Effect of soil characteristics on cadmium absorption and plant growth of *Theobroma cacao* L. seedlings

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INTRODUCTION

Cadmium uptake by cacao plants can affect plant growth, consumer health and commercialization. To develop mitigation strategies, it is essential to identify the soil characteristics that could influence this absorption. To determine the relationships between cadmium absorption and the soil characteristics of cacao areas, the responses at concentrations of 0, 2, 5, 10 and 20 ~g g−1 of cadmium in three soils of these areas and an andisol were evaluated, using 120-day-old seedlings of four cultivars of Theobroma cacao L.

MATERIALS AND METHODS

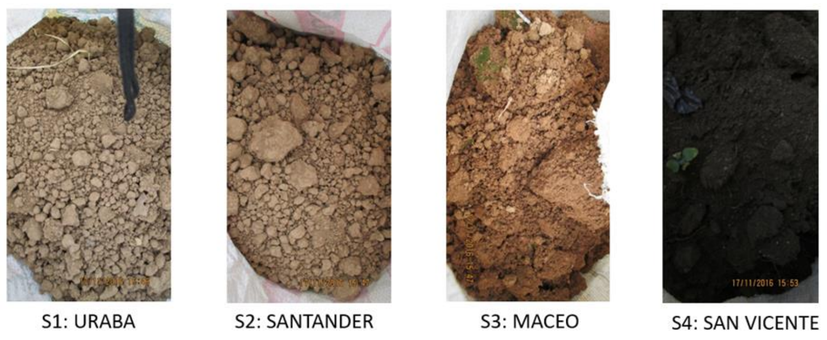


Table 1. Physical and chemical characteristics of soils

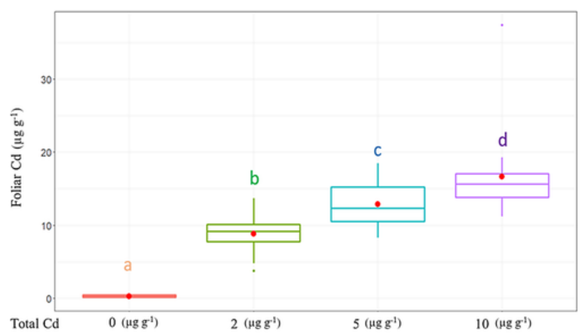
Characteristic	S1 Urabá Mean ± SD	S2 Santander Mean ± SD	S3 Maceo Mean ± SD	S4 Vicente Mean ± SD
Bulk density (g cm^{-3})	1.32 ± 0.06	1.34 ± 0.08	1.32 ± 0.06	0.66 ± 0.10
Real density (g cm^{-3})	2.73 ± 0.04	2.80 ± 0.04	2.86 ± 0.05	2.38 ± 0.13
Porosity (%)	51.82 ± 2.29	52.29 ± 2.75	53.72 ± 1.80	72.06 ± 4.11
Moisture retention 0.03 MPa (%)	33.71 ± 2.08	37.99 ± 1.95	34.04 ± 1.62	60.84 ± 3.82
Moisture retention 1.5 MPa (%)	19.80 ± 1.92	27.24 ± 1.59	18.64 ± 1.18	42.48 ± 0.74
Sand (%)	30.00 ± 3.74	15.60 ± 3.85	35.60 ± 5.37	60.80 ± 6.42
Silt (%)	45.20 ± 3.35	34.00 ± 4.24	25.20 ± 4.15	26.80 ± 7.29
Clay (%)	24.80 ± 2.28	50.40 ± 2.61	39.20 ± 4.82	12.40 ± 2.61
pH	5.20 ± 0.19	4.02 ± 0.15	4.70 ± 0.16	4.92 ± 0.20
Organic matter (%)	1.84 ± 0.11	2.82 ± 0.35	0.92 ± 0.08	19.94 ± 1.47
Al (cmol kg^{-1})	0.07 ± 0.01	1.02 ± 0.10	0.62 ± 0.13	0.56 ± 0.08
Ca (cmol kg^{-1})	6.03 ± 0.26	1.21 ± 0.04	0.26 ± 0.18	0.04 ± 0.01
Mg (cmol kg^{-1})	2.30 ± 0.11	0.10 ± 0.02	0.12 ± 0.10	0.03 ± 0.02
K (cmol kg^{-1})	0.15 ± 0.01	0.11 ± 0.01	0.10 ± 0.02	0.15 ± 0.06
Na (cmol kg^{-1})	0.11 ± 0.01	0.04 ± 0.00	0.04 ± 0.01	0.04 ± 0.01
P (µg g^{-1})	20.20 ± 2.49	11.40 ± 0.89	3.00 ± 1.73	3.00 ± 0.00
S (µg g^{-1})	4.80 ± 0.45	6.60 ± 0.89	14.00 ± 2.35	8.80 ± 0.84
Fe (µg g^{-1})	65.80 ± 5.07	410.40 ± 65.52	21.00 ± 3.24	157.80 ± 22.24
Mn (µg g^{-1})	11.00 ± 2.83	5.80 ± 0.45	8.60 ± 2.07	2.00 ± 0.00
Cu (µg g^{-1})	4.60 ± 0.55	2.00 ± 0.00	1.00 ± 0.00	1.80 ± 0.45
Zn (µg g^{-1})	1.00 ± 0.00	2.20 ± 0.45	2.20 ± 0.45	1.80 ± 0.45

Table 2. Total, available and foliar cadmium mean values

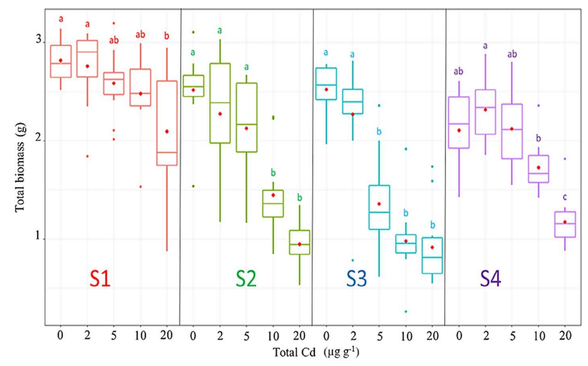
Cd (µg g−1)	Soil	Total Cd target values (µg g−1) 0 Mean ± SD	2 Mean ± SD	5 Mean ± SD	10 Mean ± SD	20 Mean ± SD
Total	S1	0.13 ± 0.03	1.89 ± 0.38	4.80 ± 0.13	11.25 ± 0.58	21.12 ± 0.32
	S2	0.24 ± 0.06	1.82 ± 0.42	4.63 ± 1.03	10.14 ± 1.15	20.94 ± 1.78
	S3	0.49 ± 0.12	2.18 ± 0.62	4.81 ± 0.81	8.95 ± 0.99	16.87 ± 1.58
	S4	0.38 ± 0.09	1.72 ± 0.37	5.13 ± 0.60	8.87 ± 0.97	17.73 ± 0.46
Available	S1	< 0.05–	0.66 ± 0.14	2.01 ± 0.26	4.77 ± 0.25	7.14 ± 0.31
	S2	< 0.05–	1.06 ± 0.12	2.62 ± 0.23	5.42 ± 0.32	11.76 ± 0.53
	S3	< 0.05–	1.17 ± 0.12	2.57 ± 0.24	4.74 ± 0.40	8.00 ± 0.57
	S4	< 0.05–	0.60 ± 0.13	2.79 ± 0.24	3.65 ± 0.28	7.13 ± 0.50
Foliar	S1	0.41 ± 0.13	9.47 ± 0.88	9.68 ± 1.05	14.46 ± 1.83	–
	S2	0.46 ± 0.12	8.95 ± 0.44	14.22 ± 0.67	18.04 ± 1.30	–
	S3	0.16 ± 0.02	11.99 ± 1.80	16.94 ± 1.25	20.52 ± 2.26	–
	S4	0.11 ± 0.01	4.85 ± 0.86	10.54 ± 0.98	13.55 ± 2.46	–

RESULTS

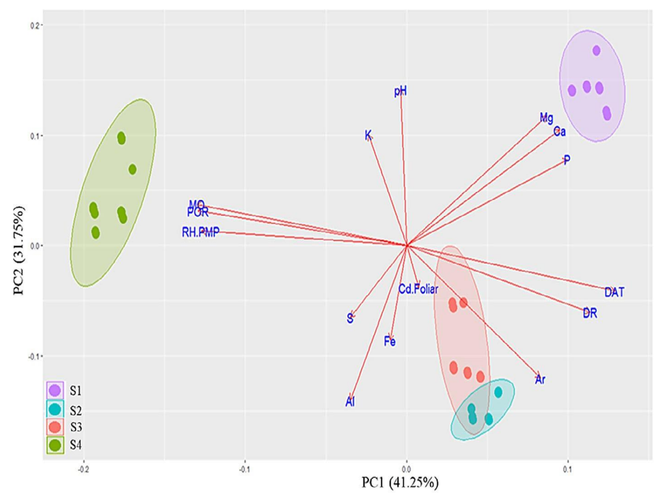
In the present study, several relationships were found between chemical and physical soil characteristics and available cadmium, such as real and bulk densities, as well as contents of iron, sand, magnesium, potassium, sodium and copper. Additionally, moderate to strong correlations between potassium (r2 = −0.56) and real density (r2 = 0.42), with foliar cadmium, were found. Moreover, a differential deleterious effect on cacao growth in variables such as biomass was corroborated in cadmium concentrations from 5 µg g−1 in soils. There were no statistical differences between cultivars with respect to cadmium uptake or plant growth. Finally, a multiple linear regression model is proposed to estimate the foliar cadmium content (r2 = 0.878).



Wilcoxon signed-rank test, P values adjusted with the Holm method α = 0.05. Different letters indicate significant differences.



Different letters indicate significant differences, Tukey test, α = 0.05.



MO: Organic matter, POR: Porosity, RH.PMP: Moisture retention at 1.5 MPa, Ar: Clays content, DR: Real density, DAT: Bulk density..

Table 3. Pearson correlations between available and foliar cadmiumand soil characteristics

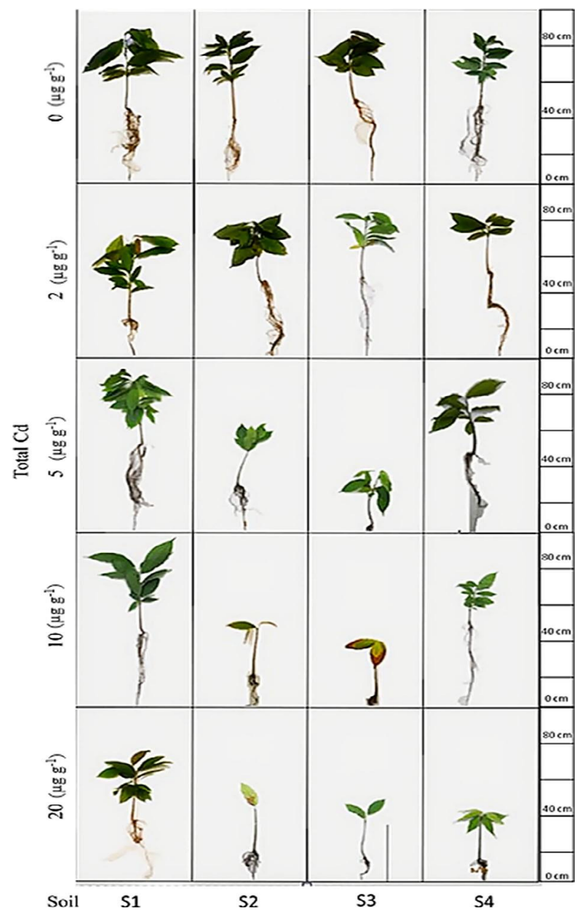
Characteristic	Available Cd (r²)	Foliar Cd (r²)
Bulk density	0.41***	**0.18**
Real density	0.48***	**0.42*** **
Porosity	−0.36**	**−0.09**
Moisture retention 0.03 MPa	−0.36**	**−0.28***
Moisture retention 1.5 MPa	−0.20	**−0.23**
Sand	−0.65***	**−0.31***
Silt	−0.11	**−0.23**
Clay	0.81***	**0.37****
pH	−0.86***	**−0.38****
Organic matter	−0.39**	**−0.31***
Al	0.74***	**0.28***
Ca	−0.34**	**−0.12**
Mg	−0.44***	**−0.14**
K	−0.57***	**−0.56*****
Na	−0.49***	**−0.17**
P	−0.16	**−0.08**
S	0.17	**0.25**
Fe	0.56***	**0.02**
Mn	−0.01	**0.10**
Cu	−0.41***	**−0.20**
Zn	0.48***	**0.30***
Available Cd	–	**0.81*****

Significant correlations.
*P < 0.05.
** P < 0.01.
*** P < 0.001.

Model development For the prediction of foliar Cd, the following multiple linear regression model was developed:

(1)

where foliar Cd units are µg g−1, LN (Cd.disp) is the natural logarithm of available Cd in µg g−1, K in cmol kg−1, and P and S in µg g−1, and the model presented a Pearson's regression coefficient of r2 = 0.8783.



CONCLUSIONS

The methodology used to quantify available cadmium showed a high correlation with foliar cadmium and could be a useful diagnostic tool in soils with cacao potential. No statistically significant differences were found with respect to the accumulation of foliar cadmium, nor plant development between the cultivars used. Soils characterised by a low pH, high bulk and real density, and high contents of clay, aluminium, iron and zinc presented a higher availability of cadmium, a more pronounced negative effect on plant growth, and a more significant accumulation of foliar cadmium compared to soils with a higher pH and organic matter, potassium, magnesium, sodium and copper content. Such information could be relevant when selecting zones to establish cacao crops. The application of potassium could be significant in mitigating the impact of cadmium in cacao crops. It is suggested more studies are carried out in this regard.