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Influence of Foliar Fertilization with Boron and Zinc for Maize Grain Crop in the Hilly Area of South-Western Romania

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ABSTRACT

For 2 years, in the hilly area of south-western Romania, a single-plant experiment was set up for maize, with 4 foliar fertilization variants: V1 = untreated control; V2 = Treatment 1 at BBCH 14-18 (maize with 4-6 leaves) with Lebosol products 1 l/ha Zinc700 + 1.5 l/ha Bor; V3 = Treatment 2 BBCH 24-28 (maize with 8-10 leaves) with the same products; V4 = Treatment 1 + Treatment 2.

Before the first application (T1) leaf and soil samples were taken, and after the second application (T2) leaf samples were taken from the 4 variants for analysis. The foliar analysis before the first application showed normal values for nitrogen, phosphorus, calcium, magnesium, sulfur, iron, manganese, boron, iron, and molybdenum; low value for potassium; slightly low value for zinc and high value for calcium. After the application of the second treatment, in the leaves, the values of zinc content were much improved, boron remained constant but the molybdenum content decreased a lot. Although at the borderline, the nitrogen content in the leaf at T1 and T2 remained at the normal value, after application of T1 + T2 it decreased from 4.6% before application to 2.96%.

ANOVA yield analysis showed that the yield increase of 840 kg/ha at T2 is highly significant compared to the untreated control and that at T1 + T2 of 370 kg/ha is distinctly significant compared to the same control. Although the maize yield was high compared to the control after application of T1, it was not statistically assured. Of the yield and quality elements studied, the most stable were: hectolitre mass, protein content and fat content. Large ranges of values were evident for the mass of 1000 kernels and starch content.

Keywords: foliar fertilization, maize, boron, zinc, production.

INTRODUCTION

In order to meet the nutrient requirements of agricultural crops, a number of fertilization measures and methods are adopted, which have both advantages and disadvantages, depending on the crop, soil conditions, agroclimate, etc. For this reason, the use of fertilizers is still a major concern, and it is difficult to determine the most effective method of fertilization.

Foliar fertilization is an important tool for sustainable and productive crop management and has significant commercial importance worldwide.

As an additional fertilization strategy, foliar fertilization can have greater efficiency in nutrient utilization by plants, reduce negative environmental impacts, and enhance consumer health benefits (Otálora et al., 2018; Reza Safari et al., 2023).

Current understanding of the factors that influence the effectiveness of foliar nutrient application is still incomplete, and the decision to apply foliar fertilizer is determined by the magnitude of the financial risk associated with failure to correct a nutrient deficiency and the perceived likelihood of foliar fertilizer effectiveness (Fernandez and Brown, 2013).

To maximize the effects of foliar nutrition, attention should be paid to the timing and concentration of formulation (including the interactions thereof), according to the characteristics of the crops treated and the soil fertility. Further studies of these issues are still required, especially with regard to the

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combination of soil and leaf fertilization (Murtaza et al., 2022).

Maize, one of the most important crop plants due to its productivity, high yields, and multiple uses, is a plant with a high requirement of macronutrients, especially nitrogen (N) and potassium (K), but also micronutrients, especially iron (Fe), manganese (Mn), boron (B) and zinc (Zn).

It can be said that about 50% of maize yield is due to the effect of fertilizers, if other technological factors are also at optimal levels (Zhang et al., 2017; Haraga and Ion, 2023; Jiang et al., 2024).

Maize response to macronutrients has been extensively investigated in the past (Kihara et al., 2016; Mutambu et al., 2023).

Among the micronutrients zinc (Zn) and boron (B) play an important role in plants and are also responsible for root development and higher crop yields.

Severe zinc deficiency can cause crop failure and almost 50% of the world's soils are Zn deficient. Zinc is a micronutrient essential for the normal growth and development of maize. Insufficient supply of this micronutrient can have a significant negative impact on yield.

The uptake of boron by plants correlates with extractable boron in the soil (Rashid, 1996), and boron availability decreases with increasing soil pH. Boron deficiency is widespread in acidic sandy loam soils with low organic matter content.

As early as 1923, Warington considered boron to be an essential micronutrient for both monocotyledonous and dicotyledonous plants (Bienert et al., 2023).

On field, boron deficiency has a major impact on maize performance concretized by abnormal development of cobs, silks and anthers, leading to reduced yield and yield quality (Lordkaew et al., 2011).

Soil application of Zn and B is of great help in improving maize productivity (Kanwal et al., 2010), but economically, foliar application or seed treatment is more effective than soil application.

One recent report states that micronutrient fertilizer use is growing in Europe, especially for elements like Zn (Global Monitor, 2020). It is unclear whether this is economically driven due to increased marketing of specialty fertilizers or whether this is the result of more knowledge, the application of precision agriculture, or an increased incidence of micronutrient deficiencies for crop production in Europe (Van Eynde et al., 2023).

Although the role of zinc and boron in improving the productivity and yield of maize crop is well known, as a result of research carried out so far, less information is known about the effect of combined application of these micronutrients. Therefore, the aim of the present work is to highlight the effect of combined application of zinc and boron foliar fertilizers on plant development, yield and productivity elements in grain maize crop.

MATERIAL AND METHODS

For 2 years (2020 and 2021) in the hilly area of southwestern Romania, at an altitude of 250-300 m, a single-factor maize experiment was planted on a preluvosol type soil with a weakly acidic reaction (pH = 6.1). Chemical analysis of the soil showed very low molybdenum and sodium content and low sulphur, boron and zinc content. A high magnesium content was noted and the rest of the other elements were within normal limits (Table 1).

KWS hybrid Kapitolis of FAO 410 was sown. Seedbed preparation was done by plowing at 30 cm and then by disk harrowing.

Sowing was carried out in the second decade of April at a density of 65000 grains/ha.

Simple as well as complex solid mineral fertilizers applied to the soil and liquid fertilizers for foliar fertigation were used to fertilize the crop.

In order to ensure uniform emergence, a complex fertilizer NP 20-20-20-0 at a rate of 200 kg/ha was applied at the same time as sowing, and ammonium nitrate (NH_4NO_3) with 33.5% N at a rate of 250 kg/ha was applied at the end of May, together with mechanical harrowing.

In order to study the effect of zinc and boron on the maize crop, foliar fertilization was carried out with two Lebosol products containing these microelements: Lebosol®-Zinc 700 SC, a zinc-based concentrated suspension containing 40% ZnO (700 g/l Zn) and Lebosol®-Bor with 11% B, as boron-ethanolamine, water-soluble (150 g/l B).

Table 1. Soil analysis

Soil analysis	Result	Limit	Interpretation
pH	6.1	6.5	Slightly low
Phosphorus (ppm)	23	16	Normal
Potassium (ppm)	269	121	Normal
Magnesium (ppm)	595	50	High
Calcium (ppm)	4361	1600	Normal
Sulphur (ppm)	5	10	Low
Manganese (ppm)	51	25	Normal
Copper (ppm)	6.3	4.1	Normal
Boron (ppm)	0.87	1.6	Low
Zinc (ppm)	2.2	4.1	Low
Molybdenum (ppm)	0.03	0.6	Very low
Iron (ppm)	621	50	Normal
Sodium (ppm)	32	90	Very low
C.E.C. (meq/100g)	32.3	15	Normal

The experiment included 4 foliar fertilization variants: V1 = untreated control; V2 = Treatment 1 at BBCH 14-18 (maize in 4-6 leaves) with Lebosol products 1 l/ha Zinc700 + 1.5 l/ha Boron; V3 = Treatment 2 at BBCH 24-28 (maize in 8-10 leaves) with the same products; V4 = Treatment 1 + Treatment 2.

To analyze the uptake of zinc and boron from the tested foliar fertilizers, leaf and soil samples were taken before the first application (T1) and after the second application (T2) leaf samples from the 4 variants were taken for analysis.

Also, depending on the experimental parameters, the yield obtained and some of its quantitative and qualitative indices were analyzed, such as: mass of 1000 grains (g), hectoliter mass (kg/hl), starch content (%), protein content (%) and fat content (%).

RESULTS AND DISCUSSION

Macronutrients play a vital role in plant nutrition and crop production, but the role of micronutrients in plant growth and development should not be underestimated. The levels of micronutrients required by plants differ from species to species (Hänsch and Mendel, 2009).

Micronutrients play a crucial role during vegetative and reproductive growth of plants (Stevenson, 2018). Varieties with high yield potential have low yield under NPK application, which can be attributed to insufficient utilization of micronutrients (Rehman et al., 2018).

The optimum yield potential of high yielding varieties can be realized by applying micronutrients in combination with macronutrients (Nataraja et al., 2006). Chaudry et al. (2007), reported that application of micronutrients, especially zinc (Zn) and boron (B), significantly increased the yield of wheat compared to the control group, whether applied singly or in combination, while Mandal et al. (2007), indicated a significant correlation between fertilizer application and physiological growth process.

The absence of micronutrients in plant nutrition causes severe reduction in crop yield (Gupta et al., 2008; Uthman et al., 2022). Agricultural soils are generally deficient in micronutrients such as zinc, boron, iron and copper. Deficiency may occur due to low micronutrient content (Sharma and Agarwal, 2005; Abid et al., 2019).

It is already known that cereals respond very well to the application of several macro- and micronutrients during the vegetative growth stages, the end result being increased production and good yield.

The organic matter and the humic substances are the energetic substrate of the microflora activity in the rhizosphere and represent an important reservoir of chelate-type compounds, which have a great capacity to bind various metal ions (B, Cu, Ca, Fe, Mg, Mo, Zn) and to form organo-metallic complexes with an important role in the formation of the soil characteristics and plant nutrition (Pârvan et al., 2013).

Zinc (Zn) and boron (B) deficiency is one of the most prevalent micronutrient disorders in crops and occurs predominantly in calcareous soils in arid and semi-arid regions (Farshid, 2011).

Foliar fertilization is a procedure frequently and increasingly used recently for plant cultivation technologies. In agricultural practice, foliar spraying is often preceded by an assessment of the plant's nutritional status and field architecture (Rosculete et al., 2023)

Foliar application of nutrients is credited with the advantage of rapid and efficient utilization of nutrients, eliminating losses through leaching and fixation and helps to regulate nutrient uptake by plants (Manomani and Sirmathi, 2009). The benefit of foliar application of nutrients is that they reach the leaf cells very quickly and directly where they are utilized (Spiro, 1984; Uthman et al., 2022).

Arif et al. (2006), found that foliar application of micronutrients at tillering, jointing and booting stages help in improving yield of wheat.

Results obtained by Tahir and Yasin in 2016, showed that foliar application of micronutrients significantly improved 1000 grain weight of maize.

Foliar fertilization of maize crop provides an effective solution for a rapid and targeted supply of nutrients and to fully exploit the yield potential of maize.

In the present case, the foliar analysis carried out prior to the application of foliar fertilizers showed normal values for all the elements analyzed, except for potassium, zinc and copper (Table 2).

Table 2. Foliar analysis before application

Analysis	Result	Limit	Interpretation
Nitrogen (%)	4.6	3.5	Normal
Phosphorus (%)	0.39	0.35	Normal
Potassium (%)	2.13	3	Low
Calcium (%)	0.82	0.3	Normal
Magnesium (%)	0.29	0.25	Normal
Sulphur (%)	0.45	0.1	Normal
Iron (ppm)	347	75	Normal
Zinc (ppm)	29	30	Slightly low
Manganese (ppm)	59.4	40	Normal
Boron (ppm)	8.7	7	Normal
Copper (ppm)	17.8	7	High
Molybdenum (ppm)	0.31	0.2	Normal

After application of the treatments, changes compared to the control appeared in the leaves for nitrogen, zinc and molybdenum. Boron remained within normal limits. Although borderline, the leaf nitrogen content at T1 and T2 remained at normal value and after application of T1 + T2 it decreased from 4.6% before application to 2.96% (Table 3).

Table 3. Foliar analysis after application

Control		T1		T2		T1 + T2	
Result	Interpretation	Result	Interpretation	Result	Interpretation	Result	Interpretation
3.07	Slightly low	3.55	Normal	3.62	Normal	2.96	Slightly low
0.28	Slightly low	0.31	Slightly low	0.33	Slightly low	0.32	Slightly low
2.02	Low	2.76	Slightly low	2.16	Low	2.37	Slightly low
0.37	Normal	0.49	Normal	0.52	Normal	0.4	Normal
0.17	Low	0.13	Low	0.23	Slightly low	0.17	Low
0.27	Normal	0.28	Normal	0.28	Normal	0.23	Normal
196	Normal	158	Normal	167	Normal	147	Normal
24.1	Slightly low	32.2	Normal	284.9	High	178.3	High
53.8	Normal	62.4	Normal	57.5	Normal	40.1	Normal
10.2	Normal	9.9	Normal	9.1	Normal	12.5	Normal
9.5	Normal	11.7	Normal	11.9	Normal	10.1	Normal
< 0.05	Very low	0.09	Very low	< 0.05	Very low	0.11	Low

Regarding the yield obtained following the treatments, the lowest yield was recorded for the untreated control - 5210 kg/ha, and the highest yield for the T2 variant - 6050 kg/ha.

ANOVA yield analysis showed that the yield increase of 840 kg/ha at T2 was highly significant compared to the untreated control and that at T1 + T2 of 370 kg/ha was distinctly significant compared to the same control. Although the maize yield was high relative to the control after application of T1, it was not statistically assured.

Given that the products and rates used in the second treatment are identical to those of the first treatment, but the yield results are much higher, the data obtained suggest that the difference is made by the timing of application. This was also highlighted by Stewart et al. (2021), concluding that the timing of micronutrient requirement and accumulation by maize (*Zea mays* L.) is nutrient specific and is associated with key vegetative and reproductive growth stages.

The best nutrient management practices require synchronized nutrient application with plant needs and nutrient uptake.

To maximize fertilizer uptake and utilization, it is essential to apply or have nutrients available at the time of greatest demand (Roberts, 2007). Bender et al. (2013) highlighted the need to develop recommendations of time bound nutrient applications to sync up nutrient's uptake and mobilization during periods of high plant uptake for modern maize hybrids. This is especially critical for micronutrient applications, as micronutrients are needed in relatively small but critical amounts by maize at specific growth stages during the growing season (Engels et al., 2012).

Of the productivity and quality traits studied, the most stable were hectoliter mass (values ranged from 69.9 - 71.8 kg/hl), protein content (values ranged from 5.79 - 6.55%) and fat content (values ranged from 3.13 - 3.26%). The hectoliter mass has not a high influence on the released grain yield (Popescu et al., 2021).

In this regard, other studies show that foliar application of micronutrients increased the protein content of maize seeds (Zarabimafi and Pour, 2014), or reported that foliar application of micronutrients improved the fat content of maize (Ghaffari et al., 2011).

Large ranges of values of the obtained yield and quality elements were evident in the mass of 1000 grains (values ranged from 300.3 - 352.4 g) and starch content (values ranged from 67.76 - 69.54%) (Table 4 and Photo 1-5).

Table 4. Values of the yield and quality elements

Variant	Production (kg/ha)	Difference (%)	MMB (g)	MH (kg/hl)	Starch (%)	Protein (%)	Fat (%)
Control	5210	100	300.3	69.9	69.39	5.79	3.13
T1	5430	104	317.8	70.07	68.58	6.28	3.15
T2	6050***	116	352.4	70.05	69.54	5.94	3.24
T1 + T2	5580**	107	337.6	71.8	67.76	6.55	3.26
DL 5% = 145 kg/ha DL 1% = 368 kg/ha DL 0,1% = 671 kg/ha							

Photo 1. Kapitolis hybrid maize cobs - control variant (Mt)

Photo 2. Kapitolis hybrid maize cobs - variant 2 (T1)

Photo 3. Kapitolis hybrid corn cobs - variant 3(T2)

Photo 4. Kapitolis hybrid maize cobs - variant 4 (T1+T2)

Photo 5. Kapitolis hybrid corn cobs - comparative analysis of the four variants

In terms of the influence of zinc and boron on the elements analyzed, it is clearly distinguishable that the grain size is greatly improved by the contribution of the two microelements, the maximum value reaching an increase of about 17%.

Similar results were obtained by Horuz and Özcan in 2017 in an experiment set up in randomized blocks in 3 replicates at Samsun in Turkey. Analysis of variance showed that application of boron at increased rates in maize significantly influenced yield and 1000-kernel mass at the 5% level and boron content in grain and leaf at the 1% level. Optimum yield (5972.4 kg/ha), 1000-kernel mass and grain boron content (8.06 ppm) were statistically assured at the 0.25 kg B/ha dose and also optimum leaf boron content (8.34 ppm) was determined at the 0.5 kg B/ha dose. The highest increases were determined in the following order: boron content in grain > boron content in leaf > mass of 1000 grains > grain yield.

The obtained results, corroborated with similar ones in the literature, indicated that both boron and zinc are involved in plant metabolism directly influencing a number of physiological processes and contributing to the maintenance of plant nutrient balance. These two micronutrients might be due to facilitate in more protein synthesis (Rahman et al., 2020).

Foliar application of nutrients can improve nutrient accumulation in the plant, biomass production, increase crop profitability, nutrient translocation in cereals and hence improve quality indices. Therefore, foliar application strategies and new nutrient formulations in crop fertilization should be tested.

CONCLUSIONS

The combined foliar application of zinc and boron positively influenced all studied traits in maize crop, being suitable and beneficial for increasing the yield potential of maize under the agroclimatic conditions of the studied area.

The yield results obtained suggest the effectiveness of combined application of zinc and boron in the BBCH 24-28 (8-10 leaf corn) phenophase (maize in 8-10 leaves).

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