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MAIZE GRAIN YIELD FORMATION DEPENDING ON MACRO– AND MICROFERTILIZERS

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The research results of the foliar fertilization influence with different levels of mineral nutrition on the maize grain yield were presented, and the economic efficiency of growing of grain products was clarified. It was found that when increasing the mineral fertilizer dose from $N_{30}P_{30}K_{30}$ to $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$, the height of plants increased by 3 and 7 cm, the leaf surface area of one plant – by 4.8 and 10.9 %, respectively. Due to foliar fertilization, the height of plants increased by 2–5 cm, and the leaf area changed insignificantly. Depending on the background of mineral nutrition, it was accounted 98–99 ears per 100 maize plants, and in the case of foliar fertilization – 98–100 ears.

The maize grain yield on the background of $N_{30}P_{30}K_{30}$ was 7.56 t/ha, on the background of $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ – 8.65 and 8.68 t/ha, respectively. In the control variant (without spraying) the yield was 7.77 t/ha, and when plants fertilizing with urea (15 kg/ha) – 8.09 t/ha. The grain yield in the variants with maize plant fertilizing with a mixture of urea and micronutrients reached to 8.30–8.78 t/ha.

The prime cost of 1 ton of maize grain when growing on the background of $N_{30}P_{30}K_{30}$ was 1808 UAH, with increasing the fertilizer dose to $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ – 1781 and 1903 UAH, respectively. In the control variant, it was equal to 1828 UAH, in the variants under maize fertilization with urea (15 kg/ha) or a mixture of urea and micronutrients – 1827–1836 UAH. The conditional profit on the background of $N_{30}P_{30}K_{30}$ was 21878 UAH/ha, it enlarged to 24264–25265 UAH/ha in the case of fertilizer dose increasing. In the control variant (without spraying) the conditional profit was equal to 22310 UAH/ha, when plants were fertilized with urea (15 kg/ha) – 23257 UAH/ha, with a mixture of urea and micronutrients – 23823–25155 UAH/ha. The highest level of profitability (163.9 %) was on the background of $N_{45}P_{45}K_{45}$; the impact of foliar fertilization on this indicator was insignificant.

Key words: *maize, fertilizers, foliar fertilization, grain yield, economic efficiency.*

Maize (*Zea mays L.*) is quite demanding to increased mineral nutrition, and as a long–season crop is able to absorb nutrients throughout the life cycle. For creating of 1 ton of grain and corresponding amount of leaf mass, the maize consumes an average of 24–30 kg of nitrogen, 10–12 kg of phosphorus and 25–30 kg of potassium from soil and fertilizers. Therefore, for the formation of grain yield at the level of 7.0–7.5 t/ha this crop removes from the soil an average of 168–225 kg of nitrogen, 70–90 kg of phosphorus and about 175–225 kg of potassium. This amount of nutrients in the forms available to plants, even at the high fertility, the soil is unable to provide [1].

Due to the high cost of mineral fertilizers, the agricultural producer task is the minimizing losses and achieving rational use of nutrients. It is known that the nutrient utilization rate by plants from the soil (nutrient use efficiency) is low. Thus, it ranges from 30 to 60 % for nitrogen and potassium fertilizers, and from 15 to 40 % for phosphorus on different soils. Therefore, the fertilizers remain one of the most influential factors in the crop yield increasing. The research results, which performed in different soil and climatic conditions of Ukraine, indicated the importance of mineral nutrition for high yields of maize grain [2–4].

During the growing season, maize plants use both macronutrients and micronutrient (Fe, Mn, Zn, Cu, B, Mo, Co, Ni, etc.) from the soil, the utilization rate from the soil is less than 1 % of the mobile forms.

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But the plants cannot always absorb sufficient micronutrients from soil. On acidic soils Mo, on alkaline soils – Mn and Zn become almost inaccessible to plants, during drought or at the moisture excess Boron absorbed poorly. The lack of any nutrient can be a limiting factor for the formation of high crop productivity [5–7].

Recently, the use of chelated micronutrient fertilizers at the crop cultivation to regulate growth processes and increase plant resistance to the adverse hydrothermal conditions, increase yield and grain quality are becoming increasingly important, as they are ecologically safe for environment and human health. [8–9]. Therefore, the fertilization system optimization and maximum cost recovery at the maize cultivation are important in the context of global climate change and high cost of mineral fertilizers.

Aim. To establish the influence of the mineral nutrition background and foliar fertilization on the maize grain yield. We should determinate economic efficiency of growing grain production.

Materials and methods. In 2016–2018 the field experiments were performed by the State Enterprise Experimental Farm "Dnipro" of the State Enterprise Institute of Grain Crops of NAAS in the Laboratory of Sorghum and Maize Agrobiological Resources. The soil was represented by ordinary loligohumous full-profile chernozems. In the arable soil layer the humus content is consisted of 3.14 % (according to Tiurin's method), total nitrogen – 10.7 mg/kg (according to CINAO method, GOST 26488–85), mobile phosphorus – 199 mg/kg of soil and exchangeable potassium – 106 mg/kg (according to Chyrykov, DSTU 4115–2002), the level of mobile micronutrient as Cu (0.11 mg/kg), Fe (1.23 mg/kg) and Mn (14.1 mg/kg) was high, and Zn (0.79 mg/kg) – low, the soil solution reaction of humus horizon of chernozems was close to neutral (pH of the aqueous suspension is equal 6.75).

On different mineral nutrition backgrounds of $N_{30}P_{30}K_{30}$, $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ (A factor) in 6–8 leaf stage of maize the foliar fertilization was carried out (B factor): without foliar fertilizers (control variant); urea (15 kg/ha); urea (15 kg/ha) + Corn Mix (3.0 l/ha); urea (15 kg/ha) + Spectrum Zn + S (1.5 l/ha); urea (15 kg/ha) + Corn Mix (3.0 l/ha) and Spectrum Zn + S (1.5 l/ha). In the experiments, a DN Fiiesta early-season maize hybrids was grown. Sowing period was on April 24 (2016), and on April 13 (2017 and 2018). Seeds were sown by hand with 70 cm inter-row spacing. Pre-harvest density of standing plants was equal to 50 thousand plants/ha. Maize plants were sprayed in 6–8 leaf stage according to the experimental scheme. The scheme of variants was sequential, the sown area was 15.12 m^2, the accounting area was 10.08 m^2; the replication was three times. Maize cultivation technology is generally accepted for the northern part of the Steppe of Ukraine, except for the studied factors. During the research we used generally accepted methods, methodical recommendations for field experiments with maize. [10].

The foliar fertilization of maize were with urea (15 kg/ha) and Corn Mix microfertilizers (3.0 l/ha) with following components in percent: N – 7, P2O5 – 21; K2O – 7; Zn – 0.1; Cu – 0.1; B – 0.1 ; Mg – 0.6; Mo – 0.1; Fe – 0.02; and the Spectrum Zn + S (1.5 l/ha) – Zn – 14; SO_3 – 17.2, humic acids – 0.016.

The research results showed that the maize plant height on the $N_{30}P_{30}K_{30}$ background during tasseling stage averaged 216 cm under the foliar fertilization, and with fertilizer dose increasing to $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ the indicators enlarged by 3 and 7 cm, respectively (Table 1).

In the control variant (without foliar fertilization), the plants height on the fertilization background averaged to 217 cm and increased by 2–5 cm under the foliar fertilization. The plant height was higher under the foliar fertilization with a mixture of urea (15 kg/ha) and Corn Mix (3.0 l/ha) and the Spectrum Zn + S (1.5 l/ha).

The height of lower ear insertion was 67 cm on the $N_{30}P_{30}K_{30}$ background and increased by 3–4 cm under $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ fertilizer doses. In the control and variant with urea fertilization (15 kg/ha), its indicators were 67 and 68 cm, respectively. When maize was sprayed with a mixture of urea + Corn Mix or Spectrum Zn + S, the height of lower ear insertion was 70 cm, and with a mixture of urea + Corn Mix + Spectrum Zn + S – 73 cm.

The leaf area of one plant on average under $N_{30}P_{30}K_{30}$ fertilization was 45.7 dm^2, and $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ it increased by 4.8 and 10.9 %, respectively (Table 2).

1. The influence of mineral nutrients background and foliar fertilization on plant and lower ear insertion height (2016–2018)

Foliar fertilization	Plant height, cm				Ear insertion height, cm			
	1*	2**	3***	average (A factor)	1	2	3	average (A factor)
Without foliar fertilization (control variant)	213	218	219	217	65	67	68	67
Urea (15 kg/ha)	216	218	222	219	65	69	70	68
Urea (15 kg/ha) + Corn Mix (3,0 l/ha)	218	220	225	221	69	70	72	70
Urea (15 kg/ha) + Spectrum Zn + S(1,5 l/ha)	217	218	222	219	67	70	72	70
Urea (15 kg/ha) + Corn Mix (3,0 l/ha) + Spectrum Zn + S (1,5 l/ha)	218	223	225	222	70	74	75	73
Average (B)	216	219	223	–	67	70	71	–

* $N_{30}P_{30}K_{30}$. ** $N_{45}P_{45}K_{45}$. *** $N_{60}P_{60}K_{60}$.

It was found that the leaf area of one plant under foliar fertilization changed insignificantly. When maize was sprayed with Urea (15 kg/ha), it averaged 47.6 dm^2 in variants with fertilization, and in the control variant (without foliar fertilization) – 47.4 dm^2. The leaf area of one plant in variants at spraying with a mixture of Urea (15 kg/ha) + Corn Mix (3.0 l/ha) and Urea (15 kg/ha) + Spectrum Zn + S (1.5 l/ha) was equal to 48.2 and 48.4 dm2, respectively. At the foliar fertilizing with a mixture of Urea + Corn Mix + Spectrum Zn + S, it reached 48.8 dm^2. The leaf area of one maize plant was the largest (52.4 dm^2) at the foliar fertilizing with mixture of Urea + Corn Mix + Spectrum Zn + S on the background of $N_{60}P_{60}K_{60}$.

On the average for three years, under $N_{30}P_{30}K_{30}$ fertilization 98 ears per 100 plants were formed, and under $N_{45}R_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ – 99 ears.

2. The leaf area and individual plant productivity depending on macro– and microfertilizers (2016–2018)

Foliar fertilization	Leaf area of one plant, dm^2				Number of ears per 100 plants, pcs.			
	1*	2**	3***	average	1	2	3	average
Without foliar fertilization (control variant)	45.6	47.9	48.8	47.4	97	99	97	98
Urea (15 kg/ha)	45.5	47.4	49.8	47.6	97	99	98	98
Urea (15 kg/ha) + Corn Mix (3.0 l/ha)	45.7	47.8	51.0	48.2	98	100	99	99
Urea (15 kg/ha) + Spectrum Zn + S (1.5 l/ha)	45.6	48.1	51.4	48.4	97	99	99	98
Urea (15 kg/ha) + Corn Mix (3.0 l/ha) + Spectrum Zn + S (1.5 l/ha)	45.9	48.1	52.4	48.8	99	100	101	100
Average (B)	45.7	47.9	50.7	–	98	99	99	–

* $N_{30}P_{30}K_{30}$. ** $N_{45}P_{45}K_{45}$. *** $N_{60}P_{60}K_{60}$.

The 98 ears per 100 plants were in such variants as: the control (without foliar fertilization), under foliar fertilization with urea (15 kg/ha) and mixture of urea (15 kg/ha) + Spectrum Zn + S (1.5 l/ha); 99 ears were with mixture of Urea + Corn Mix. There were 100 ears per 100 plants under foliar fertilization with a mixture of Urea + Corn Mix + Spectrum Zn + S. The 101 ears per 100 maize plants were formed due to AB factor interaction: when foliar fertilization of plants with a mixture of Urea + Corn Mix + Spectrum Zn + S on the background of $N_{60}P_{60}K_{60}$.

The maize grain yield on the background

of $N_{30}R_{30}K_{30}$ by B factor (foliar fertilization) average for three years was 7.56 t/ha, and on the background of $N_{45}R_{45}K_{45}$ and $N_{60}R_{60}K_{60}$ – 8.65 and 8.68 t/ha, respectively (Table 3).

3. The influence of mineral nutrition and foliar fertilization on maize grain yield, t/ha

Foliar fertilization (B)	Years				Average by factor	
	2016	2017	2018	2016–2018	A	B
$N_{30}P_{30}K_{30}$ (A)						
Without foliar fertilization (control variant)	6.63	7.39	7.03	7.02	7.56	7.77
Urea (15 kg/ha)	7.03	7.86	7.38	7.42		8.09
Urea (15 kg/ha) + Corn Mix (3.0 l/ha)	7.29	8.33	7.66	7.76		8.54
Urea (15 kg/ha) + Spectrum Zn + S (1.5 l/ha)	7.06	8.10	7.42	7.53		8.30
Urea (15 kg/ha) + Corn Mix (3.0 l/ha) + + Spectrum Zn + S(1.5 l/ha)	7.54	8.81	7.92	8.09		8.78
$N_{45}P_{45}K_{45}$ (A)						
Without foliar fertilization	6.91	9.14	8.21	8.09	8.65	
Urea (15 kg/ha)	7.28	9.48	8.57	8.44		
Urea (15 kg/ha) + Corn Mix (3.0 l/ha)	7.53	10.41	8.87	8.94		
Urea (15 kg/ha) + Spectrum Zn + + S (1.5 l/ha)	7.44	9.82	8.75	8.67		
Urea (15 kg/ha) + Corn Mix (3.0 l/ha) + + Spectrum Zn + S(1.5 l/ha)	7.68	10.67	9.05	9.13		
$N_{60}P_{60}K_{60}$ (A)						
Without foliar fertilization	7.43	8.69	8.52	8.21	8.68	
Urea (15 kg/ha)	7.72	8.84	8.70	8.42		
Urea (15 kg/ha) + Corn Mix (3.0 l/ha)	8.05	9.59	9.16	8.93		
Urea (15 kg/ha) + Spectrum Zn + + S (1.5 l/ha)	8.02	8.96	9.12	8.70		
Urea (15 kg/ha) + Corn Mix (3.0 l/ha) + + Spectrum Zn + S(1.5 l/ha)	8.25	9.77	9.36	9.13		
LSD_{05}, t/ha	mineral nutrition – 0.06 foliar fertilization – 0.04 interaction – 0.09					

In the control variant, the average maize grain yield on mineral nutrition backgrounds was 7.77 t/ha, and under foliar fertilization with Urea (15 kg/ha) – 8.09 t/ha. The maize grain yield under foliar fertilization with mixtures of Urea (15 kg/ha) + Corn Mix (3.0 l/ha) or Spectrum Zn + S (1.5 l/ha) was 8.54 and 8.30 t/ha, respectively; Urea + Corn Mix + Spectrum Zn + S – 8.78 t/ha. Due to AB interaction the highest grain yield (9.13 t/ha) was obtained under foliar fertilization of maize with mixture of Urea + Corn Mix + Spectrum Zn + S on the background of $N_{45}R_{45}K_{45}$ and $N_{60}P_{60}K_{60}$.

The prime cost of 1 ton of maize grain on the background of $N_{30}P_{30}K_{30}$ with average foliar fertilization was equal to 1808 UAH. This indicator was slightly lower (1781 UAH) on the background of $N_{45}P_{45}K_{45}$ and higher (1903 UAH) when increasing the fertilizer dose to $N_{60}P_{60}K_{60}$ (Table 4). The prime cost of 1 ton of grain slightly depended on foliar fertilization of plants. The prime cost in the control variant without foliar fertilization was 1828 UAH, in variants with Urea (15 kg/ha) or mixture of Urea (15 kg/ha) + micronutrients – 1827–1836 UAH.

On average for foliar fertilization variants, the highest level of profitability (163.9 %) was on the background of $N_{45}P_{45}K_{45}$, and this indicator decreased at $N_{60}P_{60}K_{60}$ or increased at $N_{30}P_{30}K_{30}$ mineral fertilizer doses and it was equal 147.0 and 160.0 %, respectively (Table 4). This indicator in the control (without foliar application) and with foliar fertilization variants was practically the same.

Conclusions. With increasing of the mineral nutrition doses from $N_{30}P_{30}K_{30}$ to $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$, the plant height increased by 3 and 7 cm, and the leaf area of one plant – by 4.8 and 10.9 %, respectively.

4. The economic efficiency of maize grain cultivation depending on level of mineral nutrition (2016–2018)

Foliar fertilization	Grain yield, t/ha	Prime cost, UAH/t	Conditional profit, UAH /ha	The level of profitability, %
$N_{30}P_{30}K_{30}$				
Without foliar fertilization (control variant)	7.02	1805	20320	160.3
Urea (15 kg/ha)	7.42	1823	21349	157.8
Urea (15 kg/ha) + Corn Mix (3.0 l/ha)	7.76	1827	22292	157.2
Urea (15 kg/ha) + Spectrum Zn + S(1.5 l/ha)	7.53	1789	21923	162.8
Urea (15 kg/ha) + Corn Mix (3.0 l/ha) + + Spectrum Zn + S(1.5 l/ha)	8.09	1794	23513	162.1
$N_{45}P_{45}K_{45}$				
Without foliar fertilization	8.09	1774	23675	165.0
Urea (15 kg/ha)	8.44	1803	24455	160.7
Urea (15 kg/ha) + Corn Mix (3.0 l/ha)	8.94	1756	26323	167.7
Urea (15 kg/ha) + Spectrum Zn + S(1.5 l/ha)	8.67	1811	25052	159.6
Urea (15 kg/ha) + Corn Mix (3.0 l/ha) + + Spectrum Zn + S(1.5 l/ha)	9.13	1763	26818	166.6
$N_{60}P_{60}K_{60}$				
Without foliar fertilization	8.21	1906	22935	146.5
Urea (15 kg/ha)	8.42	1854	23966	153.5
Urea (15 kg/ha) + Corn Mix (3.0 l/ha)	8.93	1924	24792	144.3
Urea (15 kg/ha) + Spectrum Zn + S(1.5 l/ha)	8.70	1885	24495	149.4
Urea (15 kg/ha) + Corn Mix (3.0 l/ha) + + Spectrum Zn + S(1.5 l/ha)	9.13	1947	25134	141.4

In the result of foliar fertilization, the height of plants increased by 2–5 cm and the leaf area changed slightly. Depending on the background of mineral nutrition, there were the 98–99 ears, and with foliar fertilization – 98–100 ears per 100 maize plants.

The maize grain yield on the background of $N_{30}P_{30}K_{30}$ was 7.56 t/ha, on the background of $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ – 8.65 and 8.68 t/ha, respectively. In field under maize without foliar fertilization, this indicator was 7.77 t/ha, in the case of foliar fertilization with Urea (15 kg/ha) – 8.09 t/ha. In the variants under foliar fertilization with a mixture of Urea + micronutrients, the grain yield reached 8.30–8.78 t/ha.

The prime cost of 1 ton of grain on the background of $N_{30}P_{30}K_{30}$ was 1808 UAH, with increasing of fertilizer doses to $N_{45}P_{45}K_{45}$ and $N_{60}P_{60}K_{60}$ – 1781 and 1903 UAH, respectively; in the variants with Urea (15 kg/ha) or a mixture of Urea (15 kg/ha) + micronutrients – 1827 UAH. In the case of $N_{30}P_{30}K_{30}$ application, the conditional profit was 21878 UAH/ha, with increasing of fertilizer doses it enlarged to 24264 – 25265 UAH/ha, under foliar fertilization with Urea (15 kg/ha) – 23257 UAH/ha, and a mixture of Urea + micronutrients – 23823–25155 UAH/ha. The highest profitability (163.9 %) was on the background of $N_{45}P_{45}K_{45}$ and insignificantly depended on foliar fertilization.

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