Theses of Doctoral (PhD) Dissertation

Effect of zinc foliar fertilization on the main measuring properties of maize (*Zea mays* L.) with the same potassium basic fertilizer

Written by:

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1. INTRODUCTION AND OBJECTIVES

1.1. Introduction

World crop production has undergone significant changes in recent decades. This change has been made possible by the biological, chemical, agronomic, technical and technological revolution that began in the early 1900s and has unfolded dynamically over the last half century in the more developed countries of Western Europe and North America. The driving force behind this development has been the growing demand for the products of crop production. While in 1975 there were 4 billion people to feed, today, in 2020, the world's population will exceed 7.8 billion and is projected to grow to 10.9 billion by 2100. Feeding this growing population is a huge challenge that can be met by improving current technologies and increasing crop yields.

High yields and satisfactory quality can only be achieved through professional crop nutrition, the most common and obvious method being fertilisation. In addition to the three most important macro-nutrients (N, P, K), attention must also be paid to the supply of micro-nutrients, since for proper plant development it is not enough to supplement these three macro-nutrients alone, but other micro-nutrients and their appropriate proportions must also be provided. In many areas, essential elements are still not being supplemented, and crops grown on soil deficient in microelements are likely to suffer a reduction in yields and a deterioration in quality.

Zinc is an essential micronutrient that is actively involved in protein metabolism and in the regulation of plant growth by stimulating auxin production. Zinc also plays an essential role in the formation of stable metalloenzyme complexes in cells. Zinc can be replenished by seed treatment or by application through soil or foliar application.

Among our economic crops, maize (Zea mays L.) is a major contributor to the food supply of the world's population. In our country, it has been the most widely cultivated crop for many years, with a total of 1.048 million hectares sown in 2019. In Hungary, it is grown mainly for its role in animal feed. Due to its high starch and low protein content, it is mainly used as a source of energy in animal diets.

Taking the above into account, it is important to improve the yield and the main measuring properties of maize, which in many cases can be achieved by supplementing the nutrients in the right amounts and in the right proportions. In Hungary, due to the high prevalence of zinc-deficient areas, special attention should be paid to the replenishment of the micro-nutrient zinc.

1.2. Research objectives

Because of its high importance, maize was chosen as the test crop for our experiments. Our experiments investigated how the application of zinc as a foliar fertilizer and potassium as a basic fertilizer, both essential nutrients for maize, influences the yield and some main measuring properties of maize.

The following objectives were set:

- Examining the results of soil treatment with potassium, and zinc replenishment by foliar fertilization in potassium- and zinc-deficient areas.
- Examining how the plant utilises the zinc compound (basic zinc carbonate) applied during foliar treatments in the presence or absence of sufficient potassium fertilisation.
- Examining how an adequate supply of potassium (as defined in the nutrient management plan) influences the Zn demand of the plant and the utilisation of the applied Zn foliar fertiliser.

- Examining, what is the optimal dose of zinc that will increase maize yields and improve its nutritional value to the greatest extent?
- Examining whether there is any synergistic effect between the two nutrients used.

2. MATERIALS AND METHODS

2.1. Small plot field experiments

My studies were conducted at the Faculty of Agriculture and Food Sciences, Department of Water and Environmental Sciences at Széchenyi István University, under the professional supervision of Dr. Renátó Kalocsai. Our experiments were set up at the border of Bogyoszló, Győr-Moson-Sopron county. During the investigations, 4 replicated small field experiments with random block design were set up to test the effect of zinc and potassium containing preparations in 2018-2020. The experimental plot size was 22.5 m^2.

2.1.1. Describing the soil of the growing area

Soil testing was carried out in the experimental area prior to the start of the investigations. Sampling was carried out according to field sampling standards from the upper 0-30 cm layer of the surface soil, using a diagonal sampling method according to *MSZ-08-0202:1977*. The soil chemistry is slightly acidic (5.5-6.7), which is the most optimal for plant nutrient uptake. The physical composition of the soil is loamy, clay-loam soil. The humus content is around 3 %, which is classified as "Good" on brown forest soils above 38 KA (according to the 1978 MÉM-NAK advisory system). According to the table, the area is deficient in zinc (< 2.5, KA 38-50) and potassium, and it was therefore considered appropriate to focus the experiment on the supplementation of these two elements.

2.1.2 Describing the climate of the growing area

The climate of the area is temperate, humid continental. The average annual temperature is around 10 °C. The average temperature was slightly higher in all three experimental years: 11.95 °C in 2018, 12.17 °C in 2019 and 11.55 °C in 2020.

The amount and distribution of rainfall during the experimental years varied. In the three years studied, the rainfall during the growing season was almost the same in 2018 and 2020 (369 mm and 340 mm, respectively), but the rainfall in 2019 was much lower than in the other two years (278 mm). The rainfall in all three years is well below the optimal water demand for maize. In 2020, the rainfall was adequate, but its distribution had a negative impact on maize germination. The 4 mm in April and 26 mm in May made maize emergence difficult and inconsistent. The initial lack of rainfall also had an impact on the yield.

2.1.3. Grown crops and agrotechnology

In all three years the hybrid Konfites was sown in the experimental area. The field was regularly supplemented with nutrients in accordance with intensive farming practices. In addition to the zinc and potassium fertilizers applied during the experimental years, 300 kg ha^{-1} of CAN (81 kg ha^{-1} N) were applied to the area before sowing in all three years. Crop protection treatments were applied twice in all three years.

2.1.4. Applied treatments

The experiment was set up in 22.5 m^2 (4.5 × 5 m) plots in a random block design, with four replicates of the same maize variety in all three years. As a first

step, the study area was divided into two equal parts: one area received no potassium fertilizer, while the other area received the potassium fertilizer according to the advisory system (180 kg ha^{-1}) every year. In the experiment, both fields were divided into 20 plots, since the zinc replenishment experiment (foliar fertilizer containing zinc carbonate) was set up as a control + 4 doses (0.25 kg ha^{-1}, 0.5 kg ha^{-1}, 1 kg ha^{-1}, 2 kg ha^{-1}) in 4 replicates. Thus, data were collected from a total of 40 plots each year.

In the experiment, potassium was supplemented with a commercially available potassium fertilizer (60% potash) applied in autumn (by hand, sowing movement), while foliar applied zinc fertilizer was carried out with the use of basic zinc carbonate, patented by Professor Dr. Pál Szakál. The foliar treatments were applied when the plant had already grown 6-8 leaves.

2.1.5. Harvest and crop control

The corn cobs were collected in the two rows closest to the geometric centre of the plots, moving in the same direction along the rows from the centre of the plot. The harvested crop was used for further analyses. The weight of the harvested crops from the sample plots was weighed and used for milling tests.

The following measurements and calculations were made during the testing of the crop samples: measurement of tube length (mm), number of grains (pcs), weight of crushed grains (g). In the second year of the experiment, in addition to the above, the SPAD was also measured as a result of the treatments. In 2019 and 2020, the plant height was also measured.

The quality parameters (protein, oil, starch content) of the maize were determined at the Institute of Environmental Sciences, Faculty of Agriculture and Food Sciences, Department of Chemistry, in Mosonmagyaróvár, Hungary, using a Perten Inframatic 9200 grain analyser.

3. RESULTS AND DISCUSSION

3.1. Summary of the results in 2018

The treatments applied resulted in a significant increase in the yield at a zinc dose of 0.5 kg ha^{-1} with a significance level of 99 %. The maximum crushed grain weight was obtained with the application of 180 kg ha^{-1} potassium and 0.5 kg ha^{-1} zinc. During the 3 experimental years, the highest crumble mass was achieved in this year.

We also obtained a significant change in starch content of maize in response to potassium replenishment at the 99 % significance level. The highest starch content was obtained with application of potassium and a zinc dose of 0 kg ha^{-1} (75.58 %).

In the 2018 experimental year, no significant changes were obtained in the other parameters studied (maize ear length, number of rows per cob, oil content, protein content) as a result of the treatments.

3.2. Summary of the results in 2019

Also in the second year of the experiment, the treatments resulted in a significant increase in the yield. Potassium fertilization significantly increased the crumbled weight of maize at 99 %, while zinc treatment was significantly increased from 0.5 kg ha^{-1} treatment. The highest yield was obtained when applying a potassium dose of 180 kg ha^{-1} and a zinc dose of 0.5 kg ha^{-1}. At the highest treatment of 2 kg ha^{-1} zinc, slight yield depression was observed.

The effect of potassium treatments on starch content of maize was significantly demonstrated at 95 %. The highest starch content was obtained with potassium application at a zinc dose of 0.5 kg ha^{-1} (71.8 %).

There was also a significant effect of treatments on corn cob length from 0.5 kg ha^{-1} zinc treatments onwards. The maximum cob length was measured at a dose of 180 kg ha^{-1} potassium and 2 kg ha^{-1} zinc. The measured cob length (18.48 cm) represents an increase of ~14.5 % compared to the control.

The effect of the treatments on SPAD and plant height was also found to be significant from the dose levels of 0.25 kg ha^{-1} and 0.5 kg ha^{-1} zinc, respectively. For both parameters, potassium increased the result at 99 % significance level. The maximum values were obtained at a dose of 180 kg ha^{-1} potassium and 2 kg ha^{-1} zinc (56.60; 205.75 cm).

No significant differences in number of rows per cob, oil content and protein content were detected in 2019.

3.3. Summary of the results in 2020

Our experimental results in 2020 were similar to those in 2019 in terms of changes observed in yield. Foliar applied zinc fertilization increased the yield from the lowest dose of 0.25 kg ha^{-1} zinc at the 99 % significance level, and potassium fertilization increased the yield at the 95 % significance level. Due to the treatments, yield was increased by 17.7%.

The treatments increased the cob length. While with a little treatments the ear length increased slightly, and with 0.5 kg ha^{-1} zinc the ear length increased significantly ($P < 0.01$). The longest corn cob length was obtained with the potassium treatment at 2 kg ha^{-1} zinc, which represents an increase of 15% compared to the control plot.

The starch content of maize showed an increasing trend as a result of the treatments. Foliar applied zinc fertilization was found to be effective at 99% significance level at zinc doses of 1 and 2 kg ha^{-1}. Regarding the two treatments with the highest zinc doses, the values were close, but the highest starch content this year was obtained with 180 kg ha^{-1} potassium and 2 kg ha^{-1} zinc.

Similar to the results of the previous year, the treatments showed an increasing trend in plant height up to 1 kg ha^{-1} zinc. The addition of potassium ($P < 0.05$) and zinc ($P < 0.01$) also significantly increased plant height. The maximum value (192 cm) was obtained with the application of 180 kg ha^{-1} potassium and 1 kg ha^{-1} zinc.

The treatments were not effective statistically this year in number of rows per cob, oil content and protein content.

3.4. A summary of the three experimental years

In the 2018-2020 trials, yield was increased by all treatments. Significant increases were already demonstrated from the lowest dose of 0.25 kg ha^{-1} zinc (95 % significance level), and from 0.5 kg ha^{-1} zinc onwards, the treatments increased the yield at the 99 % significance level. The highest yield was achieved with the potassium treatment at 0.5 kg ha^{-1} zinc, which was 260.34 g. This represents an increase of more than 12 % compared to the control treatment. The yield function reached its maximum at a zinc dose of 1.30 kg ha^{-1}.

As a result of the treatments, the cob length data obtained showed an increasing trend with increasing zinc doses. In the experimental years of 2018-2020, all zinc and potassium treatments increased the corn cob length. Treatments with zinc doses of 0.5 kg ha^{-1} and above were effective at the 99 % significance level compared to the control. As a result of the treatment with potassium, the highest cob length was obtained at a zinc dose of 2 kg ha^{-1}, the length being 18.42 cm. The cob length function of of the treatments reached its maximum at a dose of 1.57 kg ha^{-1} zinc.

During the treatments, the highest starch content was achieved as a result of the potassium-treated treatments at 1 and 2 kg ha^{-1} zinc, the starch content being 70.88 %. The statistical analysis carried out showed no significant difference between treatments in terms of foliar applied zinc fertilization and

zinc-potassium interaction, but potassium fertilization was effective on the starch content of maize at 99 % significance level. The starch content function of the treatments reached its maximum at a zinc dose of 1.61 kg ha^{-1}.

The maximum height of the treatments averaged over 3 years was 198.25 cm as a result of the treatment with potassium at a dose of 2 kg ha^{-1} zinc. This represents an increase of more than 11.5 % compared to the control plot. Compared to the control treatment, treatments at a dose of 1 kg ha^{-1} zinc were effective at the 99 % significance level. The plant height function of the treatments reached its maximum at a zinc dose of 1.80 kg ha^{-1}.

The highest number of rows per cob in the treatments was achieved with the potassium treatment at a zinc dose of 0.5 kg ha^{-1}, which was 17.82. Based on the results obtained, the treatments with zinc were effective for the number of rows per cob at least at 95% significance level. The number of rows per cob function of the treatments reached its maximum at a zinc dose of 1.32 kg ha^{-1}.

The treatments were not statistically effective for oil and protein content on average over 3 years.

4. CONCLUSIONS, SUGGESTIONS

The evaluated data showed that the application of potassium base fertilizer and the dose of foliar applied zinc fertilizer as low as 0.5 kg ha^{-1} had a positive effect on the quantitative and qualitative parameters of maize.

The treatments resulted in an average increase of 11.5 % in cob length, 4.3 % in number of rows per cob, 12 % in yield, 2.2 % in starch content and 11.5 % in plant height over the 3 years. No significant changes in oil content and protein content were observed as a result of the treatments. The maximum yield was obtained with the application of foliar fertilizer at a dose of 1.30 kg ha^{-1} zinc, while the most favourable dose for all the parameters studied was 1.51 kg ha^{-1} zinc.

Leaf fertilization with zinc significantly increased cob length ($P < 0.01$), number of rows per cob ($P < 0.05$), yield ($P < 0.01$) and plant height ($P < 0.01$). Fertilization with potassium significantly increased yield ($P < 0.01$), starch content ($P < 0.01$) and plant height ($P < 0.01$).

The interaction of zinc and potassium did not show significant difference for any of the parameters studied.

The following findings and recommendations were made on the results of the experiment:

- The small plot field experiments carried out show that the combined application of zinc and potassium fertilizer on zinc and potassium deficient soils is suitable to alleviate the deficiency of these elements and to increase the yield. In the experiments, a zinc dose of ~1.30 kg ha^{-1} is the optimum dose for increasing the yield of the maize crop tested.
- Among the nutritional values, potassium is suitable to alleviate potassium deficiency in potassium-deficient soils and to increase starch content.
- The combined effect of zinc and potassium is also suitable for improving other visual parameters of the maize plant. The optimum amount of

basic zinc carbonate applied to increase plant height, cob length and number of rows per cob is 1,56 kg ha^{-1} on average.

5. NEW SCIENTIFIC RESULTS

1. Based on the experiments carried out, it has been demonstrated that zinc chloride and zinc sulphate, intermediate products of the pharmaceutical industry, can be used to produce a formulation of zinc carbonate basic that, when applied through the leaf surface, significantly increases the cob length, number of rows per cob, yield and plant height from a zinc dose of 0.5 kg ha^{-1}.
2. In our small plot experiments on zinc and potassium-deficient soils, significant yield increases were observed with potassium-containing potassium salt treatments applied in the fall and with zinc carbonate basic treatments applied in the spring at 6-8 leaf stage. When potassium was applied at a zinc dose of 0.5 kg ha^{-1}, the yield of maize increased by more than 12 %. Under the conditions of the field experiment, the maximum yield was obtained at a zinc dose of 1.30 kg ha^{-1}.
3. Our parameters (cob length, number rows per cob, plant height, oil content, protein content, starch content) showed the most favourable dose of 1.51 kg ha^{-1} zinc for an average of three years.
4. Potassium fertilization significantly increased the yield, starch content and plant height. Leaf fertilization with zinc significantly increased cob length, number of rows per cob, yield and plant height.

6. LIST OF PUBLICATIONS

Publications related to the doctoral dissertation:

Paper published in a foreign-language peer-reviewed journal:

Vona V. – ***Tóth E. A.*** *– Centeri Cs. – Giczi Zs. – Biró Zs. – Jakab G. – Milics G. – Kulmány I. M. – Kalocsai R. – Kovács A. J.* (2021): The effect of soil physicochemical characteristics on zinc analyses methods. Soil & Water Research., 16: 180−190. (impact factor: 0,982)

Szakál T. – Szüle B. – Kalocsai R. – Korim T. – Szalka É. – ***Tóth E. A.*** *– Szakál P.* (2021): Ion exchange with copper-tetraamine on NaA (LTA) type synthesised zeolite. Nova Biotechnologica et Chimica Volume 20, Issue 1 (impact factor: 0,73)

Paper published in a Hungarian-language peer-reviewed journal:

Tóth E. A. *– Kalocsai R. – Giczi Zs. – Vona V.* (2021): Cink lombtrágyázás hatása a kukorica (Zea mays L.) főbb értékmérő tulajdonságaira, azonos kálium alaptrágyázás mellett; Acta Agronomica Óváriensis Vol. 62. Különszám II.: 174-190 p.

Tóth E. A*. – Kalocsai R.* (2021): A cink szerepe a talajban és a növényekben; Acta Agronomica Óváriensis Vol. 61. No. 1.: 32-48 p.

Tóth E. A. *– Kalocsai R. – Dorka-Vona V. – Szakál T.* (2018): A Zn-lombtrágyázás hatása az őszi búza főbb értékmérő tulajdonságaira; Acta Agronomica Óváriensis Vol. 59. No. 1: 4-12 p.

Giczi Zs. – Kalocsai R. – Lakatos E. – Dorka-Vona V. – ***Tóth E. A.*** (2018): Réz, a mezőgazdaság nélkülözhetetlen eleme; Acta Agronomica Óváriensis Vol. 59. No. 2: 4-31. p

Tóth E. A. *– Kalocsai R. – Dorka-Vona V. – Giczi Zs.* (2018): Az esszenciális mikroelemek szerepe a növények élettani folyamataiban; Acta Agronomica Óváriensis Vol. 59. No. 2: 126-150 p.

Conference abstracts in Hungarian:

Tóth E. A. *– Kalocsai R.*: Cink és kálium trágyázás hatása a kukorica mennyiségi és minőségi paramétereire. In: Szalka É. (szerk): XXXVII. Óvári Tudományos Napok, 2018. november 9-10. : Fenntartható agrárium és környezet, az Óvári Akadémia 200 éve - múlt, jelen, jövő. SZE-MÉK, Mosonmagyaróvár, 379-386.

Scientific paper not related to the dissertation:

Dorka-Vona V. – Kalocsai R. – ***Tóth E. A****. – Giczi Zs. – Kovács A*. (2019): Spektroszkópiai módszerek alkalmazása a talaj tápanyagtartalmának meghatározására: szakirodalmi feldolgozás; Acta Agronomica Óváriensis Vol. 60. No. 1. 140-164 p.