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The Effect of Soil Heterogeneity on the Content of Macronutrients and Micronutrients in the Chickpea (*Cicer arietinum* L.)

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Abstract: Chickpea (*Cicer arietinum* L.) is one of the most important legumes currently grown. It is an important source of proteins and nutrients, such as calcium, potassium and iron. As a result, precise crop management is necessary for maximizing its production. The presented study deals with the effect of soil heterogeneity caused by variable contents of macro- and micronutrients on the uptake of nutrients by chickpea. The values measured (contents of macro- and micronutrients in plant samples) indicate that soil heterogeneity is an important factor for the contents of nutrients and soil reactions, which strongly affect the growth of chickpea. We investigated the soil heterogeneity in a chickpea field. Two zones (A and B) with different stand development were found in the model plot. Zone A showed a healthy (green) growth, while Zone B exhibited a yellow-coloured growth, indicating deficits in nutrient uptake. The contents of selected nutrients (P, K, Ca, Mg, Fe, Cu, Zn and Mn) in the soil and in the plant biomass (i.e., stems, leaves, pods and seeds) were analyzed. In the zone with the yellow-coloured biomass, the results showed significantly ($p < 0.05$) reduced contents of N, P, K, Mg, Fe, Mn, Cu and Zn in the leaves; higher values of soil reaction (pH); and higher contents of calcium and calcium carbonate in the soil. The uptake of nutrients by the plants and their translocation were affected by the above-mentioned soil parameters and by their mutual interactions. Therefore, it is possible to state that soil heterogeneity (caused by variable contents of nutrients in soil) should be taken into account in the precise crop management of chickpeas.

Keywords: chickpea; macronutrients; micronutrients; management practices; soil heterogeneity

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1. Introduction

Nowadays, mineral fertilizers have to be used to obtain proper crop yields [1], which has led to a rising demand for fertilizers [2]. Plants are able to absorb only about 50% of applied mineral fertilizers, while the rest escape into the environment with negative impacts on ecosystems [3,4]. The sustainability of ecological systems and the minimization of impacts on the environment, on the one hand, and sufficient food production, on the other hand, should be the main goals of modern agriculture [5]. The high costs of mineral fertilizers (especially nitrogenous ones), caused by the recent increase in the price of natural

gas, which is necessary for their production, has made farmers look for partial solutions, such as growing legumes [6].

One of the possible solutions to reduce the use of nitrogenous mineral fertilizers is the integration of legumes, which are able to assimilate atmospheric nitrogen through symbiosis with *Rhizobium* bacteria, into cropping systems [7]. In ideal conditions, nitrogen fixation can produce more than 100 kg/ha of N during one year, which is 85% of the overall nitrogen demand of cicer [8]. According to Flowers et al. [9], cicer can fix 140 kg/ha in one year, decreasing the occurrence of plant diseases and improving soil structure and the availability of K and P in soil [10]. According to Carlsson and Huss-Danell [11], this symbiosis enriches soil with nitrogen, which leads to reduced consumption of mineral fertilizers. Worldwide, this alternative reduces the overall fertilization of agricultural soils by 13% [7], which could lead to higher crop yields and reduced N losses into the environment.

Chickpea or cicer (*Cicer arietinum* L.), belonging to the *Fabaceae*, is a legume from southeast Turkey and Syria [12–14]. Worldwide, it is grown on approximately 17.8 million hectares, with an annual production of 17.2 million tons [15]; the main producers are India (65%), Pakistan (10%), Iran (8%) and Turkey (5.5%) [16–18]. Despite the fact that cicer is a legume grown in temperate zones and is most tolerant to high temperatures and droughts, these climatic factors can inflict 40–45% of losses in yield worldwide [19]. One reason for considering the introduction of new procedures (e.g., monitoring of soil heterogeneity) in growing chickpeas is the crop's significance for nutrition. Cicer is a high-quality source of proteins for the human population and for livestock [15,18,20]. Apart from proteins (whose concentration is twice as high as in cereals), cicer is very rich in fibre and minerals such as calcium, potassium, iron, phosphorus, magnesium, selenium and zinc [14,21].

Plot heterogeneity in terms of nutrient contents in soil and soil reactions may be reflected in the chemical composition of plants and their organs, yield and quality. There also may be some visual changes in the colour of leaves, etc. This heterogeneity can be caused by a number of biotic and abiotic factors, which may be difficult to determine. A very frequent cause of heterogeneity can be a lack of nutrients in different parts of a plot, which can be due to various factors, including a deficit of soil nutrients due to the absence of fertilization and liming and uneven application of fertilizers [22]. Many farmers try to prevent this by using technologies of precise agriculture [23]. Based on information about the contents of soil nutrients (soil sampling) and spectral analysis of growth, these technologies allow the application of optimum doses of nutrients or the identification of problematic sites in stands [24]. From the viewpoint of natural ecosystems, spatial heterogeneity in the availability of soil nutrients affects species diversity [25] and directly affects the yields of crops in agroecosystems [26,27] through the dynamics of nutrients [26,28]. Different crops have naturally different nutrient requirements (N, P, K, Ca, Mg, etc.), but there are generally valid principles which affect the uptake of nutrients in all plants [27,28]. The most important of them include mutual interactions of nutrients; for example, surplus Ca^{2+} cations in soil tend to bind P in calcium compounds [29]. In a model case, a heterogeneous plot with different contents of Ca^{2+} will have different levels of P available to crops grown in different parts of the plot. This can be resolved by variable application of fertilizers, i.e., by precision agriculture technology. According to Habib-ur-Rahman [27], the effectiveness of resources can be increased by precision agriculture when management procedures are adapted to the heterogeneity of plant growth conditions.

The goal of this study was to explain the potential influence of soil heterogeneity in terms of nutrient contents on differences in the chemical composition of individual parts of chickpea plants (stems, leaves, pods and seeds).

2. Material and Methods

2.1. Description of the Experimental Location

The health condition of chickpea plants was monitored in 2021 in Horní Moštenice, near Přerov in the Olomouc Region, Moravia, Czech Republic (Figure 1). The basic me-

teorological parameters of area of our interest are shown in Table 1. The area belongs to the sugar beet-growing region. The location is characterized by Luvisol chernozem soil on sandy–loamy sediments. The soil type of the area of interest is shown in Figure A1 (Appendix A). Two sites were selected, which exhibited different conditions for the growth of plants over the long term (Figure 1). Basic agrochemical parameters of the experimental plot (Table 2) were identified in 2019 by regular basal monitoring that is carried out in the area every three years.

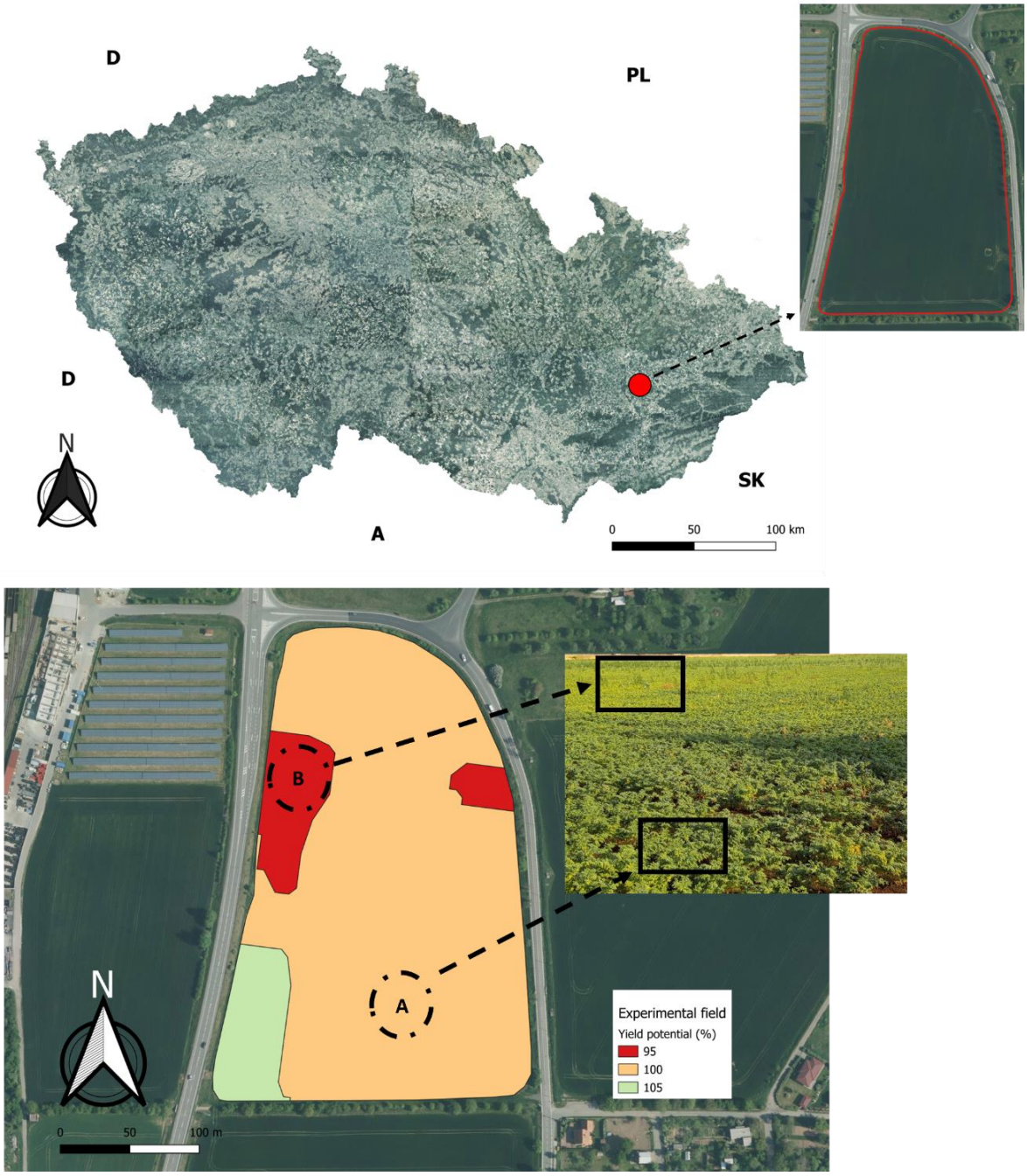

Figure 1. Map of the position of the experimental field within Central Europe and the Czech Republic (A = Austria, D = Deutschland, PL = Poland, SK = Slovakia) and the yield potential, with the zones (A and B) for the collection of soil and plant samples indicated. Source of base maps: www.cuzk.cz (accessed on 10 March 2024).

Table 1. Meteorological and climatological parameters.

Year	Mean Annual Temperature (°C)	Mean Annual Precipitation (mm)
2021	10.1	559
Long-term standard (1991–2020)	7.8	708

Comments: Meteorological data were measured using the DAVIS Vantage Pro2 weather station (Davis Instruments, Hayward, CA, USA), which was located in Horní Moštěnice (250 m a.s.l.). Data for the long-term standard (1991–2020) are for Olomouc Region and were prepared based on data available from the Czech Hydrometeorological Institute (http://portal.chmi.cz/historicka-data/ (accessed on 10 March 2024)).

Table 2. Basic agrochemical parameters of the experimental field—content of nutrients available to plants and soil reaction.

pH KCl	P ± SD	K ± SD	Ca ± SD	Mg ± SD
	mg/kg	mg/kg	mg/kg	mg/kg
6.85	46 ± 6.44	283 ± 10.75	3958 ± 384.47	220 ± 13.46

2.2. Design of the Field Experiment

The experiment was carried out with the chickpea variety Orion (*Cicer arietinum* L.), which was sown on 24 April 2021 (120 kg.ha^{-1}). The field was treated with the NP fertilizer AMMOPHOS (BelFert, Gomel, Russia; 120 kg of fertilizer/ha) 2 weeks before sowing, and 5 weeks after sowing it was treated with the nitrogen fertilizer LOVOFERT LAD 27 (80 kg of fertilizer/ha; Lovochemie Ltd., Lovosice, Czech Republic).

Plant samples (stems, leaves, pods and seeds) and soil samples were collected from two sites (Zones A and B, Figure 1), which exhibited visibly different conditions for plant growth and development, supporting (A) healthy-looking plants and (B) yellowish plants. The zones for sampling were selected based on the yield potential map. The zone with the average yield potential (=100%) represented an area (A) where the growth of chickpeas occurred without visually conspicuous changes. The zone with the lower yield potential ($\leq$95%) represented an area (B) where, evidently, there were problems with plant development that were indicated by the change in leaf colour (yellowing). The map of the yield potential (Figure 1) was prepared based on an analysis of multispectral images of the area taken over the last 8 years, and the potential was calculated by the Laboratory of Precise Agriculture PrezemLab (Assoc. Prof. Vojtěch Lukas, Mendel University in Brno), according to Lukas et al. [30].

2.3. Plant and Soil Analyses

Three mixed samples of plants and soil were collected from each zone. The mixed soil samples were collected in line with ISO 10381-6 [31] from three sampling points regularly distributed in each zone. A final mixed soil sample of 500 g (min.) was obtained from the specific sampling points after three collections from the 0–20 cm layer with the use of a sampling probe. Thus, there were three mixed soil samples collected for each variant.

The sampling of plant biomass proceeded as follows: one mixed sample contained five plants collected from three points in each repetition. There were, altogether, 3 mixed samples of plant biomass collected from each zone.

In the plant samples, contents of N, P, K, Ca, Mg, Cu, Zn, Fe and Mn were determined. All these elements (with the exception of N and P) were established with the use of atomic absorption spectrometry (AAS; Agilent 55B AA; Agilent Technologies, Santa Clara, CA, USA), according to Jones [32]. P content was measured spectrophotometrically using the Onda VIS V-10 Plus spectrophotometer (Giorgio Bormac, Carpi, Italy), according to Olsen and Summers [33]. Kjeldahl's method was used to determine the total N content in the biomass samples.

In addition to basic nutrients (macroelements) and microelements (micronutrients) in the plants, contents of macroelements (P, K, Ca and Mg) and microelements (Fe, Mn, Cu, Zn) in the soil were determined. The individual elements were established via Mehlich 3 extraction [34]. Soil reaction pH/$CaCl_2$ was determined in 0.01 M pH/$CaCl_2$ using the ion-selective electrode Radelkis OP 211 (Radelkis Electrochemical Instruments, Budapest, Hungary). The K, Mg and Ca contents of plant-available nutrients in the Mehlich 3 extract were determined using AAS (Agilent 55B AA; Agilent Technologies, Santa Clara, CA, USA), according to Sarojam [35]. P contents were determined colourimetrically, according to Olsen and Summers [33].

2.4. Statistical Analysis

For statistical analysis of the acquired data, the software STATISTICA version 13.5.0.17 (TIBCO Software Inc., Palo Alto, CA, USA) was used. The results presented in this study are means of at least 3 repetitions for each presented parameter. Statistically significant differences in the contents of selected elements in the soil, chickpea above-ground organs, and seeds of the A and B zones were obtained by *t*-tests and Tukey's post hoc HSD tests. Correlation analysis was used to establish Spearman's correlation coefficients (R) between the contents of selected elements in the soil and in the chickpea above-ground organs and seeds. The level of significance chosen for all implemented statistical analyses was $p < 0.05$. Map documents were prepared in the QGIS 3.28 programme (QGIS Development Team; General Public License), with WMS data of CUZK (State Administration of Land Surveying and Cadastre of the Czech Republic) used as underlying layers.

3. Results and Discussion

The presented study deals with the monitoring of micro- and macronutrients in soil and plant samples in plots with assumed growth differences in an experimental field. For greater clarity, the measured values are presented in two subsections.

3.1. Contents of Macro- and Micronutrients in the Soil

In general, the contents of micronutrients in the soil of the experimental variants were average to high. The highest values of microelements were measured for Mn, followed by Fe, Zn and Cu, in the two experimental variants (Table 3). There were no significant differences found between the contents of Mn and Fe within the A variants ($p > 0.05$), while a significant difference was recorded in the B variants ($p < 0.05$). In both variants, a demonstrably higher Zn content was recorded compared with that of Cu. In terms of the contents of macronutrients, a similar trend could be observed in both variants, i.e., average contents of P, K and Mg compared with high contents of Ca (Table 4).

Table 3. Contents of micronutrients in the soil.

Variants	Fe		Mn		Cu		Zn	
	mg/kg	±SD	mg/kg	±SD	mg/kg	±SD	mg/kg	±SD
Zone A	189 ± 10.44 ^{A}		205 ± 1.07 ^{B}		5.1 ± 0.006 ^{A}		9.01 ± 0.48 ^{A}	
Classification	Medium		High		High		High	
Zone B	190 ± 3.09 ^{A}		216 ± 2.92 ^{A}		5.2 ± 0.04 ^{A}		6.27 ± 0.44 ^{B}	
Classification	Medium		High		High		High	

Different letters indicate significant differences in the measured values between Zone A and Zone B at a significance level of $p < 0.05$.

The observed statistically significant differences in the contents of the selected elements in soil samples from locations A and B point to a certain degree of soil heterogeneity with respect to the presence or availability of these elements. Zone B was deficient in P, K and Zn, whereas it was enriched with Mn (Tables 3 and 4). Such soil heterogeneity can be caused by various factors and could be related to an uneven distribution of basic soil sources [36,37].

Some of the factors are of natural origin (differences in bedrock, calcium carbonate content, etc.), and others are of anthropogenic origin (level of organic and mineral fertilization, precise dosing in the individual field parts, etc.) [37–41]. Habib-ur-Rahman [27] suggested that available water capacity and slope elevation significantly affect soil heterogeneity, the latter factor being the most significant. The analysis of Shukla et al. [42] showed that soil pH is significantly correlated with concentrations of extractable Zn, Cu, Mn and Fe. In our results, statistically significant differences in soil pH were observed (Figure 2). While the value of exchange or potential soil reaction pH/$CaCl_2$ in Zone A was 6.52, i.e., slightly acid, the pH/$CaCl_2$ in Zone B was 6.84, i.e., neutral (Figure 2). The actual pH (H_2O) copied the trend of the potential pH, and it only reached higher values. The higher pH value in Zone B was related both to the higher content of soil calcium (4 504 mg/kg) and the higher content of calcium carbonate ($CaCO_3$; 0.78%) as compared with Zone B (Table 4).

Table 4. Contents of macronutrients in the soil.

Variants	$CaCO_3$		P		K (mg/kg)		Ca (mg/kg)		Mg (mg/kg)	
	%	±SD	mg/kg	±SD	mg/kg	±SD	mg/kg	±SD	mg/kg	±SD
Zone A	0.59	–	111 ± 8.06 ^{A}		190 ± 6.51 ^{A}		3 421 ± 203.05 ^{A}		180 ± 13.01 ^{A}	
Classification	Medium		Good		Good		High		Good	
Zone B	0.78	–	95 ± 0.57 ^{B}		173 ± 4.72 ^{B}		4 537 ± 33.86 ^{B}		190 ± 4.08 ^{A}	
Classification	Medium		Good		Sufficient		High		Good	

Different letters indicate significant differences in the measured values between Zone A and Zone B at a significance level of $p < 0.05$.

Furthermore, the greatest difference in our results between Zone A and Zone B was observed in the lower soil Zn content in Zone B (Table 3). In contrast, the content of Mn was higher in Zone B compared with Zone A. Such a decrease can be connected to a higher $CaCO_3$ concentration [42], which was the case in this study (0.59% $CaCO_3$ in Zone A versus 0.78% $CaCO_3$ in Zone B). Cicer improves soil zinc availability [12], which positively affects the development of symbiotic nodules and nitrogen fixation [43,44].

The contents of soil macronutrients exhibited a significant decrease in P and K in Zone B (Tables 4, A1 and A2). Conversely, the Ca content in Zone B was higher (4504 mg/kg) than in Zone A (3455 mg/kg). Contents of macronutrients in the soil (established via Mehlich 3 extraction) can be evaluated verbally, according to Joines and Hardy [45], as "low–sufficient–good–high–very high." When the content of a particular nutrient is high or very high, fertilization with the nutrient is not necessary. In our case, only high contents of calcium in the soil were found in both zones. The contents of the other macroelements (or basic nutrients) were "good" or only "sufficient" in the case of potassium in Zone B (Table 4). The low content of a nutrient in soil indicates a low content of the nutrient in plants, which was demonstrated in the case of N in the chickpea leaves in Zone B (Figure 3). Basic soil parameters measured in the two zones did not show any extreme values, and their contents in the soil were likely affected by the soil management system and the soil type in the given region.

The observed fluctuations in the contents of the macronutrients (or plant-available nutrients) P, K and Ca between the variants (zones) were probably caused by plot heterogeneity based on different soil conditions (soil nutrient contents) and water regimes (field water capacities, Table 5) [36,38,46]. According to Liu et al. [37], soil heterogeneity has two components: qualitative and configuration components. The qualitative component defines differences in the contents of specific parameters (e.g., nutrients in specific areas), and the configuration component defines the size of these areas. In the presented study, the area was not defined in terms of its size and precise location. The goal was to find out whether real differences existed between two qualitatively different zones (according to indications of growth conditions and different yield potentials) in terms of contents of plant and soil nutrients (Figure 1 and Table 5). Based on the measured values of the contents

of micro- and macronutrients, it was possible to state that a difference existed between Zone A and Zone B with respect to their suitability for growing chickpeas.

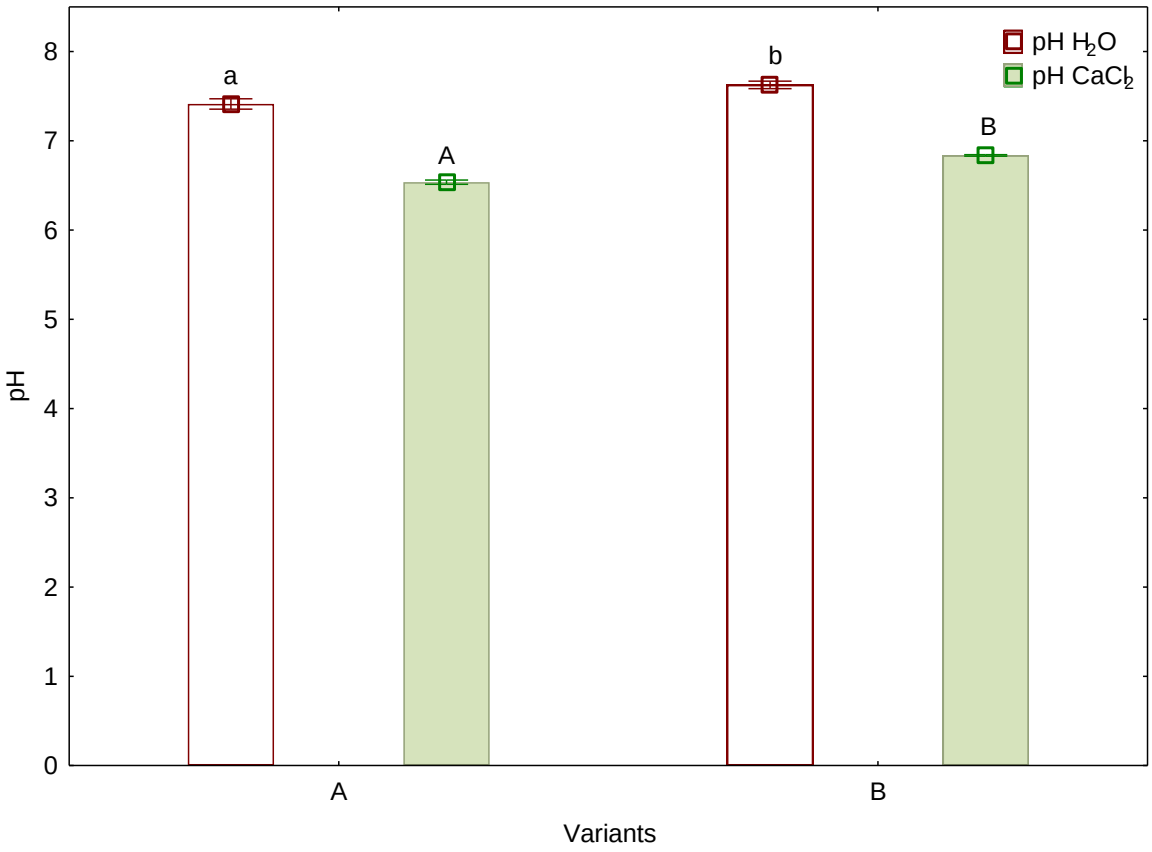

Figure 2. Mean values of actual (pH H_2O) and potential (pH $CaCl_2$) soil reaction (n = 3) ± SDs. Different lowercase letters indicate significant differences in pH H_2O ($p < 0.05$; ANOVA Tukey's post hoc HSD test); different capital letters indicate significant differences in pH $CaCl_2$.

Table 5. Differences in contents of macronutrients between individual variants of the experiment and initial states.

Differences in Contents of Plant-Available Nutrients	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
Zone A	65 *	−93 *	−537	−40
Zone B	49 *	−110 *	579	−30

The * symbol indicates a significant difference ($p < 0.05$, *t*-test) between the individual variants with respect to one nutrient and the initial state in 2019.

3.2. Contents of Macro- and Micronutrients in Plant Samples

The plant materials were analyzed separately for contents of micronutrients (Fe, Mn, Cu and Zn—Figure 3) and macronutrients (N—Figure 4; P, K, Ca and Mg—Figure 5) in roots, stems, leaves and seeds. What was particularly interesting in our observations was the reduced contents of all microelements (Figure 3) in the leaves in Zone B as compared to Zone A and there being no change in their contents in the seeds between the two zones (Figure 3). This reduction in the contents of microelements in chickpea leaves (at medium to high contents in the soil) could be attributed to inappropriate soil properties, particularly alkaline soil reactions, a high content of soil calcium and a high content of calcium carbonate in the soil of Zone B. Moreover, mutually negative interactions are likely to exist in the uptake of nutrients by roots in the form of ion antagonism.

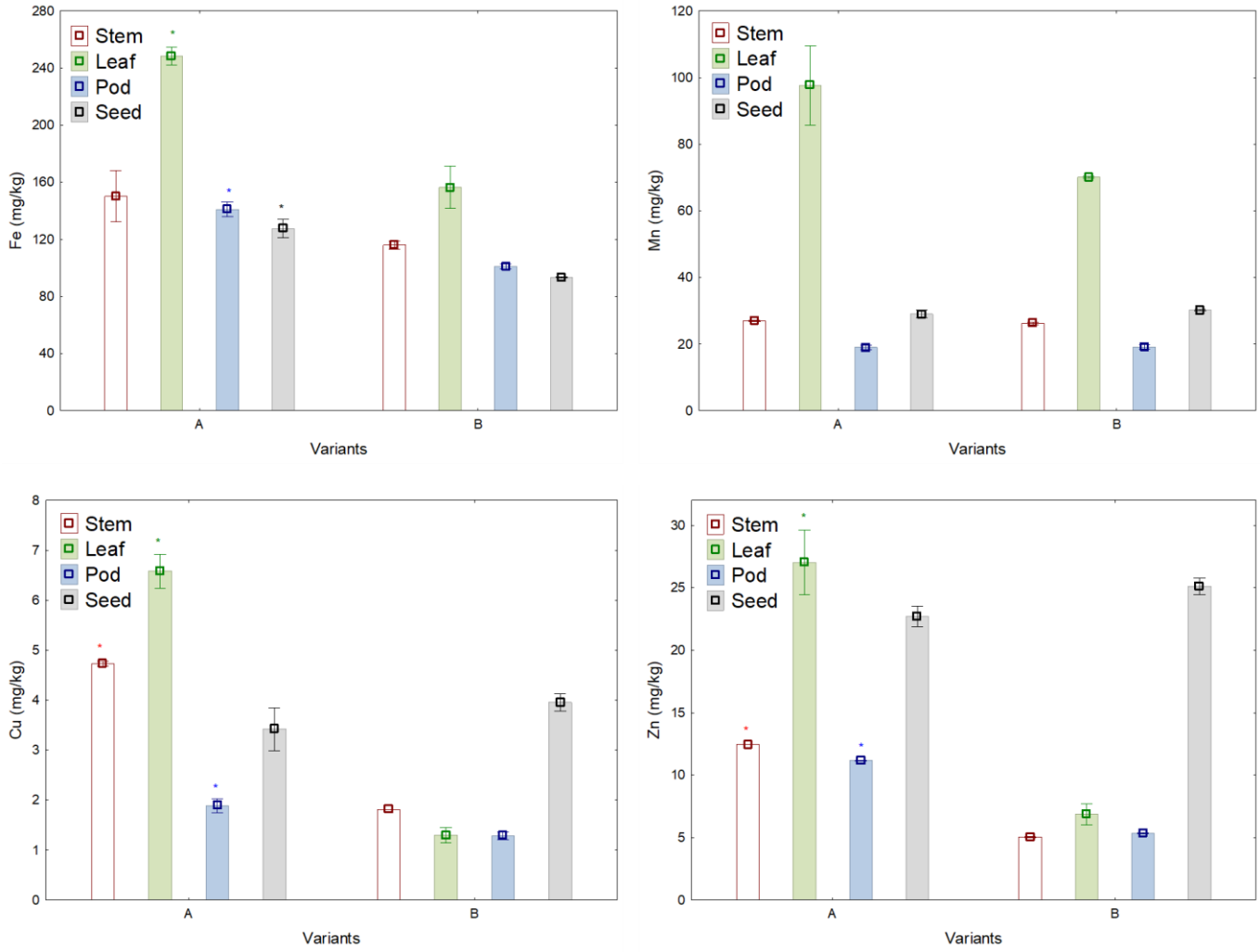

Figure 3. Contents of micronutrients—Fe (A), Mn (B), Cu (C) and Zn (D)—in selected plant organs (stem, leaves and pods) and seeds. Columns represent average values of the contents of elements (n = 3) ± SDs. The * symbol indicates a significant difference ($p < 0.05$, *t*-test) between the individual variants with respect to one nutrient and a specific plant organ.

The analysis of micronutrient (Figure 3, Table A3) contents in plant organs revealed that, in the case of Fe, its presence was significantly reduced by 44.22% in leaf tissues and by 31.98% in pods. In the case of Mn contents, no significant differences were observed in any of the selected organs or seeds. The contents of Cu in Zone B were significantly reduced in the stems, leaves and pods by 62.1, 83.43 and 40.01%, respectively. The Zn contents in Zone B were also significantly lower in the stems, leaves and pods by 58.95, 79.6 and 51.93%, respectively. The recorded contents of micronutrients in seeds differed significantly between the A and B plants only in the case of Fe.

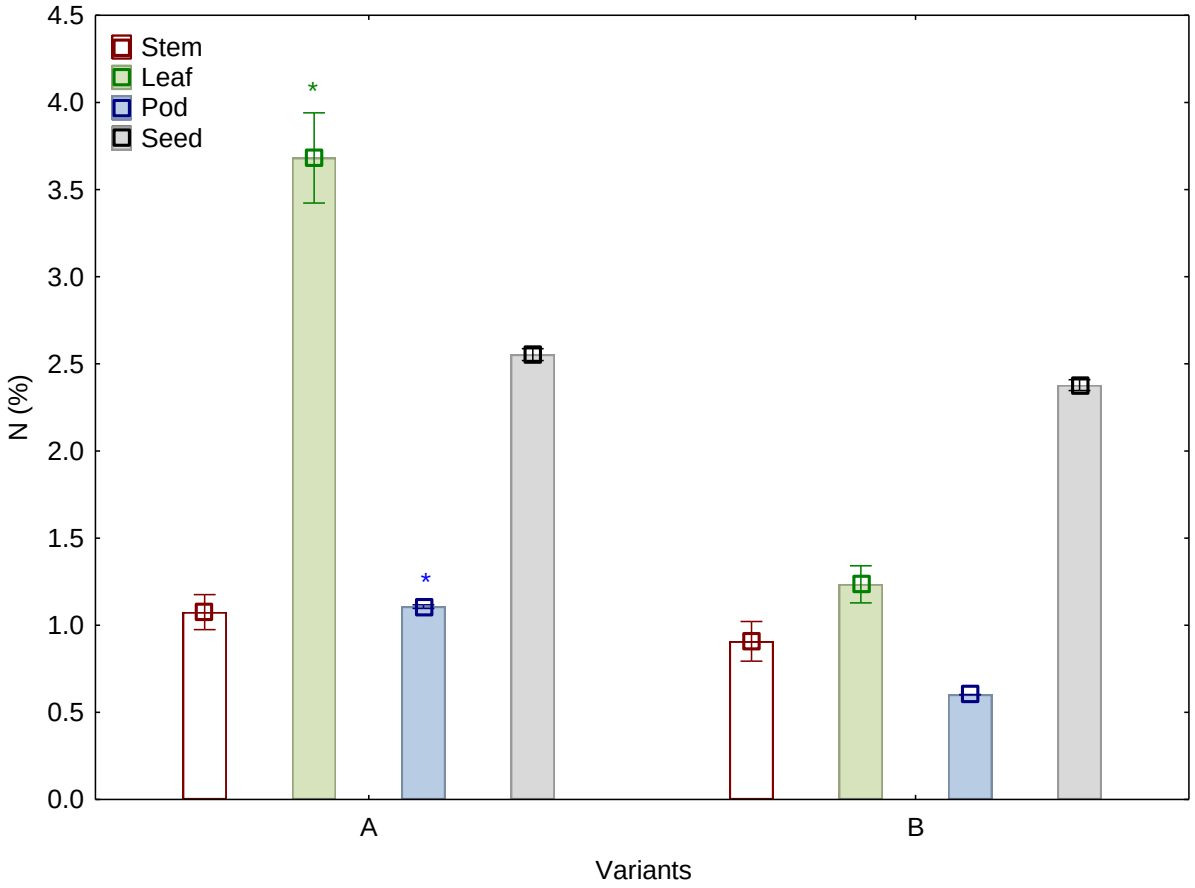

Figure 4. N contents in selected plant organs (stems, leaves and pods) and seeds. Columns represent average values for N contents (n = 3) ± SDs. The * symbol indicates a significant difference ($p < 0.05$, *t*-test) between the individual variants with respect to a specific plant organ.

The B-variant chickpea plants were recognizable by yellowish leaves, which can point to an imbalance in the availability of micro- and macronutrients. This particularly relates to the content of Fe, which was demonstrably lower in the leaves of the B plants. The analysis of the presence of the selected elements revealed deficiencies in those that are responsible for the sufficient production of chlorophyll and the proper functioning of photosynthesis. Iron (Fe), which is an important element in the biosynthesis of chlorophyll [47], is a vital component of various enzymes [48]. It is also present in various protein complexes involved in the processes of photosynthesis [49]. In a study by Mahmoudi et al. [50], chickpeas with iron deficiency suffered from yellowing of young leaves, a large decrease in chlorophyll concentration and a significant decline in plant biomass. However, a decrease in iron content is more damaging in roots than in shoots [51]. When compared to other legumes, chickpea shows stronger resistance to Fe deficiency. This resistance could be explained by the higher seed iron reserves in chickpea [51]. In our analysis, the Fe content in the leaves of the B plants was reduced to 156.49 mg/kg as compared with 248.40 mg/kg recorded in the leaves of the A plants (Figure 3).

The main factors responsible for reduced cicer yields include a lack of nutrients, namely, zinc (Zn), and low soil fertility [52,53]. Zinc is important for the proper development of plants, especially pollen, and can negatively affect their reproduction [44]. The content of Zn in leaves was markedly reduced to 6.86 mg/kg in Zone B, while in Zone A it reached 27.02 mg/kg. The differences in Zn contents recorded in the individual parts of plants between Zone A and B, namely, in the stems, leaves and pods, were some of the most distinct for all the micronutrients assessed (Figure 3).

Copper (Cu) is an important micronutrient, and it is necessary for proper growth of the plant body. In our study, the Cu contents in the B variants were significantly reduced; for example, the Cu content in the leaves in Zone A was 6.58 mg/kg, and in Zone B it was 1.29 mg/kg. Chickpea can increase the bioavailable content of Cu in the soil. In mixed cropping systems, chickpea significantly increased the content of Cu in the roots of *Eucalyptus globulus* [54]. According to Kambhampati et al. [55], chickpea is a cost-effective and environmentally friendly accumulator of Cu. However, the addition of Ethylenediaminetetraacetic acid (EDTA) is necessary for the acceleration of Cu absorption. Cu deficiency results in smaller and chlorotic leaves as well as reduced contents of nitrogen, starch and sugars [56].

Manganese (Mn) is involved in a number of enzymatic processes in plants. Its content in the leaves was 97.68 mg/kg in Zone A and 70.13 mg/kg in Zone B. However, the difference was not statistically significant ($p > 0.05$).

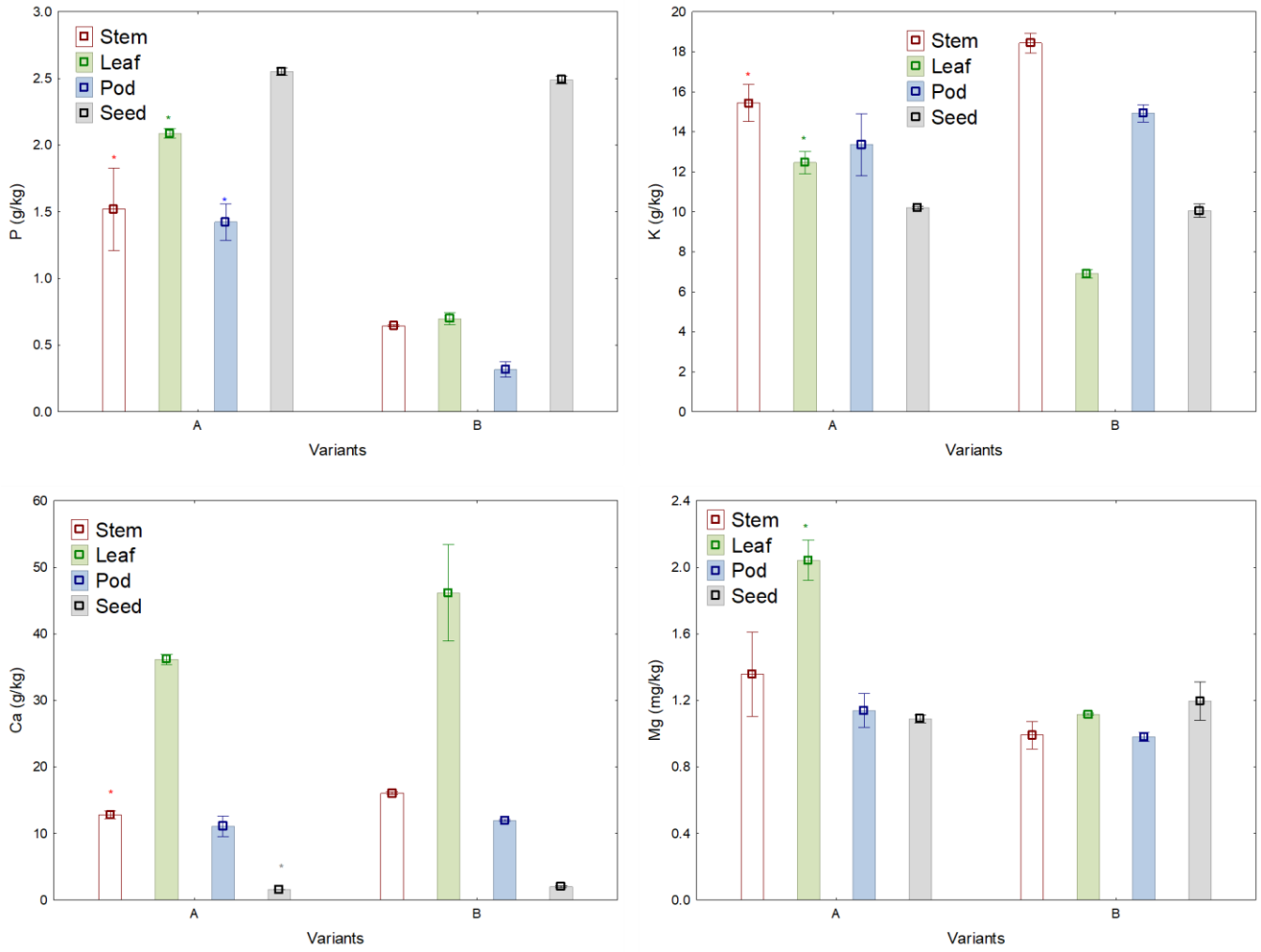

Figure 5. Contents of P, K, Ca and Mg macronutrients in selected plant organs (stems, leaves and pods) and seeds. Columns represent average values of the contents of elements (n = 3) ± SDs. The * symbol indicates a significant difference ($p < 0.05$, *t*-test) between the individual variants with respect to one nutrient and a specific plant organ.

In many instances, the contents of macronutrients (N—Figure 4; P, K, Ca and Mg—Figure 5) in plant organs and seeds showed a similar trend to those of microelements. Particularly interesting was the significant decrease in N, P, K and Mg in the leaves of plants growing in Zone B compared with Zone A and an increased content of Ca in Zone B as compared with Zone A. However, the differences were not significant (Figure 5, Tables A4 and A5). The

reduced contents of macronutrinetss in the chickpea leaves were caused mainly by alkaline soil reactions, the high Ca content in the soil, and the higher content of $CaCO_3$ in the soil of Zone B compared to Zone A. Antagonism between Ca, K and Mg resulted in reduced K and Mg contents in the leaves (Figure 5).

Plants of the B variant (location) were less able to take up nitrogen, and its content (%) was significantly decreased in the chickpea leaves and pods. The largest decrease was detected in leaves, where the N content was lower by 83.43% (Figure 4). A noticeable depletion of P in Zone B was recorded, the content of which was significantly reduced in the chickpea stems, leaves and pods by 64.93%, 69.22% and 76.03%, respectively. There were no statistically significant differences observed in the seeds of the A and B chickpea variants. The contents of K in the stems and leaves varied significantly between Zones A and B. The content of K in the stems of the A-variant plants increased by 9.08%, whereas in the leaves it decreased by 43.74%. In Zone B, contents of Ca in the stems, leaves and seeds of the chickpea plants significantly increased by 17.71%, 30.66% and 16.24%, respectively. In the case of Mg, a statistically significant difference was recorded only in the leaves, where Mg was decreased by 48.08% (Figure 5). No significant differences were observed in the stems, pods and seeds of chickpeas grown in the A and B zones (Figure 5). Mg is also important in the primary productivity of plants due to its crucial role in the structure of chlorophyll [57].

Another important macronutrient, P, was significantly decreased in the stems, leaves and pods in Zone B (Figure 5). A lack of P is detrimental to the overall fitness of chickpea [58]. Yahiya et al. [59] investigated the effect of P on the nodulation and N fixation of chickpea, and the results showed that P had no direct effect on the nodules. However, the inoculation of chickpea with phosphate-solubilizing bacteria increased the fitness of chickpeas [60]. P is a basic macronutrient, and legumes which bind atmospheric N have higher P requirements than legumes fertilized with mineral N. Therefore, P deficiency results in lower activity with respect to the symbiotic fixation of N, as well as growth retardation and lower subsequent P accumulation in plant biomass [61].

Multiple studies [61–63] have researched the effect of excessive salt content (Mg^{2+}, K^+, Na^+, Cl^-, etc.) in soil on the overall fitness of chickpeas. In our results, only the content of K in the soil was determined to be an indicator of soil salinity (Table 2—initial state from 2019 and Table 4—situation during the field experiment in 2021). This is very important, because Gul and Ullah [62] found that the sodium cation (Na^+) content in chickpeas was significantly affected by salinity. High concentrations of chlorine anions (Cl^{-1}) in chickpea leaves were tolerated, while the increased presence of Na^+ caused growth impairment in multiple phenotypes. Saxena and Rewari [63] found that Na^+ affected the nodulation ability of chickpea, and nodule and shoot dry weights were reduced to 55% and 58%, respectively, in the control. The presence of elevated Na^+ content could have also decreased the content of K^+ [64]. Different results were obtained by Turner et al. [65], where chickpea genotypes more susceptible to salt stress exhibited higher concentrations of Na^+ and K^+ (106 and 364 $\mu mol.g^{-1}$ DW, respectively) under salt stress. The excessive accumulation of Na^+ in the leaf mesophyll cells resulted in structural damage to chloroplasts. The resistance of some of the studied genotypes was caused by the ability to exclude excessive Na^+ from the photosynthetically active mesophyll cells [66]. The ability of chickpea to create nodules under salt stress is mediated by the presence of Zn and phosphates [63]. In our results, the Zn and P contents in the above-ground chickpea parts were significantly decreased in Zone B (Figures 3 and 5).

The regression analysis showed that the dependence of the concentrations of selected elements in plant organs on their contents in the soil was lowest in seeds, where only the Ca content depended on the presence of Ca in the soil (Table 6). In stems, the presence of Ca, Cu, Zn and Mg correlated with their presence in the soil. In leaves, the contents of Cu, K, and Zn correlated with their contents in the soil. Finally, Cu, Zn and Mg contents in pods depended on the presence of these selected elements in the soil. The content of Mn in the selected chickpea organs was not correlated with the Mn content in the soil (Table 6).

Table 6. Simple linear regression analysis results of the relation between the contents of selected macronutrients (Ca, K and Mg) and micronutrients (Fe, Mn, Cu and Zn) in the chickpea plant organs (stems, leaves, pods and seeds) and in the soil.

Organ	Element	Regression Coefficient	*p* Value	SE of Estimation	F
Stem	Ca	0.9872	0.0002 *	0.3397	153.1783
	P	0.3729	0.4666	0.6085	0.6461
	Cu	0.8896	0.0176	0.8156	15.1795
	Fe	0.7721	0.0720	19.3931	5.9057
	K	0.8356	0.0383	1.2312	9.2553
	Zn	0.8973	0.0153	1.9978	16.5316
	Mn	0.3623	0.4804	0.6615	0.6043
	Mg	0.9771	0.0008 *	0.0844	84.3579
Leaf	Ca	0.5832	0.2243	8.8070	2.0622
	P	0.8054	0.0531	0.5065	7.3876
	Cu	0.9116	0.0114	1.3431	19.6772
	Fe	0.2896	0.5778	57.1325	0.3662
	K	0.9616	0.0022 *	0.9558	49.0872
	Zn	0.9732	0.0011 *	2.9401	71.7409
	Mn	0.7297	0.0997	15.2389	4.5561
	Mg	0.5980	0.2099	0.4700	2.2271
Pod	Ca	0.4926	0.3208	1.7234	1.2818
	P	0.6901	0.1292	0.5077	3.6377
	Cu	0.9025	0.0138	0.1796	17.5632
	Fe	0.3396	0.5101	23.8670	0.5216
	K	0.6277	0.1821	1.7115	2.6011
	Zn	0.8998	0.0146	1.5591	0.7518
	Mn	0.3106	0.5491	1.0739	0.4270
	Mg	0.9645	0.0019 *	0.0425	53.3639
Seed	Ca	0.8664	0.0256	0.1572	12.0407
	P	0.1919	0.7158	0.06	0.1529
	Cu	0.2580	0.6216	0.6332	0.2852
	Fe	0.4121	0.4169	20.3876	0.8181
	K	0.5086	0.3029	0.3605	1.3957
	Zn	0.3977	0.4348	1.7868	0.7518
	Mn	0.3194	0.5372	1.5507	0.4544
	Mg	0.0446	0.9331	0.1578	0.0080

Results of a simple linear regression analysis of the relation between the contents of selected elements in the soil and in selected chickpea plant organs and seeds are shown. Statistical significant correlation at level of $p < 0.05$ is illustrated with red colour. The * symbol indicates that the difference was significant, also at a significance level of $p < 0.01$.

To obtain certain elements, especially micronutrients, plants need to control several steps during the journey from soil to seed, such as uptake, transport, remobilization and storage [67]. Apart from internal factors, the environment also influences the rate of micronutrient absorption [68–70]. The presence of phosphorus increases the contents of Ca, Mg, Fe, Mn and Zn in wheat, while it decreases the contents of Ca, Mg, Fe and Zn in chickpea [68]. In our results, we could observe a decreased content of phosphorus in the soil of Zone B and decreased contents of Mg, Fe and Zn in the chickpea leaves. Another external factor that affects the uptake of micronutrients is arbuscular mycorrhiza [69].

In our results, we did not observe a correlation between Fe contents in any of the observed chickpea organs and seeds. Contrary to this result, Mahmoudi et al. [51] revealed that the Fe content in plant tissues was strongly dependent on the Fe content in the soil.

4. Conclusions

The measured values confirm that, to reach the maximum effectiveness in producing important crops such as chickpea (*Cicer arietinum* L.), field and soil heterogeneity must be

considered. In our study, we revealed the effect of the heterogeneity of certain elements (nutrients) and soil reactions on the ability of chickpea to uptake and translocate these elements into plant organs and seeds, thus proving that soil heterogeneity strongly affects the overall fitness of chickpea. The experimental plot we used was situated in a flatland with a relatively homogeneous chernozem soil type. The measured data indicated that extreme soil heterogeneity could be detected, even on the site which did not otherwise show it, at a level that affects the development of plants. The heterogeneity in the presented study consisted in the variable contents of carbonates in the soil and related changes in soil reactions, which were demonstrated by changes in plant uptake of nutrients and their translocation within the plant. In many cases, farmers can influence detected plot heterogeneity by taking appropriate measures (mineral and organic fertilization, liming, etc.) using a system of precision agriculture—in other words, a system of targeted farming. In this case, a crucial measure appears to be reduced input of calcium fertilizers in the parts of a plot that exhibit increased contents of carbonates in the soil.

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Appendix A

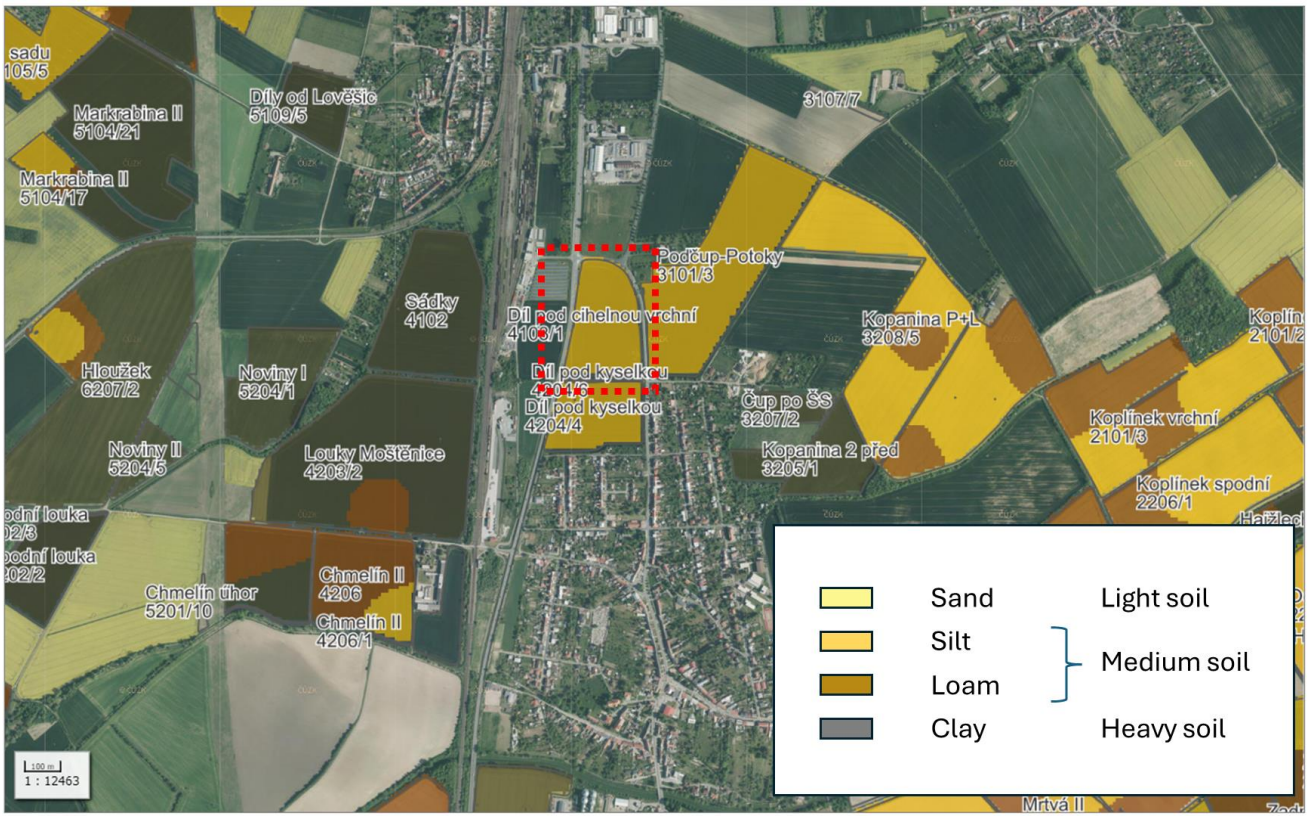

Figure A1. Soil type in the area of interest and the experimental field (marked in red). Source of data: PREFARM© system (MJM, Ltd., Litovel, Czech Republic).

Appendix B

Table A1. Results of *t*-test statistical analysis for independent samples according to groups—contents of macroelements in the soil.

Variable	Average A	Average B	Value		*p*	Number of A Values	Number of B Values	±SD A	±SD B	F	*p*
P	113.578	95.233	3.60617	4	0.022634	3	3	8.7538	1.00167	76.37357	0.025849
K	190.333	173.000	2.87122	4	0.045413	3	3	6.5064	8.18535	1.58268	0.774390
Mg	180.333	190.333	−1.12827	4	0.322297	3	3	13.3167	7.63763	3.04000	0.495050
Ca	3421.500	4537.000	−7.06657	3	0.005826	2	3	287.7925	58.66004	24.06989	0.078248

Statistical significant differences between individual variants of experiment in content of macro(nutrients)elements ($p < 0.05$) is illustrated with red color.

Table A2. Results of *t*-test statistical analysis for independent samples according to groups—contents of microelements in the soil.

Variable (mg/kg)	Average A	Average B	Value		*p*	Number of A Values	Number of B Values	±SD A	±SD B	F	*p*
Fe	188.1700	190.5440	−0.21800	4	0.838095	3	3	18.08849	5.344287	11.45578	0.160568
Mn	204.7267	215.6800	−3.51752	4	0.024505	3	3	1.85133	5.065807	7.48735	0.235645
Cu	5.1200	5.0500	1.91703	4	0.127708	3	3	0.01000	0.062450	39.00000	0.050000
Zn	9.0267	6.2700	4.27192	4	0.012930	3	3	0.82470	0.754387	1.19510	0.911119

Statistical significant differences between individual variants of experiment in content of micro(nutrients)elements ($p < 0.05$) is illustrated with red color.

Table A3. Results of *t*-test statistical analysis for independent samples according to groups—contents of microelements in individual plant parts.

Variable	Average A	Average B	Value		*p*	Number of A Values	Number of B Values	±SD A	±SD B	F	*p*
Parameter: Fe (mg/kg)											
Stem	150.1387	116.1050	1.869704	4	0.134877	3	3	31.10846	5.12638	36.8244	0.052876
Leaf	248.4022	156.4934	5.662339	4	0.004796	3	3	11.15334	25.80693	5.3538	0.314772
Pod	141.0395	101.0936	7.249932	4	0.001922	3	3	9.03939	3.06005	8.7261	0.205632
Seed	127.6415	93.4381	5.321621	4	0.005999	3	3	11.11641	0.59497	349.0868	0.005713
Parameter: Mn (mg/kg)											
Stem	27.00713	26.19582	1.960562	4	0.121476	3	3	0.40521	0.591214	2.129	0.639239
Leaf	97.68317	70.12653	2.318110	4	0.081305	3	3	20.58257	0.547139	1415.155	0.001412
Pod	19.00216	19.18008	−0.193791	4	0.855783	3	3	1.21092	1.030787	1.380	0.840323
Seed	29.04051	30.19522	−0.958327	4	0.392167	3	3	2.07546	0.218916	89.882	0.022007
Parameter: Cu (mg/kg)											
Stem	4.728312	1.813914	54.20307	4	0.000001	3	3	0.093062	0.003547	688.5556	0.002900
Leaf	6.581654	1.297449	14.22110	4	0.000142	3	3	0.582956	0.272701	4.5698	0.359080
Pod	1.891200	1.291513	3.71838	4	0.020503	3	3	0.245971	0.132395	3.4516	0.449274
Seed	3.422010	3.957789	−1.15651	4	0.311839	3	3	0.742713	0.303711	5.9803	0.286522
Parameter: Zn (mg/kg)											
Stem	12.44880	5.05823	131.9236	4	0.000000	3	3	0.010227	0.096492	89.02685	0.022216
Leaf	27.02489	6.86004	7.3801	4	0.001797	3	3	4.493783	1.484147	9.16791	0.196697
Pod	11.16978	5.33553	93.8513	4	0.000000	3	3	0.059551	0.089706	2.26919	0.611773
Seed	22.71773	25.11203	−2.2877	4	0.084068	3	3	1.412992	1.135567	1.54830	0.784838

Statistical significant differences between individual variants of experiment in content of Fe, Mn, Cu and Zn ($p < 0.05$) is illustrated with red color.

Table A4. Results of *t*-test statistical analysis for independent samples according to groups—contents of macroelements in individual plant parts.

Variable	Average A	Average B	Value		*p*	Number of A Values	Number of B Values	±SD A	±SD B	F	*p*
Parameter: N (%)											
Stem	1.519458	0.645628	2.82313	4	0.047676	3	3	0.535946	0.013353	1611.008	0.001241
Leaf	2.089035	0.698369	23.83607	4	0.000018	3	3	0.062298	0.079565	1.631	0.760119
Pod	1.423570	0.316445	7.52089	4	0.001673	3	3	0.234417	0.100289	5.463	0.309431
Seed	2.552791	2.490321	1.60241	4	0.184325	3	3	0.048473	0.047010	1.063	0.969376
Parameter: P (g/kg)											
Stem	1.519458	0.645628	2.82313	4	0.047676	3	3	0.535946	0.013353	1611.008	0.001241
Leaf	2.089035	0.698369	23.83607	4	0.000018	3	3	0.062298	0.079565	1.631	0.760119
Pod	1.423570	0.316445	7.52089	4	0.001673	3	3	0.234417	0.100289	5.463	0.309431
Seed	2.552791	2.490321	1.60241	4	0.184325	3	3	0.048473	0.047010	1.063	0.969376
Parameter: K (g/kg)											
Stem	15.43472	18.43853	−2.87274	4	0.045343	3	3	1.598768	0.850849	3.53074	0.441429
Leaf	12.45889	6.90129	9.25038	4	0.000759	3	3	0.977703	0.356329	7.52856	0.234506
Pod	13.35620	14.92493	−0.97146	4	0.386330	3	3	2.695461	0.746606	13.03417	0.142509
Seed	10.19347	10.05765	0.40544	4	0.705904	3	3	0.116292	0.568471	23.89572	0.080335
Parameter: Ca (g/kg)											
Stem	12.82150	16.06492	−5.17691	4	0.006620	3	3	1.018377	0.37480	7.3825	0.238591
Leaf	36.17069	46.16988	−1.36870	4	0.242925	3	3	1.308391	12.58589	92.5322	0.021383
Pod	11.08363	11.99436	−0.58697	4	0.588754	3	3	2.681937	0.17110	245.7086	0.008107
Seed	1.56556	2.01582	−3.62568	4	0.022245	3	3	0.042804	0.21080	24.2534	0.079197
Parameter: Mg (g/kg)											
Stem	1.357471	0.991020	1.373126	4	0.241656	3	3	0.440246	0.140879	9.7655	0.185778
Leaf	2.042080	1.116067	7.580073	4	0.001624	3	3	0.211358	0.010004	446.3230	0.004471
Pod	1.139188	0.980919	1.508301	4	0.205970	3	3	0.176385	0.043826	16.1981	0.116292
Seed	1.088609	1.196372	−0.919453	4	0.409888	3	3	0.039462	0.199129	25.4636	0.075575

Statistical significant differences between individual variants of experiment in content of N, P, K, Ca and Mg ($p < 0.05$) is illustrated with red color.

Table A5. Results of statistical analysis via Tukey's post hoc HSD test—contents of macroelements in individual plant parts.

Parameter: P (mg/kg)								
Variants	**A—Stem**	**A—Leaf**	**A—Pod**	**A—Seed**	**B—Leaf**	**B—Pod**	**B—Seed**	**B—Stem**
A—Stem		0.073303	0.999106	0.000592	0.004728	0.000238	0.001018	0.002699
A—Leaf	0.073303		0.026185	0.207612	0.000181	0.000175	0.353142	0.000178
A—Pod	0.999106	0.026185		0.000321	0.013572	0.000360	0.000463	0.007574
A—Seed	0.000592	0.207612	0.000321		0.000175	0.000175	0.999947	0.000175
B—Leaf	0.004728	0.000181	0.013572	0.000175		0.409081	0.000175	0.999983
B—Pod	0.000238	0.000175	0.000360	0.000175	0.409081		0.000175	0.580214
B—Seed	0.001018	0.353142	0.000463	0.999947	0.000175	0.000175		0.000175
B—Stem	0.002699	0.000178	0.007574	0.000175	0.999983	0.580214	0.000175	
Parameter: K (mg/kg)								
Variants	**A—Stem**	**A—Leaf**	**A—Pod**	**A—Seed**	**B—Leaf**	**B—Pod**	**B—Seed**	**B—Stem**
A—Stem		0.134553	0.490919	0.002107	0.000177	0.999512	0.001652	0.128371
A—Leaf	0.134553		0.984106	0.391229	0.001219	0.298115	0.326429	0.000638
A—Pod	0.490919	0.984106		0.097769	0.000364	0.778691	0.077000	0.002800
A—Seed	0.002107	0.391229	0.097769		0.077875	0.005323	1.000000	0.000179
B—Leaf	0.000177	0.001219	0.000364	0.077875		0.000182	0.098860	0.000175
B—Pod	0.999512	0.298115	0.778691	0.005323	0.000182		0.004137	0.052254
B—Seed	0.001652	0.326429	0.077000	1.000000	0.098860	0.004137		0.000178
B—Stem	0.128371	0.000638	0.002800	0.000179	0.000175	0.052254	0.000178	
Parameter: Mg (mg/kg)								
Variants	**A—Stem**	**A—Leaf**	**A—Pod**	**A—Seed**	**B—Leaf**	**B—Pod**	**B—Seed**	**B—Stem**
A—Stem		0.014492	0.881953	0.735994	0.821678	0.369054	0.972995	0.399907
A—Leaf	0.014492		0.001256	0.000769	0.000999	0.000345	0.002315	0.000366
A—Pod	0.881953	0.001256		0.999982	1.000000	0.975447	0.999959	0.982905
A—Seed	0.735994	0.000769	0.999982		1.000000	0.997426	0.997415	0.998631
B—Leaf	0.821678	0.000999	1.000000	1.000000		0.989867	0.999609	0.993576
B—Pod	0.369054	0.000345	0.975447	0.997426	0.989867		0.888437	1.000000
B—Seed	0.972995	0.002315	0.999959	0.997415	0.999609	0.888437		0.909912
B—Stem	0.399907	0.000366	0.982905	0.998631	0.993576	1.000000	0.909912	
Parameter: Ca (mg/kg)								
Variants	**A—Stem**	**A—Leaf**	**A—Pod**	**A—Seed**	**B—Leaf**	**B—Pod**	**B—Seed**	**B—Stem**
A—Stem		0.000399	0.999698	0.115134	0.000175	0.999998	0.141609	0.985386
A—Leaf	0.000399		0.000264	0.000175	0.202119	0.000322	0.000175	0.001387
A—Pod	0.999698	0.000264		0.247113	0.000175	0.999996	0.295686	0.874817
A—Seed	0.115134	0.000175	0.247113		0.000175	0.167709	1.000000	0.023143
B—Leaf	0.000175	0.202119	0.000175	0.000175		0.000175	0.000175	0.000180
B—Pod	0.999998	0.000322	0.999996	0.167709	0.000175		0.203907	0.950893
B—Seed	0.141609	0.000175	0.295686	1.000000	0.000175	0.203907		0.029132
B—Stem	0.985386	0.001387	0.874817	0.023143	0.000180	0.950893	0.029132	

Statistical significant differences between individual plant organs in content of P, K, Mg and Ca (Tukey's post hoc HSD test, $p < 0.05$) is illustrated with red color.

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