Theses for doctoral dissertation (PhD)

PLANT HEALTH EFFECTS OF THE CROP PHYSIOLOGICAL CHANGES OF MAIZE HYBRIDS

Csaba Bojtor
PhD candidate

Supervisor:
Prof. Dr. Csaba L. Marton, DSc

UNIVERSITY OF DEBRECEN

KERPELY KÁLMÁN DOCTORAL SCHOOL

Debrecen
2023

1. INTRODUCTION

The different soil, nutritional, water, and other climatic conditions have a combined effect on plant development. The aim of crop production is to provide the best growing environment for plants throughout their development.

Maize (*Zea mays* L.) is one of the most important crops grown around the world and increasing the quantity and quality of its yield is a major focus in crop production (Xin et al., 2016). Precision farming, which can ensure high yields and high-quality yields through precision nutrient replenishment, is coming to the fore in crop production practices, as climate change and climate variability increases. In his research, Nagy (2007) noted that the choice of the proper nutrient dose is particularly difficult in crop production, as many environmental and genotype-specific parameters have to be taken into account simultaneously. Field experiments provide a reliable basis for applied research, leading to the practical application of the results of crop production research, thus creating the opportunity to meet the challenge of increasing food and feed crop production necessitated by global population growth.

Crop production systems around the world are diverse and can be divided into at least two different levels of intensity, low and high input fertilisation systems. The future of modern complex nutrient supply strategies is not clear (Fischer and Connor, 2018). Optimal nutrient supply is a essential for producing high yields with desirable quality parameters. Plant health can be determined by interactions between the soil and plants and the complex nutrient use during the growing season, among other environmental factors. This has a significant impact on the quantitative and qualitative parameters of maize grain yield (Széles et al., 2019).

Farmers are attempting to optimise crop nutrient supply and reduce environmental loads through the use of precision farming techniques, which they plan to apply while managing the soil and the region's environmental heterogeneity. The competitiveness of maize production can be successfully improved by adapting these technologies (Nagy and Széles, 2018).

The precision implementation of crop nutrient supplementation, beginning with genotype selection, has several basic requirements that together can ensure the technology is implemented to a high standard. These include technical and IT innovations such as the use of geographic information systems, the renewal of agronomic methodology, the further development of fertilisation - nutrient supply advice based on plant sampling, measurements, in situ non-destructive instrumental analytical tests. In addition, the partial or complete plant analysis is an excellent tool for determining the availability of essential nutrients and their interactions (Kádár, 1992; Izsáki, 2009).

The adequate availability of these essential nutrients for plants promotes the establishment and maintenance of plant health, which, through their role in physiological and metabolic processes and the structural organisation of plants, are essential for proper development, growth, as well as the tolerance to abiotic and biotic stresses, and thus for maximising yield quantity and quality (Achari and Kowshik, 2018; Souri and Hatamian, 2019).

The development of conscious fertilisation and nutrient replenishment practices is of paramount importance for crop production to be sustainable economically and environmentally. Determining fertiliser doses and understanding the nutrient uptake dynamics of new maize genotypes provide the basis for this aim.

Main objectives of my research:

- Complex study of nutrient responses in maize, determining the optimal dose of nutrient replenishment.
- Evaluation of the nutrient uptake and conversion characteristics of maize, with a primary focus on nitrogen.
- Evaluation of dry matter accumulation, analysis of the effect of nitrogen supply on dry matter accumulation.
- Determination of complex macro-, secondary- and micronutrient uptake characteristics of maize in each vegetative and generative part of the plant, to evaluate the complex effects of fertiliser supply on nutrient uptake.
- Evaluation of the effects of macro-, secondary- and micronutrient supply of maize on yield and yield quality.

2. MATERIALS AND METHODS

2.1 Experimental Area

The experiment was performed on the Látókép Crop Production Experimental Site, Institutes for Agricultural Research and Educational Farm (IAREF), Farm and Regional Research Institutes of Debrecen (RID), University of Debrecen. The experimental site is located 13 km west of Debrecen, at latitude 47°33' N and longitude 21°26' E, at an altitude of 111 m above sea level. The calcareous chernozem soils of the area, formed on a loess ridge in the Hajdúság region, have soil physico-chemical properties provide favourable conditions for maize production.

2.2. Weather conditions of the experimental area

The experimental area has a typical continental climate, characterised by frequent weather extremes such as changes in rainfall and distribution, and temperature fluctuations both during and outside the growing season. In the growing season from 01/04 to 31/10 in 2019, only 311.8 mm of rain fell. In contrast, the year 2021, saw an adequate water supply from rainfall at the time of maize sowing followed by a significant deficit in the later stages of vegetative and generative development, with a total of 90.7 mm of rainfall in the 4 months from June to September, which also contributed to the nationally observed decrease in yield in the experimental area.

2.3. Experiment design and treatments

The complex multifactorial long-term fertilisation experiment of the Látókép Crop Production Experimental Site, founded in 1983 by Prof. Dr. János Nagy, makes it possible to examine and evaluate the effects of applying the same nutrient supply technology for nearly forty years. The experiment provides a complex comparison of the fertiliser response of different maize genotypes in unfertilised control plots and five increasing fertiliser doses in both irrigated and non-irrigated conditions. The experimental design was a small plot field experiment with four replications, in which the main plots were the examined genotypes, and the split plots were the applied fertiliser doses. The plot size was 7.2 m^2 and the genotype evaluated in the experiment was a medium maturity (FAO 420), dent type maize hybrid.

2.4. Research methodology

2.4.1. Evaluation of dry matter accumulation

In accordance with the different phenological stages, vegetative and generative parts of the plant were analysed in each sampling for a complex evaluation of dry matter accumulation and nutrient uptake of maize. In the vegetative stages of maize, individual tests were performed on the leaf and stem, and later, with the appearance of the cobs, at the 4-leaf- (V_4), 8-leaf- (V_8) and tasselling (V_T) phenophases. The performed sampling method was supplemented with grain yield and cob tests at the physiological maturity (R_6) phenophase. The dry matter content of the vegetative parts was determined with a thermometric method. After weighing the fresh samples, they were dried in a laboratory drying oven (ED 720, Binder GmbH, Tuttlingen, Germany) at 65°C to constant weight. After cooling to room temperature, they were measured on an analytical balance (E10640, OHAUS Europe GmbH, Nänikon, Switzerland) to determine the dry matter content and the moisture content of the fresh plant samples.

2.4.2. Analytical determination of essential nutrients

An accredited laboratory performed the complex determination of the essential nutrient content of the samples. The following nutrient components were determined according to the relevant Hungarian standards: nitrogen content was determined with the Kjeldahl method (MSZ-08-1783-6:1983) and phosphorus (MSZ-08-1783-28: 1985), potassium (MSZ-08-1783-29:1985), calcium (MSZ-08-1783-26:1985), magnesium (MSZ-08-1783-27:1985), zinc (MSZ-08-1783-33:1985), copper (MSZ-08-1783-34:1985), iron (MSZ-08-1783-31:1985), sulphur (MSZ-08-1783-38:1985), manganese (MSZ-08-1783-32:1985) were measured using ICP-OES (Thermo Scientific iCAP 7400, Thermo Fisher Scientific, Waltham, MA, USA)

2.4.3. Evaluation of yield and yield quality

After physiological maturity, the experimental plots were harvested with an SR2010 (Sampo Rosenlew Ltd., Pori, Finland) plot harvester. The harvester's built-in weight meter was used to determine the yield of the plot, which was converted to tons per hectare based on the plot area and plant density. After harvesting, 1 kg mean sample of grain yield from each experimental plot was used for subsequent evaluation of the main nutritional quality parameters (protein, starch, oil, grain moisture), using a Perten DA7250 (PerkinElmer Inc., Waltham, MA, USA) NIR instrument.

2.4.4. Statistical analysis

Statistical evaluation of the experimental results was performed in the statistical environment R 3.2.4, using the graphical interface RStudio, and the statistical software GenStat (VSN International, Rothamsted, England) and Minitab (Minitab LLC., Pennsylvania, USA). The goodness of fit of the measured data was tested using the Kolmogorov - Smirnov normality test. Individual and combined effects of different nitrogen fertilisation and crop years were tested using single and multi-factor analysis of variance. Fisher's least significant difference (LSD) test was used to determine significant differences between individual values. Cluster analysis was performed to examine the interrelationship between nutrient analysis data, as well as quantitative and qualitative parameters of yield. GGE biplot analysis was used for graphical analysis. Graphs were generated using Ms Excel 365 and Datawrapper.

3. RESULTS

Based on the results of the dry matter accumulation analysis, I found that the combined effect of nitrogen fertilisation, crop year, phenophase and phenophase x crop year significantly influenced dry matter uptake of the vegetative parts of the plant ($P<0.001$). In contrast, maize leaf dry matter growth was most significantly affected by nitrogen fertilisation, phenophase and phenophase x crop year ($P<0.001$). In addition, the combined effects of nitrogen fertilisation x crop year and phenophase x crop year ($P<0.01$) and nitrogen fertilisation x phenophase x crop year were also statistically significant ($P<0.05$).

During the analysis of the dry matter uptake of generative plant parts, I found that, for both grain and cob, the interaction of nitrogen fertilisation, crop year and nitrogen fertilisation x crop year produced significant effects, the former at $P<0.001$, while the combined interaction produced a weaker effect at $P<0.05$.

The dynamic processes of dry matter accumulation measured at the various phenological stages were different for each plant part. As regards the vegetative plant parts, stem dry matter accumulation at the V_4 phenophase was significantly affected by all treatments except N_1, resulting in a 60-80% increase in the accumulated dry matter content.

The amount of leaf dry matter, as the primary provider of the assimilation surface for organic matter formation, significantly depended on increasing the amount of nitrogen fertilisation. In the initial V_4 phenophase, all treatments significantly increased dry matter content, ranging from 39 to 64 %. As the vegetative development progressed, the values measured at the V_8 stage increased significantly with the performed treatments. The smallest increase was observed in the N_1 treatment by 33.9 % and the largest increase in the N_3 and N_5 treatments by 96.4 % and 98.3 %, respectively.

My research also focused on the nutrient accumulation characteristics of maize vegetative parts and the effects of different nitrogen fertilisation on macronutrient uptake dynamics. Of the three macronutrients in the vegetative parts of the plant, potassium was of primary importance for both the stalk and leaves. Nitrogen was used as a supplement, whereas phosphorus was not dominant. Of the different nitrogen fertilisation levels, the high-dose nitrogen treatments N_4 - N_5 resulted in the highest macronutrient accumulation (Fig. 1).

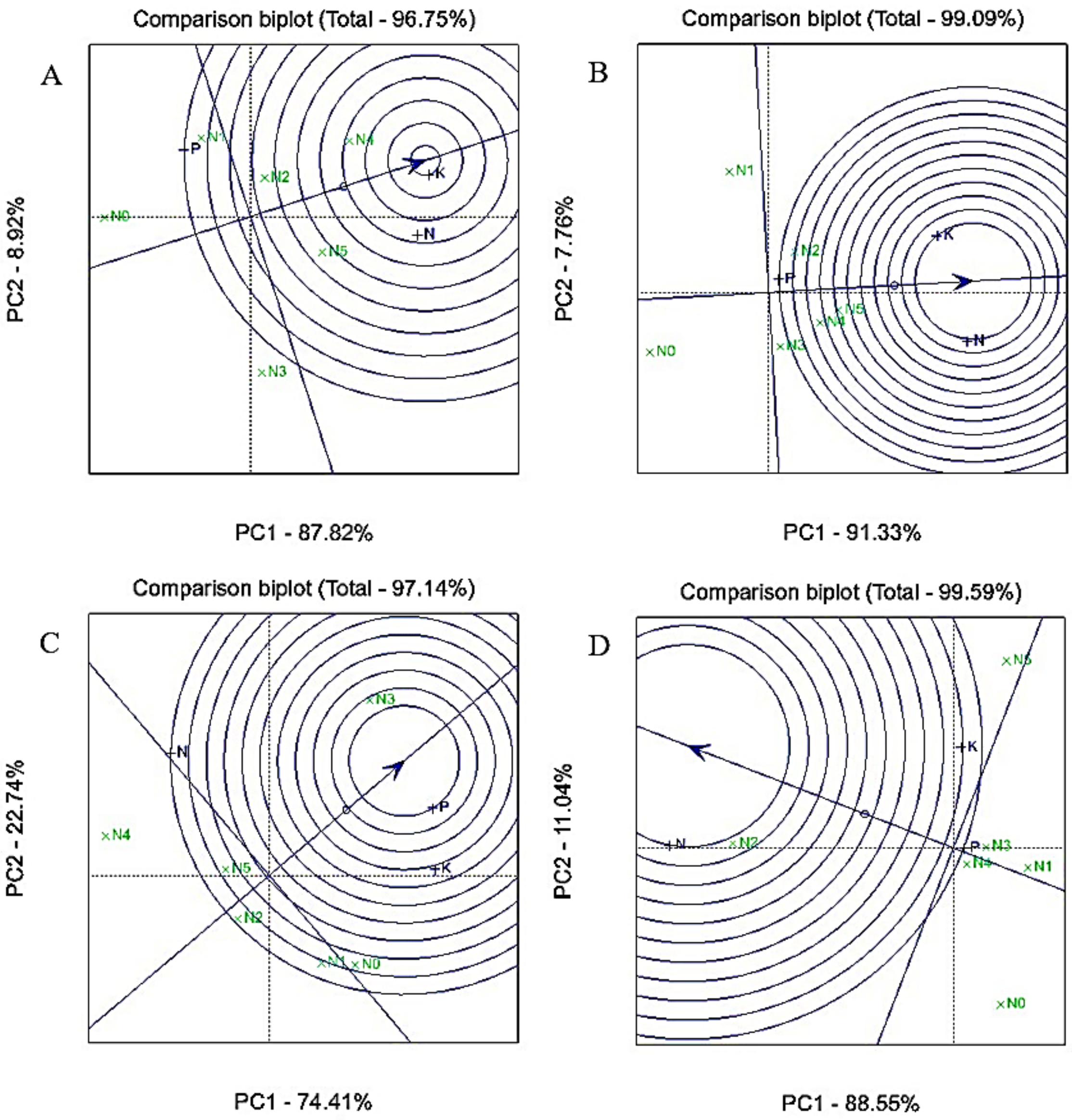


Figure 1. Analysis of the interaction between nitrogen supply and the accumulation of macronutrients (N, P, K) based on GGE Biplot analysis. A: Stem, B: Leaf, C: Grain, D: Cob. Debrecen - Látókép

Based on the individual and combined effects of each examined experimental parameter, such as nitrogen fertilisation rates, crop year and phenological stages, I found that nitrogen fertilisation, crop year, phenophase (*P<0.001*) and phenophase x crop year (*P<0.01*) had a significant combined effect on maize stalk nitrogen accumulation. As regards phosphorus uptake, the individual and combined effects of each of the examined factors had a significant effect (*P<0.001*). During the evaluation of the specificity of potassium uptake, I found that nitrogen fertilisation, phenophase, phenophase x crop year, and nitrogen fertilisation x phenophase x crop year had significant effects, the former at *P<0.001* and the latter at *P<0.05*. In addition to adequate stem vigour, the proper development of leaves is a key factor in the vegetative development of plants, providing maximum assimilation surface during photosynthesis by ensuring maximum assimilation of organic matter. During the analysis of leaf macronutrient uptake, I found that nitrogen accumulation was significantly affected by phenophase, nitrogen fertilisation, phenophase x crop year and nitrogen fertilisation x crop year at $P<0.001$ and $P<0.05$, respectively. The individual and combined effect of each examined factor, except nitrogen fertilisation, resulted in a significant ($P<0.001$) change in leaf phosphorus content. Significant effects on potassium accumulation were measured in all cases except for nitrogen fertilisation x crop year.

During the examination of macronutrient uptake in generative plant parts, I found that nitrogen fertilisation, year and nitrogen fertilisation x crop year significantly affected both the phosphorus and potassium uptake characteristics of the stover ($P<0.001$). In the grain yield, only the effect of nitrogen fertilisation x crop year resulted in a significant change in the concentration of both nutrients.

In the generative parts, the grain yield nitrogen content increased the least (+3 %) with the N_1 treatment, while the N_4 fertiliser dose resulted in a 56 % increase (+0.55 m/m % N). Each treatment resulted in a significant increase in the specific nitrogen content of cobs of more than 10 %, but the changes were not significant in any of the cases due to sample variability.

During the examination of the phosphorus concentration, I observed that increasing nitrogen doses resulted in significantly decreasing values in the stem and the generative parts, without significantly affecting the phosphorus supply to the leaves. The specific phosphorus content of the stem was most affected by the medium N_3 treatment, causing 16 % reduction of about 572 mg/kg P. Compared to the respective stem values, a more balanced effect on leaf potassium concentration was measured, with an increase between 19 and 31 %, with the greatest effect observed in the N_5 treatment (+ 6706 mg/kg K). In contrast, the change in grain yield concentration, although not significant, showed a decreasing trend between 2 and 10 % with each treatment.

The examination of secondary nutrient uptake revealed that magnesium accumulation in the leaves was less affected by increasing nitrogen fertilisation, resulting in a decrease between 8 and 17 %. The high-dose N_4 treatment caused the largest decrease (478 mg/kg) in magnesium concentration. In the generative parts of the plant, magnesium concentrations were not significantly different from the control values, except for the N_4 treatment (7% decrease) (Fig. 2).

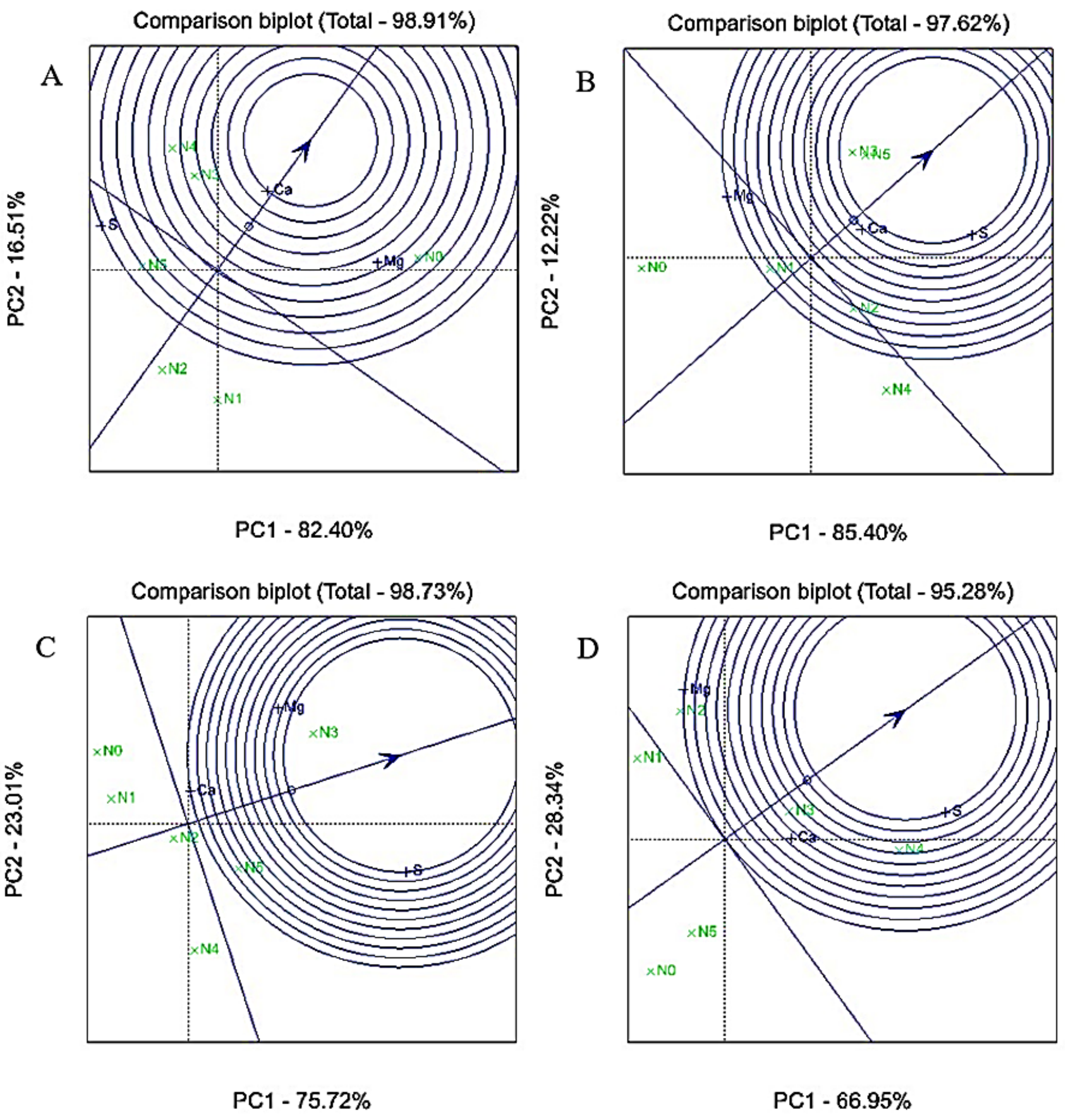


Figure 2. Interaction analysis of nitrogen supply and the accumulation of secondary nutrients (Mg, Ca, S) based on GGE Biplot analysis. A: Stem, B: Leaf, C: Grain, D: Cob. Debrecen - Látókép

There was no significant effect of increasing nitrogen fertilisation on the concentration of calcium in the vegetative parts of the plant. The amount of calcium uptake was evaluated as an independent factor of nitrogen supply, with only a slight decrease of 1-7 %.

In the vegetative parts of the plant, the sulphur content of stems and leaves was increased by 20 - 27 % and 38 - 54 %, respectively, with the highest increase observed in the N_4 treatment, i.e., 328 mg/kg in the stem and 800 mg/kg in the leaves. It was shown that high nitrogen doses (N_3 and N_5 treatments) had a significant positive effect on grain sulphur content in the generative plant parts, with excess sulphur uptake of 18 and 15 %, i.e., 157.8 and 125.7 mg/kg, respectively.

During the micronutrient uptake evaluation, I investigated the dynamic processes of accumulation of the essential micronutrients zinc, iron, manganese and copper. In the separate evaluation of the vegetative and generative parts of the plant, I found that manganese was of primary importance in the micronutrient uptake of maize stalk, followed by zinc and copper, respectively. Of the different treatments, the control, N_0 was found to be ideal for micronutrient uptake (Fig. 3).

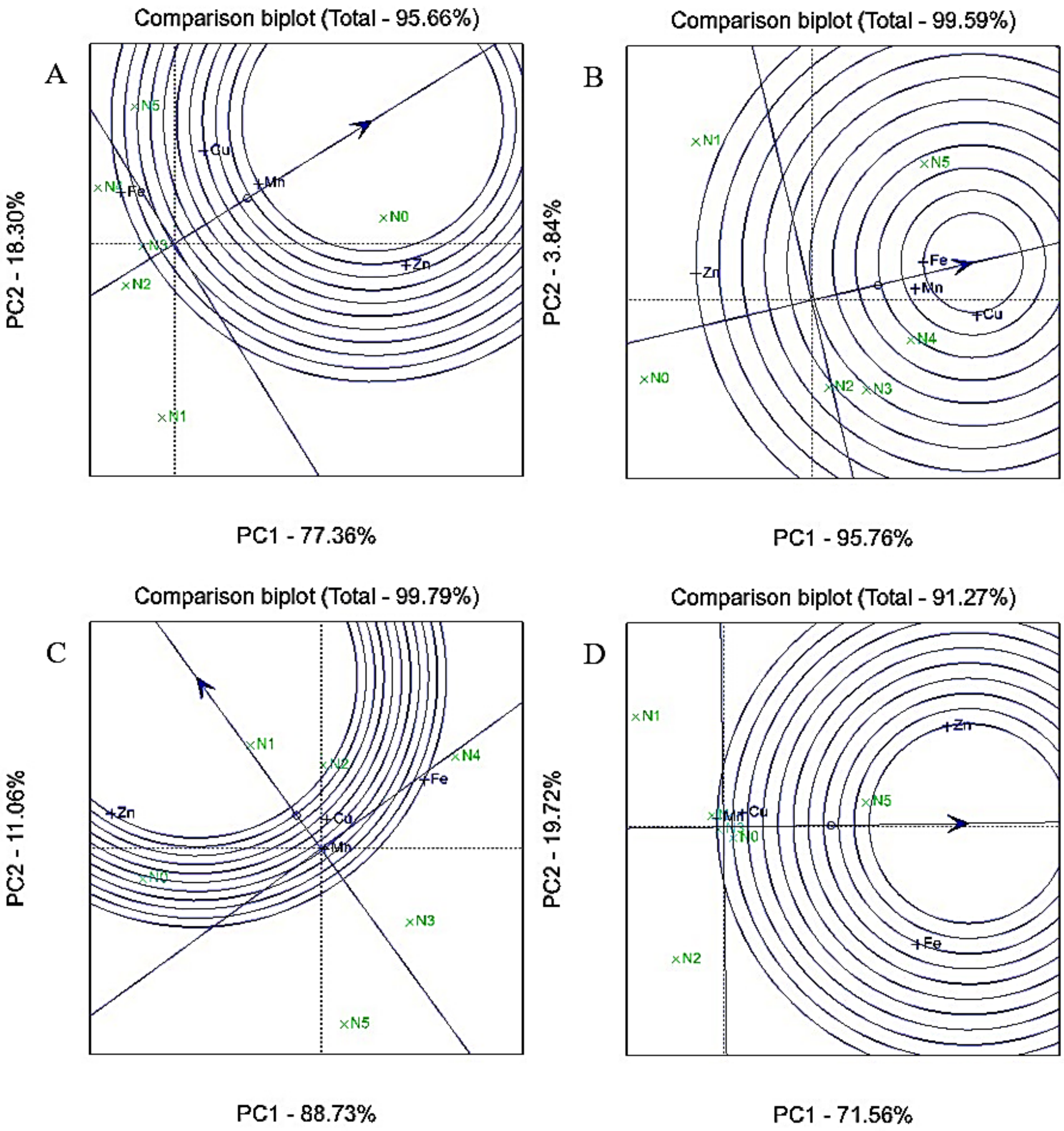


Figure 3. Interaction analysis of nitrogen supply and accumulation of micronutrients (Zn, Fe, Mn, Cu) based on GGE Biplot analysis. A: Stem, B: Leaf, C: Grain, D: Cob. Debrecen – Látókép

The leaf zinc content was slightly negatively affected by increasing nitrogen supply. Again, the decrease ranged from 5 to 18 %. For the generative parts of the plant, grain zinc content decreased significantly in all treatments. Again, the greatest negative change was observed in the N_4 treatment, resulting in a 40 % (9.04 mg/kg) decrease in concentration.

The iron content responded positively to the increase in nitrogen fertilisation. An increasing, and, in several cases, significant trend was observed for all plant parts. Significantly increased iron accumulation was found during maize leaf analysis under all fertiliser treatments, with the highest increase of 48 % under the N_5 treatment.

Based on the relationships between copper content and nitrogen supply in the vegetative parts, I found that increasing nitrogen fertiliser treatments resulted in significantly increased concentrations both in maize leaves and ears, ranging from 5 to 57 % and 8 to 39 %, respectively. During the examination of nitrogen fertilisation effects on manganese concentration in maize, the most notable change in manganese content was found in the leaf, which was a significant positive effect. The largest increases were obtained as a result of the N_4 and N_5 treatments (31 – 33 %).

I also evaluated quantitative and qualitative yield parameters of yield. I found that the N_3 treatment proved to be the ideal treatment in terms of quantitative and qualitative yield characteristics for the given hybrid concerning nitrogen supply, achieving 15.52 and 8.98 tons/ha yield in the two examined years, respectively. This value was followed by the N_2 and N_4 nutrient levels, and then N_5, indicating that fertiliser applied above N_3, i.e., 180 $kg*ha^{-1}$ nitrogen fertilisation level, could not be utilised by the hybrid.

A detailed analysis of yield quality characteristics showed that increasing nitrogen fertilisation resulted in the greatest change in protein content, with increases of 11 – 20 % in 2019 and 2 – 25 % in 2021, compared to the control. Different crop year effects were shown in oil content, with increases of between 2 and 5 % in 2019 and decreases of between 1 and 6 % in 2021, compared to the control. Increasing nitrogen fertilisation had a minimal effect on starch content, with a slight decrease of between 0 and 2 % in both examined years. The moisture content also showed different seasonal effects, with changes of 0 – 1 % in 2019 and increases of 5 – 11 % in 2021, due to increasing nitrogen fertilisation compared to the control.

Cluster analysis was used to examine and evaluate the relationship between the average accumulated essential macro-, meso- and microelement content of the vegetative parts of maize, as well as the quantitative and qualitative parameters of yield. While maximising yield is the primary objective of the farmers, quality is the main concern during extensive maize processing. Optimum nutrient supply is an important factor in achieving high yield of high-quality maize.

During the analysis of the relationship between yield and essential nutrient concentrations in the vegetative parts, the performed cluster analysis classified nutrients into three categories. The first cluster included nitrogen, sulphur, potassium, iron, copper and manganese, as well as yield. The iron, potassium, and sulphur content of maize were the most closely related to yield variation, with a similarity index of 79.94 %, i.e., a decisive determinant of potential available yield. A close correlation was also found with the values of nitrogen, copper, and manganese concentrations, with a similarity index of 75.1 %.

The nutrient uptake characteristics of the vegetative parts of maize also had a significant effect on yield protein content. The closest significant correlation was measured between accumulated iron concentration and protein content, with a similarity index of 74.95 %, followed by the nutrient group of nitrogen, copper and manganese, with a similarity index of 62.45 %. Uptake values of potassium, sulphur, zinc and magnesium showed weaker interaction, with a similarity index of 46.88 %.

The starch content of maize is of major importance for the processing industry as it represents most of the grain yield, i.e., 65 – 73 %. This value showed different characteristics when tested for correlation with essential nutrients. In the cluster analysis, the closest significant relationship was found for the phosphorus content of maize, with a similarity index of 79.68 %, followed by magnesium and zinc content, with a similar close similarity index of 73.31 %, and a significant relationship (53.53 %) between the calcium content of vegetative parts and the starch content of grain yield.

The oil content of maize grain ranged between 3 and 5 %, showing a weaker correlation with the nutrient content of maize. The closest correlations were observed with the nutrient group of nitrogen, potassium, sulphur, copper, manganese and iron, although the similarity index for these relationships was also only 51.54 % in total. Grain moisture at harvest, as a fundamental determinant of the drying cost related to yield quality, was found to be most closely related to the uptake of nitrogen, copper and manganese, with a similarity index of 77.58 %, followed by the group of nutrients including potassium, sulphur and iron (70.04 % similarity index).

4. CONCLUSIONS AND RECOMMENDATIONS

Optimum nutrient supply is essential in maize production technology to maximise yield parameters. In my research, the effects of nitrogen fertilisation on dry matter accumulation, nutrient uptake dynamics, and yield characteristics were evaluated. The obtained results were analysed using data from two years with different agrometeorological characteristics. Reliability of the effects of fertilisation was ensured by comparing the data with those from the non-fertilised control plots of the long-term field fertilisation experiment established in 1983.

Based on the results of dry matter accumulation, I found that stem dry matter accumulation was influenced by the main examined factors (nitrogen fertilisation, crop year, phenophase) at $P<0,001$ each, apart from the non-significant effect of crop year on leaf dry matter accumulation. For both grain yield and stover, both nitrogen fertilisation and crop year factors resulted in significant effects at $P<0.001$. I found that, in the initial V_4 phenophase, all treatments significantly increased maize leaf dry matter content between 39 and 64 %, whereas in the V_T phenophase, only the high-dose N_4 and N_5 fertiliser treatments resulted in significant increases, 33.1 and 33.7 %, respectively. In the R_6 phase, all treatments increased leaf dry matter content, with significant effects in the N_3 (+36.7 %), N_4 (+61.4 %) and N_5 (+46.3 %) treatments. My results confirm the findings of Ma et al. (2021), who found that dry matter accumulation rate and yield were highest when the applied dose of nitrogen fertilisation was 306.5 kg*ha^{-1}.

During the evaluation of macronutrient uptake, I found different effects on element uptake in various parts of the plant. In the stem, the lowest increase (4 %) was observed at the N_1 nutrient level and the highest (28 %) at the N_4 treatment. In the leaves, the same positive changes were 6% and 31%, respectively, with the highest changes observed at the N_5 treatment. Changes in leaf N concentration values are in agreement with the results of Izsáki (2012) and Boomsma et al. (2009), based on which increasing N fertilisation resulted in increased plant N content. However, they are in contrast to the findings of Kincses et al. (2002), who found that the highest N concentrations were measured in control plants with the lowest N dose during initial plant development at the V_{3-4} and V_{6-7} stages. My results on phosphorus concentration are in accordance with the data measured in the study of Jakab (2003), who found that maize phosphorus content was the highest in non-fertilised treatments. Conversely, the decreasing phosphorus concentration values measured in my experiments are in contrast with the results of Kincses et al. (2002), who found that increasing nitrogen fertilisation had no effect on the phosphorus uptake of the whole plant. The specific phosphorus content of the stalk was most affected by the medium-dose N_3 treatment, resulting in 16 % reduction of about 572 mg/kg P. Increasing nitrogen dose in the grain yield resulted in a slight decrease in phosphorus concentration, with the greatest effect observed in the N_4 treatment (-10 %). Individual nitrogen doses had different effects on stem potassium content, with the greatest increase (45 % (12392 mg/kg K)) in the N_4 treatment compared to the control. Leaf potassium concentration was affected to a lesser extent by nitrogen fertilisation, with an increase of between 19 and 31 %. The greatest effect was shown in the N_5 treatment (+ 6706 mg/kg K).

During the evaluation of secondary nutrient uptake, I found that nitrogen fertilisation reduced magnesium concentrations in both the stem (17-27 % reduction) and leaves (8-17 % reduction). In the leaves, the N_4 treatment caused the greatest reduction of 478 mg/kg. In the generative parts, magnesium concentration in the grain yield was not significantly different from the control value, except in the case of the N_4 treatment (7 % reduction). Thus, my results contrast with the findings of Izsáki (2011) that increasing nitrogen fertilisation positively affects the magnesium content of maize leaves. Increasing nitrogen fertilisation had no significant effect on the concentration of calcium in the vegetative plant parts. This result is in conformity with the study of Riedell (2010) study, who found that, in contrast to the N concentration in maize stalks, stalk calcium concentration in the V_6 and V_{12} stages was not affected by nitrogen fertilisation treatments. In the generative parts of the crop, grain calcium concentration was significantly affected by increasing nitrogen doses, with the largest reduction found in the N_2 treatment (23%, 385 mg/kg). This result contradicts the research findings of Jakab (2003), according to which similar significantly higher calcium concentration was measured with applying a fertiliser dose of 120 $kg*ha^{-1}$ N. However, I measured a significant increase in sulphur concentration with increasing nitrogen dose, both in the stalk (20 - 27 %), leaf (38 - 54 %) and grain yield (N_3 and N_5 treatments +157.8 and 125.7 mg/kg applied S).

During the microelement uptake evaluation, I found that increasing nitrogen supply resulted in a significant decrease in zinc concentration in all plant parts. The most significant of these effects was the decrease in the stem in the vegetative parts of the plant, amounting to least 40% in all treatments, with the greatest decrease in the N_4 treatment at 18.71 mg/kg. These measured trends are in contrast to the research results of Izsáki (2011), who reported a reliable increase in several years following nitrogen fertilisation. The grain zinc content decreased significantly in all treatments, with the largest negative change also in the case of the N_4 treatment, with a 40

% (9.04 mg/kg) decrease in concentration. The processes measured in the grain yield are in accordance with the results of Jakab (2003), who demonstrated a similar decrease in the zinc content of grain yield with increasing nitrogen fertilisation.
I found that the N_3 treatment, i.e., a nitrogen dose of 180 $kg*ha^{-1}$, resulted in the highest yield increase in 2019 (81 %) and in 2021 (84 %) compared to the control. The obtained results confirm the findings of yield depressing effects in the case of nitrogen overfertilisation (Pepó, 2001., Nagy, 2012; Széles et al., 2018).

In the protein content analysis, it was found that increasing nitrogen fertilisation resulted in increasing protein content. The amount of protein content increase was between 11 and 20 % in 2019 and between 2 and 25 % in 2021, compared to control values. As regards oil content, a different crop year effect was shown, with an increase of between 2 and 5 % in 2019 and a decrease of between 1 and 6 % in 2021, compared to the control. Increasing nitrogen fertilisation had a minimal effect on starch content, with a slight decrease of 0 – 2 % in both examined years. Moisture content also showed different seasonal effects, with changes ranging from 0 – 1 % in 2019 and an increase of 5 – 11 % in 2021, due to increasing nitrogen fertilisation compared to the control.

I found that the factors most closely correlated with yield were the accumulated iron, potassium and sulphur content in maize tissues, with a similarity index of 79.94 %, determining potential yield. The closest significant correlation in terms of the development of protein content was the concentration of accumulated iron, with a value of 74.95 %. The closest significant correlation with starch content in the cluster analysis was the phosphorus content of maize at 79.68 %. The oil content of maize yield showed a weaker correlation with the nutrient uptake of plants. The closest correlation was found with the macronutrients nitrogen and potassium, sulphur, and the micronutrients copper, manganese and iron. However, the similarity index for these correlations was also 51.54 % in total.

5. NEW SCIENTIFIC RESULTS

1. I have demonstrated that significantly increased dry matter accumulation at the beginning of the generative development stage (V_T phenophase) can only be achieved with high nitrogen fertiliser doses (+33.1 and +33.7 %) of 240-300 kg*ha^{-1}. The increase in 2019, a year with more favourable rainfall characteristics, was +51.8 % and +57.5 %, respectively, which is significantly higher than the increase in 2021.

2. I have shown that increasing nitrogen fertilisation significantly reduced phosphorus concentration in both stalk and the generative plant parts of maize. The maximum reduction was 16% in the stalk, 10 % in the grain and 52 % in the cob. In contrast, there was no significant effect on the phosphorus content of maize leaves.

3. I confirmed the potassium uptake enhancing effect of increasing nitrogen fertilisation. The N_4 (240 kg*ha^{-1} N) treatment increased potassium the most (45% - 12392 mg/kg K) compared to the control, each treatment resulting in at least a 20 % increase in concentration. The increase was higher in 2019, a year with more favourable rainfall characteristics, resulting in +4082 mg/kg of additional potassium uptake.

4. I have demonstrated the effect of increasing nitrogen fertilisation on enhancing sulphur accumulation in both the vegetative parts of the plant and in the yield. On average, increasing nitrogen supply resulted in an increase in stem and leaf sulphur content of between 20 and 27 % and between 38 and 54 %, respectively, with the highest increases observed in the case of the N_4 treatment (+ 328 mg/kg and + 800 mg/kg). High nitrogen doses (N_3 and N_5 treatments) had a particularly positive effect on grain sulphur content, with an increase of 18 and 15 %, or 157.8 and 125.7 mg/kg, respectively, of additional sulphur uptake.

5. Zinc concentrations decreased in all examined plant parts as a result of increasing N fertilisation. The decrease was predominant in the grain yield and the vegetative parts, with the highest decrease observed in the N4 treatment. In 2019, the decrease was 50.4 % in the stem, 35.2 % in the leaf and 39.8 % in the grain, while in 2021, the decrease was 58.2 % in the stem, 10.3 % in the leaf and 40.2 % in the grain.

6. I confirmed the effect of iron content in plant tissues on yield and protein content, with similarity index values of 79.94 % and 74.95 %, respectively, indicating a relationship between iron concentration and yield, as well as the protein content of yield.

6. PRACTICAL USE OF RESULTS

1. Based on my research results, the 180 kg/ha dose of nitrogen fertilisation is the most favourable for achieving maximum yield and yield quality in a medium maturity maize hybrid of the FAO 400-450 maturity group.

2. My results suggest that the effects of increasing nitrogen fertilisation on macro-, secondary- and micro-nutrient accumulation will assist producers in determining the need for additional fertiliser treatments in addition to nitrogen fertilisation and fertiliser composition.

3. Determination of the dry matter content of vegetative and generative parts of the plant in the V_T and R_6 phenophases, in addition to other parameters of the applied crop production technology, can be used to determine the yield of the area, thus helping to properly schedule the harvesting process.

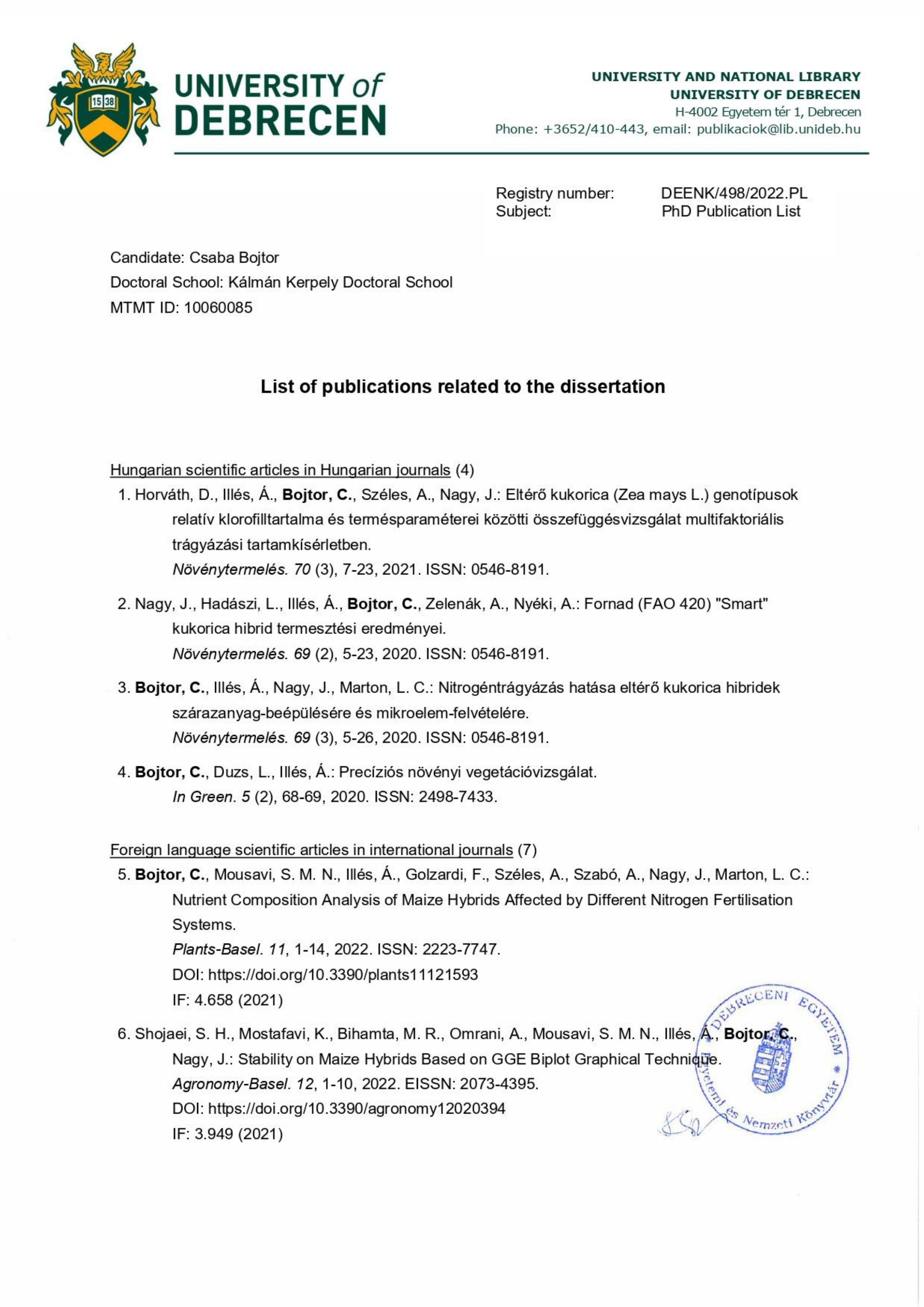
4. Knowing the essential nutrient content of yield and the green parts of the plant, and appropriate nitrogen fertilisation practices, will help to produce high quality feed and base materials for processing.

5. Sampling at development stages crucial for plant development and the resulting data, once evaluated, can be used as a baseline database for decision support systems for on-farm nutrient supply in maize, contributing to the efficient, system-wide development and implementation of precision nutrient supply.

REFERENCES

1. Achari, G.A. – Kowshik, M.: 2018. Recent developments on nanotechnology in agriculture: plant mineral nutrition, health, and interactions with soil microflora. *Journal of Agricultural and Food Chemistry*, 66(33), pp. 8647-8661.
2. Boomsma, C.R. – Santini, J.B. – Tollenaar, M. – Vyn, T.J.: 2009. Maize morphophysiological responses to intense crowding and low nitrogen availability: An analysis and review. Agronomy Journal, 101(6), pp.1426-1452.
3. Fischer, R.A. – Connor, D.J.: 2018. Issues for cropping and agricultural science in the next 20 years. *Field Crops Research*, 222, pp.121-142.
4. Győri, Z. – Boros, N.: 2013. A kukorica kéntartalmának vizsgálata agrotechnikai kísérletekben. *60 éves a magyar hibridkukorica*, p.57.
5. Jakab, P.: 2003. A kukoricahibridek makro-, mezo-és mikroelemtartalmának változása a tápanyagellátás függvényében. *Acta Agraria Debreceniensis*, Debrecen, 10, pp.126-130.
6. Kádár I. 1992: A növénytáplálás alapelvei és módszere. Magyar Tudományos Akadémia Talajtani és Agrokémiai Kutató Intézete. Budapest.
7. Kincses, S. – Filep, T. – Loch, J.: 2002. Az NPK-trágyázás hatása a kukorica tápelemfelvételének dinamikájára, öntözött és nem öntözött viszonyok között. *Acta Agraria Debreceniensis*, pp.23-27.
8. Izsáki, Z.: 2009. Effect of nitrogen supply on nutritional status of maize. *Communications in soil science and plant analysis*, 40(1-6), 960-973
9. Izsáki, Z.: 2011. A N-trágyázás hatása a kukorica levél tápelem-koncentrációjára és a tápelemek közötti kölcsönhatásokra. *Növénytermelés*, 60(4), pp.43-68.
10. Izsáki, Z.: 2012. Using crop analysis in the precision nutrient supply system of maize. *Acta Agraria Debreceniensis*, (49), pp.183-186.
11. Ma, L. – Zhang, X. – Lei, Q. – Liu, F.: 2021. Effects of drip irrigation nitrogen coupling on dry matter accumulation and yield of Summer Maize in arid areas of China. *Field Crops Research*, 274, p.108321.
12. Nagy, J.: 2007. Kukoricatermesztés. Akadémiai Kiadó. Budapest. 42–276.
13. Nagy, J.: 2012. The effect of feritilization and precipitation on the yield of maize (*Zea mays* L.) in long-term experiment. *Időjárás*, 116.1: 39-52.
14. Nagy, J. – Széles, A.: 2018. The scientific background of competitive maize production. *Acta Agraria Debreceniensis*, pp.33-46.
15. Pepó, P.: 2001. A genotípus és a vetésváltás szerepe a kukorica tápanyagellátásában csernozjom talajon. *Növénytermelés*, 50. 2-3: 189-202.
16. Riedell, W.E.: 2010. Mineral-nutrient synergism and dilution responses to nitrogen fertilizer in field-grown maize. *Journal of Plant Nutrition and Soil Science*, 173(6), pp.869-874.
17. Souri, M.K. – Hatamian, M.: 2019. Aminochelates in plant nutrition: a review. *Journal of Plant Nutrition*, 42(1), pp. 67-78.
18. Széles, A. – Horváth, É.– Vad, A. – Harsányi, E.: 2018. The impact of enviromental factors on the protein content and yield of maize grain at different nutrient supply levels. *Emirates Journal of Food and Agriculture*, 30 .9: 764-777.
19. Széles, A. – Nagy, J. – Rátonyi, T. – Harsányi, E.: 2019. Effect of differential fertilisation treatments on maize hybrid quality and performance under environmental stress condition in Hungary. *Maydica*, 64(2), 14.
20. Xin, X. – Zhang, J. – Zhu, A. – Zhang, C.: 2016. Effects of long-term (23 years) mineral fertilizer and compost application on physical properties of fluvo-aquic soil in the north china plain. *Soil Tillage Res.* 156, 166–172.

PUBLICATIONS RELATED TO THE DISSERTATION



UNIVERSITY of DEBRECEN

UNIVERSITY AND NATIONAL LIBRARY
UNIVERSITY OF DEBRECEN
H-4002 Egyetem tér 1, Debrecen
Phone: +3652/410-443, email: publikaciok@lib.unideb.hu

Registry number: DEENK/498/2022.PL
Subject: PhD Publication List

Candidate: Csaba Bojtor
Doctoral School: Kálmán Kerpely Doctoral School
MTMT ID: 10060085

List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (4)

1. Horváth, D., Illés, Á., **Bojtor, C.**, Széles, A., Nagy, J.: Eltérő kukorica (Zea mays L.) genotípusok relatív klorofilltartalma és termésparaméterei közötti összefüggésvizsgálat multifaktoriális trágyázási tartamkísérletben.
   Növénytermelés. 70 (3), 7-23, 2021. ISSN: 0546-8191.
2. Nagy, J., Hadászi, L., Illés, Á., **Bojtor, C.**, Zelenák, A., Nyéki, A.: Fornad (FAO 420) "Smart" kukorica hibrid termesztési eredményei.
   Növénytermelés. 69 (2), 5-23, 2020. ISSN: 0546-8191.
3. **Bojtor, C.**, Illés, Á., Nagy, J., Marton, L. C.: Nitrogéntrágyázás hatása eltérő kukorica hibridek szárazanyag-beépülésére és mikroelem-felvételére.
   Növénytermelés. 69 (3), 5-26, 2020. ISSN: 0546-8191.
4. **Bojtor, C.**, Duzs, L., Illés, Á.: Precíziós növényi vegetációvizsgálat.
   In Green. 5 (2), 68-69, 2020. ISSN: 2498-7433.

Foreign language scientific articles in international journals (7)

5. **Bojtor, C.**, Mousavi, S. M. N., Illés, Á., Golzardi, F., Széles, A., Szabó, A., Nagy, J., Marton, L. C.: Nutrient Composition Analysis of Maize Hybrids Affected by Different Nitrogen Fertilisation Systems.
   Plants-Basel. 11, 1-14, 2022. ISSN: 2223-7747.
   DOI: https://doi.org/10.3390/plants11121593
   IF: 4.658 (2021)
6. Shojaei, S. H., Mostafavi, K., Bihamta, M. R., Omrani, A., Mousavi, S. M. N., Illés, Á., **Bojtor, C.**, Nagy, J.: Stability on Maize Hybrids Based on GGE Biplot Graphical Technique.
   Agronomy-Basel. 12, 1-10, 2022. EISSN: 2073-4395.
   DOI: https://doi.org/10.3390/agronomy12020394
   IF: 3.949 (2021)

7. **Bojtor, C.**, Illés, Á., Mousavi, S. M. N., Széles, A., Tóth, B., Nagy, J., Marton, L. C.: Evaluation of the Nutrient Composition of Maize in Different NPK Fertilizer Levels Based on Multivariate Method Analysis.
   Int. J. Agro. 2021, 1-13, 2021. ISSN: 1687-8159.
   DOI: https://doi.org/10.1155/2021/5537549

8. Mousavi, S. M. N., **Bojtor, C.**, Illés, Á., Nagy, J.: Genotype by Trait Interaction (GT) in Maize Hybrids on Complete Fertilizer.
   Plants-Basel. 10 (11), 1-16, 2021. ISSN: 2223-7747.
   DOI: https://doi.org/10.3390/ plants10112388
   IF: 4.658

9. **Bojtor, C.**, Illés, Á., Horváth, É., Nagy, J., Marton, L. C.: Hybridspecific nutrient interactions and their role in maize yield quality.
   Agron. Res. 19 (4), 1698-1710, 2021. ISSN: 1406-894X.
   DOI: https://doi.org/10.15159/ar.21.148

10. **Bojtor, C.**, Mousavi, S. M. N., Illés, Á., Széles, A., Nagy, J., Marton, C. L.: Stability and Adaptability of Maize Hybrids for Precision Crop Production in a Long-Term Field Experiment in Hungary.
    Agronomy-Basel. 11 (11), 1-14, 2021. EISSN: 2073-4395.
    DOI: https://doi.org/10.3390/agronomy11112167
    IF: 3.949

11. Mousavi, S. M. N., Illés, Á., **Bojtor, C.**, Nagy, J.: The impact of different nutritional treatments on maize hybrids morphological traits based on stability statistical methods.
    Emir J Food Agric. 32 (9), 666-672, 2020. ISSN: 2079-052X.
    DOI: http://dx.doi.org/10.9755/ejfa.2020.v32.i9.2147
    IF: 1.041

Hungarian conference proceedings (1)

12. **Bojtor, C.**, Illés, Á., Nagy, J.: Levélen keresztüli növénytáplálás eredményei.
    In: Prega Science 2020 : Scientific Conference on Precision Agriculture and Agro-Informatics, [Agroinform Média Kft.], [Budapest], 1-4, 2021.

Hungarian abstracts (1)

13. **Bojtor, C.**, Illés, Á., Horváth, É., Duzs, L., Nagy, J., Marton, L. C.: Eltérő nitrogénellátottság hatása a kukoricahibridek kezdeti fejlődésének mikroelemfelvételi dinamikájára.
    In: XXIII. Tavaszi Szél Konferencia 2020: Nemzetközi Multidiszciplináris Konferencia. Absztrakt kötet I.. Szerk.: Barna Boglárka Johanna, Kovács Petra, Molnár Dóra, Pató Viktória Lilla, Doktoranduszok Országos Szövetsége, Budapest, 28, 2020. ISBN: 9786155586705

Foreign language abstracts (5)

14. Csatári, N., **Bojtor, C.**: Analysing salty chernozem soil by soil scanning in consecutive years.
    In: Abstract book of the 19th Alps-Adria Scientific Workshop. Ed.: by Zoltán Kende, Szent István Egyetemi Kiadó Nonprofit Kft., Gödöllő, 32, 2020. ISBN: 9789632698960
15. **Bojtor, C.**, Illés, Á., Nagy, J., Marton, L. C.: Nitrogen fertilization level: an important factor of plant's nutrient distribution in long-term field experiment.
    In: Abstract book of the 19th Alps-Adria Scientific Workshop. Ed.: by Zoltán Kende, Szent István Egyetemi Kiadó Nonprofit Kft., Gödöllő, 22, 2020. ISBN: 9789632698960
16. Kith, K., **Bojtor, C.**, Illés, Á., Dorogi, Z., Zelenák, A.: Analysis of the correlation between yield results and soil in the case of different genotype maize hybrids.
    In: Abstract book 18th Alps-Adria Scientific Workshop. Ed.: Zoltán Kende, Csaba Bálint, Viola Kunos, Szent István Egyetemi Kiadó Nonprofit Kft., Gödöllő, 94-95, 2019. ISBN: 9789632698182
17. **Bojtor, C.**, Illés, Á., Nagy, J.: Application of microalgae-containing bio-fertilizer in maize.
    In: 9th Microalgae and Seaweed Products in Plant/Soil-Systemps: Mosonmagyaróvár, Hungary, June 25-26, 2019 : Book of abstracts, Széchenyi István University, Mosonmagyaróvár, 32, 2019.
18. **Bojtor, C.**, Illés, Á., Marton, L. C., Nagy, J.: Effect of microalgae-containing bio-fertilizer on the magnesium content and growth parameters of maize (Zea mays L.).
    In: 4th Biostimulants World Congress : Abstract book for Oraland poster presentations, [s.n.], [Barcelona], 204, 2019.

List of other publications

Hungarian book chapters (2)

19. **Bojtor, C.**: A mangán-toxicitás mérséklésének lehetősége baktériumtrágyákkal.
    In: Interdiszciplináris tudományos konferencia : tanulmánykötet. Szerk.: Dajnoki Krisztina, Szőllősi László, Debreceni Egyetem Gazdaságtudományi Kar és a Mezőgazdaság-, Élelmiszertudományi és Környezetgazdálkodási Kar, Debrecen, 99-104, 2015. ISBN: 9789634737698
20. **Bojtor, C.**: Néhány ipari melléktermék vizsgálata talaj-növény rendszerben.
    In: Interdiszciplináris tudományos konferencia : tanulmánykötet. Szerk.: Dajnoki Krisztina, Szőllősi László, Debreceni Egyetem Gazdaságtudományi Kar és a Mezőgazdaság-, Élelmiszertudományi és Környezetgazdálkodási Kar, Debrecen, 95-98, 2015. ISBN: 9789634737698

Foreign language international book chapters (1)

21. Tóth, B., **Bojtor, C.**, Hankovszky, G., Kaczur, D., Illés, Á., Kovács, B.: Effects of industrial by-products on the food chain.
In: Land Reclamation in Ecological Fragile Areas. Ed.: Hu Zhenqi, Crc Press-Taylor & Francis Group, London, 539-542, 2017. ISBN: 9781138051034

Hungarian scientific articles in Hungarian journals (14)

22. Illés, Á., **Bojtor, C.**, Szabó, A., Nagy, J.: Eltérő agrotechnikai paraméterek hatása a különböző kukoricahibridek kelésdinamikai és termésparamétereire szántóföldi tartamkísérletben.
Növénytermelés. 71 (1), 21-32, 2022. ISSN: 0546-8191.

23. Nagy, Z., Széles, A., Demeter, C., Illés, Á., **Bojtor, C.**, Zelenák, A., Nagy, J.: Az agrometeorológiai hatások elemzése csemegekukorica (Zea mays L. convar. saccharata Koern.) üzemi termesztési kísérletekben.
Növénytermelés. 70 (1), 7-21, 2021. ISSN: 0546-8191.

24. Szabó, A., Illés, Á., **Bojtor, C.**, Széles, A., Zelenák, A., Nagy, J.: Az amerikai kukoricabogár (Diabrotica virgifera virgifera LeConte) lárvakártétel hatása a kukorica (Zea mays L.) termésének mennyiségi és minőségi paramétereire szántóföldi tartamkísérletben.
Növénytermelés. 70 (3), 41-62, 2021. ISSN: 0546-8191.

25. Bojté, C., Helenkár, A., Nagy, N. E., Tóth, B., Hajósné Novák, M., Micsinai, A., Parádi, I., Szemán-Nagy, G., Tálas, L., **Bojtor, C.**, Nagy, J.: Búza (Triticum aestivum L.) vetőmagok minősítése MALDI-TOF MS módszerrel.
Növénytermelés. 70 (1), 45-57, 2021. ISSN: 0546-8191.

26. Radócz, L., Illés, Á., **Bojtor, C.**, Radócz, L., Szabó, A., Tamás, A., Kovács, G. E.: Fogékonysági vizsgálat Cryphonectria parasitica (Murr.) Barr gombával fertőzött tölgy (Quercus) fajokon.
Növénytermelés. 70 (4), 59-72, 2021. ISSN: 0546-8191.

27. Demeter, C., Széles, A., Illés, Á., **Bojtor, C.**, Szabó, A., Bakos, Z., Zelenák, A., Nagy, J.: Normálédes és szuperédes csemegekukorica (Zea mays L. convar. sacharata Koern) hibridek beltartalmi értékeinek összehasonlító elemzése.
Növénytermelés. 70 (2), 5-20, 2021. ISSN: 0546-8191.

28. Demeter, C., Széles, A., Illés, Á., **Bojtor, C.**, Nagy, J.: Eltérő genotípusú csemegekukorica (Zea mays L. convar. saccharata Koern.) hibridek fenometriai és terméselem vizsgálatainak eredményei.
Növénytermelés. 69 (4), 26-36, 2020. ISSN: 0546-8191.

29. Illés, Á., **Bojtor, C.**, Nagy, J.: Eltérő NPK-ellátottság hatása a kukorica hibridek lipidperoxidációjának mértékére.
Növénytermelés. 69 (3), 53-65, 2020. ISSN: 0546-8191.

30. Zsigrai, G., **Bojtor, C.**, Horváth, É., Juhász, C.: Különböző ökológiai K- és Mn-lombtrágya készítmények hatásának összehasonlító vizsgálata a Tokaji Borvidéken: - klorofill fluoreszcencia és NDVI vizsgálatok eredményei.
    Szőlő-levél 10 (4), 40-60, 2020.
31. Illés, Á., **Bojtor, C.**, Ördög, V., Nagy, J.: Nostoc piscinale biostimulátor levéltrágya kezelés hatása a kukorica prolintartalmára, relatív víztartalom (RWC) értékére, termésmennyiségére és annak fehérjetartalmára.
    Növénytermelés. 69 (1), 5-20, 2020. ISSN: 0546-8191.
32. **Bojtor, C.**, Radócz, L., Tóth, B.: A babrozsda (Uromyces appendiculatus) fertőzés hatása a bab klorofilltartalmára, a fotoszintézis fényszakaszának hatékonyságára, a szuperoxid-dizmutáz aktivitására és a lipidperoxidáció mértékére.
    Növénytermelés. 68 (3), 29-50, 2019. ISSN: 0546-8191.
33. Kaczur, D., Illés, Á., **Bojtor, C.**, Győri, Z., Tóth, B.: Az alumínium toxicitás mérséklése baktérium készítménnyel a kukorica kezdeti növekedési stádiumában.
    Gradus. 4 (2), 279-283, 2017. EISSN: 2064-8014.
34. Illés, Á., **Bojtor, C.**, Kaczur, D., Győri, Z., Tóth, B.: Az ólom toxicitás hatásának vizsgálata a kukorica kezdeti növekedési stádiumában.
    Gradus. 4 (2), 274-278, 2017. EISSN: 2064-8014.
35. **Bojtor, C.**, Tóth, B.: Mangán-ellátottság és baktériumtrágya közötti kölcsönhatás vizsgálata hidropóniásan nevelt kukoricánál.
    Növénytermelés. 66 (2), 7-24, 2017. ISSN: 0546-8191.

Foreign language scientific articles in Hungarian journals (8)

36. Huzsvai, L., Fejér, P., Illés, Á., **Bojtor, C.**, Bojté, C., Horváth, É., Demeter, C.: Analysis of sweet corn nutritional values using multivariate statistical methods.
    Agrártud. Közl. 1, 103-108, 2021. ISSN: 1587-1282.
    DOI: http://dx.doi.org/10.34101/ACTAAGRAR/1/8587
37. Illés, Á., **Bojtor, C.**, Széles, A., Mousavi, S. M. N., Tóth, B., Nagy, J.: Effect of nitrogen fertiliser on the rate of lipid peroxidation of different maize hybrids in a long-term multifactorial experiment.
    Acta Aliment. 50 (2), 162-169, 2021. ISSN: 0139-3006.
    DOI: http://dx.doi.org/10.1556/066.2020.00177
    IF: 1
38. Szabó, A., Illés, Á., **Bojtor, C.**, Bakos, Z., Nagy, J.: Effect of the different nitrogen supply on the leaf area index and yield parameters of maize.
    Növénytermelés. 70 (3), 117-120, 2021. ISSN: 0546-8191.
39. Bakos, Z., **Bojtor, C.**, Illés, Á., Demeter, C., Zelenák, A.: Nutritional values and yield parameters of a sweet maize variety (Zea mays L. convar. saccharata Koern).
    Növénytermelés. 70 (3), 109-111, 2021. ISSN: 0546-8191.

40. Illés, Á., **Bojtor, C.**, Mousavi, S. M. N., Marton, L. C., Ragán, P., Nagy, J.: Maize hybrid and nutrient specific evaluation of the population dynamics and damage of the western corn rootworm (Diabrotica Virgifera Virgifera LeConte) in a long-term field experiment.
    Progress in Agricultural Engineering Sciences. 16 (1), 1-14, 2020. ISSN: 1786-335X.
    DOI: https://doi.org/10.1556/446.2020.00003

41. Illés, Á., Mousavi, S. M. N., **Bojtor, C.**, Nagy, J.: The plant nutrition impact on the quality and quantity parameters of maize hybrids grain yield based on different statistical methods.
    Cereal Res. Commun. 48, 565-573, 2020. ISSN: 0133-3720.
    DOI: https://doi.org/10.1007/s42976-020-00074-5
    IF: 0.85

42. **Bojtor, C.**, Győri, Z., Sipos, P., Radócz, L., Tóth, B.: Effect of bean rust (Uromyces appendiculatus (pers.) strauss) on photosynthetic characteristics, superoxide-dismutase activity and lipid peroxidation of common bean (Phaseolus vulgaris L.).
    Acta Aliment. 48 (2), 253-259, 2019. ISSN: 0139-3006.
    DOI: http://dx.doi.org/10.1556/066.2019.48.2.13
    IF: 0.458

43. Kaczur, D., **Bojtor, C.**, Hankovszky, G., Veres, S., Tóth, B.: Effect of aluminum and bacteria fertilizer treatment on the Vigna radiata root growth and photosynthetic activity on early growth stage.
    Columella. 4 (1), 101-106, 2017. ISSN: 2064-7816.
    DOI: http://dx.doi.org/10.18380/SZIE.COLUM.2017.4.1.suppl

<u>Foreign language scientific articles in international journals</u> (16)

44. Szabó, A., Mousavi, S. M. N., **Bojtor, C.**, Ragán, P., Nagy, J., Vad, A., Illés, Á.: Analysis of Nutrient-Specific Response of Maize Hybrids in Relation to Leaf Area Index (LAI) and Remote Sensing.
    Plants-Basel. 11 (9), 1-14, 2022. ISSN: 2223-7747.
    DOI: https://doi.org/10.3390/plants11091197
    IF: 4.658 (2021)

45. Shojaei, S. H., Mostafavi, K., Omrani, A., Illés, Á., **Bojtor, C.**, Omrani, S., Mousavi, S. M. N., Nagy, J.: Comparison of Maize Genotypes Using Drought-Tolerance Indices and Graphical Analysis under Normal and Humidity Stress Conditions.
    Plants-Basel. 11, 1-15, 2022. ISSN: 2223-7747.
    DOI: https://doi.org/10.3390/ plants11070942
    IF: 4.658 (2021)

46. Szabó, A., Széles, A., Illés, Á., **Bojtor, C.**, Mousavi, S. M. N., Radócz, L., Nagy, J.: Effect of Different Nitrogen Supply on Maize Emergence Dynamics, Evaluation of Yield Parameters of Different Hybrids in Long-Term Field Experiments.
Agronomy-Basel. 12 (2), 1-13, 2022. EISSN: 2073-4395.
DOI: uhttp://dx.doi.org/10.3390/agronomy12020284
IF: 3.949 (2021)

47. Omrani, A., Omrani, S., Khodarahmi, M., Shojaei, S. H., Illés, Á., **Bojtor, C.**, Mousavi, S. M. N., Nagy, J.: Evaluation of Grain Yield Stability in Some Selected Wheat Genotypes Using AMMI and GGE Biplot Methods.
Agronomy-Basel. 12 (5), 1-14, 2022. EISSN: 2073-4395.
DOI: https://doi.org/10.3390/agronomy12051130
IF: 3.949 (2021)

48. Shojaei, S. H., Mostafavi, K., Amirparviz, L., Omrani, A., Omrani, S., Mousavi, S. M. N., Illés, Á., **Bojtor, C.**, Nagy, J.: Evaluation of stability in maize hybrids using univariate parametric methods.
J. Crop Sci. Biotech. 25, 269-276, 2022. ISSN: 1975-9479.
DOI: https://doi.org/10.1007/s12892-021-00129-X

49. Csajbók, J., Bódi, E., Nagy, A., Fehér, Z. Z., Tamás, A., Virág, I. C., **Bojtor, C.**, Forgács, F., Vad, A., Kutasy, E.: Multispectral Analysis of Small Plots Based on Field and Remote Sensing Surveys-A Comparative Evaluation.
Sustainability. 14 (6), 1-22, 2022. ISSN: 2071-1050.
DOI: https://doi.org/10.3390/su14063339
IF: 3.889 (2021)

50. Mousavi, S. M. N., Illés, Á., **Bojtor, C.**, Demeter, C., Bakos, Z., Vad, A., Abakeer, R. A., Sidahmed, H. M. I., Nagy, J.: Quantitative and qualitative yield in sweet maize hybrids.
Braz. J. Biol. 84, 1-9, 2022. ISSN: 1519-6984.
DOI: http://dx.doi.org/10.1590/1519-6984.265735

51. Khatibi, A., Omrani, S., Omrani, A., Shojaei, S. H., Mousavi, S. M. N., Illés, Á., **Bojtor, C.**, Nagy, J.: Response of Maize Hybrids in Drought-Stress Using Drought Tolerance Indices.
Water. 14 (7), 1-10, 2022. EISSN: 2073-4441.
DOI: https://doi.org/10.3390/w14071012
IF: 3.53 (2021)

52. Tóth, B., Moloi, M. J., Mousavi, S. M. N., Illés, Á., **Bojtor, C.**, Szőke, L., Nagy, J.: The Evaluation of the Effects of Zn, and Amino Acid-Containing Foliar Fertilizers on the Physiological and Biochemical Responses of a Hungarian Fodder Corn Hybrid.
Agronomy-Basel. 12, 1-17, 2022. EISSN: 2073-4395.
DOI: https://doi.org/10.3390/agronomy12071523
IF: 3.949 (2021)

53. Illés, Á., Szabó, A., Mousavi, S. M. N., **Bojtor, C.**, Vad, A., Harsányi, E., Sinka, L.: The Influence of Precision Dripping Irrigation System on the Phenology and Yield Indices of Sweet Maize Hybrids.
Water. 14 (16), 1-14, 2022. EISSN: 2073-4441.
DOI: https://doi.org/10.3390/w1416248
IF: 3.53 (2021)

54. Illés, Á., **Bojtor, C.**, Széles, A., Mousavi, S. M. N., Tóth, B., Nagy, J.: Analyzing the Effect of Intensive and Low-Input Agrotechnical Support for the Physiological, Phenometric, and Yield Parameters of Different Maize Hybrids Using Multivariate Statistical Methods.
Int. J. Agro. 2021, 1-11, 2021. ISSN: 1687-8159.
DOI: https://doi.org/10.1155/2021/6682573

55. Széles, A., Horváth, É., Rácz, D., Duzs, L., **Bojtor, C.**, Huzsvai, L.: Development of stomatal conductance of maize under moderately hot, dry production conditions.
Agron. Res. 19 (4), 2013-2025, 2021. ISSN: 1406-894X.
DOI: https://doi.org/10.15159/AR.21.151

56. Illés, Á., **Bojtor, C.**, Mousavi, S. M. N., Széles, A., Tóth, B., Szabó, A., Nagy, J.: Evaluation of Complete Fertilizer in the Aspect of the Antioxidant Enzyme System of Maize Hybrids.
Agronomy-Basel. 11 (11), 1-14, 2021. EISSN: 2073-4395.
DOI: http://dx.doi.org/10.3390/agronomy11112129
IF: 3.949

57. Ördög, V., Stirk, W. A., Takács, G., Pőthe, P., Illés, Á., **Bojtor, C.**, Széles, A., Tóth, B., Staden, J. v., Nagy, J.: Plant biostimulating effects of the cyanobacterium Nostoc piscinale on maize (Zea mays L.) in field experiments.
S. Afr. J. Bot. 140, 153-160, 2021. ISSN: 0254-6299.
DOI: https://doi.org/10.1016/j.sajb.2021.03.026
IF: 3.111

58. Kovács, G. E., Szőke, L., Tóth, B., Kovács, B., **Bojtor, C.**, Illés, Á., Radócz, L., Moloi, M. J., Radócz, L.: The Physiological and Biochemical Responses of European Chestnut (Castanea sativa L.) to Blight Fungus (Cryphonectria parasitica (Murill) Barr).
Plants-Basel. 10 (10), 1-15, 2021. ISSN: 2223-7747.
DOI: https://doi.org/10.3390/plants10102136
IF: 4.658

59. Shojaei, S. H., Mostafavi, K., Omrani, A., Omrani, S., Mousavi, S. M. N., Illés, Á., **Bojtor, C.**, Nagy, J.: Yield Stability Analysis of Maize (Zea mays L.) Hybrids Using Parametric and AMMI Methods.
Scientifica. 2021, 1-9, 2021. EISSN: 2090-908X.
DOI: https://doi.org/10.1155/2021/5576691

Hungarian conference proceedings (11)

60. Illés, Á., **Bojtor, C.**, Ragán, P., Nagy, J.: Precíziós növénytermesztés növényvédelmi aspektusai. In: Prega Science 2020 : Scientific Conference on Precision Agriculture and Agro-Informatics, [Agroinform Média Kft.], [Budapest], 1-6, 2021.

61. Illés, Á., **Bojtor, C.**, Nagy, J.: Amerikai kukoricabogár (Diabrotica virgifera virgifera LeConte) kártételének vizsgálata szántóföldi tartamkísérletben. In: Magyar Növényvédő Mérnöki és Növényorvosi Kamara XV. Növényorvos nap, Magyar Növényvédő Mérnöki és Növényorvosi Kamara, Budapest, 109-112, 2020.

62. Kaczur, D., Illés, Á., **Bojtor, C.**, Győri, Z., Tóth, B.: Az alumínium toxicitás mérséklése baktérium készíménnyel a kukorica kezdeti növekedési stádiumában. In: LIX. Georgikon Napok Nemzetközi Tudományos Konferencia 2017. szeptember 28-29., PE Georgikon Kar, Keszthely : [elektronikus dokumentum]. Szerk.: Nagy Zita Barbara, Pannon Egyetem Georgikon Kar, Keszthely, 190-197, 2017. ISBN: 9789639639898

63. Illés, Á., Kaczur, D., **Bojtor, C.**, Győri, Z., Tóth, B.: Az ólom toxicitás mérséklési lehetőségének vizsgálata élő baktériumokat tartalmazó biológiai készítménnyel. In: LIX. Georgikon Napok Nemzetközi Tudományos Konferencia 2017. szeptember 28-29., PE Georgikon Kar, Keszthely. Szerk.: Nagy Zita Barbara, Pannon Egyetem Georgikon Kar, Keszthely, 183-189, 2017. ISBN: 9789639639898

64. Tóth, B., **Bojtor, C.**, Illés, Á., Nkebiwe, P. M., Győri, Z., Neumann, G.: Az újrahasznosítható melléktermékek és néhány baktérium vizsgálata a foszfor-utánpótlás tekintetében. In: LIX. Georgikon Napok Nemzetközi Tudományos Konferencia 2017. szeptember 28-29., PE Georgikon Kar, Keszthely. Szerk.: Nagy Zita Barbara, Pannon Egyetem Georgikon Kar, Keszthely, 538-544, 2017. ISBN: 9789639639898

65. **Bojtor, C.**, Illés, Á., Kaczur, D., Győri, Z., Tóth, B.: Két őszibarack fajtajelölt vasfelvételének vizsgálata. In: LIX. Georgikon Napok Nemzetközi Tudományos Konferencia 2017. szeptember 28-29., PE Georgikon Kar, Keszthely : [elektronikus dokumentum]. Szerk.: Nagy Zita Barbara, Pannon Egyetem Georgikon Kar, Keszthely, 39-44, 2017. ISBN: 9789639639898

66. **Bojtor, C.**, Gombás, D., Nagy, L. G., Hankovszky, G., Tóth, B.: A mangán-toxicitás mérséklése baktérium tartalmú trágyákkal. In: 56. Georgikon Napok, PE Georgikon Kar, Keszthely, 64-71, 2015.

67. **Bojtor, C.**, Tóth, B.: Egy mangánbánya iszapjának növényfiziológiai vizsgálata. In: LVII. Georgikon Napok : kivonat-kötet : programfüzet, valamint az elhangzó és poszter előadások rövid kivonatainak gyűjteménye : [agrárgazdaság a növekedéskor után] : [2015. október 1-2., Keszthely], PE Georgikon Kar, [Keszthely], 65-71, cop. 2015. ISBN: 9789639639812

68. Tóth, B., Gombás, D., **Bojtor, C.**, Hankovszky, G., Lehoczky, É.: Ipari melléktermékek vizsgálata a növények tápanyag-utánpótlásában. In: 56. Georgikon Napok, PE Georgikon Kar, Keszthely, 457-464, 2015.

69. Hankovszky, G., **Bojtor, C.**, Nagy, L., Gombás, D., Tóth, B.: Komplementációs vizsgálatok a biogáz üzemi présvíznél.
    In: 56. Georgikon Napok, PE Georgikon Kar, Keszthely, 144-152, 2015.
70. **Bojtor, C.**, Tóth, B.: Mangán toxicitás hatásának vizsgálata kukoricánál.
    In: XXI. Növénynemesítési Tudományos Napok : Összefoglalók. Szerk.: Veisz Ottó, Magyar Tudományos Akadémia Agrártudományi Kutatóközpont, Martonvásár, 65, 2015.

Hungarian abstracts (4)

71. Horváth, É., Illés, Á., Duzs, L., **Bojtor, C.**, Széles, A.: A N ellátottság hatása különböző genotípusú kukoricahibridek klorofilltartalmára eltérő évjáratban.
    In: XXIII. Tavaszi Szél Konferencia 2020: Nemzetközi Multidiszciplináris Konferencia. Absztrakt kötet I.. Szerk.: Barna Boglárka Johanna, Kovács Petra, Molnár Dóra, Pató Viktória Lilla, Doktoranduszok Országos Szövetsége, Budapest, 39-40, 2020. ISBN: 9786155586705
72. Illés, Á., Horváth, É., Duzs, L., **Bojtor, C.**, Nagy, J.: Cianobaktréium lombtrágyakezelés hatása a kukorica szemtermésének mennyiségére, makro és mikroelem tartalmára.
    In: XXIII. Tavaszi Szél Konferencia 2020: Nemzetközi Multidiszciplináris Konferencia. Absztrakt kötet I.. Szerk.: Barna Boglárka Johanna, Kovács Petra, Molnár Dóra, Pató Viktória Lilla, Doktoranduszok Országos Szövetsége, Budapest, 41, 2020. ISBN: 9786155586705
73. Bojté, C., **Bojtor, C.**, Hajósné Novák, M., Illés, Á., Horváth, B., Lovász, C., Nagy, J., Czerődiné Kempf, L., Nagy, N. E., Tímár, E., Micsinai, A.: A szója (Glycine max L.) vetőmagok genetikai homogenitás vizsgálata Maldi-TOF Készülékkel.
    In: Hungalimentaria 2019 : "Ésszel a kosárba" : konferencia és kiállítás, Wessling Hungary Kft., Budapest, 24-25, 2019.
74. **Bojtor, C.**: Mangán toxicits enyhítési lehetőségeinek vizsgálata kukoricánál.
    In: "VI. Kerpely Kálmán Szakmai Napok a Gyakorlatorientált Oktatásért" konferencia kiadvány. Szerk.: Diósi Gerda, DE Kerpely K. Szakkollégium, Debrecen, 18, 2016.

Foreign language abstracts (6)

75. Szabó, A., Illés, Á., **Bojtor, C.**, Nagy, J.: Analysis of SPAD values in FAO 380-410 maize under different nitrogen levels in long-term field experiment.
    In: Modern development of science and the latest perspectives, International Science Group, Vancouver, 13-16, 2022. ISBN: 9798887575636
76. Szabó, A., Illés, Á., **Bojtor, C.**, Nagy, J.: Evolution of maize leaf area index dynamics under different nitrogen levels.
    In: 19th Wellmann International Scientific Conference : Book of abstract. Ed.: Kiss Orsolya, University of Szeged Faculty of Agriculture, Hódmezővásárhely, 64, 2022. ISBN: 9789633068601

77. Illés, Á., **Bojtor, C.**, Bojté, C., Nagy, J.: Effects of biostimulant foliar fertilization on maize (Zea mays L.) hybrid zinc content and yield parameter.
    In: 4th Biostimulants World Congress : Abstract book for Oraland poster presentations, [s.n.], [Barcelona], 203, 2019.

78. Zelenák, A., Illés, Á., **Bojtor, C.**, Vad, A., Kith, K.: Phenometric comparison of different genotype and maturity maize hybrids.
    In: Abstract book 18th Alps-Adria Scientific Workshop. Ed.: Zoltán Kende, Csaba Bálint, Viola Kunos, Szent István Egyetemi Kiadó Nonprofit Kft., Gödöllő, 172-173, 2019. ISBN: 9789632698182

79. **Bojtor, C.**, Győri, Z., Sipos, P., Radócz, L., Tóth, B.: Effect of bean rust (Uromyces appendiculatus (Pers.) Strauss) on physiological characteristics, superoxide-dismutase and lipidperoxidase activities of common bean (Phaseolus vulgaris L.).
    In: Abstract book 17th Alps-Adria Scientific Workshop. Ed.: Kende Zoltán, Szent István Egyetemi Kiadó Nonprofit Kft., Gödöllő, 50-51, 2018. ISBN: 9789632697345

80. **Bojtor, C.**: Examination for the reduction of Manganese toxicity in case of maize.
    In: "VI. Kerpely Kálmán Szakmai Napok a Gyakorlatorientált Oktatásért" konferencia kiadvány. Szerk.: Diósi Gerda, DE Kerpely K. Szakkollégium, Debrecen, 19, 2016. ISBN: 9789634733713

Total IF of journals (all publications): 64,393
Total IF of journals (publications related to the dissertation): 18,255

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

13 December, 2022