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# Evaluation of mineral content in maize under flooding

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**ABSTRACT** - *This study examined the effects of plant mineral content on different cycles of recurrent selection of the flood-tolerant, open-pollinated maize variety BRS 4154 - "Saracura", under soil flooding. Experiments with the main treatments flooded or unflooded were conducted in Sete Lagoas, MG – Brazil. Samples of the cycles 1, 5, 9 and 15 were sown in a randomized block design. The open-pollinated variety BR 107 and single-cross hybrid BRS 1010 were used as flood-susceptible controls. The stress caused by water excess in the soil reduced the nitrogen content in the cycles 5 and 9, and calcium in cycle 15; but increased potassium in cycle 1. However, it did not significantly influence the content of phosphorus, magnesium, sulfur, zinc, and copper. Additionally, recurrent selection under flooding diminished potassium and calcium content along the cycles.*

**Key words**: corn, flooding tolerance, macronutrient and micronutrient content.

## INTRODUCTION

Anoxic conditions in the rhyzosphere are a result of overflowing rivers, over-irrigation, inadequate drainage, and full impoundment of reservoirs (Herschbach et al. 2005). Low soil oxygen concentration (hypoxia) or total absence of oxygen (anoxia) affect the nutrient uptake, synthesis and translocation of growth regulators, as well as photosynthesis, respiration and carbohydrate partitioning, decreasing the yield of crops grown in soil with inadequate drainage or subjected to transient flooding (Ferrer et al. 2005).

Plant species with tolerance or even resistance to hypoxia develop morphological and biochemical adaptation mechanisms which may be useful criteria for the selection of genotypes with increased tolerance to waterlogging (Ferrer et al. 2005).

In the case of waterlogging, even in tolerant plants the growth rate, nutrient uptake and root–shoot ratio is reduced (Kleiman et al. 1992, Vignolio et al. 1999). Low soil oxygen concentration due to flooding or transient waterlogging severely reduces maize yield. Nonetheless, recent studies have identified tropical maize cultivars with some degree of tolerance to hypoxia. This has been attributed to biochemical and physiological adaptations that lead to stomatal closure during the stress period, as well as morphological modifications, including formation of adventitious roots, aerenchymas and root porosity thereby facilitating the aeration of flooded tissue in tolerant plants (Drew et al. 1979, Kleiman et al. 1992, Vignolio et al. 1999, Dantas et al. 2000, Romero et al. 2003, Mano et al. 2006, Mano and Omori 2007, Mano et al. 2007).

Few studies on the influence of flooding in cultivated plants have been conducted in Brazil. The species and cultivars are rarely tested in order to verify the tolerance to these soil conditions. One reason for

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the lack of interest is that fertile valleys have been almost exclusively planted with rice and native pasture (Lopes et al. 2005). In the country there are 28 million hectares of fertile valleys for agricultural use and maize, if tolerant to intermittent flooding, could be an interesting alternative for a better exploitation of these areas (Vitorino et al. 2001).

In Brazil, the National Research Center for Maize and Sorghum (Embrapa) bred an open-pollinated maize variety with a broad genetic basis denominated BRS-4154 (Saracura) in 15 cycles of mass recurrent selection, under very wet soil conditions. This plant material turned out to be one of the most ideal for flooding-susceptible areas. The commercial production of BRS-4154 in flooded areas began in the summer of 1997/98. The open-pollinated variety Saracura was improved by recurrent selection, grown under intermittent flooding. Although Saracura is recommended for flooded areas, its nutrient content has not yet been studied (Vitorino et al. 2001). This variety may also be used as a parent in breeding programs abroad to incorporate waterlogging tolerance.

Soil flooding adversely affects nutrient uptake in plants (Pezeshki et al. 1999). The mineral nutrition of plants in response to flooding depends on the plant species and soil type (Kozlowski 1984, Pezeshki 2001). In flood-intolerant species, the N, P and K leaf concentrations are often, but not always, reduced by flooding (Kozlowski 1984, Pezeshki 1995). In some relatively low-P, alkaline soils, flooding may cause an increase in P availability, leading to a temporary increase in P content. But prolonged flooding reduces P uptake and concentration in plants due to root dysfunction, damage and death (Kozlowski 1984). The uptake of Ca and Mg uptake are less affected by flooding than N, P or K (Kozlowski 1984). Under flooded conditions, flood-tolerant species generally absorb more minerals than flood-intolerant species (Pezeshki et al. 1999).

The purpose of this work was to verify the effects of flooding on mineral content in the flooding-tolerant variety Saracura under temporary flooding in Brazil.

## MATERIAL AND METHODS

The experiment was carried out at an experimental station of Embrapa – National Research Center for Maize and Sorghum, in Sete Lagoas, MG - Brazil (lat 19°28' S, long 44° 15' W, 732m asl) in a lowland soil. The lowland soil used was classified as Typical Tb Entropic Fluvic Neosol, clay soil texture, in a wet flatland area. According to Köppen's classification, the climate is AW.

The material used in this study consisted of plants of four of the 15 recurrent selection cycles of the flooding tolerant variety BRS 4154, "Saracura" (cycles 1, 5, 9 and 15), and variety BR 107 and the single-cross hybrid BRS 1010 as susceptible controls. The experiment was arranged in a split plot design with four replications, in completely randomized blocks, under two conditions (normal irrigation and intermittent flooding). Experiments began in spring (October) 2003. The soil was flooded three times a week, to a water level of 20 cm above the soil, from the V6 stage until maturation.

To simplify the flooding operation, the field was leveled and flooded to a water level of 20 cm above the soil surface, three times a week, initially in V6 (six developed leaves) before flowering, and was maintained until physiological maturity (R6). Fertilizer was applied on the plots at the recommended levels for each site. Specific field operations were similar to those used in maize crop. The experimental plots ($14.4 m^2$) consisted of four rows, each four meters long, at a row-spacing of 0.90 m and plant-spacing of 0.20 m. Seeds were sown excessively and thinned to 80 plants $plot^{-1}$ (55,000 plants $ha^{-1}$). The mineral content was determined in the flag leaf of five randomly sampled plants in the central rows of the plots.

The content of the following minerals was tested in the leaf dry matter: nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, and copper (in dag $kg^{-1}$ dry matter for macronutrient and in mg $kg^{-1}$ dry matter for micronutrients). The samples were harvested during flowering (development stage R1) according to Sarruge and Haag (1974), Malavolta et al. (1989), and Silva (1999). Analysis of variance and the Tukey test were carried out using SAS/STAT® software.

## RESULTS AND DISCUSSION

The summary of the analysis of variance for nutrients studied here is shown in Table 1. It was observed that flooded conditions did not significantly affect magnesium and phosphorus contents. The genotype-environment interaction (GxE) and genotype (G) effects were not significant either for nitrogen, phosphorus, magnesium, sulfur, and zinc contents.

Table 1. Summary of analyses of variance for contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), zinc (Zn) and copper (Cu) for four cycles of recurrent selection of the variety Saracura, variety BR 107 and single-cross hybrid BRS 1010, evaluated in two growth conditions

| Sources of variation | df | Mean Square | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | S | Zn | Cu |
| Blocks (B) | 3 | 0.064974 | 0.000962 | 0.325829** | 0.020191* | 0.002288** | 0.000274 | 146.67** | 0.65 |
| Environment (E) | 1 | 2.10** | 0.003141 | 0.852000** | 0.019940* | $0.7x10^{-5}$ | 0.004408** | 258.30** | 75.00** |
| E x B (Error A) | 3 | 0.1939* | 0.001015 | 0.246876** | 0.000173 | 0.001768* | 0.000532 | 134.81** | 32.18** |
| Genotypes (G) | 5 | 0.073939 | 0.002410 | 0.476328** | 0.013822* | 0.000397 | 0.000145 | 10.48 | 5.62* |
| G x E | 5 | 0.015240 | 0.001197 | 0.370755** | 0.028450** | 0.000309 | 0.000448 | 7.39 | 13.87** |
| Residue (Error B) | 30 | 0.051151 | 0.001157 | 0.043629 | 0.004756 | 0.000477 | 0.000275 | 10.62 | 2.20 |
| Mean | | 1.81 | 0.28 | 1.66 | 0.62 | 0.14 | 0.14 | 20.63 | 7.87 |
| CV (%) error A | | 24.33 | 11.30 | 30.00 | 5.53 | 30.45 | 9.8 | 56.28 | 72.00 |
| CV (%) error B | | 12.52 | 12.06 | 12.55 | 11.14 | 15.81 | 12.16 | 15.79 | 18.83 |

**, *: significant by the F test at 1% and 5% probability.

The genotypes did not differ for nitrogen content (N) in normal (non-flooded) conditions (Table 2). However, flooding decreased N content in plants of the cycles C5, C9 and of control BR 107. On average, the N content was reduced by 18% in the four recurrent selection cycles. The slightly reduced N content observed here is in agreement with results of Kozlowski (1984), Huang et al. (1995), and Pezeshki (1995).

Phosphorus content varied among genotypes under normal conditions, but no significant difference was observed under flooding (Table 2). Romero et al. (2003) observed that the effect of flooding on P uptake is complex and depends strongly on the soil type. Coelho et al. 2006 found that maize forms a lysigenous aerenchyma under P deficiency and flooding stress. Although this was not the main focus of our study it was observed that waterlogged plants of the selection cycles formed aerenchyma as well, which may have increased the efficiency of absorption and/or translocation of P.

Opposite to Cycle 9 plants, flooding reduced the calcium content in Cycle 15 and in BRS-1010 plants (Table 2). In a study on the effect of Ca on some biophysical and morphological traits Romero et al. 2003 observed a decrease in Ca content in an advanced selection cycle (C14) of waterlogged Saracura, in agreement with our observations. Moraes and Dynia (1992) found that in waterlogged rice, Ca increases in soil solution and in plants. According to Kozlowski (1984), the uptake of Ca uptake in waterlogged plants is less affected than that of other nutrients. Hocking et al. (1987) found that flooding in cotton did not affect Ca leaf contents. A linear regression equation of selection cycles for calcium content in flooded plants is presented in Figure 2. It is further noteworthy that although the coefficient of determination was not high, calcium tended to decrease along the selection cycles.

The K content decreased by 37% along the selection cycles when evaluated under flooding (Table 2 and Figure 1). In our results, the K content did not vary in plants of three of the four selection cycles. Ferrer et al. (2004) found that variation in K content in maize was independent of environmental conditions. On average, a tendency of K content increase under flooding was observed. This can be explained by the displacement of this nutrient by iron in soil colloids, thus increasing its concentration in the soil solution under flooded conditions (Moraes and Freire 1974).

**Table 2.** Mean values for nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca) contents in four cycles of recurrent selection of the variety Saracura (C1, C5, C9 and C15), variety BR 107 and single-cross hybrid BRS 1010, evaluated in two growth conditions

| Genotype | N (dag kg$^{-1}$) | | P (dag kg$^{-1}$) | | K (dag kg$^{-1}$) | | Ca (dag kg$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | Growth conditions | | | | | | | |
| | Control | Flooded | Control | Flooded | Control | Flooded | Control | Flooded |
| C 1 | 1.93 Aa | 1.74 Aa | 0.26 Ba | 0.28 Aa | 1.30 Bb | 2.11 Aa | 0.72 Aa | 0.68 Aa |
| C 5 | 1.89 Aa | 1.45 Ab | 0.29 ABa | 0.26 Aa | 1.64 ABa | 1.59 Ba | 0.65 ABa | 0.62 ABa |
| C 9 | 2.06 Aa | 1.60 Ab | 0.28 ABa | 0.25 Aa | 1.55 ABa | 1.62 Ba | 0.51 Bb | 0.65 Aa |
| C 15 | 1.94 Aa | 1.62 Aa | 0.29 ABa | 0.28 Aa | 1.55 ABa | 1.32 Ba | 0.64 ABa | 0.49 Bb |
| BR 107 | 2.19 Aa | 1.63 Ab | 0.33 Aa | 0.29 Aa | 1.42 ABa | 1.63 Ba | 0.64 ABa | 0.58 ABa |
| BRS 1010 | 2.08 Aa | 1.74 Aa | 0.29 ABa | 0.30 Aa | 1.75 Ab | 2.51 Aa | 0.69 Aa | 0.52 ABb |
| C V (%) | 7.8 | 17.45 | 10.65 | 13.60 | 15.18 | 20.14 | 11.16 | 14.99 |

Means followed by at least one same upper case letter in columns, for genotypes, and lower case letter, for environment, did not differ significantly by the Tukey test at 5% probability

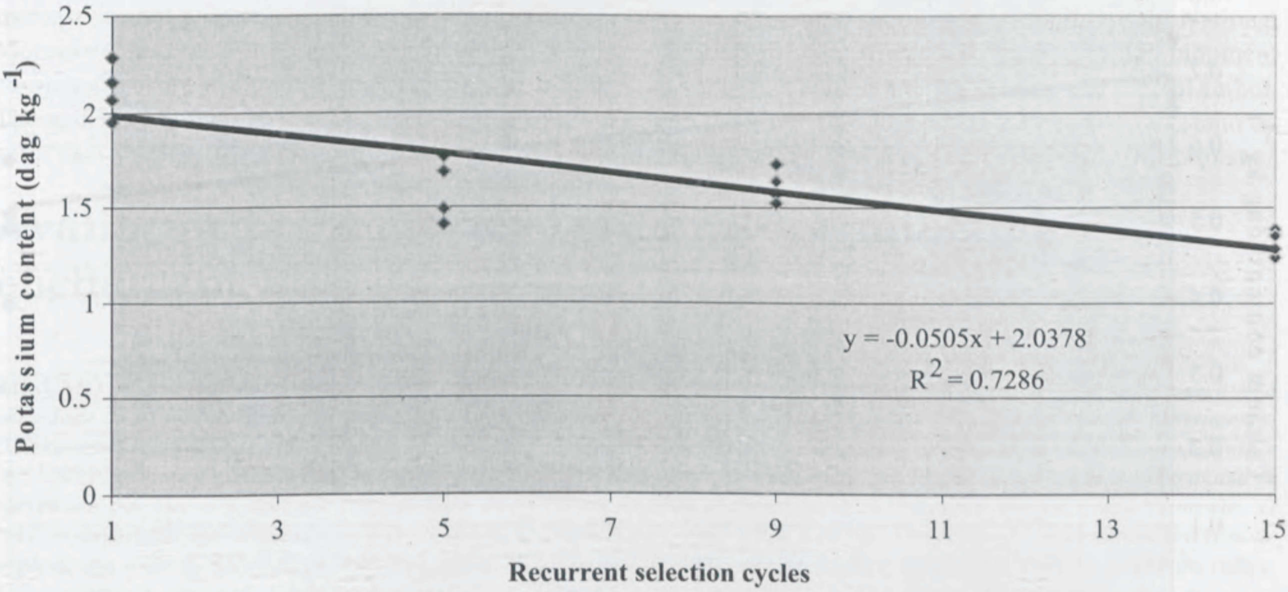


**Figure 1.** The graph of linear regression shows the dry matter potassium content of the aerial part of maize plants in the recurrent selection cycles of the variety Saracura under intermittent flooding

The data for magnesium (Table 3) indicate no difference among genotypes under both conditions. Working with cycle-C14 plants under the same environmental conditions in Brazil, Romero el al. (2003) did not find any significant variation for Mg content. Moreover, Kozlowski (1984) also postulated that Mg uptake is less affected than other nutrients under flooding. This could explain why our results did not show any significant variation in this nutrient.

Sulfur content did not differ among genotypes under both conditions, except for BRS1010, which decreased in sulfur content when grown under flooding (Table 3). In maize, adaptations to increase sulfate uptake include modifications of root architecture to maximize sulfate adsorption efficiency. Removal of the S-source from the medium of young maize seedlings resulted in a three to eight-fold increase in sulfate uptake capacity. This coincided with an increase in root length, mass, and root-shoot ratio, as well as lateral root proliferation (Bouranis et al. 2006). Generally, plants respond to a restricted S supply by an increased expression of genes that code for components of sulfur uptake and assimilation pathway (Hopkins et al. 2004). Moreover, Bouranis et al. (2006) observed the formation of aerenchyma under S deficiency, which could clarify why there are no problems with S uptake in Saracura plants (Ferrer et al. 2004).

**Table 3.** Mean values of magnesium (Mg), sulfur (S), zinc (Zn) and copper (Cu) in four cycles of recurrent selection of the variety Saracura (C1, C5, C9 and C15), variety BR 107 and single-cross hybrid BRS 1010, evaluated under two different growth conditions

| | **Mg** (dag kg$^{-1}$) | | **S** (dag kg$^{-1}$) | | **Zn** (dag kg$^{-1}$) | | **Cu** (dag kg$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | **Growth conditions** | | | | | | | |
| **Genotype** | **Control** | **Flooded** | **Control** | **Flooded** | **Control** | **Flooded** | **Control** | **Flooded** |
| C 1 | 0.13 Aa | 0.13 Aa | 0.14 Aa | 0.13 Aa | 22.31 Aa | 16.92 Aa | 11.00 Aa | 4.86 Ab |
| C 5 | 0.14 Aa | 0.12 Aa | 0.15 Aa | 0.13 Aa | 22.31 Aa | 21.00 Aa | 9.33 ABCa | 6.22 Aa |
| C 9 | 0.13 Aa | 0.14 Aa | 0.13 Aa | 0.14 Aa | 22.60 Aa | 18.01 Aa | 10.11 ABa | 7.97 Aa |
| C 15 | 0.14 Aa | 0.15 Aa | 0.14 Aa | 0.12 Aa | 22.60 Aa | 15.97 Aa | 10.69 Aa | 6.22 Aa |
| BR 107 | 0.14 Aa | 0.14 Aa | 0.15 Aa | 0.13 Aa | 22.61 Aa | 18.81 Aa | 6.42 Ca | 6.80 Aa |
| BRS 1010 | 0.16 Aa | 0.14 Aa | 0.16 Aa | 0.12 Ab | 25.28 Aa | 19.18 Aa | 7.19 BCa | 7.66 Aa |
| CV (%) | 15.07 | 17.02 | 13.18 | 12.10 | 17.36 | 19.90 | 18.01 | 19.67 |

Means followed by at least one same upper case letter in columns for genotypes, or lower case letter for environment, did not differ significantly by the Tukey test at 5% probability

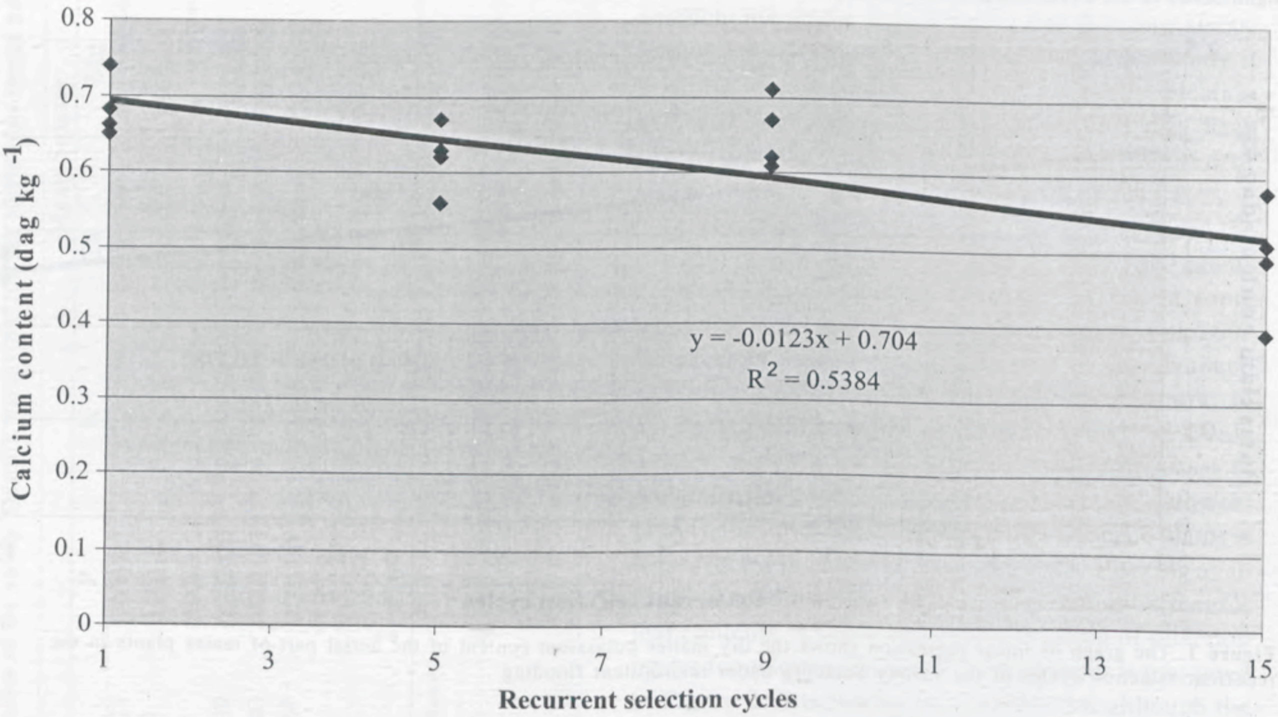


**Figure 2.** The graph of linear regression shows the dry matter calcium content of the aerial part of maize plants in the recurrent selection cycles of the variety Saracura under intermittent flooding

The growth conditions had no significant effect on zinc content (Table 3). Copper concentrations, under non-flooding, were higher in plants of the four recurrent selection cycles than in the controls (Table 6). Yu et al. (1982) stated that Zn and Cu plant concentration could decrease under waterlogging, although some Cu would remain in solution.

The amount of nutrients that maize varieties need for growth and reproduction varies. A common perception is that plant response to insufficient nutrient supply involves physiological changes that are unique to nutrient stress. Nutrient uptake is greatly influenced by root morphology, soil properties, climate, and cultural and management practices. The quantity of a nutrient taken up by a plant generally depends on the configuration and growth rate of the root extension, mean root radius, mean root hair density, root porosity, and root length (Alam 1994, Mano and Omori 2007). Among the various physiological factors contributing to plant growth, nutrient element availability plays a vital role. However, these factors may interact simultaneously, antagonistically or synergistically in the nutrient solution soil, plant, and or at the root absorption sites of the plant. Many nutrient elements are actively taken up by plants. Potential energy is required for an active nutrient uptake, and aerobic respiration in the soil system is the chief supply of this energy. For adequate aeration, plant roots generally need air in the soil to survive. The ways in which flooding influences plant mineral nutrition are very complex, determined by several concomitant effects on the soil, initial soil conditions and nutrient absorption mechanisms, as well as other physiological processes and response of the particular genotype (Alam 1994). The formation of aerenchymas in soil flooding (Mano et al. 2006) and increase in root porosity is well documented in maize. Moreover, several morphological adaptations allow continued absorption under waterlogging conditions. These different factors may explain why, along the selection cycles, the concentration level of some nutrients taken up by BRS-4154 remain the same, decrease in some, and increase in others.

Summing up, the stress caused by flooding condition reduced the nitrogen content in cycles 5 and 9, and calcium in cycle 15; increased potassium in cycle 1. However, there was no significant effect on the content of phosphorus, magnesium, sulfur, zinc, and copper. Additionally, in flooded condition, the recurrent selection along the cycles diminished the potassium and calcium content.

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# Avaliação da composição mineral em milho sob encharcamento

**RESUMO** - *Esse estudo examinou os efeitos da composição mineral de plantas nos diferentes ciclos de seleção recorrente da variedade de milho tolerante ao encharcamento intermitente do solo BRS-4154 – "Saracura", sob condições de alagamento. Os experimentos foram conduzidos em Sete Lagoas, MG – Brasil, com os tratamentos principais sendo encharcamento e condições normais de irrigação. Amostras do ciclos 1, 5, 9 e 15 foram semeadas em um delineamento em blocos ao acaso. A variedade BR 107 e o híbrido simples BRS 1010 foram usados como testemunhas suscetíveis ao encharcamento. O encharcamento temporário reduziu o conteúdo de nitrogênio no ciclo 5 e 9, e o de cálcio no ciclo 15, mas aumento o teor de potássio no ciclo 1. Além disso, não teve efeito significativo no conteúdo de fósforo, magnésio, enxofre, zinco ou cobre. Adicionalmente, na condição de encharcamento, a seleção diminui o teor de potássio e cálcio ao longo dos ciclos.*

**Palavras-chave**: conteúdo de macro e micronutriente, milho, tolerância ao encharcamento.

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