PHD DISSERTATION
THESES

Effects of the application of zinc as a micro-element on the quantity and nutritive value factors of the yield of maize
(*Zea mays L.*)

Author:

LÁSZLÓ MATUS
PhD Candidate

Mosonmagyaróvár
2016

PHD DISSERTATION
THESES

SZÉCHENYI ISTVÁN UNIVERSITY
FACULTY OF AGRICULTURAL AND FOOD SCIENCES

WITTMANN ANTAL
CROP-, ANIMAL- AND FOOD SCIENCES
MULTIDISCIPLINARY DOCTORAL SCHOOL

HABERLANDT GOTTLIEB
PLANT SCIENCES DOCTORAL PROGRAMME

Doctoral School and Programme Leader:
Prof. Dr. Miklós Neményi, DSc, University Professor
Full Member of the Hungarian Academy of Sciences

Consultant:
Dr. habil. Rezső Schmidt, CSc
Head of Department, University Professor

Effects of the application of zinc as a micro-element on the quantity and nutritive value factors of the yield of maize
(*Zea mays L.*)

Author:
LÁSZLÓ MATUS
PhD Candidate

Mosonmagyaróvár
2016

1. THEME AND OBJECTIVE

Micro-nutrients – including zinc – are of essential importance throughout the entire food chain. Zinc is indispensable for the processes taking place in soils as well as for the production of organic matter by plants and animals (*Gupta et al.*, 2008).

Nearly 50% of the world's soils that are suitable for the production of cereals are potentially zinc-deficient today (*Graham* és *Welch,* 1996; *Cakmak*, 2012).

Kalocsai et al. (2006a), and *Schmidt* and *Matus* (2009), reported that Hungary's soils have particularly low zinc levels, even by international comparison. Nearly 50 % of Hungary's soils have medium supplies but for example in Fejér County and Békés County the ratio of the areas of soils with low zinc contents may be as high as up to 85-87%.

Plants take up zinc primarily in the form of Zn^{2+}-ions, besides chelate-type organic compounds containing zinc (*Holmes* and *Brown*, 1955, in *Bákonyi*, 2013). In plant cells zinc plays an indispensable role in building up stable metallo-enzyme complexes (*Füleky*, 1999). Moreover, it is a key component and activator of a number of enzymes regulating metabolic processes (*Broadley et al.*, 2007; *Hänsch* and *Mendel*, 2009). As a specific enzyme-activator, zinc plays a key role in the functioning of a variety of dehydratases
(e.g.: glutamic acid dehydratase, alcohol dehydratase, lacto-acid dehydratase) and peptidases (e.g. dihydro-peptidase, dipeptidase, carboxypeptidase), consequently, it also affects N-metabolism by activating peptidases (*Lindsay*, 1972, in *Szabó et al.*, 1987; *Alloway*, 2008).

Maize (*Zea mays L.*) is a key element of the world's food supply. For the most part, it is produced in zinc-deficient soils all over the world (*Graham* és *Welch*, 1996). At present the area under maize is the largest among the areas used for cereal production in Hungary as well: maize was harvested on a total of 1,243 million hectares in 2013. (*URL*[8]).

In livestock nutrition it is primarily a source of energy but on account of the scale of its production in Hungary it also plays a notable role in protein supply.

In view of the above, increasing the amount of maize produced and improving the nutritive value factors of the produce are equally important tasks.

The goal of the research

My research was aimed at proving the effects of a variety of compounds that are suitable for use in increasing the soil's zinc content by produce component tests – as the most exact method available – along with, as a secondary focus, examining changes in the relevant nutritive value factors.

I aimed at finding answers to the following questions:

- is a zinc-carbonate solution of a predominantly basic reaction produced from by-products of galvanising – whose only way of disposal is landfilling – suitable for use as a source of zinc supply in crop production?
- what results can be achieved in supplying the soil with zinc as a micro-element for maize production in the form of a solid micro-granulate fertiliser with zinc-chloride as active component that was newly introduced to the market at the time of the commencement of my experiments (in 2008)?
- would foliar treatments or soil treatments be more effective on the whole, over the three years of my experiment?
- would the various active agents be more efficacious through foliar treatment or soil treatment?
- in what doses should the various active agents be applied?
- does any of the active agents examined in my experiments have any retard (multi-year) effect?
- is there any treatment – in terms of active agent, locality and dosing – that has a beneficial impact on both the various yield elements and the nutritional value factors?

2. MATERIAL AND METHOD

In the course of our experiments conducted at the Institute of Crop Production of the Faculty of Agriculture and Food Sciences of the University of West Hungary under the professional direction of Dr. Rezső Schmidt it was examined whether maize (*Zea mays L.*) responds to supplies of zinc as a micro-element by increased yield levels and/or improvements in any of its nutritional value components (oil, protein and starch contents increase).

2.1 General information on the experiments

Our field experiments were conducted in an area belonging to a farming company called Farkas Mezőgazdasági Kft. near the village of Zimány, on the slopes of the Somogy hilly region in South-West Hungary.

The experiments were set up in three consecutive years: 2009 (I); 2010 (II) and 2011 (III).

In each of the three years the same maize hybrid (NK Symba) was sown on the same field (Zimány 16,7) as a test crop.

The experiments were, in each case, set up in a random block arrangement in control + 4 doses, in 4 iterations.

The soil of the site belongs to the brown forest soil with clay illuviation sub-type of the brown forest main soil type, with low zinc contents.

2.2 Weather conditions during the years of the experiments

In terms of the growing season's mean temperature year 2010 was colder than the multi-year average (15.8 ºC, an extremely low temperature), while 2011 was hotter than the multi-year average (with 16.8 C, an extremely high temperature).

As to the total rainfall during the growing season, year 2010 was far more rainy than the multi-year average (with 720 mm as an extremely high figure), while 2011 was in line with the multi-year average.

2.3 *The materials used in the experiments*

The material used in the experiments for both top-dressing and soil fertiliser was a mixture of zinc-tetramine-hydroxide $[Zn(NH_3)_4](OH)_2$ and a basic zinc-carbonate, a patented product developed by Dr. Pál Szakál, for the sake of simplicity, hereinafter: referred to as basic zinc carbonate.

In our experiments a micro-granulate fertiliser with an organic substrate (ground corn cob) developed in 2008 by a company called Fertilia Kft. was applied exclusively in the soil treatments. Some 95% of the material is made up of granules sized 0.5-1.0 mm, with a bulk density of 800-900 gl^{-1}.

2.4 *Year I of the experiment (2009)*

2.4.1 Large parcel foliar treatment with basic zinc-carbonate as active agent

The active agent was used in the following doses:

- control (A0)
- 0.1 $kgha^{-1}$ (A1)
- 0.15 $kgha^{-1}$ (A2)
- 0.2 $kgha^{-1}$ (A3)
- 0.25 $kgha^{-1}$ (A4)

The dimensions of the experiment plots were 120 m by 18 m (four times the combine harvester’s working width), that is, 0.216 ha each. The total area of the experimental plots was thus 4.32 ha. Foliar treatment was carried out at the maize plants’ 8-leaf stage.

2.5 Year II of the experiment (2010)

2.5.1 Large parcel foliar treatment with basic zinc-carbonate as active agent

The active agent was used in the following doses:

- control (A0)
- 0.2 $kgha^{-1}$ (A1)
- 0.4 $kgha^{-1}$ (A2)
- 0.6 $kgha^{-1}$ (A3)
- 0.8 $kgha^{-1}$ (A4)

The dimensions of the experiment plots were 55 m by 18 m (four times the combine harvester's working width), that is, 0.099 ha each. The total area of the experimental plots was thus 1.98 ha. Foliar treatment was carried out at the maize plants' 8-leaf stage.

2.5.2 Small plot soil treatment with basic zinc-carbonate as active agent

The active agent was used in the following doses (7.0 litre/22.5 m^2):

- control (A0); (0 litre zinc-carbonate solution + 0 litre water)
- 25 $kgha^{-1}$ (A1); (1.4 litre zinc-carbonate solution + 5.6 litre water)
- 50 $kgha^{-1}$ (A2); (2.8 litre zinc-carbonate solution + 4.2 litre water)
- 75 $kgha^{-1}$ (A3); (4.2 litre zinc-carbonate solution + 2.8 litre water)
- 100 $kgha^{-1}$ (A4) (5.6 litre zinc-carbonate solution + 1.4 litre water)

The dimensions of the experiment plots were 10 m by 4.5 m (equalling combine harvester's working width), that is, 45 m^2 each. The total area of the experimental plots was thus 0.9 ha. Soil treatment was carried out at the maize plants germination stage.

2.5.3 Small plot soil treatment with zinc-chloride as active agent

The active agent was used in the following doses (x kg/11.25 m^2):

- control (A0); (0 kg)
- 25 $kgha^{-1}$ (A1); (0.28 kg)
- 50 $kgha^{-1}$ (A2); (0.56 kg)
- 75 $kgha^{-1}$ (A3); (0.84 kg)
- 100 $kgha^{-1}$ (A4) (1.12 kg)

The dimensions of the experiment plots were 10 m by 4.5 m (equalling combine harvester's working width), that is, 45 m^2 each. The total area of the experimental plots was thus 0.9 ha. Soil treatment was carried out at the maize plants germination stage.

2.6 Year III of the experiment (2011.)

2.6.1 Large parcel foliar treatment with basic zinc-carbonate as active agent

2.6.2 Small plot soil treatment with basic zinc-carbonate as active agent

2.6.3 Small plot soil treatment with zinc-chloride as active agent

2.6.4 Year 2010 retard effect test (basic zinc-carbonate)

2.6.5 Year 2010 retard effect test (zinc-chloride)

The applied active agents, active agent doses and the areas of the plots corresponded to those described in regard to year II of the experiment (2010). The retard effects of the treatments were checked by examining samples taken in 2011 from the plots treated in 2010.

2.7 *Yield sample analyses (yield element examinations)*

An average of 15-22 ears were picked from each parcel and were analysed separately, plot by plot.

The following yield elements were measured and calculated:

- ear length [mm] (measurement),
- length of the unfertilised part of the ear [mm] (measurement),
- number of rows of kernels [db] (counting),
- ear weight [g] (measurement),
- mass of shelled kernels [g] (measurement),
- cob mass [g] (measurement),
- cob mass [g] (calculation),
- cob mass [g]
  (arithmetic average of measured and calculated weight figures - calculation),
- kernel to cob ratio [%] (calculation).

2.8 *Analysis of the produce samples (examination of nutritional value factors)*

The nutritional value factors (oil, protein and starch content) of the produce samples were examined at the Department of Chemistry of the Institute of Environmental Sciences of the Faculty of Agriculture and Food Sciences using a Perten Inframatic 9200 grain analyser device.

2.9 *The methods of statistical analysis*

The basic data were put together and organised with the help of the Microsoft Office Excel 2007 program. The effects, of the applied foliar and soil treatments applying different doses of the active agents, on the produce elements concerned, were studied by the statistical method of variance analysis in each of the years of the experiment. After the completion of variance analysis, the doses of the various treatments that had significant resulted in significant differences in terms of the produce elements on which our studies were focused, were identified by simultaneously tests of sample pairs. Multiple comparisons were carried out with the help of Fisher's LSD post-hoc test. The calculations were carried out and the figures were generated using the Statistica 11.0 computer program.

3. RESULTS AND EVALUATION

3.1 The results of the large parcel foliar treatments with basic zinc-carbonate as active agent

The application of the active agent in different doses was followed by taking measurements of the lengths of the maize ears and the length of the unfertilised part of the ears, counting the number of rows of kernels, measuring the ear mass, the mass of the shelled kernels and the mass of the cob, calculating the kernel-cob ratio and analysing the oil, protein and starch content of the maize kernels.

In the first year of the experiments each applied dose (0.1-0.25 $kgha^{-1}$) of the basic zinc-carbonate produced an increase in the average length of the maize ears in comparison to the control samples. The doses (0.2-0.8 $kgha^{-1}$) of basic zinc-carbonate applied in the second year of the experiment from those applied in the first year. In that year the ear lengths were increased by the 0.2 and the 0.4 $kgha^{-1}$ doses. The 0.6 and the 0.8 $kgha^{-1}$ doses resulted in ear lengths more or less equal to those picked from the control plots. In the third year of the experiment the lengths of the ears decreased in response to the increasing doses of basic zinc-carbonate in comparison to the control samples, i.e. none of the doses resulted in any increase in the lengths of the sample maize ears. The extent of the decrease in the ear lengths in response to the 0.4 and the 0.6 $kgha^{-1}$ was "highly" significant (p=0.01) in comparison to the control sample.

As regards the length of the unfertilised part of the ears in the first year of our experiment the 0.1 $kgha^{-1}$ dose significantly increased – quite unfavourably for our purposes – the length of the unfertilised part of the ears, while the other doses resulted in no material change. In the second year of the experiment the 0.2 $kgha^{-1}$, the 0.4 $kgha^{-1}$ and the 0.8 $kgha^{-1}$ doses reduced the length of the unfertilised part or the ears. The 0.6 $kgha^{-1}$ treatment resulted in unfertilised parts of the ears even longer than those of the control sample. In the third year of the experiment each of the doses reduced the unfertilised part of the ears in comparison to the control sample, quite favourably for the purposes of our experiment. The effects of the 0.4 $kgha^{-1}$, the 0.6 $kgha^{-1}$ and the 0.8 $kgha^{-1}$ treatments had "highly" significant (p=0.01) effects in comparison to the control sample.

The number of rows of kernels per ear was not significantly affected by the applied foliar treatments in any year of the experiments.

The ear mass was increased in the first year of the experiment by the majority of the applied doses of basic zinc-carbonate (with the exception of the 0.1 $kgha^{-1}$ dose). In the second year of the experiment the 0.2 and the 0.4 $kgha^{-1}$ doses increased the average mss of the maize ears but no significant difference resulted from the application of the 0.6 and the 0.8 $kgha^{-1}$ doses. In the third year of the experiment each of the applied doses caused an decrease in comparison to the control sample.

Clearly, the changes in the shelled kernel mass figures corresponded to the changes in the maize ear mass data.

The doses applied in the first year of the experiment resulted in no change in the cob mass. In the second year of the experiment the application of increasing basic zinc-carbonate doses resulted in an increase in the average cob mass. An analysis of the changes in cob mass and shelled kernel mass however, revealed that the kernel to cob ratio remained nearly constant. In the third year of the experiment on the other hand, the average cob mass gradually diminished in response to the increasing doses of the active agent. The increase in the ear mass and the shelled kernel mass in response to the treatments was even more significant.

In the first year of the experiment the kernel to cob ratio slightly improved in response to each of the applied doses. An increase corresponding to that observed in the first year (0.3%) was recorded in the second year of the experiment. In the third year of the experiment the 0.2 $kgha^{-1}$, the 0.4 $kgha^{-1}$ and the 0.6 $kgha^{-1}$ dose resulted in no change in the kernel to cob ratio but the largest – 0.8 $kgha^{-1}$ – dose improved the kernel to cob ratio by a significant 0.5% in comparison to the preceding years.

The oil content of the kernels was not affected significantly by the foliar treatments in any of the years of our experiments, in other words, no treatment effect was detected.

The protein content of the kernels was not affected by the doses of the active agent applied in the first year. In the second year of the experiment only the smallest – 0.2 $kgha^{-1}$ – applied dose increased the protein content by an approx. 1 %. In the third year of the experiment the protein content of the kernels was increased slightly by each dose in comparison to the control sample, but the rate of the increase was as small as 0.3 % even in the case of the highest applied dose of the active agent.

In the first year of the experiment the starch content of the kernels increased – though slightly but steadily – in response to the applied doses. In the second year of the experiment only the smallest applied dose – 0.2 $kgha^{-1}$ – managed to raise the starch content of the kernels, where the effect was found to be “highly” significant (p=0.01). In the third year of the experiment the applied doses triggered a consistent decrease in the starch content of the kernels in comparison to the control sample.

3.2 The results of the small-parcel soil treatments with basic zinc-carbonate as active agent

The effectiveness of the active agent already applied successfully in the foliar treatments was studied in the last two years of the experiment (in 2010 and 2011), by delivering and incorporating it into the topmost soil layer in different doses, in terms of the same yield elements and nutritional value factors as in the case of the foliar treatments, i.e. maize ear length, the length of the unfertilised part of the ear, the number of rows of kernels per ear, the ear mass, the mass of the shelled kernels, the cob mass, the kernel to cob ratio and the oil, protein and starch content of the kernels.

The doses of basic zinc-carbonate applied in the course of the treatments in the second year of the experiment (25-100 $kgha^{-1}$) resulted, in the majority of cases, in shorter average ear lengths than the control sample. The length of the maize ears grew back to the same size as the control ears only in response to the 100 $kgha^{-1}$ dose. The basic zinc-carbonate doses applied in the third year of the experiment were the same as those applied in the second year of the experiment. The length of the maize ears increased only in response to the 50 $kgha^{-1}$ and the 100 $kgha^{-1}$ doses. The increase in the length of the maize ears as a result of the 50 $kgha^{-1}$ treatment was “highly” significant (p=0.01) in comparison to both the control sample and the sample picked from the plot where a 25 $kgha^{-1}$ dose had been applied. In the same – the third – year of the experiment the study of the retard effect of the active agent showed that the highest – 100 $kgha^{-1}$ dose – had the most favourable, “highly” significant (p=0.01) lasting effect.

Unfortunately, in the second year of the experiment the length of the unfertilised part of the maize ears increased in response to the increasing doses of the active agent up to the 75 $kgha^{-1}$ dose. Though as a result of the 100 $kgha^{-1}$ treatment the length of the unfertilised part of the maize ears did not grow any further but it was still longer than those of the control sample. In the third year of the experiment the length of the unfertilised part of the maize ears grew steadily in response to the growing doses of the active agent. The effect of each of the applied doses was “highly” significant (p=0.01) in comparison to the control sample.

The soil treatments had no material impact on the number of rows per ear in each of the years of the experiments.

The majority of the different doses of basic zinc-carbonate applied in the second year of the experiment (with the exception of the 100 $kgha^{-1}$ dose) decreased the ear mass. In the third year of the experiment each of the doses – with the exception of the 50 $kgha^{-1}$ dose – resulted in reduced ear masses in comparison to the control sample. The examination of the retard effects of the active agent showed that even the smallest – 25 $kgha^{-1}$ – dose produced a substantial increase in the ear mass in comparison to the control sample.

As a matter of course, the changes in the shelled kernel mass data always correlated to the change in the maize ear mass data.

The majority of the different doses of basic zinc-carbonate applied in the second year of the experiment (with the exception of the 100 $kgha^{-1}$ dose) decreased the average cob mass. In the third year of the experiment however, no change was triggered by the application of increasing doses of basic zinc-carbonate in the average mass of the maize cobs.

The kernel to cob ratio remained practically unchanged in response to the doses applied in the second year of the experiment, while in the third year of the experiment each of the applied doses resulted – unfortunately – in a decrease in the kernel to cob ratio in comparison to the control sample.

The oil content of the kernels was not materially affected by the soil treatments applied in the second year of the experiment – with the exception of the highest, 100 $kgha^{-1}$ dose – while in the third year of the experiment both the 50 $kgha^{-1}$ and the 75 $kgha^{-1}$ dose had a positive impact on the kernels' oil content, with a "highly" significant ($p=0.01$) treatment effect in the case of the 75 $kgha^{-1}$ dose, in comparison to the control sample.

The data recorded in the second year of the experiment concerning the protein content of the kernels make no sense, probably as a result of errors of measurement. Each of the doses applied in the third year of the experiment reduced the kernels' protein content in comparison to that of the control sample. The smallest rate of decrease was observed in the case of the 75 $kgha^{-1}$ dose.

Each of the doses applied in the second year of the experiment – with the exception of the – a 75 $kgha^{-1}$ dose – increased the starch content of the kernels in comparison to the control sample. Also with the exception of the 75 $kgha^{-1}$ dose each of the doses applied in the third year of the experiment raised the starch content of the kernels in comparison to the control sample. It should be noted that even the smallest – 25 $kgha^{-1}$ – dose caused a substantial increase.

3.3 The results of the small parcel treatments with zinc-chloride as active agent

Besides basic zinc-carbonate the effectiveness of another active agent – zinc-chloride – was also examined in the last two years of the experiment (in 2010 and 2011). After delivering the substance on the soil surface before seeding and then incorporating it into the top most layer we examined the same yield elements and nutritional value factors as in the case of the foliar treatments: i.e. maize ear length, the length of the unfertilised part of the ear, the number of rows of kernels per ear, the ear mass, the shelled kernel mass, the cob mass, the kernel to cob ratio and the oil, protein and starch contents of the kernels.

In the second year of the experiments the zinc-chloride doses applied in the course of the treatments (25-100 $kgha^{-1}$) increased the average length of the maize ears in comparison to the control sample up to the 50 $kgha^{-1}$ dose. From the 75 $kgha^{-1}$ dose up however, the length of the maize ears started to decrease. The doses of the active agent applied in the third year of the experiment corresponded to the doses applied in the second year. Each of the applied doses triggered a slight increase in comparison to the control sample, but the 50 $kgha^{-1}$ dose resulted in an outstanding rate of increase. The assessment of the retard effects of the active agent showed that only the largest – 100 $kgha^{-1}$ – dose caused an increase in the maize ear length equivalent to that caused by the above 50 $kgha^{-1}$ treatment.

In the second year of the experiment the length of the unfertilised part of the ears decreased in response to each dose of the active agent, quite favourably for us. In the third year of the experiment the length of the unfertilised parts of the maize ears increased up to 75 $kgha^{-1}$ dose and then in response to the 100 $kgha^{-1}$ dose. The retard impact of the largest dose of the zinc-chloride active agent resulted in a higher rate of decrease than did the active agent applied in the same year.

The number of rows of kernels per ear were not materially affected by the soil treatments in any year of the experiment.

In the second year of the experiment the ear mass was increased by each zinc-chloride dose in comparison to the control. Each treatment was also successful in the third year of the experiment too. The growth curve was only broken as a result of the 75 $kgha^{-1}$ treatment.

As a matter of course, the changes in the kernel mass data always correlated to the changes in the ear mass figures.

The zinc-chloride treatments applied in the second year of the experiment resulted in increased cob mass figures up to the 50 $kgha^{-1}$ dose, thereafter the average cob mass decreased in response to the larger doses of the active agent. In the third year of the experiment each of the applied zinc-chloride doses produced increased average cob mass figures in comparison to the control sample. As in the case of the ear mass figures, the growth curve was only broken as a result of the 75 $kgha^{-1}$ treatment. The retard impact of the largest – 100 $kgha^{-1}$ dose – resulted in a higher rate of increase in the cob mass than did the impact of the active agent delivered in the same year.

In the second year of the experiments the kernel to cob ratio remained unchanged in comparison to the control sample up to the 50 $kgha^{-1}$ dose but in response to the 75 $kgha^{-1}$ and the 100 $kgha^{-1}$ dose it increased. In the third year of the experiment each of the applied zinc-chloride doses increased the average cob mass in comparison to the control sample. Again the growth curve was broken by the 75 $kgha^{-1}$ treatment. The examination retard effect of the active agent showed that – unfavourably for us – the larger the applied dose, the lower the kernel to cob ratio was.

In the second year of the experiment the oil content of the kernels dropped slightly in response to the larger (75 $kgha^{-1}$ and the 100 $kgha^{-1}$) doses. In the second year of the experiment the oil contents of the kernels remained more or less unchanged, with the exception of the 25 $kgha^{-1}$.

The kernels' protein content – again with the exception of the 25 $kgha^{-1}$ treatment – did not change in response to the treatments. In the third year of the experiment each of the applied doses increased the kernels' protein content in comparison to the control sample. The smallest increase was caused by the 75 $kgha^{-1}$ dose. In the way of a retard effect of the active agent the largest – 100 $kgha^{-1}$ – dose of zinc-chloride induced a significant increase in the protein content of the kernels in comparison to the active agent applied in the same year.

In the second year of the experiment each of the doses applied resulted in an increase in the starch content of the kernels. Even the largest – 100 $kgha^{-1}$ – dose caused an increase but of a smaller rate than had been induced by the smaller doses. In the third year of the experiment each of the treatments reduced the kernels' starch content in comparison to the control sample, except for the 25 $kgha^{-1}$ dose. The 50 $kgha^{-1}$ treatment resulted in a greater decrease than the other doses applied in the experiment.

Table 1: The impacts of the treatments applied in 2010 on the most important yield elements and nutritional value components

Ear weight	A1	A2	A3	A4
foliar treatment	1,08	1,11	1,03	1,04
soil t. (zinc-carbonate)	0,98	0,93	0,89	1,03
soil t. (zinc-chloride)	1,04	1,04	1,01	1,02

Length of the unfertilised part of the ear	A1	A2	A3	A4
foliar treatment	0,88	0,92	1,03	0,91
soil t. (zinc-carbonate)	1,10	1,16	1,19	1,06
soil t. (zinc-chloride)	0,87	0,92	0,87	0,86

Kernel to cob ratio	A1	A2	A3	A4
foliar treatment	0,99	1,00	1,00	1,04
soil t. (zinc-carbonate)	0,99	1,00	1,03	1,00
soil t. (zinc-chloride)	1,00	0,99	1,04	1,03

Kernel oil content	A1	A2	A3	A4
foliar treatment	0,97	1,00	1,00	1,00
soil t. (zinc carbonate)	1,00	1,00	0,97	1,03
soil t. (zinc-chloride)	1,00	1,00	0,97	0,97

Kernel protein content	A1	A2	A3	A4
foliar treatment	1,13	1,10	1,07	1,08
soil t. (zinc carbonate)	0,93	1,00	0,91	1,01
soil t. (zinc-chloride)	1,05	1,00	1,00	1,00

Kernel starch content	A1	A2	A3	A4
foliar treatment	1,02	1,01	1,01	1,01
soil t. (zinc carbonate)	1,00	1,01	1,00	1,02
soil t. (zinc-chloride)	1,01	1,01	1,02	1,01

Table 2: The impacts of the treatments applied in 2011 on the most important yield elements and nutritional value components

Ear weight	A1	A2	A3	A4
foliar treatment	1,00	0,94	0,90	0,99
soil t. (zinc-carbonate)	0,98	1,02	0,95	0,96
soil t. (zinc-chloride)	1,08	1,12	1,04	1,12
soil t. (zinc-carbonate) R	1,13	1,03	0,98	1,08
soil t. (zinc-chloride) R	1,04	1,02	0,96	1,11

Length of the unfertilised part of the ear	A1	A2	A3	A4
foliar treatment	0,78	0,53	0,62	0,50
soil t. (zinc-carbonate)	1,34	2,75	1,72	3,41
soil t. (zinc-chloride)	0,92	1,06	1,08	0,74
soil t. (zinc-carbonate) R	0,77	1,56	1,17	1,26
soil t. (zinc-chloride) R	0,89	0,57	0,68	0,65

Kernel to cob ratio	A1	A2	A3	A4
foliar treatment	1,01	0,97	0,99	1,07
soil t. (zinc-carbonate)	0,95	0,98	0,95	0,92
soil t. (zinc-chloride)	1,02	1,00	1,00	1,00
soil t. (zinc-carbonate) R	1,02	1,06	1,02	1,05
soil t. (zinc-chloride) R	1,00	0,98	0,95	0,95

Kernel oil content	A1	A2	A3	A4
foliar treatment	1,00	0,97	1,00	1,00
soil t. (zinc-carbonate)	0,97	1,03	1,05	0,97
soil t. (zinc chloride)	1,03	0,83	1,00	1,03
soil t. (zinc carbonate) R	0,97	0,97	1,00	0,97
soil t. (zinc-chloride) R	1,03	1,03	1,03	1,00

Kernel protein content	A1	A2	A3	A4
foliar treatment	1,00	1,03	1,05	1,05
soil t. (zinc-carbonate)	0,91	0,89	0,99	0,91
soil t. (zinc chloride)	1,09	1,09	1,02	1,09
soil t. (zinc carbonate) R	1,08	0,97	0,98	0,97
soil t. (zinc-chloride) R	0,98	1,15	1,08	1,21

Kernel starch content	A1	A2	A3	A4
foliar treatment	1,00	0,99	0,99	0,99
soil t. (zinc-carbonate)	1,01	1,00	1,00	1,01
soil t. (zinc chloride)	1,01	0,96	1,00	1,00
soil t. (zinc carbonate) R	1,00	1,00	1,00	0,99
soil t. (zinc-chloride) R	0,99	1,00	0,99	0,99

4. CONCLUSIONS AND SUGGESTIONS

The author holds that both active agents (basic zinc-carbonate and zinc-chloride) applied in the three-year field experiment are suitable for improving plants' zinc micro element status.

In the wake of a detailed analysis of the results of the experiments the author considers that foliar treatment is the most effective technique for delivering zinc supplies.

In the case of soil treatment the author finds basic zinc-carbonate to be the most suitable active agent as it affects the yield in the year of application and it also has a retard – multi-year – impact.

In general, foliar treatment is an active agent saving way of delivery and it is suitable for preventing deficiency symptoms, or when such symptoms appear it is a means for quick intervention regardless of weather conditions.

Soil treatment is a suitable delivery technique for improving the soil's Zn status in a longer term. It takes a larger amount of the active agent per unit of area than do foliar treatments but it has a more favourable impact in sites with higher precipitation or in irrigated areas since in the case of foliar treatment the active agent is exposed to the risk of being rinsed off.

The following summary conclusions have been drawn from the in-depth analysis of the results of my experiments:

When the objective of the treatment is to improve one or two important parameters:

- **basic zinc-carbonate** as **active agent,** delivered by **foliar treatment in doses of 0.2 - 0.4 kgha^{-1} in** colder and **rainy years** (or in the case of irrigated fields), while in hot years of **average precipitation soil treatment with a 25 kgha^{-1} of the same active agent**, were found to be the most effective treatments for **increasing** the **ear mass**, as the yield element having the most direct impact on the total yield,
- **foliar treatment with 0.2 kgha^{-1} of basic zinc-carbonate in** cold and **rainy years** (or in the case of irrigated fields), while **in** hot **years of average precipitation soil treatment with 25 kgha^{-1} of zinc-chloride,** were found to be the most effective for **increasing the protein and the starch content** as the two most important nutritional value factors.

If the aim is to apply a treatment whereby more than two parameters are intended to be improved:

- foliar treatment with **0.4 kgha^{-1} of basic zinc-carbonate in** cold and **rainy years** (or in the case of irrigated fields) was found to be the most effective because this particular treatment resulted in the greatest increase in comparison to the control sample in 2010 in the **ear mass** which is the most important yield element, and at the same time this treatment induced the greatest increase in the also essential **protein and starch content**,
- in warm **years of average precipitation soil treatment with 25 kgha^{-1} zinc-chloride** was found to be the most suitable approach **to improving the same parameters** simultaneously.

5. NEW SCIENTIFIC RESULTS

1. In the course of my field experiments I proved that the basic zinc-carbonate compound extracted from the originally liquid state galvanising waste can be used as an efficient and efficacious source of zinc as a micro-element for plants.

2. My studies showed that the most successful means of supplying zinc as a micro-element for plants is, in the case of maize, foliar treatment in the relevant phenological phase of development.

3. It was found that basic zinc-carbonate can – in suitable doses – be applied through both soil and foliar treatment.

4. My research proved that when applied to the soil, basic zinc-carbonate has its effects in the second year after deliver as well (retard impact), realised primarily in increases in the yield elements relating to the quantity of the yield.

5. It was proven that there is no treatment – in terms of active agent, locality and dose – that would equally improve yield elements and the nutritional value factors.

6. LIST OF PUBLICATIONS CONCERNING THE SUBJECT MATTER OF THE DISSERTATION

Scientific communications abroad in foreign language, proof-read periodicals:

- **László, Matus** – Rezső, Schmidt – Zsuzsanna, Lantos – Pál, Szakál (2015): Impacts of soil treatment with basic zinc-carbonate active agent on the quantity and quality of the yield of maize (*Zea mays L.*). Nova Biotechnologica et Chimica. (in press)

Scientific communication in domestic, foreign language, proof-read periodicals:

- R. Schmidt – P. Szakál – M. Barkóczi – **L. Matus** (2008): Controlled supply of nutrients, microelements provided by ion-exchanged sythesis zeolite. Cereal Research Communications. **36.** pp. 1919-1922.

- P. Szakál, M. Barkóczi, **L. Matus** (2009): Stress caused by high doses of copper-tetramine complex applied at different phenological phases of wheat. Cereal Research Communications. **37.** pp. 341-344.

Scientific communication in Hungarian language proof-read periodicals:

- Schmidt R. – Szakál P. – Beke D. – Barkóczi M. – **Matus L.** (2008): A Zn-komplex vegyület jelentősége a burgonyatermesztésben (*The importance of Zn-complex compounds in potato production*). Acta Agronomica Óváriensis. **50.** (1.) pp. 43-48.

- Szakál P. – Barkóczi M. – Schmidt R. – Beke D. – Tóásó Gy.- **Matus L.** (2008): Hulladékból előállított réz-tetramin complex hatása az őszibúza beltartalmára (*Impact of copper-tetramine produced from waste, on the nutritional value of winter wheat*). Acta Agronomica Óváriensis. **50.** (1.) pp. 103-108.

Foreign language, proof-read conference publications:

- Rezső, Schmidt - **László, Matus** (2010): Effect of Zn on the yield components and chemical composition of maize (Zea mays L.). Növénytermelés. **59.** pp. 33-36. Proceedings of the 9th Alps-Adria Scientific Workshop, 12–17 April 2010. Špičak, Czech Republic

- Lajos, Nagy – Pál, Szakál – Margit, Barkóczi – **László, Matus** – Rezső, Schmidt (2011): Copper-carbohydrate complexes in wheat production. Növénytermelés. **60.** pp. 37-40. Proceedings of the 10th Alps-Adria Scientific Workshop, 14–19 March 2011, Opatija, Croatia

- **Matus László** – Schmidt Rezső (2013): Effect of Zn on Maize (Zea mays L.) Yield and Chemical Composition in Soil Fertilization Experiments. Proceedings of the "Science for Sustainability" International Scientific Conference for PhD Students., pp. 205-210.

Poster:

- P. Szakál, M. Barkóczi, **L. Matus** (2009): Stress caused by high doses of copper-tetramine complex applied at different phenological phases of wheat. 8^{th} Alps-Adria Scientific Workshop. Neum, Bosnia-Herzegovina

- Szakál P. - Schmidt R. - Beke D. - Barkóczi M. - **Matus L.** (2009): A magnézium hatása az őszi búza hozamára és keményítőtartalmának változására (*Impact of magnesium on the yield and starch content of winter wheat*). XI. Magyar Magnézium Szimpózium. Budapest

Publications for dissemination of knowledge:

- Schmidt R. – **Matus L.** – Péntek A. (2009): Magyarország talajainak Zn-ellátottsága, a visszapótlás lehetőségei (*Zn contents of Hungary's soils, possibilities for supply*). Agro Napló, Országos Mezőgazdasági Szakfolyóirat (*A nationwide agricultural periodical*), XIII. évfolyam. **3.** pp. 44-45.