L.) yield and grain quality. However, it is known that in addition to macronutrients (N, P, K), microelements (B, Cu, Fe, Mn, Zn, Mo) play an essential role in the processes of plant growth, development, photosynthetic activity of crops, and formation of crop productivity. The demand for these elements is low, but they are critical for plant growth and development [1–3]. In modern agricultural technologies, the application of microfertilisers for pre-sowing seed treatment or foliar feeding is an integral part of ensuring balanced plant nutrition and creating conditions for maximising the productivity potential by maize hybrids. A number of scientific studies have substantiated this, as the increase in yields and improved product quality are significantly higher than the increase in production costs per hectare of crops [4–8]. Zinc, copper, boron, manganese and other microelements are particularly important for maize nutrition.

Zinc is the main micronutrient for maize, which is particularly required when the soil has a high content of humus and mobile phosphorus compounds, in neutral and alkaline soil conditions, and in cold and wet weather conditions.

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Significant zinc deficiency results in slower growth of maize plants due to reduced internodes, reduced ear kernel content, or even failure to set ears [9].

Currently, the domestic market has a broad offer of fertilisers containing microelements, in particular zinc, the efficiency of which has been proven by scientific research in various soil and climatic zones, both for pre-sowing seed treatment and for application during sowing or other stages. In particular, according to the results of laboratory studies by N. O. Didenko and A. P. Ranskyi, using complex zinc compounds with aromatic and heterocyclic thioamides, the laboratory germination of maize seeds increased from 73 to 82 %, germination energy from 80 to 84 %, and growth-regulating activity determined by the weight of sprouts by 1.09–1.20 times [10].

Zinc fertiliser application for pre-sowing seed treatment in the Left-Bank Forest-Steppe on typical medium loamy chernozems resulted in an increase in germination energy by 3.1 % compared to the control, field and laboratory germination by 3.3 and 3.0 %, respectively [11].

In the conditions of the Right-Bank Forest-Steppe on low-humus medium loamy chernozems, under two-time foliar feeding of maize in the stages of 5–7 and 10–12 leaves with micronutrient Ekolist mono CYNK, the linear size of plants, the total leaf area. At the same time, the highest value of the ear length was observed, the 1000 grain weight increased by 7.5–12.4 %, the protein content – by 0.07–0.15%, but the fat content decreased by 0.01–0.20 % [7, 12, 13].

On grey forest soils, feeding maize with micronutrient Chelatin Zinc in the 3–5 leaf stage increased leaf surface area, yield and bioenergy coefficient [14].

An integrated approach to crop cultivation is essential for producing high and sustainable yields of maize grain, therefore, the issue of studying the influence of microelements, in particular zinc, on the growth, development, production processes, and grain productivity of maize plants in the Western Forest-Steppe is relevant.

This study was aimed to investigate the efficiency of zinc in the formulation of highly concentrated liquid fertiliser for foliar feeding of maize and its effect on plant growth and development, formation of leaf area, individual productivity, and grain yield in the Western Forest-Steppe.

Materials and Methods. The research was carried out at the Khmelnitsky State Agricultural Experimental Station of Institute of Feed Research and Agriculture Podillia of NAAS during 2021–2022. The soil of the experimental plot is podzolized medium loamy low-humus chernozem on loess loam of brownish-pale colour, with a fine-nut structure. In the wet state, it is viscous. The soil is sufficiently saturated with soil matrixes – 39.8–42.0 mg eq. per 100 g, has a 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: the content of easily hydrolysable nitrogen is 14.4–16.6 mg, mobile phosphorus –11.0–12.0 mg, exchangeable potassium –7.8–8.0 mg per 100 g of soil.

The maize cultivation technology, except for the factors studied, is generally accepted for the Western Forest-Steppe zone. After harvesting the predecessor (soybean), stubbling was carried out to a depth of 6–8 cm and the main tillage (ploughing) was carried out to a depth of 25–27 cm. Spring tillage was started with harrowing followed by two cultivations: the first cultivation to a depth of 10–12 cm, and the second (pre-sowing) cultivation to the depth of seed placement. Mineral fertilizers were introduced for pre-sowing cultivation at the rate of $N_{48}P_{48}K_{48}$. Sowing of the early ripening hybrid DN Aton and mid-early DN Astra was carried out in the optimal terms for the region – in the third ten days of April with the planned pre-harvest plant density of 90 and 85 ths. plants/ha, respectively, using the SU-12 seeder. The maize plants were fertilised in the 5–6 and 8–9 leaf stages according to the experimental design. There was used a domestically produced preparation, namely a highly concentrated liquid zinc fertiliser, Chimik Zinc (Zn – 85 g/l, N – 45 g/l, carboxylic acids – 220 g/l).

Research methods were as follows: field method for determining the reaction of maize plants to the factors under study; morphophysiological method for obtaining biometric parameters of plants; calculation and weighing method for establishing parameters of plant structure and productivity; mathematical and statistical method for determining the reliability of the experimental results.

Results. It has been scientifically proven that the productivity of maize hybrids is ensured by their biological properties to respond positively to weather factors in the growing area and the level of plant mineral nutrition. In the years of our research (2021–2022), weather conditions were characterised by significant deviations from the average long-term values for the indicators: average daily air temperature was exceeded; precipitation (in some months there was a shortage of precipitation, in others – an excessive amount of precipitation), which corresponds to the general trends of climate change in Ukraine in the direction of increasing its aridity and temperature conditions. At the same time, it should be noted that the plant growth and development, as well as the formation of the crop during the years of research, occurred under different moisture conditions (Table 1). In particular, in the first year of research, with sufficient moisture supply at the time of sowing, the sowing – seedling period was 8–10 days, while in the second year it increased to 14–16 days, due to a significantly lower supply of productive moisture in the sowing layer of soil at the sowing date and moisture conditions during the next 20 days after sowing.

At the same time, a significant deficit of precipitation in May and June 2022 (76.9 % and 59.2 % of the long-term average), combined with a significant increase in the average daily air temperature by +2.6 °C in May and +4.0 °C in June, led to a decrease in the growth rate of the vegetative mass of maize plants in both maize hybrids in the early development stages compared to the previous year. Tasseling and flowering of panicles, formation of ears also occurred at higher average daily air temperature (+2.7 °C) and significantly lower precipitation compared to the long-term average of the first year of research.

Table 1. Weather conditions of the growing season 2021–2022

Indicator	Month						During the 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
Average 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
Average 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
Average 1960–2020	1.61	1.93	2.16	1.58	1.56	2.03	1.81

In 2021, maize ripening occurred under a rather favourable temperature regime and a slight excess of the long-term average precipitation, while in 2022, a rather high amount of precipitation was recorded during the second and third ten days of September (153.4 mm and 206.8 mm) and the first ten days of October (43.6 mm) against the background of a gradual decrease in the average daily air temperature. Under such weather conditions, the growth season for the early ripening hybrid DN Aton was 128 days in 2022 and for the mid-early hybrid DN Astra – 137 days, while in 2021 it was 114 and 134 days, respectively.

Plant height is an indicator that characterises the response of maize plants to growing conditions and agronomic practices. It significantly depends on the maturity group of the hybrids, growing conditions and different cultivation technologies. The maximum plant height of both studied maize hybrids was reached in the tasseling stage and averaged over two years of research for the early ripening hybrid DN Aton

200.0–225.1 cm, and for the mid-early hybrid DN Astra 210.7–238.3 cm, depending on the microelements feeding. Foliar feeding with zinc in the 5–6 and 8–9 leaf stages increased the maize plant height of the early ripening hybrid DN Aton by 12.5 %, and the mid-early hybrid DN Astra by 13.1 % compared to the control.

The increase in the maize plant height was accompanied by an increase in the leaf area. At the time of the first foliar feeding in the stage of 5–6 leaves, the leaf area of the early ripening hybrid DN Aton was 2.77–3.04 ths.m^2/ha, and for mid-early hybrid DN Astra – 2.95–3.25 ths. m^2/ha, while it increased in the 8–9 leaf stage to 17.54–19.26 ths. m^2/ha and 18.67–20.13 ths.m^2/ha, respectively (Table 2).

Table 2. Growth dynamics of the leaf area of maize plants by development stages depending on foliar feeding, thousand m^2/ha, (average for 2021–2022)

Development stage	DN Aton		DN Astra	
	control	Chimic Zinc	control	Chimic Zinc
5-6 leaves	2.77	3.04	2.95	3.25
8-9 leaves	17.54	19.26	18.67	20.55
Tasseling	31.57	34.67	33.59	36.99
Milky ripeness	30.63	33.63	32.64	35.87
Wax ripeness	27.50	30.19	29.27	32.22

The maximum leaf area in both maize hybrids was observed in the flowering stage, namely, for the early ripening hybrid DN Aton – 31.57–34.67 ths.m^2/ha and for the mid-early hybrid DN Astra 33.59–36.99 ths.m^2/ha. Foliar zinc feeding increased this indicator by 9.8 and 10.1 %, respectively, compared to the control. Subsequently, starting from the milky ripeness stage, the leaf area indicators tended to decrease due to partial leaf death in the lower tier.

Indicators of photosynthetic potential of the crop increased in the early-ripening hybrid DN Aton from 0.542 to 0.592 mln $m^2 \cdot$ day/ha or by 9.3 % and in the mid-early hybrid DN Astra – from 0.682 to 0.748 mln $m^2 \cdot$day/ha or by 9.7 % compared to the control.

It is known that zinc deficiency leads not only to a slowdown in plant growth due to reduced internodes, reduced kernel content, but also to a decrease in the level of ear initiation.

According to the research results, foliar feeding increased the number of productive ears per 100 plants in the early ripening hybrid DN Aton to 99 pcs, in the medium early DN Astra - to 98 pcs, while this indicator was 94 and 95 pcs in the control, respectively. Foliar feeding also has a positive effect on the biometric parameters and yield structure elements of maize hybrids, namely: ear length, number of grain rows and number of kernels per row. On average, over the years of research, the ear length in the early ripening hybrid DN Aton increased by 5.2 %, in the mid-early hybrid DN Astra – by 11.4 % compared to the control, the number of grain rows on the ear – by 2, and the number of kernels per row – by 3 and 4 (Table 3).

Table 3. Biometric parameters of the ear and yield structural elements (average for 2021–2022)

Indicator	DN Aton		DN Astra	
	control	Chimic Zinc	control	Chimic Zinc
Ear length, cm	17.3	18.2	18.5	20.6
Number of kernel rows, pcs	16	18	12	14
Number of kernel per row, pcs	39	42	39	43
Grain weight per ear, g	136.9	151.0	134.2	154.2
Grain content per ear, %	80.8	83.0	79.9	82.3
1000 grain weight, g	206.8	229.9	247.0	277.1

Compared to the control, the indicators of grain weight per 1 ear and 1000 grain weight, which are essential indicators of grain value and the most stable elements of the yield structure, also increased. In particular, application of zinc formulation to the early-ripening hybrid DN Aton increased the grain weight per 1 ear by 10.3 % and the 1000 grain weight by 11.2 %, and the mid-early hybrid DN Astra by 14.9 % and 12.2 %, respectively. The grain content per ear in the early ripening hybrid DN Aton increased by 2.2 %, and by 2.4 % in the medium early hybrid DN Astra in comparison with the control.

The variation of the number of productive ears and the improvement of the yield structure indicators also influenced the grain yield of maize hybrids, which increased in the early ripening hybrid DN Aton from 8.82 t/ha (control) to 9.54 t/ha (two-time foliar feeding with Chimic Zinc), and in the mid-early hybrid DN Astra – from 9.02 t/ha to 9.80 t/ha, respectively. In general, zinc application for foliar feeding of maize in the 5–6 and 8–9 leaf stages increased grain yield in the early ripening hybrid DN Aton by 0.72 t/ha (8.2 %) and in the mid-early hybrid DN Astra – by 0.78 t/ha (8.6 %) compared to the control (Table 4).

Table 4. Grain yield of early ripening hybrids depending on micronutrient feeding, t/ha

Foliar feeding (B)		2021	2022	Average	Deviation	
					t/ha	%
DN Aton (A)						
control (without feeding)		8.87	8.76	8.82	-	-
Chimic Zinc		9.61	9.46	9.54	+0.72	+8.2
DN Astra						
control (without feeding)		9.39	8.65	9.02	-	-
Chimic Zinc		10.21	9.39	9.80	+0.78	+8.6
LSD_{05}	2021	A – 0.05		B – 0.10	AB – 0.14	
	2022	A – 0.12		B – 0.17	AB – 0.24	

Conclusions. Based on our research, it was found that the linear dimensions of plants are determined by the genetic characteristics of hybrids and significantly depend on their maturity group and mineral nutrition. Foliar feeding of maize in the 5–6 and 8–9 leaf stages with highly concentrated liquid zinc fertiliser Chimic Zinc increases the plant height of the early ripening hybrid DN Aton and the mid-early hybrid DN Astra by 11.6 and 11.9 %, respectively; the leaf area by 9.8 and 10.1 %; the photosynthetic potential by 9.3 and 9.7 %. The number of productive ears per 100 plants increased in the early ripening hybrid DN Aton by 5 pcs, in the mid-early hybrid DN Astra by 4 pcs, grain weight per 1 ear – by 14.1 and 14.9 %, 1000 grain weight – by 11.2 and 12.2 %, ear grain content – by 2.2 and 2.4 %, grain yield – by 8.2 and 8.6 %, respectively.

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Молдован В. Г., Молдован Ж. А. Ефективність використання цинку у позакореневому підживленні кукурудзи у Західному Лісостепу України. *Зернові культури. 2023. 7 (1). 135–140.*

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

Актуальність. Для оптимального розвитку кукурудза потребує не лише макроелементів – азоту, фосфору та калію, але й мікроелементів – Cu, Mo, Mn, Co, Zn, B та ін. Ефективність мікродобрив у технологіях вирощування кукурудзи досить висока незалежно від способу їх використання (допосівна обробка насіння або листкове підживлення). Серед мікроелементів, які відіграють особливе значення в життєдіяльності рослин, вартує уваги цинк, адже його дефіцит призводить до сповільнення росту через скорочення міжвузлів, зниження озерненості качанів або їх незав’язуваності. **Метою досліджень** було вивчення ефективності використання цинку у вигляді висококонцентрованого рідкого добрива для позакореневого підживлення кукурудзи та його впливу на ріст і розвиток рослин, формування площі листкової поверхні, показників індивідуальної продуктивності, урожайності зерна кукурудзи в умовах Західного Лісостепу. **Матеріали і методи.** У двофакторному досліді вивчали гібриди кукурудзи ранньостиглий ДН Атон та середньоранній ДН Астра; висококонцентроване рідке цинкове добриво Хімік Цинк, яке використовувалося для обприскування посівів у фази 5–6 та 8–9 листків. **Результати.** Встановлено, що лінійні розміри рослин визначаються генетичними особливостями гібридів та істотно залежать від їх групи стиглості й мінерального живлення. Зокрема, висота рослин кукурудзи у фазі цвітіння волоті становила на контролі у ранньостиглого гібрида ДН Атон 200,0 см і у середньораннього гібрида ДН Астра – 210,7 см, тоді як за дворазового підживлення цинком, збільшувалася до 225,1 та 238,3 см, відповідно. Площа листкової поверхні збільшувалася також у ранньостиглого гібрида ДН Атон з 31,57 до 34,67 тис. $м^2$/га, у середньораннього гібрида ДН Астра – з 33,59 до 36,99 тис. $м^2$/га. Варіювання кількості продуктивних качанів і показників структури врожаю за варіантами досліду, безумовно, впливало й на формування урожайності зерна, яка за застосування цинку для позакореневого підживлення кукурудзи у фази 5–6 та 8–9 листків, збільшувалася у ранньостиглого гібрида ДН Атон на 0,72 т/га (8,2 %) та у середньораннього гібрида ДН Астра – на 0,78 т/га (8,6 %) порівняно з контролем. **Висновки.** Позакореневе підживлення кукурудзи у фази 5–6 та 8–9 листків висококонцентрованим рідким цинковим добривом Хімік Цинк позитивно впливає на ріст і розвиток рослин, формування площі листкової поверхні й фотосинтетичного потенціалу, зумовлює збільшення кількості продуктивних качанів на 100 рослинах, покращує показники елементів структури врожаю, що забезпечує підвищення урожайності зерна.

Ключові слова: *кукурудза, гібрид, фаза розвитку, підживлення, площа листкової поверхні, індивідуальна продуктивність, урожайність*