MAIZE NUTRIENT UPTAKE AFFECTED BY GENOTYPE AND FERTILIZATION

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The content of nutrients in maize are commonly related with fertilization and soil
quality and rarely explained with the individual hybrid properties. Therefore, the aim of
this study is to access a long term fertilization system on ear leaf of Mg, Fe, Mn and Cu
content in six maize hybrids(NS 3014, NS 4015, NS 5043, NS 6010, NS 6030 and NS
7020). Samples were collected from a long-term experiment at the Rimski Šančevi
experimental field of the Institute of Field and Vegetable Crops in Novi Sad. The study
included maize monoculture and 2-year rotations with the application of NPK and
manure. Results showed that ear Mg content was influenced with the treatments, hybrid
and their interaction and ranged from 1.77-2.69 g kg^{-1}. Iron variability was significantly
affected with the treatments and interaction (hybrid x treatments) in range from 103.2
to151.9g kg^{-1}. The ear manganese content (41.1-63.6g kg^{-1}) derived from treatments and
hybrid effect and Cu (12.3-23.6 g kg^{-1}) was significantly influenced with treatments.
Across all treatments, in average, NS6030 had higher values of nutrient and NS3014 was
lower in ear nutrient content. This indicates that vegetation length could favor nutrient
accumulation. Obtained results suggested that even on fairly productive soil such as
Chernozem hybrid selection and the balanced fertilization is crucial for managing the
maize nutrient content.

Key words: genotype, fertilization, micronutrients, maize, cropping system.

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INTRODUCTION

Maize (*Zea mays* L.) is the most widespread crop in Serbia, covering a total area of 1.2-1.3 million ha. Increased yield and improved quality are the most important goals in maize breeding. However, achieving maximal genotype potential depends on the availability of water and nutrient resources in the soil, pests and diseases controls, as well as agronomic management (BEKAVAC *et al.*, 2007; JOVANOVIĆ *et al.*, 2007).

Plant analysis is an important diagnostic tool in assessing the nutritional disorders and in monitoring the nutrient levels. Differences in soil mobility of individual nutrients explain the major uptake mechanisms (BALIGAR *et al.*, 2001). Certain levels of micronutrients such as magnesium (Mn), manganese (Mn) and iron (Fe) are necessary to mediate the numerous biochemical reactions essential for growth and development of the maize plant (KOVAČEVIĆ *et al.*, 2004).

KARLEN *et al.* (1988) updated the amounts, rates, and partitioning of mineral nutrients throughout the growing season across primary (N, P, K) and secondary (Ca, Mg, S) macronutrients and some of the micronutrients (B, Cu, Fe, Mn, Zn) in high–yielding maize. The influence of soil fertilization on crop nutrient acquisition has been studied and different results have been reported. According to WARMAN (2005) and HERENCIA *et al.* (2007), the application of organic fertilizers improve soil nutrient content, but does not always increase plant nutrient concentration. Other studies (BENJAMIN *et al.*, 2003; RENGEL and MARSCHNER, 2005; KOVAČEVIĆ *et al.*, 2011) showed that nutrient content in plants is affected by plant species, nutrient type, climate and environmental conditions. Mineral fertilization influences the uptake and accumulation of nutrients and their effects on plant growth, development and yield (FAGERIA *et. al.*, 2008).

Genetic variation in nutrient efficiency has been documented for many arable crops, including maize. According to SATTELMACHER *et al.* (1994), genetic variation in nutrient efficiency may be attributed to the effectiveness in absorbing nutrients from the soil (uptake efficiency) and/or the efficiency with which the absorbed nutrients are utilized for dry matter production (utilization efficiency). In most studies N efficiency has been confirmed in relation to genotype or climatic stress O'NEILL *et al.* (2004). Micronutrient efficiency is considered as genetically controlled while the physiological and molecular mechanisms of micronutrient efficiency are at the beginning of understanding. Besides by the genotype, quantities of micro and macronutrients in leaf and grain are influenced by numerous complex factors including soil properties, environmental conditions and nutrient interactions (RENGEL, 2001; FAGERIA *et. al.*, 2008). Consequently, maize leaf nutrient concentrations reported by different authors substantially vary (ORTIZ-MONASTERIO *et al.*, 2007; MENKIR, 2008).Mineral fertilization is an important prerequisite for achieving high yields in cultivated plants. Under similar agro ecological conditions, genotypes within the species may differ in the ability to uptake and utilize the existing soil nutrients. Genetic specificity of maize mineral nutrition has been well-known for many years and new hybrids should be tested in various environmental conditions (KOVAČEVIĆ *et al.*, 2004). In calcareous soils such as Chernozem, Fe and Mn could rapidly convert to immobile forms and their applications are required to prevent deficiencies   throughout the growing season (FAGERIA and BALIGAR, 2003).

This study was undertaken to investigate the effects of different fertilization regimes on ear leaf Mg, Fe, Mn and Cu content in six domestic maize hybrids.

MATERIALS AND METHODS

Experimental site

A long–term experiment (LTE) was established at the RimskiŠančevi experimental field of the Institute of Field and Vegetable Crops in Novi Sad (N 45° 19`, E 19° 50`) on the southern border of the chernozem zone of the Pannonian Basin.Soil was calcareous chernozem on loess terrace with 2.74% of humus, 0.15% of total nitrogen, 23.6 mg of available P_2O_5 and 26.8 mg of K_2O per 100 g of soil (STARČEVIĆ *et al.*, 2003).

Experimental design and treatments

A complete randomized blocks (split–plot) design with four replications was used in this study consisting of 6 commercial high-yielding maize hybrids and 6 treatments of fertilizer and rotation combinations (Table 1). The hybrids (NS 3014, NS 4015, NS 5043, NS 6010, NS 6030 and NS 7020) originating from the Institute of Field and Vegetable Crops belong to five FAO maturity groups, with NS 3014 and NS 7020 representing the earliest and the latest, respectively. Fertilization was conducted with 60 kg ha^{-1} NPK mixture (N, P_2O_5 and K_2O, 15:15:15) and 60 kg ha^{-1} nitrogen (urea, 46% N in the spring) as part of the standard agronomic procedures. Organic fertilizer (manure) was applied every other year in the amount of 25 t ha^{-1}. Crop residues were from maize removed and two–year crop rotation included maize and spring barley.

Table 1. The combined fertilization and rotation treatments in the experiment

Designation	Treatment
MC– Control	Monoculture, without mineral or organic fertilization, crop residues removed
MC– NPK	Monoculture, with mineral (NPK) fertilization, crop residues removed
MC– CR+NPK	Monoculture, with plowing crop residues (maize) and mineral fertilization
MC– M+NPK	Monoculture, with organic (manure) and mineral fertilizers, crop residues removed
TC– M	Two-year crop rotation, with organic (manure) fertilizer, crop residues removed
TC– M+NPK	Two-year crop rotation, with organic and mineral fertilizers, crop residues removed

Used labels: **MC**– Monoculture, **TC**– Two-year Crop rotation, **CR**– Crop Residues, **M** – Manure

Maintenance and measurements

Sowing and harvest of the maize and/or spring barley were performed at standard terms. Ear leaf samples (25 per replication) were taken at the beginning of silking stage (the second decade of July). The total amount of Mg, Fe, Mn and Cu was measured by ICP–AES technique after microwave digestion using concentrated $HNO_3 + H_2O_2$ (BASSETT *et al.*, 1978).

Data analysis

The split plot model analysis of variance (ANOVA) was performed in order to estimate the significance of the main effects and the respective interactions. All effects in the model (fertilization treatments, hybrids and replications) were treated as fixed. Multiple means comparison was conducted for significant ($P < 0.05$) effects by comparing the means using least significant differences (LSD) test. All data analysis was accomplished using STATISTICA 10.0 software (StatSoftInc, Tulsa, OK, USA).

RESULTS AND DISCUSSION

Analysis of variance (Table 2) showed that all three sources of variation had a significant effect ($p < 0.01$) on the Mg content in maize leaves. The overall variability of iron in the maize leaves showed significant effect of the applied treatments and their interaction with hybrids, while hybrids effect was not statistically significant. Significant effect of treatments and hybrids was found on Mg content; while the copper content in the leaves was significantly affected with applied treatment, and hybrid T×H has no effects on its content.

Table 2. Analysis of variance including degrees of freedom (df) and Mean Squares (MS) of six treatments (different fertilization regimes) and six hybrids, for the content of mineral nutrients in the maize leaves and significances derived from the ANOVA

Source of variation	df	Mean Square			
		Mg	Fe	Mn	Cu
T (Treatments)	5	2.71**	9637.19**	1693.15**	475.64**
H (Hybrids)	5	0.36**	946.72^{ns}	1563.96**	1589.05^{ns}
T × H	25	0.08**	999.88**	56.63^{ns}	421.16^{ns}

**Indicates significance at $p<0.01$, *Indicates significance at $p<0.05$, ns − nonsignificant

However, by using the GLM (General Linear Model) Procedures, t–test (LSD) for Mg showed that the lowest value of Mg in leaves of maize accumulated in the control (MC − control 1.77 g kg^{-1}), but not statistically significantly different from the values obtained in the two year rotation (Table 3). The highest value of Mg in leaves (2.69 g kg^{-1}) was obtained in the treatment of MC − NPK followed with the MC − CR + NPK (2.34 g kg^{-1}). The value higher than 2 g kg^{-1} Mg in leaves was obtained with the manure application (MC − M + NPK). Accordingly, in the long-term maize growing, the application of mineral fertilizers, mixing crop residues and manure application in combination with mineral fertilizers have influenced the increase in the content of this element in leaves (Figure 1).

The highest copper content in leaves (23.6 mg kg^{-1}) was found on the treatment with incorporation of crop residues combined with the use of mineral fertilizers (MC − CR + NPK), but not statistically significantly different from treatment MC − NPK, MC − M + NPK and TC − M + NPK (Table 2). The lowest content of Cu was obtained in two-year rotation with manure (12.3 mg kg^{-1}) and in the control (12.6 mg kg^{-1}). The highest iron content in maize leaves was detected in the maize monoculture with mixing crop residues in combination with application of NPK fertilizers (MC − CR + NPK: 151.9 mg kg^{-1}) and was significantly higher compared to all other treatments except treatment MC − M + NPK (141.1 mg kg^{-1}). The lowest values were obtained in the control and treatment of TC − M + NPK (103.6 or 103.2 mg kg^{-1}).

The content of manganese was not significantly different when applied treatments were compared. The highest content in leaves (63.6 mg kg^{-1}) was determined by applying the manure in the two-year rotation in combination with mineral fertilizers; however, was not significantly different compared to the other treatments except the control variant. Also, all other treatments had significantly higher content of Mn in leaves compared to the control treatment (Table 3, Figure 2).
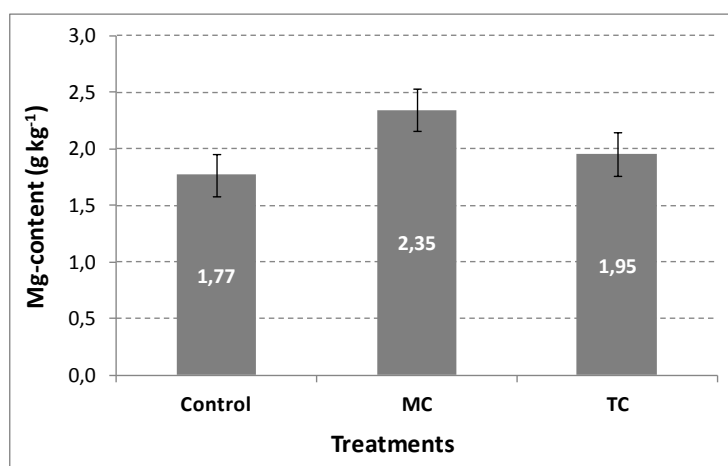
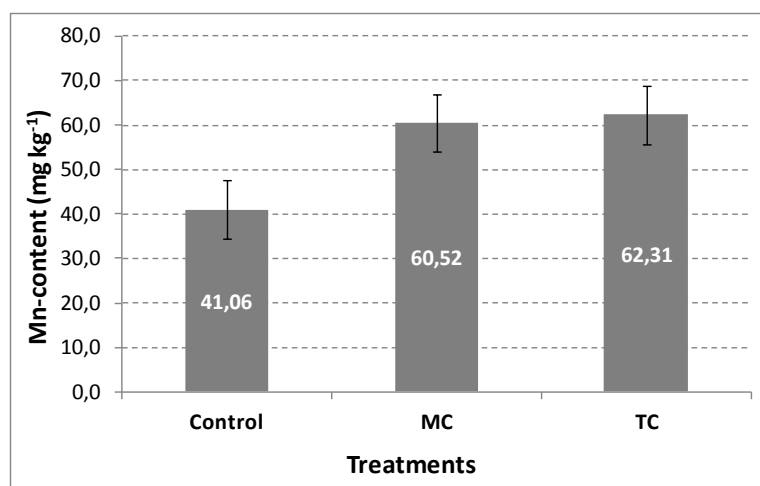Figure 1.Mg content in the maize leaves of control, monoculture and two-year rotation (bars show LSD values)

Figure 2.Mn content in the maize leaves of control, monoculture and two-year rotation (bars show LSD values)

The content of tested elements in maize leaves depended on the selected hybrids. Thus, the highest Mg content in leaves was achieved with NS 6010 and NS 6030 (2.22 or 2.23 g kg^{-1}), but not significant differences in relation to hybrid NS 4015 and NS 5043 (2.15 g kg^{-1}). The significantly lower value of Mg in leaves, compared to all other hybrids, had the earliest hybrid – NS 3014 (1.90 g kg^{-1}). The highest Cu content in leaves was determined in NS 6010 (32.6 mg kg^{-1}), that was significantly higher than all other hybrids, among which there were no significant differences, and the Cu content in them ranged from 10.2 to 16.7 mg kg^{-1}. Iron content in leaves was highest in NS 5043 (134.4 mg kg^{-1}), but no significant differences in relation to hybrid NS

4015 and NS 6030. The lowest values had the earliest hybrids – NS 3014 (116.6 mg kg^{-1}) but not a significantly different from hybrid NS 4015, NS 6010 and NS 7020. The highest content of Mn in leaves (68.7 mg kg^{-1}) was obtained with NS 6030 and was significantly higher compared to other hybrids, while the lowest content of manganese (44.0 mg kg^{-1}) was obtained in the hybrid NS 5043 where Mn content was smaller than all the other hybrids (Table 3).

Table 3. The content of the analyzed mineral nutrients in the leaves of maizegrown under different fertilization regimes in a long–term experiment

Treatment (A)	Mg (g kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
MC – Control	1.77 ± 0.18 **d**	103.6 ± 22.8 **d**	41.1 ± 7.9 **b**	12.6 ± 16.2 **b**
MC – NPK	2.69 ± 0.33 **a**	132.1 ± 15.4 **bc**	62.5 ± 12.3 **a**	19.5 ± 16.5 **ab**
MC – CR + NPK	2.34 ± 0.31 **b**	151.9 ± 35.7 **a**	60.2 ± 8.6 **a**	23.6 ± 46.9 **a**
MC – M + NPK	2.01 ± 0.20 **c**	141.1 ± 28.8 **ab**	58.9 ± 9.1 **a**	14.3 ± 9.7 **ab**
TC – M	1.95 ± 0.22 **cd**	118.3 ± 14.9 **cd**	61.0 ± 10.1 **a**	12.3 ± 6.7 **b**
TC – M + NPK	1.95 ± 0.20 **cd**	103.2 ± 10.6 **d**	63.6 ± 13.5 **a**	17.5 ± 25.9 **ab**
Hybrid (B)	**Mg (g kg^{-1})**	**Fe (mg kg^{-1})**	**Mn (mg kg^{-1})**	**Cu (mg kg^{-1})**
NS 3014	1.90 ± 0.27 **c**	116.6 ± 19.2 **c**	60.8 ± 12.4 **b**	10.2 ± 4.6 **b**
NS 4015	2.15 ± 0.44 **ab**	126.6 ± 22.7 **abc**	56.4 ± 11.2 **c**	11.9 ± 4.5 **b**
NS 5043	2.15 ± 0.41 **ab**	134.4 ± 42.6 **a**	44.0 ± 7.0 **d**	16.7 ± 9.6 **b**
NS 6010	2.22 ± 0.38 **a**	120.9 ± 22.3 **bc**	57.1 ± 7.1 **bc**	32.6 ± 53.8 **a**
NS 6030	2.23 ± 0.40 **a**	128.9 ± 26.8 **ab**	68.7 ± 12.4 **a**	14.7 ± 14.9 **b**
NS 7020	2.07 ± 0.38 **b**	122.7 ± 34.2 **bc**	60.2 ± 12.3 **b**	13.7 ± 7.5 **b**

Means within the column followed by the same letter do not differ at the *0.05* level of probability, according to LSD test

MENGEL and KIRKBY (2001) cited data concerning appraisal of the nutrient status of the ear–leaf at flowering stage of corn: adequate status (mg kg^{-1}) are from 20 to 70 (zinc), from 20 to 200 (manganese) and from 10 to 300 (iron), respectively. BERGMANN (1992) reported adequate nutritional status (mg kg^{-1}) of corn (leaves opposite ear) from 25 to 70 (zinc) and from 40 to 200 (manganese). Based on these criterions normal status of zinc, manganese and iron were found in our investigations in maize.

Agronomic management practices including hybrid and trait background selection, and soil fertility level can affect nutrient removal and subsequent maintenance fertilizer application rates (RAYMOND *et al.*, 2009).The application of organic fertilizers and two-crop rotation did not show a favorable effect on Mg uptake in maize; in fact, the determined Mg contents at these treatments were in most cases at the threshold of insufficient supply.This should be taken into account in maize cropping on the soils with lower fertility especially since inadequate Mg could exhibit unfavorable effect on nitrogen use efficiency (POTARZYCKI, 2010; SZULC, 2010). Magnesium could assist crops to access and utilize nitrogen and this is explain as "*magnesium – induced nitrogen uptake*" (GREZEBIZ, 2012). Since Mg is mainly transported by mass flow, abiotic stress such as drought or heat considerably inhibit Mg uptake and thus aggravate Mg deficiency (GRANSEE and FÜHRS, 2012). Magnesium deficient leaves contained low levels of chloroplast pigments and associated with the accumulation of starch that results in the increase of dry matter yield (MARSCHNER, 2002). According to MENGUTAY *et al.* (2013) root growth was more sensitive

to Mg deficiency compared to shoot and usually result with increased susceptibility to heat stress. In our study fertilization with NPK increases Mg in maize plants, whereas incorporation of the organic materials tends to fix Mg.

Maize is very susceptible to iron chlorosis (WIRÉN *et al.*, 1994). Most commonly, soils contain adequate amounts of iron; however, its availability to plants depends on other soil properties, such as temperature, pH, humidity etc. In addition, genotypic differences in terms of the uptake of the element have been reported (KOVAČEVIĆ *et al.*, 1997; ORTIZ–MONASTERIO *et al.*, 2007). BÄNZIGER and LONG (2000) studied genetic variation of Fe concentration in maize and found concentration of 10–63 mg kg^{-1} among >1800 maize germplasm accessions evaluated. Fe deficit may cause maize chlorosis resulting in decreased quality and yield (ÇELIK *et al.*, 2010). Maize ear leaf Fe content determined in our investigation varied among the treatments in the considerably wide range, from 103.2 (two–crop rotation, organic and mineral fertilizer) to 151.9 mg kg^{-1} (monoculture, crop residues and mineral fertilizer); however, the both values fall within the scope of sufficient content which is 50–250 or 10–300 mg kg^{-1}, according to SCHULTE and KELLING (1991), and MENGEL and KIRKBY (2001), respectively. The same was true for individual hybrids tested in all six fertilization regimes. The highest ear leaf Fe content was found in NS 5043 grown in monoculture with incorporating crop residues and mineral fertilization.

Wide and quite different ranges of optimal plant manganese contents are reported in literature; 30–100, 50–500 and 30–1000 mg kg^{-1} dry matter (BERGMAN, 1992; MARSCHNER, 2002). For maize, the plant tissue analysis showing a value of16 mg kg^{-1} would indicate that the Mn status is in the critical range. REUTER and ROBINSON (1997) classified Mn concentration in ear leaf of maize at initial silk as: < 15 mg kg^{-1} (deficient), 16 to 19 mg kg^{-1} (critical value or marginal), 20 to 150 mg kg^{-1} (normal/optimal), 151 to 200 mg kg^{-1} (high) and> 200 mg kg^{-1} (toxic or excessive). Similar to Fe, Mn content determined in our investigation varied among the treatments and hybrids; however, all values were within the optimal range.

Certain anthropogenic activities such as intensive pesticide application, fertilization, manufacturing and mining may lead to copper accumulation in soils and consequently to yield reduction in agricultural plants, including maize (GUO *et al.*, 2010; BARBOSA *et al.*, 2013). According to SCHULTE and KELLING (1991), 3–15 mg kg^{-1} in maize ear leaf is sufficient for optimal growth; 16–30 is high and > 30 is excessive. The concentrations of Cu in the both the shoot + leavesand ears portions of maize were the highest at the early stage of their formations and decreased over the time until shortly before harvesting MOLINA *et al.* (2013). Out of four analyzed nutrients Cu varied the most among the treatments, from sufficient 12.3 (two-crop rotation, organic fertilizer) to high 23.6 mg kg^{-1} (monoculture, with plowing crop residues and mineral fertilization).This could be explained with accumulation of soil organic matter that was known to mediate Cu availability to plants. In addition, significant differences have been found among the hybrids in ear leaf Cu content at different fertilization regimes. NS 3014, NS 4015 and NS 7020 accumulated approximately equal amounts of the element at all treatments and similar was noted for NS 5043 and NS 6030. However; ear leaf Cu content of the NS 6010 hybrid was in the optimal range at control and two-crop rotation with organic fertilizer treatment only, all other treatments caused high or excessive accumulation of the element. The noted genotype effects on maize Cu uptake should be considered when growing the crop on soils with the increased content of the element. NAN and CHENG (2001) reported that the average content of Cu in stems in the mature stage was 5.40 mg/kg. DEMIRKIRAN (2009) in his study in the Mediterranean area of Turkey noted that the variety could exerts had significant effects on Cu content in maize hybrids.

CONCLUSION

Development of the balanced fertilization and proper crop management in maize production on Chernozem is a result of a complex interaction of soil, crop and climatic conditions. Obtained results showed that the ear leaf content of the Mg, Fe, Mn and Cu varied significantly among the tested fertilization regimes and maize hybrids. Partially this could be explained with climatic situation in a long-term maize copping. The highest intervals of variation, for both treatments and hybrids, were noted for Cu. Among tested hybrid NS6030 had higher content of nutrients in ear and the differences that were observed could be attributed to vegetation length (FAO maturity group). The mean values of the analyzed nutrients were principally in the optimal or acceptable range. The exceptions were Cu, which was high or even in excess in certain treatments and hybrid/treatment combinations, and Mg, which was at the threshold of insufficient supply when applying organic fertilizers and two-crop rotation.The observed relations should be taken into account when choosing fertilization regimes for specific maize hybrid. Therefore improving our understanding of nutrient utilization by maize provides ability to optimize fertilizer rates and application timings.

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USVAJANJE HRANIVA KOD KUKURUZA U ZAVISNOSTI OD GENOTIPA I ĐUBRENJA

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Izvod

Sadržaj hraniva u kukuruzu uslovljen je sa nivoom đubrenja i kvalitetom zemljišta i retko se dovodi u vezu sa svojstvima pojedinačih hibrida. Cilj ovog istraživanja je ispitivanje sadržaja Mg, Fe, Mn i Cu u listu šest hibrida kukuruza (NS 3014, NS 4015, NS 5043, NS 6010, NS 6030, NS 7020) na višegodišnjem ogledu sa kukuruzom. Uzorci biljnog materijala su prikupljeni sa dugoročnog eksperimenta na Rimskim Šančevima na Institutu za ratarstvo i povrtarstvo u Novom Sadu. Istraživanja su obuhvatila monokulturu i dvopolje kukuruza na kojima se primenjuju NPK đubriva i stajnjak po odgovarajućoj šemi. Rezultati su pokazali da su na sadržaj Mg u listu uticali odabrani tretmani, hibridi i njihova interakcija za vrednosti od 1.77 do 2.69 g kg^{-1}. Na varijabilnost sadržaja gvožđa u listu značajno su uticali tretmani i interakcija (hibrid x tretmani). Prosečan sadržaj gvođa se kretao u intervalu od 103.2 do 151.9 mg kg^{-1}. Sadržaj mangana u listu (41.1–63.6 mg kg^{-1}) bio je uslovljen uticajem tretmana i hibrida, dok je sadržaj bakra (12.3–23.6 g kg^{-1}) značajno varirao u zavisnosti od primenjenih tretmana. U svim tretmanima, u proseku, hibrid NS 6030 je imao veće vrednosti hraniva Mg, Fe, Mn i Cu u listu, dok je hibrid NS 3014 imao niži sadržaj u poređenju sa ostalim hibridima. Ovo ukazuje da dužina vegetacije favorizuje akumulaciju hranljivih materija. Dobijeni rezultati su pokazali da čak i na produktivanom zemljištu, kao što je černozem, izbor hibrida i izbalansirano đubrenje je od ključnog značaja za obezbeđivanje ravnoteže u sadržaju hraniva pri gajenju kukuruza.