

GROWTH AND NUTRITION OF CACAO SEEDLINGS INFLUENCED BY ZINC APPLICATION IN SOIL¹

RAIMUNDO DE OLIVEIRA CRUZ NETO², JOSÉ OLÍMPIO DE SOUZA JÚNIOR³,
GEORGE ANDRADE SODRÉ⁴, VIRUPAX CHANABASAPPA BALIGAR⁵

ABSTRACT - Levels of Zn in tropical soils profoundly influences growth and nutrition of tree crops. Research was undertaken to assess the effect of soil Zn on growth and nutrition of clonal cacao tree seedlings of PH 16. Three acidic Oxisol soils differing in texture were used with nine doses of Zn (0, 1, 2, 4, 8, 16, 32, 48, and 64 mg dm⁻³). Rooted clonal seedlings were grown in plastic pot with 11 dm⁻³ of the soils at varying Zn levels for 240 days. At harvest growth (dry matter mass of leaves, stems, shoots, roots, and total) and nutrient concentrations were determined. The clonal cacao seedlings showed differences for production of dry matter mass and foliar nutrient concentrations for P, K, Ca, Mg, Mn, Fe, Zn, and Cu. There was Zn toxicity in all soils.

Index terms: *Theobroma cacao* L., micronutrient, calibration fertilization.

CRESCIMENTO E NUTRIÇÃO DE MUDAS DE CACAUEIRO EM FUNÇÃO DA APLICAÇÃO DE ZINCO NO SOLO

RESUMO- Os teores de Zn em solos tropicais influenciam profundamente o sobre crescimento e a nutrição de culturas arbóreas. Esta pesquisa foi realizada para avaliar o efeito de Zn no solo sobre o crescimento e a nutrição de mudas clonais de cacau da variedade PH 16. Três Latossolos ácidos com diferentes texturas foram adubados com nove doses de Zn (0; 1; 2; 4; 8; 16; 32; 48 e 64 mg dm⁻³). Mudas clonais enraizadas foram cultivadas em vasos de plástico com 11 dm⁻³ dos solos com níveis variáveis de Zn, por 240 dias. Na colheita, o crescimento (massa de matéria seca de folhas, caules, brotos, raízes e total) e os teores de macro e micronutrientes foram determinados. As mudas clonais de cacau apresentaram diferenças para a produção de massa de matéria seca e teores de nutrientes foliares para P, K, Ca, Mg, Mn, Fe, Zn e Cu. Houve toxidez de Zn em todos os solos.

Termos para indexação: *Theobroma cacao* L., micronutriente, calibração de adubação.

¹(Trabalho 238-14). Recebido em: 02-09-2014. Aceito para publicação em: 24-03-2015. Extract of the Master's Dissertation of the first author submitted to the Post-Graduation Program of Vegetal Production, Santa Cruz State University – UESC, km 16, Jorge Amado Road, 45.652-000, Ilhéus, Bahia, Brazil. Bolsista FAPESB.

²Agronomist, master in Vegetal Production, UESC. E-mail: agrocruzneto@gmail.com.

³Professor of UESC's Department of Agricultural and Environmental Sciences. E-mail: olimpio@uesc.br.

⁴Professor of UESC's Department of Agricultural and Environmental Sciences and researcher of the Executive Committee of the Cacao Cultivation Plan, Cacao Research Center – CEPLAC/CEPEC. E-mail: sodre@cepec.gov.br.

⁵Researcher of the United States Department of Agriculture – Agricultural Research Service. E-mail: v.cbaligar@ars.usda.gov.

INTRODUCTION

The cacao tree (*Theobroma cacao* L.) is a native species of the Amazon region, being under cultivation in tropical America by pre-Columbian peoples (DIAS, 2001). Currently, cacao production is located in humid tropical regions of America, Asia, Africa, and Oceania. In Brazil, the region with the highest production of cacao beans is in south Bahia, which represent for 75 % of the national production in 2012 (CONAB, 2013).

In agriculture, high productivity can only be achieved when all factors related to production are in the ideal levels or conditions or close to them. Of these factors, soil fertility and plant nutritional status are among the most easily manageable and economically responsive (RAIJ, 1991).

The use of more productive varieties, with higher nutritional demand; the use of fertilizers for the application of macronutrients with higher purity; the natural low fertility of soils in terms of some micronutrients; the decrease in the use of organic manures in agriculture and misuse of agronomic practices, such as the excessive correction of soil acidity, all these are conditions that favor the occurrence of micronutrient deficiency (FAGERIA et al., 2002).

Among the micronutrients, the Zn is observed as the one that most frequently presents deficiency in cacao plantations in the south of Bahia (CHEPOTE et al., 2013), especially cacao grown on Oxisol and Ultisol. Cases of deficiency of this nutrient have also been reported in New Guinea (SCHROO, 1959) and Ghana (GREENWOOD e HAAYFRON, 1951; CUNNIGHAM, 1964). The Zn nutrition have been studied in different cocoa-producing areas, with responses to application of nutrient in dry matter mass (CHUDE and OBIGBESAN, 1983; NAKAYAMA, 1989) and nutritional status of plants (OLIVEIRA et al., 1988; CORRÊA et al., 2006).

The zinc has important functions as enzymatic co-factor in many plant physiological processes (MARSCHNER, 1995; ALLOWAY, 2008). The soil's clay content is pointed out in several studies as a factor that influences Zn availability to plants, as well as its mobility in the soil. The relation between clay content and the capacity factor (or buffering capacity) somehow explains this availability, and in more buffered soils the Zn adsorption phenomenon is more intense (COUTO et al., 1992; OLIVEIRA et al., 1999; NASCIMENTO and FONTES, 2004; ALLOWAY, 2008; CASAGRANDE et al., 2008).

This study aimed to evaluate the growth and nutrition of cacao tree seedlings, clone PH 16, grown

in three Oxisols with different textures, in response to the application of Zn levels.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse in the Santa Cruz State University (UESC), Ilhéus, Bahia, between December 2008 and August 2009. A 3 × 9 factorial design, consisting of three soils and nine doses of zinc (0, 1, 2, 4, 8, 16, 32, 48, and 64 mg dm⁻³), in the form of ZnSO₄·7H₂O, was used. A randomized block design was used, with three replications; the experimental plot consisted of one plant per pot. For the study, soil samples were taken from the B horizon (20–60 cm-layer) of three Oxisols in South Bahia, which were initially classified in chemical and particle size distribution terms, according to Silva (2009). The soils in each pot were thoroughly mixed and sample was obtained at time of seedling transplant for chemical analysis.

The soils, identified as 1, 2, and 3, presented clay content of 22, 42, and 59 %, respectively. The seedlings were produced by rooting of apical cuttings of plagiotropic branches of cacao trees, of the PH 16 clone, with approximately 16 cm in length. Small plastic tubes of 288 cm³ containing substrate composed of pinus bark and coconut fiber powder in a ratio of 2:1 were used for seedling planting. At the time of planting the base of the cuttings were immersed in 6.0 g kg⁻¹ of indolebutyric acid, diluted with talc to induce roots. The plants were maintained in a climatic chamber for rooting for a period of 30 days, where they were irrigated by micro sprinkler for 30 seconds every five minutes.

After this period, they were transplanted in to plastic bags filled with 1.0 dm³ of a substrate composed of sand and sawdust in the volumetric proportion of 2:1 and irrigated to maintain soil water status at 80 % of field capacity. After 120 days, the plants were again transplanted into plastic pots with drainage holes with capacity for 12 L, containing 11 dm³ of the desired soils sieved through a 5 mm-mesh. Before transplanting, based on the initial soil analysis (SILVA, 2009 - Table 1), they were mixed with CaCO₃ and MgCO₃ (Ca:Mg 4:1) to correct the acidity and to raise the base saturation, to 80 %. All the soils received the same planting fertilization, in mg dm⁻³: 400 of phosphorus (P), 169 of nitrogen (N), 120 of potassium (K), 50 of sulfur (S), 10 of manganese (Mn), 2 of copper (Cu), 0,8 of boron (B), and 0,3 of molybdenum (Mo), in the form of purified monoammonium phosphate (MAP), potassium sulphate, manganous sulphate, copper sulphate, boric acid, and ammonium molybdate.

The doses of Zn of each treatment were applied, through a solution of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$. After through mixing of Zn solutions with soil samples, the seedlings were transplanted to pots. From the 30th day after transplant a biweekly fertilization with 50 mg dm^{-3} of N as urea was initiated. After 150 days of transplant, a biweekly fertilization of 10 mg dm^{-3} of P and 20 mg dm^{-3} of K was added, in the form of a solution of purified MAP and KNO_3 . The pots were irrigated to maintain the amount of water at about 80 % of field capacity.

After 240 days after transplant, leaves, stems, and roots, were separated and a sample composed of five diagnostic leaves per plot was made to assess the nutritional status of the plants. The diagnostic leaf for cacao trees was defined as the third leaf from a totally mature branch not presenting recent new leaves (SOUZA JÚNIOR et al., 2012; CHEPOTE et al., 2013). Each plant part was dried in a forced air circulation chamber at $65 \text{ }^\circ\text{C}$, until achieving a constant mass and weighted to obtain the variables: root dry weight (RDW), leaf dry weight (LDW), stem dry weight (STDW), shoots dry weight (SHDW = LDW + STDW), and total dry weight (TDW = RDW + SHDW). The diagnostic leaves were initially washed through dipping in a solution of HCl at 0.2 %, followed by a double washing with deionized water, and then dried, weighted, grounded, and chemically analyzed. Plant samples from each treatment were used for chemical analysis, according to Silva (2009). After the end of the experiment, the soil from each plot was homogenized, sampled and Zn content extracted by Mehlich-1 was determined by atomic absorption spectrophotometry (SILVA, 2009).

The results were submitted to analyses of variance and regression, with linear and quadratic or quadratic root coefficients, and the models accepted were those that presented all coefficients as significant up to 10 % probability through F-test, and higher index of determination. To define classes of the quantitative treatments (doses of Zn) that did not present statistical differences, Tukey's test with 5 % error significance was performed.

Classes of nutritional sufficiency Zn in soil and plants based and divided according to the relative percentage of the maximum yield of total dry weight (TDW_{max}) were defined because this variable reflects, in an integrated manner, the production of plant biomass achieved during the study period. The following classes were achieved: low ($\text{TDW}_{\text{max}} < 90 \%$, for deficiency of Zn), medium ($90 \% \leq \text{TDW}_{\text{max}} < 95 \%$, for deficiency of Zn), adequate ($\text{TDW}_{\text{max}} \square 95 \%$, for deficiency of Zn, up to 100 % of TDW_{max}), high ($100 \% > \text{TDW}_{\text{max}} > 95 \%$, for excess of Zn),

and toxic ($\text{TDW}_{\text{max}} \leq 95 \%$, for excess of Zn). The lower limit of the adequate range was considered the critical level (CL).

RESULTS AND DISCUSSION

The growth responses of cacao seedlings to Zn application in the three soils for the variables RDW, STDW, LDW, and SHDW are presented in Figures 1a, 1b, 1c, and 1d, respectively. For soil 1, with lower clay content, the increment of Zn doses had a negative linear effect for the RDW variable (Figure 1a); however, as there was no significant difference among the Zn doses of 0 to 2 mg dm^{-3} , by the Tukey's test such result suggests that Zn depressive effect occurred only in doses higher than 2 mg dm^{-3} . In soils 2 and 3, RDW presented quadratic adjustment with maximum production recorded for doses of 35.7 and 23.3 mg dm^{-3} of Zn, respectively (Figure 1a). This result may reflect the differences exist among soils for levels of organic matter and clay content, pH, and CEC. Amaral Sobrinho et al. (2009) suggested that these soil variables have a strong influence on the adsorption and the consequent availability of heavy metals in soil. According to Maschner (1995), the root system is affected by Zn toxicity conditions, mainly in susceptible varieties; in addition Rout and Das (2003) reported that Zn toxicity was associated with changes in the root physiology, thereby inhibiting the elongation root.

Studies involving response to Zn application in the production of RDW in perennial species seedlings presented different results according to the species and experimental conditions: Fernandes et al. (2003), applying P and Zn in cupuaçu tree seedlings (*Theobroma grandiflorum* Schum.), observed positive linear effect of soil Zn levels on the RDW for Zn doses of up to 10 mg dm^{-3} ; Corrêa et al. (2002), also evaluating fertilization with P and Zn, in acerola tree seedlings (*Malpighia emarginata* DC.), achieved the highest production of RDW with a doses of 5 mg dm^{-3} of Zn, combined with 300 mg dm^{-3} of P. On the other hand, Corrêa et al. (2005) did not achieve a significant effect of soil Zn levels on the RDW for papaya tree seedlings (*Carica papaya* L.). The way of production of cacao tree seedling that was used in this study – rooting of stem tissue induced by a phytohormone – is also an important factor to be considered, since, according to Marschner (1995) and Taiz and Zeiger (2009), the adventitious roots, originated in the stem vascular cambium, are extremely influenced by soil environmental factors, such as availability of nutrients; and one of the functions of zinc is the synthesis of indole-acetic

acid, a growth regulator responsible for the process of formation of lateral roots.

For soil 1, LDW and SHDW also presented negative linear effect in relation to the Zn doses (Figures 1c and 1d). In this case, Tukey's test did not present significant differences among Zn doses of 0 to 4 mg dm⁻³, which indicates that, for these plant parts, the Zn depressive effect would occur with Zn doses higher than 4 mg dm⁻³. In soil 2, there were no significant effects in the production of LDW and SHDW with doses of 0 to 2 mg dm⁻³ of Zn, according to Tukey's test; however, with doses higher than 2 mg dm⁻³, there was a decreasing effect for both variables (Figures 1b and 1c). In soil 3, LDW and SHDW increased until the estimated doses of 9.0 and 8.9 mg dm⁻³ of Zn, respectively (Figures 1c and 1d). In this soil, estimated foliar Zn content, in order to obtain the maximum production of SHDW, was 115.4 mg kg⁻¹. Positive responses to the Zn application, for seminal cacao seedlings, were obtained by Nakayama (1989), who achieved the maximum production of SHDW with 2.2 mg kg⁻¹ of Zn, and by Corrêa et al. (2006), who obtained positive response to Zn only for the production of LDW, with a dose of up to 5.6 mg dm⁻³ of Zn.

In soil 1, the STDW presented increments with soil Zn dose up to 1.0 mg dm⁻³, and then it decreased; in soil 2, there was no significant response to Zn doses for STDW; while in soil 3 there was an increment in STDW with dose of up to 9.1 mg dm⁻³ of Zn (Figure 1b).

For soils 2 and 3, the maximum production of RDW was achieved with doses of 35.7 and 23.4 mg dm⁻³ of Zn, respectively, and these doses are higher than those needed for achieving maximum production of SHDW (Figures 1a and 1d). These doses resulted in lower production of SHDW in relation to its maximum production, estimated in 17.4 % and 4.4 % for soils 2 and 3, respectively. High levels of Zn can induce Fe, Mg and P deficiency in different parts of the plant, resulting in limitation in root and leaf development (MASCHNER, 1995; NAGAJYOTI et al., 2010; MOUSAVI, 2011). Nagajyoti et al. (2010) ascribed this deficiency to a hindered transfer of Fe from root to shoot with the Zn increments in plant. Marschner (1995) pointed that only severe deficiency in Fe affect the leaf growth, but the higher biomass allocation to the root system with co-factor can explain the lower production of LDW and SHDW.

Decreases occurred in Fe, Mg and P concentrations with increased Zn doses in the soils 1 and 3. The soil 2 showed invariable concentrations of Fe and P in diagnostic leaves but these have the lower

levels than those corresponding initial doses of Zn in the other two soils. P deficiency that can be induced in Zn toxicity cases, results in leaf carbohydrate accumulation, high carbon levels allocated to the root and increases in the ratio of biomass of the root shoots which would explain the higher biomass allocation to the root system (HERMANS et al., 2006).

Answers similar to the present study by guava (*Psidium guajava* L.) tree seedlings for Zn applications were reported by Natale et al. (2002). On the other hand, the results obtained from a study of Favarin et al. (2007) where Zn was applied for *Coffea arabica* L. and *C. canephora* L., show a maximum yield of RDW at lower levels of soil Zn than those observed for the maximum production of the SHDW, unlike the results obtained in this study. It must be pointed out that many reported studies on soil Zn levels calibration do not present granulometric analysis of soils or any other estimates relating to the Zn buffering capacity, a factor that makes it difficult to compare results of different studies. Figure 2 shows the responses of TDW production to the various soil Zn levels; while the models of nutrient contents in the diagnostic leaf, according to applied Zn doses, are presented in Figures 3 and 4. Based on the predefined percentages of the maximum production of TDW (TDW_{max}), classes of soil fertility and of nutrition of cacao tree seedlings for Zn were established for soils 2 and 3 (Table 2).

The highest production of TDW was obtained in soil 2, with TDW_{max} estimated in the doses of 26.5 mg dm⁻³ of Zn (Figure 2a), whose application resulted, at the end of the experiment, in Zn contents in the soil and in the diagnostic leaf of 13.9 mg dm⁻³ and of 234 mg kg⁻¹, respectively (Table 2). For this soil, the recommended soil applied Zn doses to obtain 95 % of the TDW_{max} was of 9.3 mg dm⁻³ of Zn; this resulted, at the end of the experiment, in critical contents of Zn in the soil and in the plant of 4.9 mg dm⁻³ and 109 mg kg⁻¹, respectively (Table 2).

In soil 3, TDW presented quadratic root effect, and the TDW_{max} was obtained with the dose of 9.8 mg dm⁻³ (Figure 2a) corresponded, at the end of the experiment, to a Zn level in the soil of 4.0 mg dm⁻³ and in the diagnostic leaf of 143 mg kg⁻¹ (Table 2); the recommended dose of Zn is 1.7 mg dm⁻³, which results in a zinc level in the soil of 0.8 mg dm⁻³ and in the plant of 63 mg kg⁻¹ (Table 2). It must be pointed out that this soil presented the highest similarity of SHDW (Figure 1c) and TDW (Figure 2a) responses.

The estimated Zn doses in order to obtain the maximum production of TDW (TDW_{max}), in soils 2 and 3, agreed to the range of Zn doses reported by Chude and Obigbesan (1983), who obtained TDW_{max}

production with soil Zn doses of 10 and 50 mg dm⁻³ for the cacao trees of the Amazonic and Amelonado varieties, respectively. The results of these authors also indicated wide variation in the demand for Zn between the varieties of cacao tree.

In soil 1, the TDW presented no significant difference, by Tukey's test, between the doses of 0 to 2 mg dm⁻³ and after this dose, there was a decrease in the production of TDW (Figure 2a), which evidences that the toxic effect of Zn doses on the plant development. The coarser granulometry of this soil (with only 22 % of clay), in a way, helps to understand the negative effect of Zn on the dry matter production of cacao tree seedlings from doses equal to or higher than 2 mg dm⁻³ of Zn. Zn has its availability to plant severely affected by their interaction with the colloidal fraction of the soil; the intensity of these reactions is dependent on the mineral particle size, composition and mainly pH of the soil. The clay content, organic matter, Fe/Al oxides content and buffering capacity or capacity factor of soil are among the main characteristics related to decrease in availability of Zn with increase of these characteristics (COUTO et al., 1992; OLIVEIRA et al. 1999; MOUSAVI, 2011). Soil 1 was the soil that had the highest acidification, reaching, at the end of the experiment, mean values of Al³⁺ and saturation of about 30 mmol_c dm⁻³ and 43 %, respectively – values that, in addition to being toxic, can have a incremented deleterious effect in the plant physiology due to high levels of Zn, that altering the permeability of the cell membrane of the root (MARSCHNER, 1995), making them more sensitive to Al toxicity.

It is important to emphasize the difference exists from this study, with the cited experiments that assessed the soil Zn effects on cacao tree seedlings (CHUDE and OBIGBESAN, 1983; OLIVEIRA et al., 1988; NAKAYAMA, 1989; CORRÊA et al., 2006). In these reported studies were performed using seminal seedlings of varieties. This fact can make comparisons among the studies difficult due to differences in the growth patterns of the root system and of the shoots of plants of vegetative and seminal origin, and also due to differences related to the use of nutrients between cacao genotypes.

In this context, in other perennial crop cultivations, the Zn doses obtained for the production of TDW_{max} are much lower than those obtained in this study, such as in the Fernandes et al. study (2003), in which the response of cupuaçu trees was evaluated, achieving the highest TDW production in a dose of 5 mg dm⁻³ combined with the dose of 300 mg dm⁻³ of P. Corrêa et al. (2005), after the study of

fertilization with Zn for the formation of papaya tree seedlings, estimated the recommended dose of 2 mg dm⁻³ of Zn, and Lima et al. (2007), after the study of the effects of P and Zn on the growth of passion fruit (*Passiflora edulis* Sims) seedlings, estimated the TDW_{max} production at the dose of 5 mg dm⁻³ of Zn. The results obtained for the TDW production in response to the doses of Zn, when compared with the results for other cultures, also demonstrate that there is a high nutritional requirement of Zn for cacao trees of the PH 16 clone, a fact ratified by the high levels of the sufficiency ranges established in diagnostic leaves for soils 2 and 3 (Table 2), which, in addition to being extensive, approximate those suggested by Malavolta (2006) and Souza Júnior et al. (2012), from 80 to 170 and 80 to 150 mg kg⁻¹ of Zn, respectively; as well as the leaf Zn content of 144 mg kg⁻¹ found by Nakayama (1989) for the SHDW maximum production of seminal seedlings of cacao tree.

At the end of the experiment, linear models of the levels of available Zn in soils were adjusted, extracted by Mehlich-1, according to Zn doses, and with angular coefficients ranging from 0.40 to 0.52 (Figure 2b). This variation, which reflects the rate of recovery of Zn by the extractor, was inversely proportional to the values of remaining P (P-rem) of the soils and presented no proportionality with the clay content (Table 1). This result indicates that P-rem can be a more suitable characteristic than the clay content for use in studies about the adsorption and availability of this element, as suggested by Couto et al. (1992). In this context, the Zn availability ranges in soils 2 and 3, indicated as adequate for the Mehlich-1 extractor (Table 2), were broader than those suggested by Chepote et al. (2013), for fertile soil for cultivation of cacao, from 1.5 to 2.2 mg dm⁻³.

Of the nutrients analyzed in the diagnostic leaves (Figures 3 and 4), only the mean foliar content of K on the three soils (9.8, 10.2, 10.2 mg dm⁻³ to soils 1, 2 and 3 respectively) were below the sufficiency range indicated by Souza Júnior et al. (2012), for adult cacao trees. In relation to the foliar content of the nutrient studied (Zn), which varied between 22 a 780 mg kg⁻¹ and increased with the increment of the dose applied in all the soils (Figure 4c). In the treatments without the application of the nutrient, the foliar concentrations (mean Zn content in diagnostic leaf 29.3, 31.3 and 22.67 mg kg⁻¹ to the soils 1, 2 e 3 respectively) were slightly higher than in those leaves with characteristic visual symptoms of deficiency, as described by Schroo (1959) and Cunningham (1964), which were of 15 and 20 mg kg⁻¹, respectively. However, we did not observe nutrient

deficiency symptoms on leaves. The Zn content in diagnostic leaf which serves as a divider between the nutritional categories of high and toxic in the soils 2 and 3 (360 and 244 mg kg⁻¹ respectively) are close to the limit of 300 mg kg⁻¹, identified as lower limit of toxic Zn concentration in plants (MARSCHNER, 1995).

For the three soils, the K content in the cacao trees diagnostic leaf presented inverse quadratic response (Figure 3a), resulting in estimated foliar content of K lower in Zn levels similar to those for maximum production of TDW (Figure 2a), except for soil 1, which suggests effects of dilution or of concentration of the element in the plant according to the higher or lower production of TDW, respectively. Behaviors similar to that of K were observed for foliar contents of P and Cu in soil 1, and for Mg and Cu in soil 3; however, in these cases, the minimum estimated foliar contents of these elements were obtained with soil Zn levels higher than those for the obtained for her maximum production of TDW (Figure 2a), indicating that this resumption in the accumulation of the cited nutrients occurred in plants in the nutritional condition known as luxury consumption, in which high contents of a nutrient start to affect the concentrations and the physiological responses of other nutrients, and consequently affect negatively the production (MARSCHNER, 1995). These results can also be understood by the effects of dilution and of concentration due to the increases and decreases of the dry mass of the plants, according to soil Zn levels.

Negative effects of soil Zn levels on the foliar contents of other nutrients were observed for: P (soil 3), Mg (soil 1), and Fe (soils 1 and 3), Figures 3b, 3d, and 4b, respectively; this suggests the inhibition of these nutrients by Zn, by antagonism among them in the soil, such as for P, or in the process of plant root absorption, such as for P, Mg, and Fe (KOCHIAN, 1991; MARSCHNER, 1995; ALLOWAY, 2008). Foliar P and Fe content observed in the present study are similar to the values reported by Oliveira et al. (1988), in a study involving fertilization of cacao with P, Fe, and Zn.

There were no significant effects of the soil Zn levels on the foliar contents of P (soil 2), Ca (soils 1 and 3), Mn (soil 3), and Fe and Cu (soil 2), Figures 3b, 3c, 4a, 4b, and 4d, respectively. However, there were significant positive effects for foliar contents of Ca and Mg (soil 2) and Mn (soils 1 and 2), Figures 3c, 3d, and 4a, respectively. The positive effects of the soil Zn levels on foliar contents of Ca and Mg observed in soil 2 oppose the propagated negative interaction between Zn and divalent cations (MARSCHNER, 1995; MOREIRA et al., 2003; PAIVA et al., 2003;

MALAVOLTA, 2006), however, this soil had higher Ca and Mg and organic matter content than other two soils (Table 1), in addition this soil had higher pH, and mean values of Al³⁺ and of Al saturation of 5 mmol_c dm⁻³ and 19 %, respectively. These soil properties might have moderating effects on reducing the toxicity of higher levels of soil applied Zn and this is reflected in highest productions of RDW and TDW compared to other two soils. (Figures 1a and 2a, respectively). Despite Kochian (1991) pointed that Zn, Ca, and Mg in growth medium inhibits the absorption of Mn, however, Foy et al. (1978) and Fageria (2001) described the beneficial effects of Zn on the translocation of Mn in soybeans. Our findings show the positive effect of increasing soil Zn levels on the foliar contents of Mn in soils 1 and 2 (Figure 4a).

It is important to highlight that the differences in the chemical and physical compositions of the soils may have contributed to some of these divergences in the cacao nutritional responses, a fact also observed by Oliveira et al. (1988) for cacao tree seedlings, by Fernandes et al. (2007) for freijó seedlings (*Cordia goeldina* Huber), and by Paiva et al. (2003) for cedar tree (*Cedrela fissilis* Vell.) seedlings.

TABLE 1 – Results of the chemical and granulometric analyses of the three Oxisols studied.

Soil	Clay %	Silt %	Sand %	pH	O.M g kg ⁻¹	P-rem mg L ⁻¹	Ca	Mg	Al	H+Al	T	P	K	B	Cu	Fe	Mn	Zn	
						mmol _e dm ⁻³										mg dm ⁻³			
1	22	14	64	4.8	17	12.4	2	2	51	94	99	0.9	19	0.3	0.7	61	13	0.4	
2	42	11	47	5.6	38	19.9	20	8	0	52	81	0.3	27	0.1	1.0	60	7.9	1.4	
3	59	8	33	4.4	26	14.5	3	2	9	60	66	0.8	12	0.1	0.6	56	8.5	0.3	

pH in water 1:2.5; O.M = organic matter - Walkley-Black; P, K, Cu, Fe, Mn, e Zn - Mehlich-1; Ca²⁺, Mg²⁺, and Al³⁺ - KCl 1.0 mol L⁻¹; H + Al - Calcium acetate 0.5 mol L⁻¹ at pH 7; T (CEC at pH 7.0); B - hot H₂O; P-rem (remaining P), according to Silva (2009).

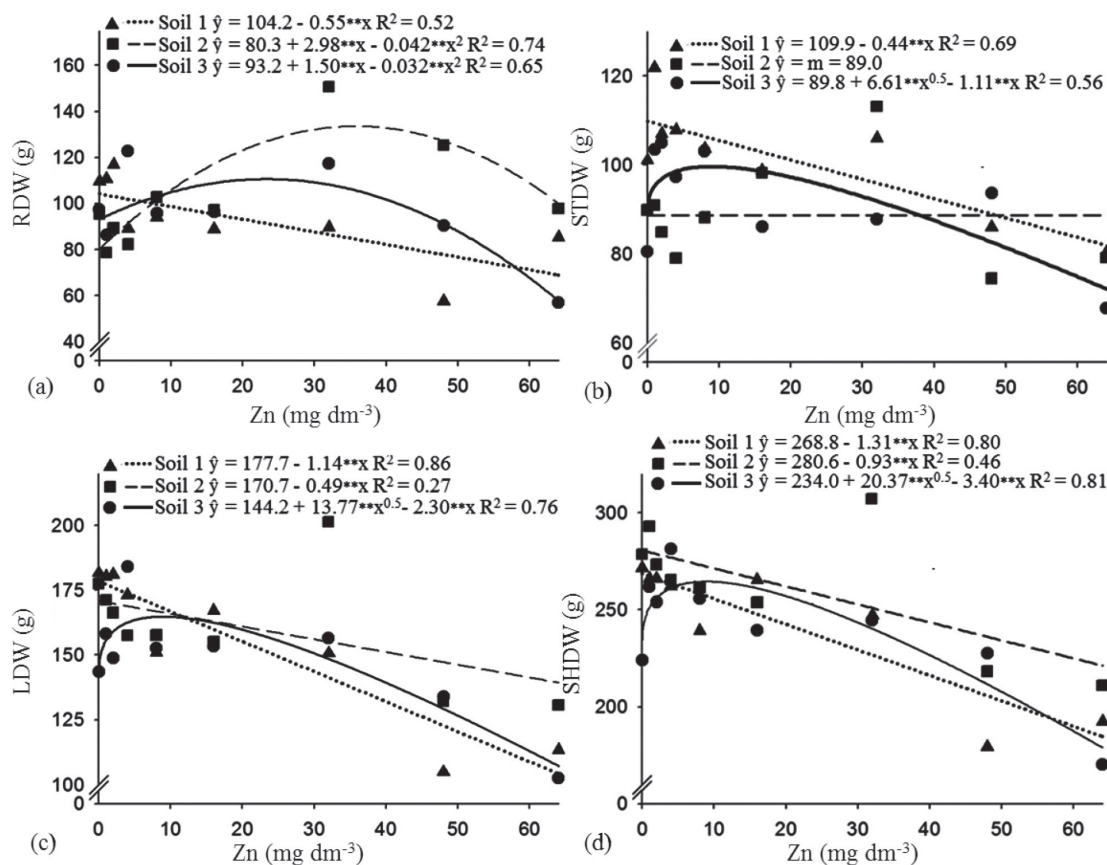


FIGURE 1 – a) Root dry weight (RDW), c.v. = 26.3 %; b) stem dry weight (STDW), c.v. = 18.6 %; c) leaf dry weight (LDW), c.v. = 19.4 %, and d) shoot dry weight (SHDW), c.v. = 16.9 %, of cacao tree seedlings (PH 16 clone), after 240 days, according to the Zn doses in the three soils studied.

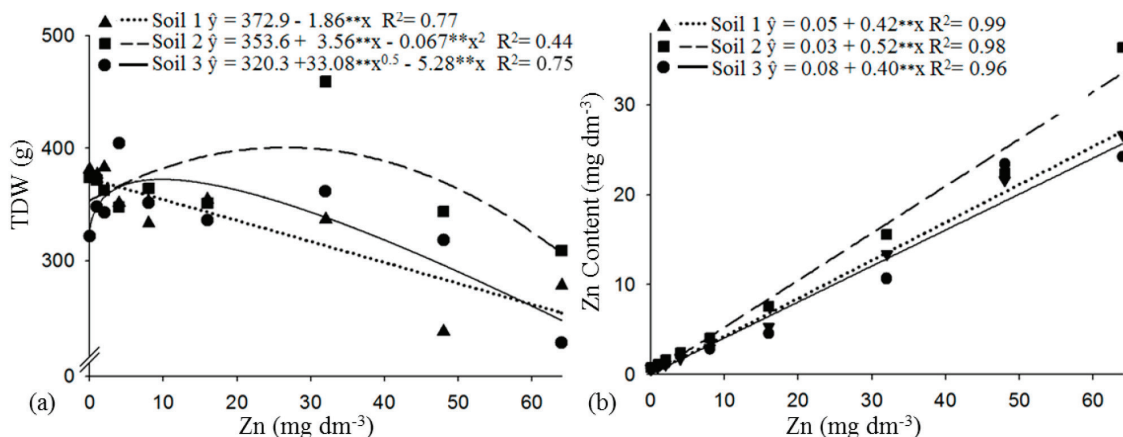


FIGURE 2 – a) Total dry weight (TDW) of cacao trees seedlings (PH 16 clone), c.v. = 16.8 %, and b) Zn contents in the soil sampled by Mehlich-1, after 240 days, according to the Zn doses in the three soils studied, c.v. = 116.2 % .

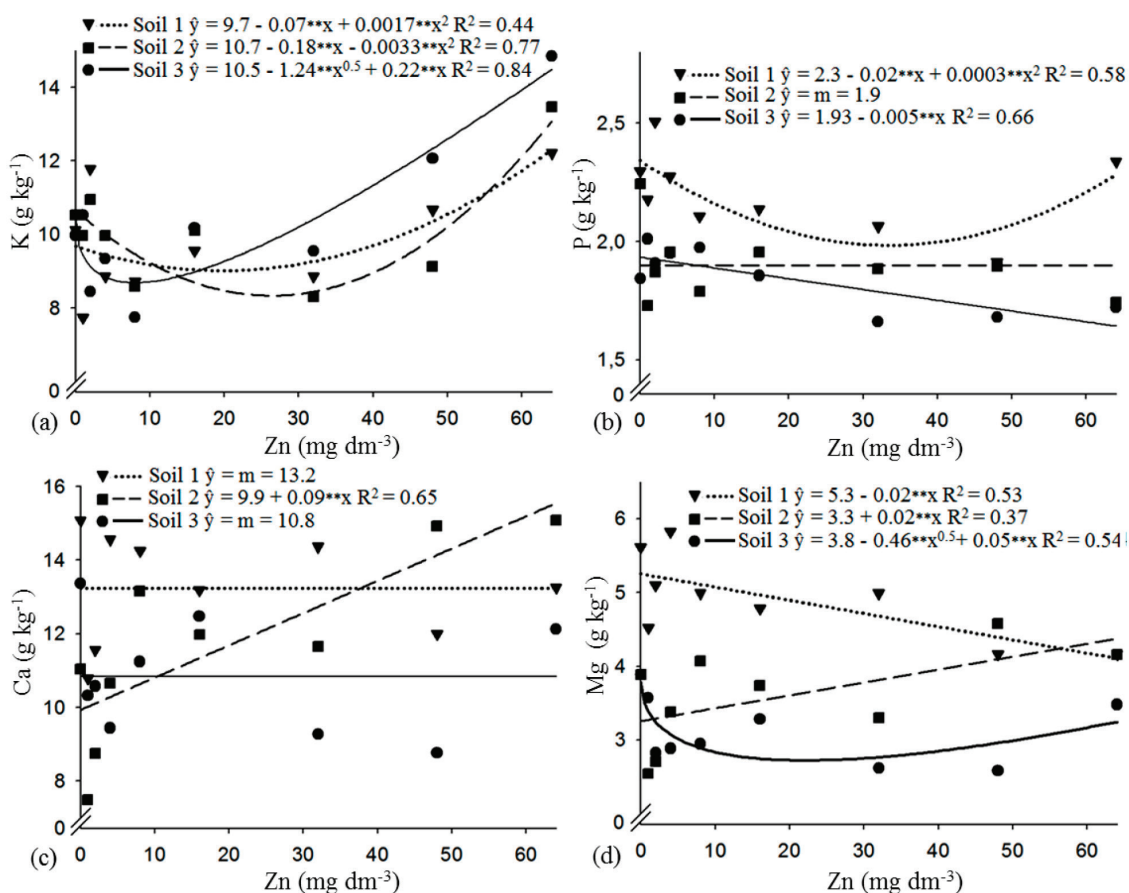


FIGURE 3 – Macronutrients contents in the diagnostic leaf of PH 16 cacao clone after 240 days of growth influenced by soil Zn levels in three soils: a) potassium, c.v. = 26.2 %; b) phosphorus, c.v. = 15.3 %; c) calcium, c.v. = 28.7 %; and d) magnesium, c.v. = 30.0 %.

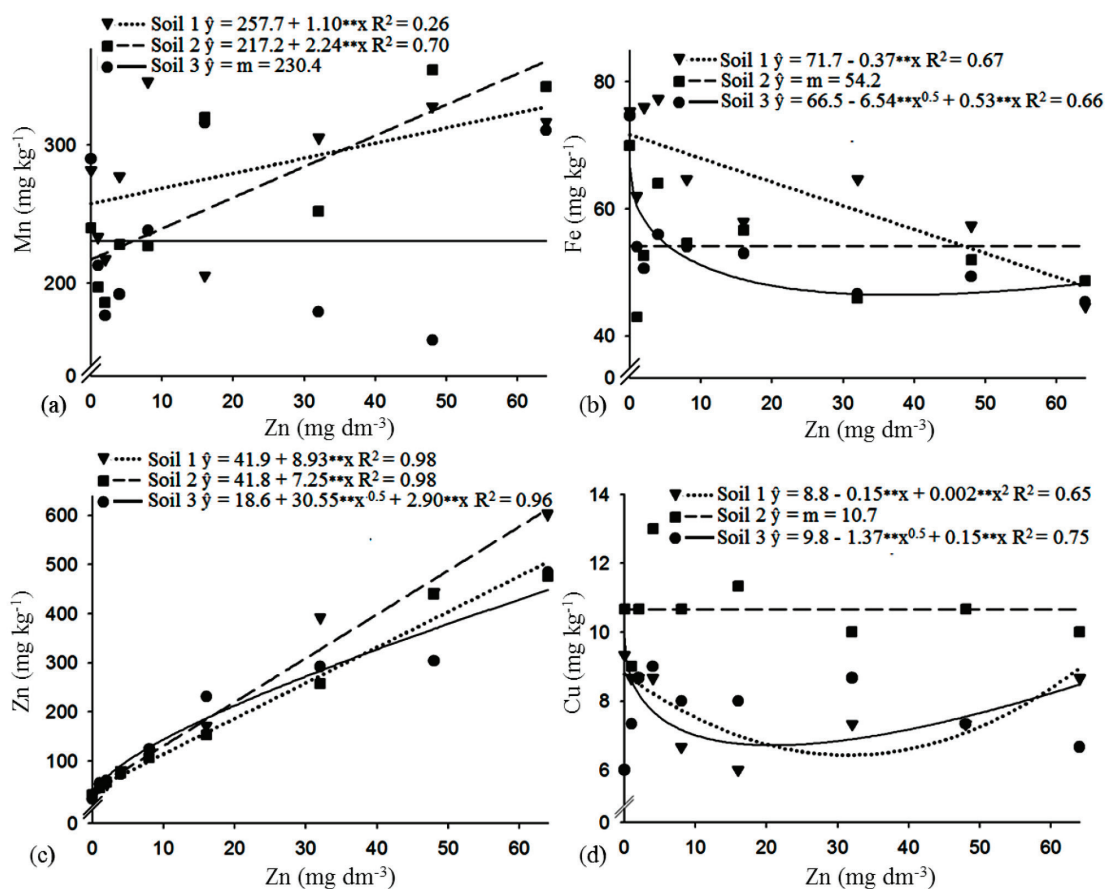


FIGURE 4 – Micronutrients contents in the diagnostic leaf of PH 16 cacao clone after 240 days of growth influenced by soil Zn levels in three soils: a) manganese, c.v. = 40.8 %; b) iron, c.v. = 26.0 %; c) zinc c.v. = 94.5 %; and d) copper, c.v. = 25.3 %.

TABLE 2 – Categories of the soils fertility for Zn and the Zn nutrition, of cocoa tree seedlings, PH 16 clone, for two Oxisols^{1/}

Soil ^{1/}	Content in the soil (mg dm ⁻³) ^{2/}					Content in diagnostic leaf (mg kg ⁻¹)				
	Low	Medium	Aproprate	High	Toxic	Low	Medium	Aproprate	High	Toxic
2	< 1.1	1.1 - 4.9	5.0 - 13.9	14.0 - 23.0	> 23.0	< 57	57 - 109	110 - 234	235 - 360	> 360
3	< 0.2	0.2 - 0.8	0.9 - 4.0	4.1 - 10.1	> 10.1	< 33	33 - 62	63 - 143	144 - 244	> 244

1/ Soil 2 (42 % of clay and 19.9 mg L⁻¹ of remaining P) and soil 3 (59 % of clay and 14.5 mg L⁻¹ of remaining P).

2/ Mehlich-1 extractant.

CONCLUSIONS

The accumulation of dry mass of cacao tree seedlings differed in relation to the response to the level of Zn application, and to the organ analyzed (root, stem, and leaves).

Higher levels of soil applied Zn, independently of the soil or plant organ analyzed, caused reduction in the growth of cacao tree plants.

REFERENCES

- ALLOWAY, B. J. **Zinc in soil and crop nutrition**. 2nd ed. Bruxelas: IZA, IFA, 2008. 139p.
- AMARAL SOBRINHO, N. M. B.; BARRA, C. M.; LÃ, O. R. Química dos metais pesados no solo In: MELO, V. F.; ALLEONI, L. R. F. **Química e mineralogia dos solos** Viçosa: Sociedade Brasileira de Ciência do Solo, 2009. v.2, p. 251-312.
- CASAGRANDE, J. C.; SOARES, M. R.; MOUTA, E. R. Zinc adsorption in high weathered soils. **Pesquisa Agropecuária Brasileira**, Brasília, v. 43, n. 1, p.131-139, 2008.
- CHEPOTE, R. E.; SODRÉ, G. A.; REIS, E. L.; PACHECO, R. G.; MARROCOS, P. C. M.; VALLE, R. R. **Recomendações de corretivos e fertilizantes na cultura do cacauero no sul da Bahia**. Ilhéus: CEPLAC/CEPEC, 2013. 44p. (Boletim Técnico, 203).
- CHUDE, V. O.; OBIGBESAN, G. O. Effect of zinc application on the dry matter yield uptake and distribution of zinc and the other micronutrients in cacao (*Theobroma cacao*). **Communications in Soil Science and Plant Analysis**, Philadelphia, v. 14, n. 10, p. 989-1004, 1983.
- CONAB - Companhia Nacional de Abastecimento. **Conjuntura Mensal**. Disponível em : <http://www.conab.gov.br/OlalaCMS/uploads/arquivos/13_06_11_11_38_00_cacaumaio2013.pdf>. Acesso em: 1 ago. 2013.
- CORRÊA, F. L. O. C.; SOUZA, C. A. S.; CARVALHO, J. G.; MENDONÇA, V. Fósforo e zinco no desenvolvimento de mudas de aceroleira. **Revista Brasileira de Fruticultura**, Jaboticabal, v. 24, n. 3, p. 793-796, 2002.
- CORRÊA, F. L. O. C.; SOUZA, C. A. S.; CARVALHO, J. G.; MENDONÇA, V.; VICHATO, M. Fósforo e zinco no desenvolvimento de mudas de cacauero. **Agrotropica**, Ilhéus, v. 18, n. 1, p. 15-24, 2006.
- CORRÊA, M. C. M.; NATALE, W.; PRADO, R. M.; OLIVEIRA, I. V. M.; ALMEIDA, E. V. Adubação com zinco na formação de mudas de mamoeiro. **Caatinga**, Mossoró, v. 18, n.4, p. 245-250, 2005.
- COUTO, C.; NOVAIS, R. F.; TEIXEIRA, J. L.; BARROS, N. F.; NEVES, J. C. L. Níveis críticos de zinco no solo e na planta para o crescimento de milho em amostras de solos com diferentes valores do fator capacidade. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 16, n. 1, p. 79-87, 1992.
- CUNNINGHAM, R.K. Micronutrient deficiency in cacao in Ghana. **Empire Journal of Experimental Agriculture**, Oxford, v.32, n.125, p. 42-50, 1964.
- DIAS, L. A. S. Origem e dispersão de *Theobroma cacao*: um novo cenário. In: DIAS, L. A. S. **Melhoramento genético do cacauero**. Viçosa: FUNAPE, UFG, 2001. p. 81-127.
- FAGERIA, N. K.; BALIGAR, V. C.; CLARK R. B. Micronutrients in crop production. **Advances in Agronomy**, New York, v. 77, p. 185-268, 2002.
- FAGERIA, V. D. Nutrient interactions in crop plants. **Journal of Plant Nutrition**, New York, v. 24, n. 8, p. 1269-1290, 2001.
- FAVARIN, J. L.; VITTI, G. C.; DOURADO NETO, D.; FAVARIN JUNIOR, J. L.; SALGADO, P. R. Teor de zinco no café como variável da disponibilidade no solo e extrator. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 31, n. 5 p. 1191-1196, 2007.
- FERNANDES, A. R., CARVALHO, J. G.; MELO, P. C. Efeito do fósforo e do zinco sobre o crescimento de mudas de cupuaçuzeiro (*Theobroma grandiflorum* Schum.). **Cerne**, Lavras, v. 9, n. 2, p. 221-230, 2003.
- FERNANDES, A. R.; PAIVA, H. N.; CARVALHO, J. G.; MIRANDA, J. R. P. Crescimento e absorção de nutrientes por mudas de freijó (*Cordia goeldiana* Huber) em função de doses de fósforo e de zinco. **Revista Árvore**, Viçosa, MG, v. 31, n. 4, p. 599-608, 2007.

- FOY, C. D.; CHANEY, R. L.; WHITE, M. C. Annual review The physiology of metal toxicity in plants. **Annual Review in Plant Physiology**, Palo Alto, v.29, p. 511-566, 1978.
- GREENWOOD, M.; HAYFRON, R. J. Iron and zinc deficiencies in cacao in the Gold Coast. **Empire Journal Experimental Agriculture**, Oxford, v. 19, n.74, p. 73-86, 1951.
- HERMANS, C.; HAMMOND, J.P.; WHITE, P.J.; VERBRUGGEN, N. How do plants respond to nutrient shortage by biomass allocation? **Trend in plant science**, London, v.11, n.12, p. 610-617, 2006.
- KOCHIAN, L. V. Mechanisms of micronutrient uptake and translocation in plants. In: MORTVEDT, J. J.; COX, F. R.; SHUMAN, L. M.; WELCH, R. M. **Micronutrients in agriculture**. Madison: Soil Science Society of America, 1991.p.229-296.
- LIMA, R. A. F. L.; MENDONÇA, V.; TOSTA, M. S.; REIS, L. L.; BISCARO, G. A.; CHAGAS, E. A. Fósforo e zinco no crescimento de mudas de maracujazeiro-amarelo. **Pesquisa Agropecuária Tropical**, Goiânia, v. 37, n. 4, p. 251-256, 2007.
- MALAVOLTA, E. **Manual de nutrição mineral de plantas**. São Paulo: Agronômica Ceres, 2006. 631p.
- MARSCHNER, H. **Mineral nutrition of higher plants**. 2nd ed. San Diego: Academic Press, 1995. 902p.
- MOREIRA, A.; MALAVOLTA, E.; HEINRICH, R.; TANAKA, R. T. Influência do magnésio na absorção de manganês e zinco por raízes destacadas de soja. **Pesquisa Agropecuária Brasileira**, Brasília, v. 38, n. 1, p. 95-101, 2003.
- MOUSAVI, S.R. Zinc in Crop Production and Interaction with Phosphorus. **Australian Journal of Basic and Applied Sciences**, Amman, v.5, n.9, p. 1503-1509, 2011.
- NAGAJYOTI, P. C.; LEE, K. D.; SREEKANTH, T. V. M. Heavy metals, occurrence and toxicity for plants: a review. **Environmental Chemistry Letters**, Secaucus, v. 8, n. 3, p. 199-216, 2010.
- NAKAYAMA, L. H. I. Influência de doses de boro e zinco no desenvolvimento e nutrição mineral do cacauero. **Agrotrópica**, Ilhéus, v. 1, n. 1, p. 34-38, 1989.
- NASCIMENTO, C. W. A.; FONTES, R. L. F. Correlação entre características de Latossolos e parâmetros de equações de adsorção de cobre e zinco. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 28, n. 6, p. 965-971, 2004.
- NATALE, W.; PRADO, R. M.; CORRÊA, M. C. M.; SILVA, M. A. C.; PEREIRA, L. Resposta de mudas de goiabeira a aplicação de zinco. **Revista Brasileira de Fruticultura**, Jaboticabal, v. 24, n. 3, p. 770-773, 2002.
- OLIVEIRA, M. F. G.; NOVAIS, R. F.; NEVES, J. C. L.; ALVES, V. M. C.; VASCONCELLOS, C. A. Fluxo difusivo de zinco em amostras de solo influenciado por textura, íon acompanhante e pH do solo. **Revista Brasileira de Ciência do Solo**, Viçosa, MG, v. 23, n. 3, p. 609-615, 1999.
- OLIVEIRA, S. S.; BRITTO, I. C.; SANTANA, C. J. L. Efeito da interação fósforo, zinco e ferro, no crescimento e produção do cacauero. **Sitientibus**, Feira de Santana, v. 5, n. 8, p. 5-23, 1988.
- PAIVA, H. N.; CARVALHO, J. G.; MOREIRA, F. M. S.; CORRÊA, J. B. D. Teor, conteúdo e índice de translocação de nutrientes em mudas de cedro (*Cedrela fissilis* Vell.) submetidas a doses crescentes de zinco. **Ciência Florestal**, Santa Maria, v. 13, n. 1, p. 1-10, 2003.
- RAIJ, B. V. **Fertilidade do solo e adubação**. Piracicaba: Ceres, Potafos, 1991. 343p.
- ROUT, G.R.; DAS, P. Effect of metal toxicity on plant growth and metabolism: I. Zinc. **Agronomie**, Les Ulis, v.23, p.3-11, 2003.
- SCHROO, H. Acute zinc deficiency observed in cacao on certain soil types in netherlands New Guinea. **Netherlands Journal Agricultural Science**, Wageningen, v. 7, n. 4, p. 309-316, 1959.
- SILVA, C.S. (Ed.). **Manual de análises químicas de solos, plantas e fertilizantes**. 2. ed. Brasília: EMBRAPA, 2009. 627p.

- SOUZA JÚNIOR, J. O.; MENEZES, A. A.; SODRÉ, G. A.; GATTWARD, J. N.; DANTAS, P. A.; CRUZ NETO, R. O. Diagnose foliar da cultura do cacau. In: PRADO, R. M. (Ed.). **Nutrição de plantas**: diagnose foliar em frutíferas. Jaboticabal: FCAV/CAPES/FAPESP/CNPq, 2012. p. 443-476.
- TAIZ, L.; ZEIGER, E. **Fisiologia vegetal**. 4. ed. Porto Alegre: Artmed, 2009. 719p.