CONCENTRATION AND UPTAKE OF P, Zn AND Fe AS INFLUENCED BY SOIL ACIDITY, AND LEVELS AND FORMS OF N, P AND Fe IN CACAO

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SUMMARY

Cacao (*Theobroma cacao* L.) is an important plantation crop for many tropical countries of South and Central America, Africa and Asia. Most of the soils of cacao growing regions have become acidic and infertile as a result of long term cultivation, lack of fertilizer and lime additions and leaching of nutrients. Data on the influence of soil acidity and interaction of macro and micronutrients in cacao production are limited. Greenhouse and growth chamber experiments were conducted to evaluate the influence of soil acidity, forms (NO_3-N, NH_4-N) and levels of N, P and Fe in artificial medium on uptake of P, Zn and Fe by cacao seedlings. Phosphorus and Fe concentrations (content per unit plant tissue weight) and uptakes (concentration x total plant dry weight) were not affected significantly by acidity treatment. However, Zn concentration was significantly decreased with increasing acidity levels. Nitrogen forms significantly influenced P, Zn and Fe concentrations and uptakes. However, N level of both forms of N did not influence concentration and uptake of these elements, except uptake of P. Phosphorus concentration and uptake were significantly increased with increasing P level from 0.1 to 3.2 mM. P levels did not influence Zn and Fe concentrations and uptake. Iron sources significantly influenced P, Zn and Fe concentrations and the uptakes of P and Zn. Results of this study suggest that both NO_3^- and NH_4^+ forms of N are important for improving the uptake of P, Zn and Fe in cacao plants. Similarly, iron forms were also important in improving the uptake of P, Zn and Fe. Sprint 330 (Fe-DTPA) was the most efficient form of iron in improving uptake of these elements. Reduction of soil acidity constraints by addition of lime and the application of N, P, Fe and Zn fertilizers to soils appear to be key factors for improving N, P, Zn and Fe nutrition in cacao.

CONCENTRATIONS DE P, Zn ET Fe EN FONCTION DE L'ACIDITÉ DU SOL ET DES TENEURS ET FORMES DE N, P ET Fe DANS LE CACAO

RESUME

De nombreux sols de plantations cacaoyères sont devenus infertiles et acides à la suite d'une longue période de culture, d'un manque d'apports d'engrais et d'un lessivage des nutriments. Une carence en P, Zn et Fe dans le cacao a été signalée. Les expériences en serre et en salle de culture ont été réalisées sur des cacaoyers pour évaluer les effets de la saturation du sol en Al, les teneurs et formes de N (NO_3-N, NH_4-N), P et Fe sur les concentrations et l'absorption de P, Zn et Fe par le cacaoyer. La saturation croissante du sol en Al, de 0.2 à 26 %, a augmenté les concentrations en P, Zn et Fe dans les pousses. Toutefois, le passage de la saturation en Al à 26 % a réduit l'absorption de ces éléments. Différentes sources de N ont eu des effets significatifs sur les concentrations et l'absorption de P, Zn et Fe. À l'exception de l'absorption en P, les teneurs en N n'ont aucun effet significatif sur les concentrations et l'absorption de Zn et Fe. Les teneurs en phosphore du milieu de culture ont eu des effets significatifs sur la concentration et l'absorption de P, mais n'en ont pas eu sur la concentration et l'absorption de Zn et Fe. En outre, à l'exception de l'absorption de Zn, les formes de Fe ont eu des effets significatifs sur la concentration et l'absorption de P et Fe. La réduction des contraintes liées à l'acidité du sol et l'apport d'engrais avec N, P, Fe et Zn apparait comme un facteur clé dans l'amélioration de l'alimentation en P, Zn et Fe du cacaoyer.

CONCENTRAÇÃO E ABSORÇÃO DE P, Zn E Fe INFLUENCIADAS PELA ACIDEZ DO SOLO, E PELOS NÍVEIS E FORMAS DE N, P, E DE Fe NO CACAU

SUMARIO

O Cacau (*Theobroma cacao* L.) é uma importante cultura para muitos países tropicais da América doSul e Central, África e Ásia. Muitos dos solos das regiões cultivadoras de cacau têm-se tornado ácidos e inférteis em resultado de cultivo prolongado, falta de adições de fertilizante e coação de nutrientes. Os dados sobre a influência da acidez do solo e da interacção dos macro e micronutrientes na produção do cacau são limitados. As experiIncias em estufas e em salas de crescimento foram conduzidas em cacau para avaliar a influência da acidez do solo, formas (NO_3-N, NH_4N) e o nível de N, P e de Fe na absorção de P, Zn e de Fe pelo cacau. As concentrações de Fósforo e de Fe (teor por peso de tecido por unidade de planta) e as retenções (concentração x peso total seco da planta) não foram significativamente afectados pelo tratamento de acidez. No entanto, a concentração de Zn baixou significativamente com o aumento dos níveis de acidez. As formas de Nitrogénio influenciaram significativamente as concentrações e as absorções de P, Zn e de Fe. No entanto, o nível de N não influenciou a concentração e a absorção destes elementos, excepto a absorção de P. A concentração e a absorção Fosfórica aumentaram significativamente com o aumento do nível de P de 0.1 para 3.2 mM. Os níveis de P não influenciaram as concentrações e as absorções de Zn e de Fe. As fontes de Ferro influenciaram significativamente as concentrações e as absorções de P, Zn e de Fe, excepto a absorção de Zn. Os resultados deste estudo sugerem que ambas as formas de NO_3^- e de NH_4^- de N são importantes para melhorarem a absorção de P, Zn e de Fe nas plantas de cacau. De igual modo, as formas de Ferro foram também importantes para melhorarem a absorção de P, Zn e de Fe e a forma de Ferro Sprint 330 (Fe-EDTA) foi mais eficaz para melhorar a absorção destes elementos. A redução das restrições na acidez do solo e a adição de fertilizantes de N, P, Fe e de Zn aos solos parece ser o factor chave para melhorar a nutrição do cacau com P, Zn e Fe.

CONCENTRACIÓN Y ASIMILACIÓN DE P, Zn Y Fe COMO INFLUENCIA DE LA ACIDEZ DEL SUELO Y LOS NIVELES Y FORMAS DE N, P Y Fe EN EL CACAO

RESUMEN

Muchos de los suelos de las plantaciones de cacao se han vuelto infértiles y ácidos como resultado del cultivo en el largo plazo, la falta de agregado de fertilizantes y la lixiviación de nutrientes. Se han registrado deficiencias de P, Zn y Fe en el cacao. Se llevaron a cabo experimentos con cacao en vivero y cuarto de crecimiento para evaluar los efectos de la saturación de Al del suelo, los niveles y forma de N (NO_3-N, NH_4N), P y Fe en concentraciones y la asimilación de P, Zn y Fe por el cacao. El aumento de la saturación de Al en el suelo de 0,2 a 26% aumentó las concentraciones de P, Zn y Fe en retoÒos. Sin embargo, el aumento de la saturación de Al al 26% redujo la asimilación de estos elementos. Diferentes fuentes de N tuvieron efectos significativos en las concentraciones y asimilación de P, Zn y Fe. Con la excepción de la asimilación de P, los niveles de N no tuvieron efectos significativos en las concentraciones y asimilación de Zn y Fe. Los niveles de fósforo en el medio de crecimiento tuvieron efectos significativos en la concentración y asimilación de P, pero no tuvieron efectos en la concentración y asimilación de Zn y Fe. Además, con excepción de la asimilación de Zn, las formas de Fe tuvieron efectos significativos en la concentración y asimilación de P y Fe. La reducción de la acidez del suelo limita y la adición de fertilizantes N, P, Fe y Zn a suelos parece ser un factor clave para mejorar la nutrición de P, Zn y Fe en el cacao.

INTRODUCTION

Cacao is an important plantation crop for many tropical countries of South and Central America, Africa and Asia (Hartemink, 2005). Soils of most cacao growing regions are acidic and infertile (Hardy, 1960; Smyth, 1966; Wood and Lass, 2001; Hartemink, 2005). Aluminum toxicity and deficiency of macro and micronutrients in cacao producing soils have been reported (Santana and cabala-Rosand, 1984; Chew et al., 1984; Shamashuddin et al., 2004). Intensive longterm cultivation, use of low rates of fertilizers and lime, soil erosion and nutrient losses by leaching are the main causes of acidification and low fertility of cacao growing soils (Hardy, 1953; Smyth, 1966; Wessel, 1971; Wood and Lass, 2001).

Phosphorus deficiency or unavailability has been generally identified as one of the major limiting factors for crop production in highly weathered tropical soils. Low P availability in soils under cacao is due to inherently low levels of soil P, lack of P fertilizer addition and a large fraction of applied P being immobilized or fixed by amorphous hydrated oxides of Fe and Al (Baligar and Fageria, 1997). When P fertilizers are applied to these soils, about 70-90% of the P fertilizers is adsorbed and becomes locked in various soil P compounds of low solubility without giving any immediate contribution to crop production (Holford, 1977).

Deficiencies of micronutrients are increasing worldwide, especially those of Fe and Zn. Deficiencies of these elements occur not only because of their scarcity in soil but because of various soil and plant factors that affect their availability, inhibit their absorption or impair their metabolic use (Marschner, 1998; Fageria et al., 2002). Soil factors such as pH, organic matter content, temperature and moisture affect the availability of Fe and Zn to plants (Fageria et al., 2002). Increasing soil pH reduces the availability of Zn and Fe. Each unit of increase in soil pH reduces availability of Fe by 1000-fold and Zn availability by 100-fold (Fageria et al., 2002). As soil pH increases above pH 5.0, Zn is adsorbed on hydrous oxides of Al, Fe and Mn (Moraghan and Mascagni, 1991). Zinc adsorption is a major factor contributing to the low concentration of sluble Zn in some soils. Over liming of soils may decrease Zn availability and induce Zn deficiency (Fageria et al., 2002). Soil organic matter (OM) appears to affect the availability of Zn. The decomposition of OM releases OH^-, HCO_3^- and organic ligands that tend to immobilize Zn in root rhizospheres (Yoon et al., 1975). High clay and P supply and low soil temperatures are also known to promote Zn deficiency (Marschner, 1998).

Forms of N influence uptake of other nutrients by crop plants (Fageri and Baligar, 2005). Under plantation crops, such as cacao, a substantial amount of leaf residue is deposited on the soil surface, and upon decomposition, a considerable amount of N is released as ammonium (NH_4^+) and nitrate (NO_3^-). These forms of N in the rhizosphere are known to influence rhizosphere pH and anion- cation uptake by plants (Marschner, 1998, Mengel et al., 2001). The forms of N absorbed by roots could influence secretion of either H^+ or OH^-, and this could decrease or increase rhizosphere pH (Barber, 1995). When the N source is NH^-_4, plant roots release H^+ and this results in lowering of pH. The forms of N and soil acidity could affect plants ability to take up nutrients (Barber, 1995; Marschner, 1998). Decreasing the rhizosphere pH by the uptake of NH_4^+ is reported to be effective at increasing Fe uptake plants (Barak and Chen, 1984). Subsequently, when N is supplied as NH_4^- cations the rhizospehere pH of the plant is lowered, which increases Fe availability and uptake (Marschner, 1998).The objectives of our study were to evaluate the influence of soil acidity, forms and levels of N and Fe and levels of P on the concentrations and uptake of P, Zn and Fe in early growth stages of cacao in soil and an artificial medium.

MATERIALS AND METHODS

Cacao Genotype

Experiments reported here are with cacao (*Theobroma cacao* L.) the cultivar comum. Pods of cacao comum were received from Almirante Cacao Center, Itajuipe, Bahia Brazil. Seedlings were grown in sand and perlite mixture for 10 days before being used in the study.

Soil Acidity

Porter acid soil with a pH of 4.3 (1:1 soil: water) was used and dolomitic lime was added to achieve Al saturations of 26, 19 and 0.25% (pH of 4.3, 4.4, and 5.3). All soil Al treatments included adequate amounts of N, P, K and micronutrient fertilizers. Ten day old seedlings were transplanted into 2 kg capacity plastic pots containing soil having various levels of Al saturation. Plants were grown for 90 d at estimated field capacity moisture status in growth rooms at 28°C, and 75% RH with photosynthetic photon flux density (PPFD) of 350 $\mu mol\ m^{-2}\ s^{-1}$.

Forms and Levels of N

For the nitrogen study, ten day old cacao cv. comum seedlings were grown in 2 L capacity plastic pots containing vermiculite in growth chamber at 30∝C, 75 % RH with 14 h of PPFD of 350 $\mu mol\ m^{-2}\ s^{-1}$ Two forms of N [$Ca(NO_3)_2\ 4H_2O$, $(NH_4)_2SO_4$] were mixed to achieve five levels of total N (1.5, 3.0, 6.0, 9.0, 12.0 mmol L^{-1}-N) and added as solution. A modified Snyder nutrient solution with pH of 5.5 was used for both N sources. This solution contained all the other essential nutrients required to support good cacao growth. Pots were surface irrigated daily for five days with 100 ml of a given nutrient. On the sixth day each container was rinsed with deionized water until water was dripping from the bottom of the pots to reduce the nutrient accumulation. Split plot design was used with the N source as main factor and N levels as sub treatments; each treatment was replicated 3 times. Plants were harvested on the 58th day of growth.

Levels of P

To assess the response of cacao to P levels, experiments were carried out in growth rooms with cacao cv.comum. Plants were grown in 2 L capacity plastic pots containing Ottawa sand. The experiment was carried out in a growth room and growth conditions were similar to those of N study. Plants were surface irrigated twice a week with 100ml of modified Snyder nutrient solution containing various levels of P. On the 6th day pots were rinsed with deionized water until water was dripping from the bottoms to reduced salt buildup. Four P levels were used (0.1, 0.8, 1.6, 3.2 mmol L^{-1} P) and treatments were replicated five times. Plants were harvested on the 60 th day of growth for elemental determination.

Source of Fe

For the Fe study, four Fe sources were used: none (control), $FeSO_4$, SPRINT 138[Derived from sodium ferric ethylenediamine di-(o-hydroxyphenyl-acetate) (Fe-EDDHA, 6% Fe)] and SPRINT 330 [Derived from sodium ferric dietheylenetriamine pentaacitic acid (Fe-DTPA, 10% Fe)]. Fe was applied at the rate of 10 mg Fe/kg growth medium. Growth medium was prepared by mixing perlite, sand and promix (2:2:1 volume basis),and adequate amounts of N, P, K and micronutrients were added to avoid deficiency. Fifteen day old cacao comum seedlings were transplanted into each 2kg capacity plastic pot containing 2 kg growth medium. Plants were grown in a greenhouse and watered daily to maintain water levels at approximate field capacity. Plants were harvested after 61st d of growth.

Plant Analysis and Statistical Evaluation

At harvest shoot samples were blotted dry, oven dried at 70°C for 5 d, and ground to pass through a 0.55 mm mesh sieve for chemical analysis. Chemical analysis of the shoot samples from the acid soil and N studies was done at the A & L Southern Agricultural Lab, Pompano Beach FL[1]. Modified methods suggested by Wolf (1982) were used for elemental determinations: Briefly, plant samples were wet digested in conc. sulfuric acid and 30% hydrogen peroxide. A Gilford STASAR II spectrophotometer was used to determine P and a Perkin Elmer Analyst 400 Atomic Absorption Spectrometer was used to determine Zn and Fe. Plant samples from the P and Fe source studies were analyzed at Indian River Research and Education Center, University of Florida, Fort Pierce, FL. Elements were determined by digesting 0.4 g plant samples in 5 mL of conc. nitric acids (14 N), and concentrations in the digested solution were determined by using Inductively Coupled Plasma Atomic Emission Spectrometry (ICPAES, Ultima JY Horiba Inc. Edison, NJ, USA). Results were subjected to analysis of variance using general linear model (GLM) procedures of SAS (Ver. 8, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Effects of Soil Acidity on P, Zn and Fe Concentrations and Uptake

Increasing the soil Al saturation from 0.2 to 26.0 % increased the concentrations and reduced the uptake of P, Zn and Fe (Table 1). However soil Al saturation had a significant effect only for concentration of Zn, which was reduced. Zinc and to some extent Fe deficiencies have been reported in field grown cacao (Cunningham 1964; Cabala-Rosand et al. 1989; Wilson, 1999). Increasing the soil Al saturation tended to reduce the uptake of P, Zn and Fe by cacao. Al in the root medium is known to compete for common binding sites with micronutrients at or near root surfaces thereby reducing the uptake of these elements (Hiatt and Leggett, 1974). Root growth is inhibited by Al, which reduces the ability of roots to explore larger soil volumes and to intercept slow diffusing micronutrients, and thus reduces the uptake of these elements

Table 1: **Soil Al saturation effects on concentrations and uptake of P, Zn, and Fe in cacao comum in acid Porter soil.**

Soil Al Saturation (%)	Total Dry Wt. (g/plant)	P		Zn		Fe	
		C^{+}	U^{++}	C^{+}	U^{++}	C^{+}	U^{++}
26.0	5.15	1.08	4.48	68	283.87	129	552.02
19.0	5.82	1.10	5.22	51	246.20	79	379.11
0.2	6.86	0.84	4.67	52	286.07	128	710.17
Significance	*	NS	NS	**	NS	NS	NS

$^{+}$Concentration is given in mg/g for P and µg/g for Zn and Fe.
$^{++}$Uptake is given in mg · plant^{-1} for P and µg · plant^{-1} for Zn and Fe.
*, ** Significant at 0.05 and 0.01 levels of probability, respectively. NS = Not significant.

Effects of Forms and Levels of N on Concentration and Uptake of P, Zn and Fe

Increasing levels of NO_3^- N from 1.5 to 6.0 mM increased concentrations and uptake of P and Fe, whereas further increases in NO_3^- N levels to 12.0 mM continued to increase concentration and uptake of Zn. When the source of N was NH_4^+, increases in concentrations and uptake of these elements were observed (Table 2). Overall the concentrations of P were higher where the N-source was NO_3^-N and the concentrations of Zn and Fe were higher where the source of N was NH_4^+ - N. It has been reported that when plants are supplied with only NO_3^- as source of N, anion uptake exceeds cation uptake and OH^- or HCO_3^- are released from roots to balance the charge and this

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[1] Mention of trademark, proprietary product, or vender does not constitute a guarantee or warranty of the product by the US Dept. of Agriculture and does not imply its approval to the exclusion of other products or venders that also may be suitable (Barber, 1995). Concentrations of P, Zn and Fe observed in the current study were slightly lower than sufficiency levels reported for these elements in cacao (Snoeck, 1987). Reduction of plant growth with increasing soil Al saturation is the reason for lower uptake (reduced nutrient demand) of these elements. In acid soils Al toxicity and nutrient deficiency are the major constraints for cacao production (Santana and Cabala-Rosand, 1984; Chew et al., 1984, Shamashuddin et al., 2004). In soil, Al saturations higher than 15 % appear to be toxic to cacao growth (Santana et al., 1971; Wood and Lass 2001). In the current study, addition of lime to reduce Al saturation from 26.0 to 0.2% increased shoot growth significantly. Nakayama et al., (1988) also reported significant improvement in growth of cacao grown on Oxisols and Ultisols due to liming.

results in increasing rhizosphere pH. However when, NH_4^- is the only N source, cation uptake exceeds anion uptake, H^- is released from the roots to balance the charge and this results in lowering of rhizospere pH (Barber, 1995 and Mengel et al., 2001). With the exception of P concentrations, overall higher concentrations and uptake of P, Zn and Fe were observed where the N source was NH_4^+. Increased Fe uptake, where N source was NH_4^+ has been reported (Barak and Chen, 1984). The form of N had significant effects on the concentrations and uptake of thse elements, with the exception of P uptake; where levels of N had no significant effects on the concentrations and uptake of these elements. In both N forms increasing N levels to 6 mM increased total dry wt/plant and where N was applied as NH_4^+a total dry wt increase was observed even up to 9 mM of N. Form of N had significant effects on total dry matter/plant.

Effects of levels of P on concentrations and uptake of P, Zn and Fe

Increasing applied P levels from 0.1 to 3.2 mM increased concentrations and uptake of P, Fe and Zn (Table 3). However, effects were only significant for concentrations and uptake of P. Reported sufficiency levels of P concentrations in cacao shoots are around 2 mg/g (Snoeck, 1987; Bhargava and Raghupathi, 1993). In the present study sufficiency levels of P concentrations in cacao leaves were reached at external P supply of 0.8 mm. Further increases in P supply increased P concentrations to 4.34 mg/kg and these values were comparable to adequate P concentrations reported for plants (Bennett, 1993). It appears that cacao requires higher levels of P supply than reported to achieve adequate concentration of P in shoot. Concentrations of Zn and Fe observed were at the reported adequate levels for cacao (Snoeck, 1987). Total dry wt/plant increased with increasing applied P up to 0.8 mM, but further increase in applied P reduced total dry wt/plant.

Table 2: Forms and levels of N in the growth medium on concentration and uptake of P, Zn, and Fe in cacao comum seedlings.

N Form	N Level (mM)	Total Dry Wt (g/plant)	P		Zn		Fe	
			C$^+$	U^{++}	C$^+$	U^{++}	C$^+$	U^{++}
NO^{3-}	1.5	3.1	4.1	8.08	28.0	56.49	73.3	148.85
	3.0	3.0	4.6	8.91	29.0	55.57	62.7	118.87
	6.0	6.3	4.6	18.88	36.3	167.55	93.7	455.59
	9.0	2.1	4.2	6.16	34.0	48.86	72.3	106.47
	12.0	3.4	4.2	9.75	43.7	109.29	69.7	170.12
NH^{4-}	1.5	5.6	3.1	11.44	42.7	155.39	93.0	337.40
	3.0	5.1	3.7	13.91	47.0	178.65	118.7	456.34
	6.0	6.6	3.8	8.43	47.7	233.02	115.7	567.46
	9.0	8.9	3.3	22.10	45.0	310.38	174.7	1227.94
	12.0	5.0	2.8	10.96	45.7	181.70	122.0	504.12
Significance								
Form		**	*	**	**	**	**	**
Level		NS	NS	**	NS	NS	NS	NS

$^+$Concentration is given in mg/g for P and μg/g for Zn and Fe.

$^{++}$Uptake is given in mg · plant^{-1} for P and μg · plant^{-1} for Zn and Fe.

*,** Significant at 0.05 and 0.01 levels of probability, respectively. NS = Not significant.

Table 3: Levels of growth medium P on concentration and uptake of P, Zn and Fe in cacao comum seedlings grown in Ottawa sand.

P (mM)	Total Dry Wt (g/plant)	P		Zn		Fe	
		C$^+$	U^{++}	C$^+$	U^{++}	C$^+$	U^{++}
0.1	6.55	1.43	7.19	290.78	1614.30	50.35	258.50
0.8	9.87	2.69	19.48	279.67	2048.98	51.31	371.31
1.6	8.68	3.33	21.08	394.26	2208.00	47.73	327.69
3.2	7.64	4.34	24.29	265.39	1514.77	70.76	408.23
Significance	NS	**	**	NS	NS	NS	NS

$^+$Concentration is given in mg/g for P and μg/g for Zn and Fe.

$^{++}$Uptake is given in mg · plant^{-1} for P and μg · plant^{-1} for Zn and Fe.

*,** Significant at 0.05 and 0.01 levels of probability, respectively. NS = Not significant

Effects of source of Fe on concentrations and uptake of P, Zn and Fe

With the exception of Zn uptake the source of iron had significant effects on the concentration and uptake of all three nutrients (Table 4). The highest concentrations of P and Zn were observed when iron was supplied as FeSO$_4$ and the highest concentrations and uptake of Fe were observed, when iron was supplied as Sprint 330. Sprint 138 and Sprint 330 are chelated sources of iron. Sprint 138 is very effective at soil pH of 7.0 and above, whereas Sprint 330 is known to perform best at soil pH of 4.0- 7.0. Soils under cacao cultivation invariably range in pH from 4.0 to 7.5 with the optimum pH of 6.5 (Wood and Lass, 2001). Therefore Sprint 330 appears to be best chelated iron source for cacao. Chelates are capable of maintaining Fe in a soluble form in chemical environments where Fe would otherwise precipitate, but the efficiency of chelates depends on the chemical nature of the chelate and soil pH. Even though P concentrations observed were slightly higher than reported as adequate levels, the overall concentrations of Zn and Fe observed were comparable to sufficiency levels previously reported for cacao (Snoeck, 1987; Bhargava and Raghupathi, 1993). The source of Fe had a tendency to affect total dry wt/plant, but the influence was not statistically-significant.

Table 4: Source of added Fe (10 mg/ kg soil) on concentration and uptake of P, Zn, and Fe in cacao comum seedlings.

Fe Source	Total Dry Wt (g/plant)	P		Zn		Fe	
		C$^+$	U^{++}	C$^+$	U^{++}	C$^+$	U^{++}
Control	2.00	10.29	16.53	125.40	198.55	27.88	45.21
FeSO$_4$	1.86	12.72	19.18	130.63	203.93	29.91	45.64
Sp. 138	2.99	7.48	17.80	87.93	216.07	41.45	101.44
Sp. 330	2.95	7.26	17.27	85.22	200.14	60.95	145.78
Significance	NS	**	**	*	NS	**	**

$^+$Concentration is given in mg/g for P and µg/g for Zn and Fe.

$^{++}$Uptake is given in mg · plant^{-1} for P and µg · plant^{-1} for Zn and Fe.

*,** Significant at 0.05 and 0.01 levels of probability, respectively. NS = Not significant.

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