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GROWTH AND MICRONUTRIENT CONCENTRATION IN MAIZE PLANTS UNDER NICKEL AND LIME APPLICATIONS[1]

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ABSTRACT - The experiment was conducted in a greenhouse located at the Federal University of Mato Grosso, Cuiaba-MT, from March to May 2012. The objective was to assess the effects of different rates of nickel application with and without liming on maize growth and micronutrient levels. The study was a randomized block design in a 2 x 5 factorial arrangement with four replicates, for a total of 40 plots, including with and without liming and five rates of nickel application, on a clayey Red Yellow Latosol (Oxisol, USDA classification and Ferralsol, FAO classification). Both lime and nickel applications influenced plant growth, reducing plant development with increased nickel application without liming. It was also observed that both lime and nickel applications altered micronutrient levels in the maize plants, independent of which part of the plant was evaluated. Nickel played an antagonistic role with manganese and zinc and a synergistic role with copper and iron.

Keywords: Micronutrients. Toxicity. Antagonism. Synergism.

CRESCIMENTO E TEOR DE MICRONUTRIENTES EM PLANTAS DE MILHO SOB DOSES DE NÍQUEL E CALAGEM

RESUMO - O experimento foi realizado em casa de vegetação na Universidade Federal de Mato Grosso, em Cuiabá/MT no período de março a maio de 2012 com o objetivo de avaliar o crescimento de plantas de milho e o teor de micronutrientes em doses de níquel com e sem calagem. O delineamento foi o de blocos casualizados, em um arranjo fatorial 2 x 5 com quatro repetições, totalizando 40 parcelas, sendo: com e sem calagem e cinco doses de níquel, em um Latossolo Vermelho Amarelo de textura argilosa. A calagem e a aplicação de níquel interferiram no crescimento das plantas de milho. Foi registrada a redução do desenvolvimento das plantas com o aumento das doses de níquel sem a calagem. Tanto a calagem quanto a aplicação de doses de níquel alteraram os teores de micronutrientes nas plantas de milho, independente da parte da planta avaliada. O níquel exerceu ação antagônica com manganês e zinco e sinérgica com o cobre e ferro.

Palavras-chave: Micronutrientes. Toxicidade. Antagonismo. Sinergismo.

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INTRODUCTION

Maize is one of the cereals most grown throughout the world, providing widely used products for human and animal consumption and raw materials for industry (LANA, et al., 2012; FERREIRA, et al., 2014). Being one of the most consumed cereals, maize studies are of great importance, mainly in order to maintain nutritional quality. Little attention has been given to nickel, the element most recently included as essential to plant development. Along with other micronutrients, nickel enters the metabolic process of plants. According to Hansch and Mendel (2009), nickel participates in urease activity, transforming urea into ammonia within the plant and, according to Reis et al. (2014), participates in the synthesis of phytoalexins, which improves plant resistance to diseases.

Nickel in adequate quantities has a vital role in a large variety of physiological processes, from seed germination to productivity, so plants cannot complete their life cycle without adequate supply of this metal. For this reason, nickel was registered in the essential micronutrients list. However, high levels of this micronutrient can alter various metabolic activities of the plant including: the ratio of water and mineral nutrients, enzyme inhibition, functioning of the stomata, photosynthetic transport of electrons, and degradation of chlorophyll molecules, consequently reducing the photosynthetic rate and biological yield of plants (YUSUF et al., 2011).

Normal concentrations of nickel in plant dry matter vary from 0.05 to 10 mg kg^{-1} in the majority of species (YUSUF et al., 2011). Acidification can increase the absorption and accumulation of nickel in plant roots (ZARKOVIC; BLAGOJEVIC, 2009).

Authors such as Bybordi and Gheibi (2009) and Campanharo et al. (2013) advocate the use of nickel in crops where the nitrogen source is urea. For others such as Marschner (2008), nickel is required to increase the productivity of crops regardless of the type of nitrogen fertilizer used.

Although nickel is included as an essential micronutrient, there is concern about the toxicity of this element for plants, as numerous agricultural practices have shown increasing concentrations of this element in the soil. According to Berton et al. (2006), it is estimated that, worldwide, 106,000 to 544,000 tons of nickel are added annually to soils, originating from metallurgical activities, the burning of fossil fuels and the addition of sewage sludge and industrial compounds.

Nickel's polluting potential can be observed directly in soil organisms, through its availability to plants at phytotoxic levels, and through the possibility of its transference into the food chain through plants (SILVA et al., 2007). Among the factors that affect nutrient availability, a key factor is pH, as nickel availability is inversely related to this index (PAVINATO; ROSOLEM, 2008; MA, et al., 2013).

In addition to causing toxicity in plants when present at high concentrations in the soil, nickel can also interfere with the absorption of other nutrients. Nickel is absorbed in the form of Ni^{+2}, so its absorption at high concentrations can significantly decrease the absorption of other divalent cations, such as Mg, Fe, Mn, Cu and Zn, with Mn the element that is most restricted (PALACIOS et al., 1998). In soils with high levels of nickel, liming can promote a significant reduction in the absorption and accumulation of this element by plants, thus reducing its toxic effects. This study aimed to evaluate growth and micronutrient concentration in maize plants subjected to nickel doses and liming.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Federal University of Mato Grosso (UFMT), Cuiaba, MT, from March to May 2012.

The design was a factorial 2 x 5 randomized complete block design (with and without liming and five nickel doses) with four repetitions, totaling 40 installments. The nickel doses used were: 0, 2.5, 5.0, 7.5, and 10.0 mg kg^{-1} of soil. Each plot was represented by a pot with a volume of 8 dm^{-3} of a clayey Red Yellow Latosol (SANTOS et al., 2013)

Chemical analysis of the soil was carried out on the 0–20 cm layer (Table 1).

Base saturation in the soil was 38.8% and CEC 6.6 cmol$_c$ dm^{-3}, aluminum saturation 0% and hydrogen saturation 61.2%.

Liming was carried out on March 3, 2012 using a limestone filler with 30% CaO and 20% MgO, with a base saturation method, considering an increase in base saturation to 60% (SOUSA; LOBATO, 2004).

A fertilization regime was performed according to Sousa and Lobato (2004), following their recommendations for soil nutrient and clay content levels, applying to the soil: 100 mg dm^{-3} of N (200 kg ha^{-1}), 50 mg dm^{-3} of P_2O_5 (100 kg ha^{-1}), 20 mg dm^{-3} of K (40 kg ha^{-1}), and 25 mL of Micro solution containing 1,000 mg L^{-1} of Cu, 1,000 mg L^{-1} of Zn, and 1,000 mg L^{-1} of B per pot.

Table 1. Chemical characteristics of soil used in the experiment.

pH		P	K	S	Ca+Mg	Ca	Mg	Al	H	O.M.
H_2O	$CaCl_2$	mg kg^{-3}			cmol$_c$ kg^{-3}					g kg^{-3}
6	4.8	7.1	95	22	2.3	1.7	0.6	0	4	41

Ni	Fe	Zn	Cu	Mn	B	Sand	Silt	Clay
mg kg^{-3}						g kg^{-1}		
2.8	170	2	1.5	9.1	0.45	228	262	510

Sowing was carried out 50 days after setting up the pots and liming, with periodic watering by hand to maintain soil moisture at 60% field capacity. Three hybrid maize seeds (AG 7088RR2 cultivar) were planted per pot and thinned down to one plant per pot after the establishment of seedlings. Fifty days after sowing, the following parameters were measured: plant height, using a graduated measuring tape; stem diameter with a digital pachymeter; leaf area by measuring the length (L) and width (W) of all the leaves obtained through the expression: A = L x W x 0.75 (Pereira, 1987). These values were added to obtain the leaf area per plant and total dry matter. Excess soil on plant material was removed with distilled water. After recording the fresh weight, fresh biomass was placed in labeled paper bags and into a circulating air oven to dry at 65 °C until constant mass was achieved. Subsequently, dry samples were weighed, and the material was ground using a Wiley mill and stored in plastic bags.

Nitropercloric digestion was carried out for copper, iron, manganese, zinc and nickel extraction. Concentrations were determined by atomic absorption spectrophotometry (SILVA, 1999).

Analysis of variance was used to determine differences between treatments. Where differences were significant at the 1% and 5% error probability for nickel doses, regression analysis was employed using SPSS Statistics 17 software.

RESULTS AND DISCUSSION

Significant differences between analyzed treatments were observed, as well as the interaction between them (Table 2).

Table 2. Summary of the analysis of variance: plant height (H - cm), stem diameter (StD - mm), leaf area per plant (LAP – cm^{-2}), total dry matter (TDM - g).

S.V.	DF	H	StD	LAP	TDM
Block	3	3.98**	2.61^{ns}	5.17**	4.84**
Liming (L)	1	254.80**	117.06**	178.30**	150.15**
Nickel (Ni)	4	13.23**	7.08**	4.97**	3.01**
L x Ni	4	9.69**	3.14**	6.63**	2.69^{ns}
Residue	27	23.85	0.6425	134168	13.23
C.V. (%)		7.0	14.01	11.1	13.59
General Mean		110.575	15.908	4531.451	26.954

*- significant at 5% probability; **- significant at 1% probability; ^{ns}- not significant.

Liming resulted in higher growth and increased plant dry biomass, sustaining a development pattern independent of the nickel doses applied. In the absence of liming, there was lower plant growth and a negative nickel effect, with lower growth and dry biomass production with increasing dose (Figure 1).

In the plants grown without liming, symptoms of phytotoxicity due to nickel applications were observed, such as chlorosis, abscission of the first leaves in the early stages of plant development, reduction in growth, dry biomass production and necrosis of the roots that received higher nickel doses (7.5 and 10 mg dm^{-3}). Although the mechanisms of its phytotoxicity are still poorly understood, it is known that high nickel levels in plant tissue inhibit photosynthesis and plant respiration. In addition, toxic levels have been correlated with tissue injury, growth retardation, chlorosis and other specific symptoms for plant species (GUPTA, 2001).

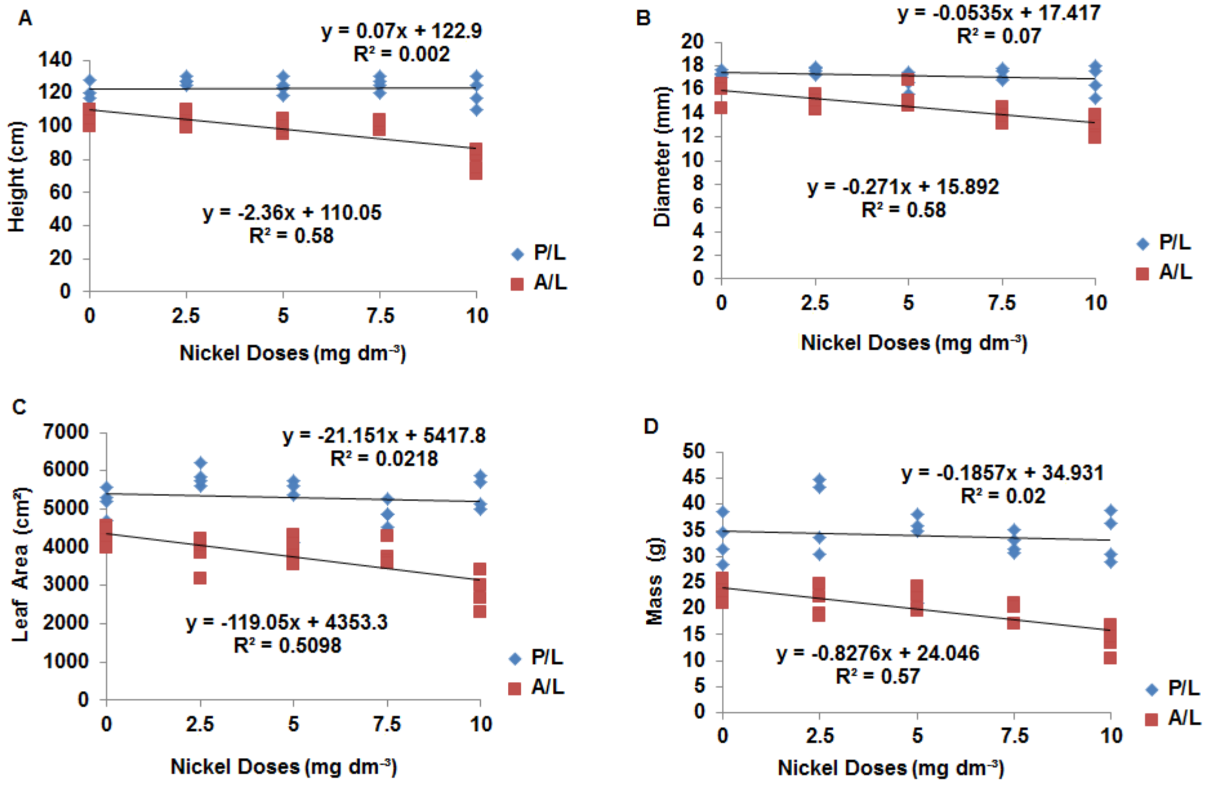

Figure 1. Plant height (A), stem diameter (B), leaf area per plant (C) and total dry biomass per plant (D) as a function of nickel dose, presence of liming (P/L) and absence of liming (A/L).

In the plants grown without liming, symptoms of phytotoxicity due to nickel applications were observed, such as chlorosis, abscission of the first leaves in the early stages of plant development, reduction in growth, dry biomass production and necrosis of the roots that received higher nickel doses (7.5 and 10 mg dm^{-3}). Although the mechanisms of its phytotoxicity are still poorly understood, it is known that high nickel levels in plant tissue inhibit photosynthesis and plant respiration. In addition, toxic levels have been correlated with tissue injury, growth retardation, chlorosis and other specific symptoms for plant species (GUPTA, 2001).

Nickel phytotoxicity varies according to species. Results by Yang et al. (1996) indicate that, although nickel reduces shoot and root growth of cabbage (*Brassica oleracea* L.) and ryegrass (*Lolium perenne* L.), maize and white clover (*Trifolium repens* L.), roots are more sensitive to increased nickel content that their shoots. Parida et al. (2003) observed decreases in dry biomass of fenugreek only at the 20 mg kg^{-1} dose in soil.

Micronutrients

Application of nickel and liming had a significant effect (*P* <0.01) on manganese concentrations in maize plants, this effect clearly visible in the leaves. Manganese concentrations in leaves, stems, and roots decreased with liming and with increasing nickel doses (Figures 2A, 2B and 2C). It is noteworthy that there was a decrease in manganese content with and without liming, although the levels of this nutrient were greater under liming.

The reduction of foliar manganese due to increasing nickel doses may be the result of an antagonistic action between these elements (KABATA-PENDIAS, 2010). A decrease in manganese concentration in barley shoots was observed by Rahman et al. (2005) in response to nickel application.In tomato plants, manganese was the divalent cation that suffered the most restriction in terms of absorption when nickel was present (PALACIOS et al., 1998).As in the case of manganese, he application of nickel and liming significantly reduced (*P* <0.01) zinc concentrations in leaves and roots (Figures 3A and 3C), but not in stems (Figure 3B). The greatest differences in zinc concentrations in leaves and roots under liming were observed at lower doses, and consequently there was a reduction of this difference as nickel doses increased.

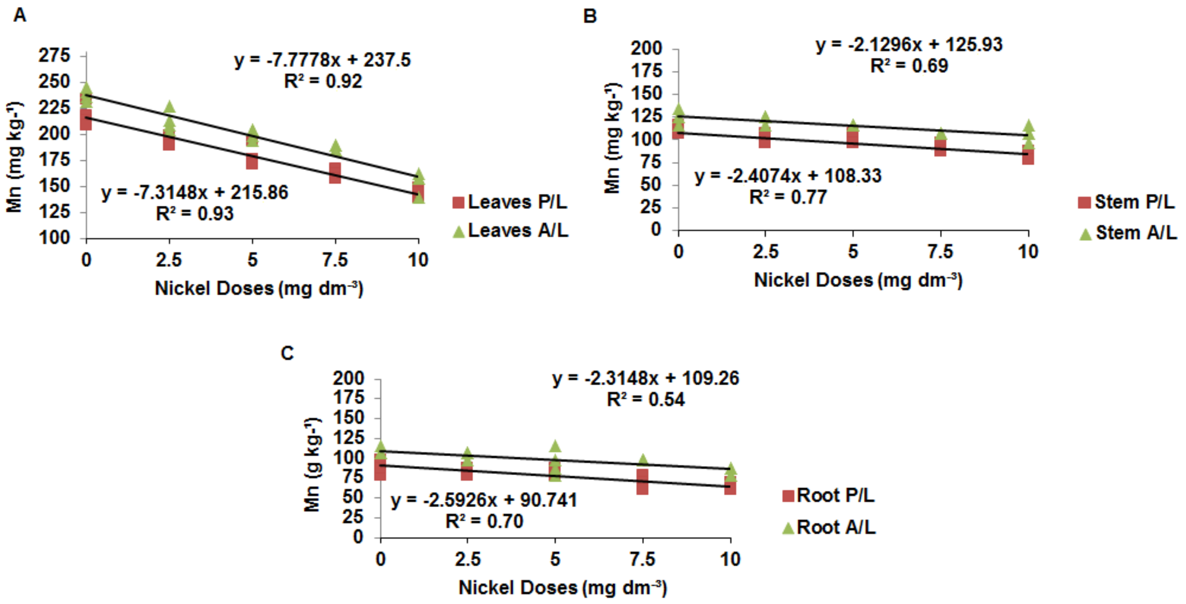

Figure 2. Concentration of manganese in leaves (A), stem (B) and roots (C) nickel doses related to the presence (P/L) and absence of liming (A/L).

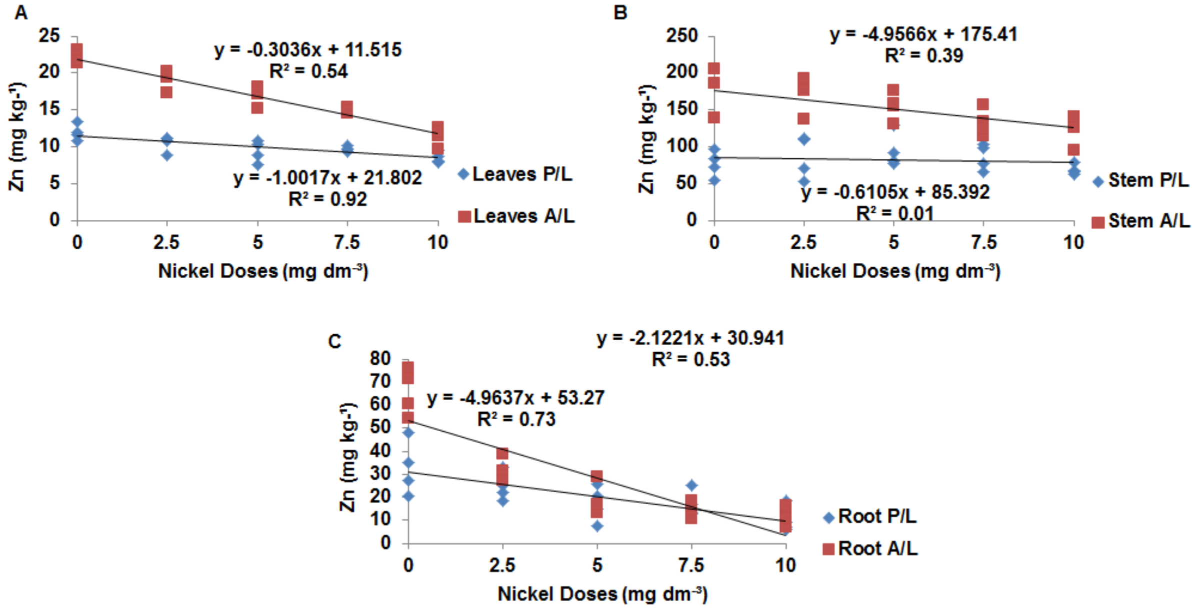

Figure 3. Concentration of zinc in the leaves (A), stem (B) and roots (C) for in nickel doses in the presence (P/L) and absence of liming (A/L).

According to Kabata-Pendias (2010), metals like nickel can be antagonistic to zinc. Paiva et al. (2002) demonstrated that nickel applications led to a positive quadratic response in the root zinc content of *Cedrela fissilis Vell*, suggesting an antagonistic response up to a dose of 200.2 mmol. Likewise, Palacios et al. (1998) observed a reduction in root zinc content in tomato plants exposed to nickel doses.

As for copper content in maize leaves, no difference was observed relative to liming. However, as nickel doses increased, a small increase in copper content was noted (Figure 4). In stems and roots, liming and nickel doses did not alter copper content.

While Kabata-Pendias (2010) stated that the presence of nickel may be antagonistic in some plants, it can also be synergistic in others, as was the case in this study. According to Israr et al. (2011), with the binary mixture of copper + nickel and copper + zinc, the copper root uptake of *Sesbania drummondii* increased in the presence of nickel. Yang et al. (1996) found that there was a reduction in copper absorption in the presence of nickel in *Trifolium repens* and *Brassica oleracea* plants, while copper absorption was not affected by nickel in *Lolium perenne* plants. In tomato plants, Palacios et al. (1998) found that the presence of nickel significantly decreased copper absorption.

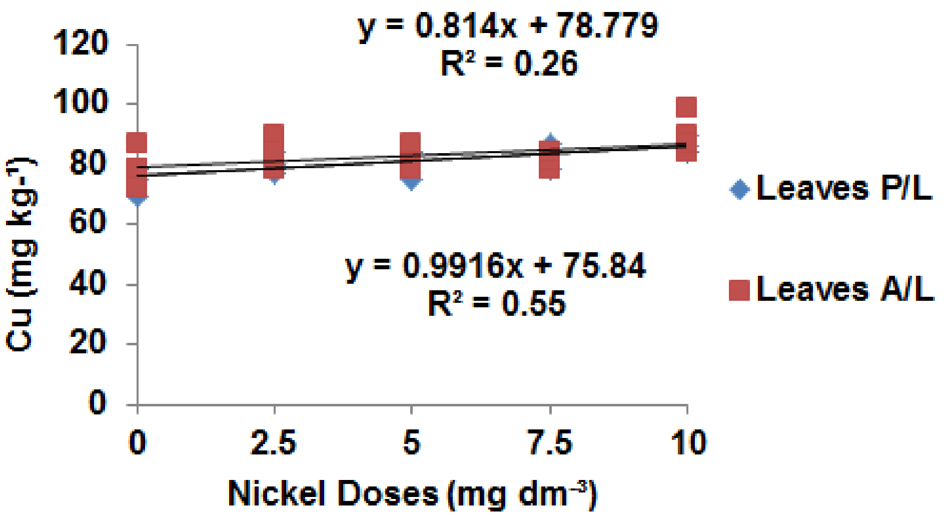

Figure 4. Copper concentrations in leaves relative to nickel doses in the presence (P/L) and absence of liming (A/L).

In the case of iron, there were significant differences in iron concentration in leaves at various nickel doses, with iron increasing linearly with increasing nickel dose (Figure 5A). Liming, however, had no effect. In stems, iron content decreased with increasing nickel doses (Figure 5B). In roots, there were significant differences between iron content only for liming (Figure 5C), whereas an iron increase was observed in the absence of liming. Nickel may increase iron absorption, but it can also inhibit its metabolism by reducing its bioavailability, thus resulting in iron-induced deficiency symptoms (WOOD, 2013). These symptoms were not observed in this study.

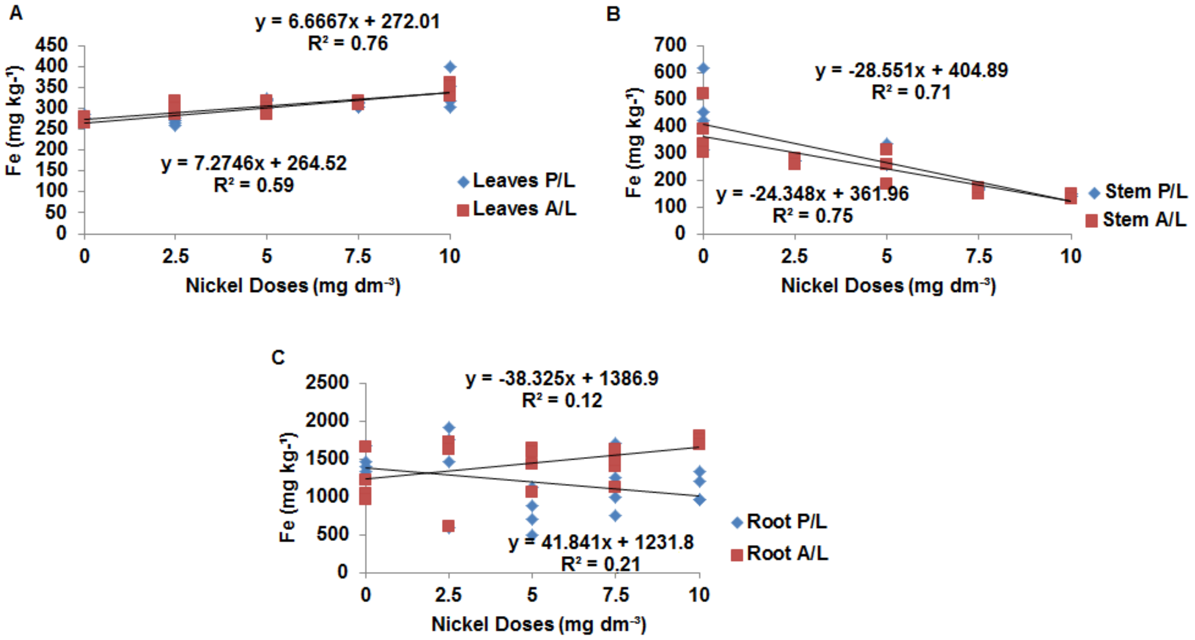

Figure 5. Iron concentration in leaves (A), stems (B) and roots (C) relative to nickel doses in the presence (P/L) and absence of liming (A/L).

Paiva et al. (2002) observed that in stems and leaves of cedar seedlings, the iron content had a positive quadratic response, falling to doses of 128.4 and 98.0 mmol of nickel, respectively, and increasing with higher doses, indicating that, up to a certain dose of nickel, there is restricted iron transport from the root to the shoot. This effect has been observed in many plant species (YANG et al., 1996), although in tomato plants a reduction in iron absorption occurred when the nickel dose of the nutrient solution ranged from 0 to 510 mmol (PALACIOS et al., 1998).

The application of nickel doses and liming to soil influenced nickel concentrations (Figure 6), resulting in a higher level in roots with values up to 596.23 mg kg^{-1} (Figure 6B). In stems, levels of this element were smaller than those found in the roots, yielding a linear pattern of nickel content in stems.

An increase in nickel content in leaves (Figure 6A) suggests that this element is very mobile in plants, while the increase in content, regardless of the part of the plant analyzed, shows that nickel is absorbed in proportion to its concentration during growth. Mazej and Germ (2009) observed relatively high nickel mobility in *Nelumbo Lutea* based on increases in aerial sections.

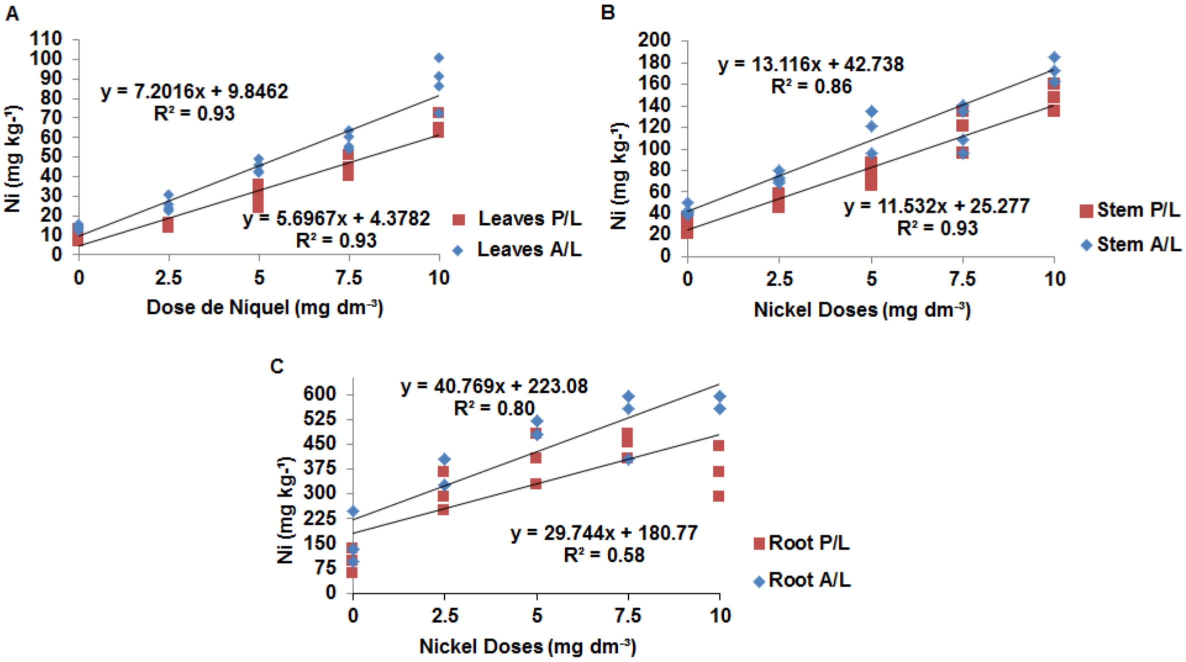

Figure 6. Nickel concentrations in leaves (A), stems (B) and roots (C) relative to nickel doses in the presence (P/L) and absence of liming (A/L).

Nickel toxicity levels may vary according to plant species, with toxic levels of nickel in plants ranging from 8 to 147 mg kg^{-1} (Gupta et al. 2008). Sengar et al. (2008) stated that, in general, nickel toxicity is expressed when the concentration in plant dry biomass is greater than 50 mg kg^{-1}, except for accumulating and hyperaccumulating species such as *Alyssum murale* (9,129 mg kg^{-1}) (BANI et al., 2007). Paiva et al. (2003) found that in the roots of ipe-purple seedlings, the maximum nickel level reached was 669.1 mg kg^{-1} at the 190.9 µmol L^{-1} nickel dose, this being 716% higher than the control treatment.

Meers et al. (2005), evaluating the potential of some species for phytoextraction of toxic elements from sediments derived from calcareous soils, observed higher dry biomass yields and lower concentrations of toxic elements in the shoots of maize plants. The authors concluded that, due to its high production of biomass and tolerance to heavy metals, maize can be as efficient as other crops in phytoextraction, despite its low level of accumulation compared to hyperaccumulator plants.

Special attention should be given to concentrations of these elements in soil to avoid high levels in food. According to Berton et al. (2006), an increase in nickel concentrations up to 2.3 mg kg^{-1} in soils is sufficient to increase the concentration of this element in beans above 5 mg kg^{-1} fresh weight, making them unsuitable for human consumption.

CONCLUSIONS

Liming has an important role in maintaining maize dry biomass production with increasing nickel doses. The presence of nickel exerts an antagonistic effect with the micronutrients manganese and zinc and a synergistic effect with the micronutrients copper and iron.

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