COFFEE TREE (*Coffea arabica* L.) RESPONSE TO LIMESTONE IN SOIL WITH HIGH ALUMINUM SATURATION
Coffee-tree lime response in soil with high aluminum saturation(1)

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ABSTRACT: Although *Coffea arabica* L. is not particularly sensitive to Al toxicity, the species presents different tolerance among varieties. The varieties previously classified as sensitive, Catimor (232T15-PN- UFV 3880), moderately tolerant, Catuaí 99 (IAC 99) and Catuaí Vermelho (IAC 15), and tolerant, Icatu (IAC 4045), were evaluated under field conditions. They were subjected to four limestone levels: 0.0; 0.5; 1.0; and 1.5 times the limestone requirement (LR) calculated by the base saturation method, considering 70% as the saturation reference value. The shoot and root growth were evaluated after 23 and 34 months, respectively, and the concentrations of Ca, Mn, Zn and Cu in the leaf tissues after 34 months. The shoot development of the variety 'UFV 3880' was not affected by liming levels. For roots development, limestone doses from ranging 0.74 to 0.84 LR, provided the largest concentrations of Ca in the foliar tissues. 'IAC 99' presented the best shoot development with limestone doses from 0.25 to 0.54 LR, and the best root development with doses from 0.33 to 0.40 LR. 'IAC 15' had a linear increase of root length and root specific surface with the increase of the limestone doses, which caused root thinning and elongation. This suggests that this variety is more sensitive to soil Al saturation than the other tested varieties. The 'IAC 4045' presented the best shoot and root development with liming ranging from 1.06 to 1.14 LR. It seems that other soil constraints, such as Mn content, impaired this variety development in lower limestone doses. Aluminum soil saturation up to 30 % in the superficial soil layer did not interfere in the development of the roots and shoots of the tested varieties.

Key words: *Coffea arabica*, aluminum, manganese, base saturation.

RESPOSTA DO CAFEEIRO (*Coffea arabica* L.) À CALAGEM EM SOLO COM ALTA SATURAÇÃO POR ALUMÍNIO

***RESUMO:** Embora o cafeeiro (Coffea arabica L.) não seja particularmente sensível à toxidez de alumínio, a espécie apresenta tolerância diferencial entre variedades. Foi avaliado, no campo, o desenvolvimento de variedades previamente classificadas como sensível: Catimor (232T15-PN-UFV 3880); moderadamente tolerante: Catuaí 99 (IAC99) e Catuaí Vermelho (IAC 15); e tolerante: Icatu (IAC 4045), submetidas a quatro níveis de calagem, 0,0; 0,5; 1,0 e 1,5 vez a necessidade de calagem (NC) calculada pelo método de saturação em bases, considerando-se 70% de saturação como valor de referência. Foram avaliados o desenvolvimento da parte aérea e do sistema radicular aos 23 e 34 meses após a instalação do experimento, e as concentrações de Ca, Mn, Zn e Cu no tecido foliar aos 34 meses. O desenvolvimento da parte aérea de 'UFV 3880' não foi afetado pelos níveis de calagem. Seu sistema radicular apresentou o melhor desenvolvimento quando se empregaram doses de calcário entre 0,74 e 0,84 NC, as quais promoveram maiores concentrações de Ca nos tecidos foliares. 'IAC 99' apresentou melhor desenvolvimento da parte aérea com doses de calcário entre 0,25 e 0,54 NC, e melhor desenvolvimento radicular com doses situadas entre 0,33 e 0,40 NC. 'IAC 15' pareceu ser mais sensível à saturação do solo por Al que as demais variedades estudadas, apresentando aumentos lineares no comprimento e superfície específica radiculares com o aumento das doses de calcário. Para a 'IAC 4045', o melhor desenvolvimento da parte aérea e raízes ocorreu quando se empregaram doses de calcário entre 1,06 e 1,14 NC. Possivelmente outro fator, como a concentração de Mn no solo, impediu seu desenvolvimento em doses menores. Saturações de alumínio da ordem de 30% na camada superficial do solo (0-20 cm) não prejudicaram o desenvolvimento de raízes e parte aérea das variedades estudadas.*

Palavras-chave: Coffea arabica, alumínio, manganês, saturação por bases.

1 INTRODUCTION

The Brazilian coffee crop (*Coffea arabica* L.) has expanded significantly in the "cerrado" area, which has soils with high acidity and low macro and micronutrient levels. These limitations mean that a better knowledge of their physical and chemical features, proprieties and management is required in order to obtain quality, cost-effective and productive coffee crops (GUIMARÃES & LOPES, 1986).

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The high levels of Al in these soils results in the death of root cells, hindering root development. The damaged roots explore less soil volume, decreasing the amount of water and nutrients absorbed by the plants (BRACCINI et al., 1998b).

Since exchangeable Al impairs the development of the root system, it interferes in P, Ca and Mg absorption and movement by the plant. On the other hand, high soil Al content leads to high P absorption (BALIGAR et al., 1993; BENNET et al., 1986).

Nevertheless, some plants are able to explore deep soil layers, even with high Al levels, due to their tolerance mechanisms. These mechanisms can be related to the capacity of the roots in absorbing, translocating and compartmentalizing the element into the plant (FOY, 1974), their capacity of absorbing and translocating P in the presence of Al (CAMBRAIA et al., 1991) and their capacity to exudate organic acids, forming less toxic Al-organic acid complexes (BUCIO et al., 2000).

Al toxicity has been associated with P accumulation in the root system and to low P levels in the shoot, sometimes accompanied by shoot P deficiency symptoms (MACKLON & SIM, 1992). These effects occur because Al can precipitate with P in the root apoplasm, decreasing P translocation to the shoot (CALBO & CAMBRAIA, 1980). Al also reduces P solubility in the soil, making it less available to the plants (PAVAN & BINGHAN, 1982).

Liming is an easy and economic way to correct soil acidity, supplying Ca and Mg to the plants, releasing unavailable iron and aluminum hydroxides, contributing to organic matter mineralization, minimizing the toxic effects of Mn and Al and increasing the efficiency of chemical fertilization (PAVAN & BINGHAM, 1982).

Some studies have been done on the negative effects of Al on coffee plants. The varieties Caturra Vermelho and Mundo Novo, submitted to Al doses higher than 4 mg/L in a nutritive solution during four months, presented reductions in height, internode length and leaf area. The lower leaves of the Caturra Vermelho variety also presented yellow and diffuse spots when submitted to16 mg/L of Al. The root tips of the two varieties turned thick and yellowish. The emission of lateral roots was delayed, and then they were thick and short (4 to 6 mm long) with a wrinkled surface. In 8 or 16 mg/L of Al, the root surface presented yellowish or brownish spots. There were reductions in the dry matter production of shoots and roots and in the shoot/root ratio. In the coffee plants, Al accumulated in the roots and a small part of it was translocated to the aerial part (MARTINEZ & MONNERAT, 1991).

Working with nine coffee populations submitted to 0 and 8 mg/L of Al in a nutritive solution, Braccini et al. (1998a,b) verified differences in their Al tolerance. Al tolerance was related to low P precipitation in root tissues and low impairing of P translocation from the roots to the shoots, leading to high P utilization efficiency. High Ca utilization efficiency and low restriction to it’s absorption in the presence of Al were both related to coffee’s Al tolerance. Root length, root dry matter and number of lateral roots were the best plant traits for early Al tolerance screening. The Al tolerance did not seem to be related to pH changes in the coffee rizosphere (BRACCINI et al., 2000b).

In alic soil columns, Rodrigues et al. (2001, 2006) verified less expressive Al tolerance differences among coffee varieties than in a nutritive solution. Liming the soil superficial layer allowed for normal shoot growth for up to 6,5 months, regardless of the Al saturation in the sub-surface. However, high Al saturation in the sub-surface resulted in reduced percentages of dry matter weight, root length and root surface area in the lower horizon. Sub-surface liming resulted in high Ca and Mg contents in both the roots and shoots of the tested varieties Catuaí and Icatú, as well as high P and low Al contents in the shoots of the more Al tolerant variety Icatú.

Coffee plants deficient in Ca and Mg might have their development reduced up to 50%, in relation to plants cultivated in limed soils with low acidity and normal Ca and Mg levels. The correction of soil acidity makes coffee plants more tolerant to drought and avoids the cation competition effect of K, which is supplied in high doses due to its importance to grain fulfillment (ANDRADE, 2001).

The aim of this work was to evaluate the responses of four coffee varieties, previously classified as Al sensible, Al moderately tolerant and Al tolerant, to liming doses in high Al soil field conditions.

2 MATERIALS E METHODS

Seeds of four varieties previously classified (BRACCINI et al., 2000a) as sensitive - UFV 3880

(232T15-PN, Catimor); moderately tolerant - UFV 2147 (IAC H 2077-2-5-99, Catuaí Vermelho) and UFV 2237 (IAC 2077-2-5-15, Catuaí Vermelho); and tolerant to Al - IC 4045 (IAC 4045, Icatu Vermelho) were treated with Captan fungicide, wrapped in towel paper wet with distillated water and stored in a germination chamber at 26°C for 35 days. The emerged plants were transferred to polyethylene bags containing a mixture of soil, organic matter and fertilizers and cultivated for four months in a nursery with 50% sunlight. These plants were irrigated daily and periodically monitored for pests and diseases. The plants were then submitted to two months of acclimatization to total sunlight and transferred to the field.

The young plants were planted and cultivated for 34 months at a farm located in Dores do Indaiá, Minas Gerais state, Brazil (Agropecuária Cocais Ltda). The soil used was a Yellow Red Dystrophic Latosol with the following chemical-physical characteristics in the 0-20 and 20-40 cm deep layers, respectively: pH_{H2O} (4.8 and 4.8); P (2.3 and 0.9 mg/dm^3); Al (2.9 and 2.7 cmolc/dm^3); base saturation (7.2 and 9.4%); and Al saturation (67.9 and 80.5%). The plants were irrigated by aspersion every other day until the 17th month. After this phase the irrigation was suspended.

The trial was set in randomized blocks with four replications. A factorial scheme with four varieties and four limestone levels was used. The limestone levels corresponded to 0.0; 0.5; 1.0; and 1.5 times the limestone requirement (LR). The LR was calculated by the base saturation method, considering 70% as the reference value, which corresponded to 0.0; 2.1; 4.2 and 6.3 ton/ha of dolomitic limestone, respectively. The limestone doses were distributed in the total plot area and incorporated by disk harrows. Plant spacing was 2.5 m between rows and 1.0 m between plants in the rows. 12 plants were established per plot, considering the two central plants as useful. At planting, 300g of simple super phosphate, 30g of potassium chloride, and 30g of amonium sulfate were added per plant. Thirty and 60 days later, each plant received 30g of amonium sulfate. Annual maintenance fertilizations were done with 400 g/plant of the formula 20-05-20, divided in three superficial applications, and foliar spraying with zinc sulfate 0.3% and boric acid 0,5%.

Twenty-three months after planting plant height, the number of productive branches and the number of internodes per productive branch were evaluated. After 34 months, 8 to 10 leaves of each plot's useful plants were collected to determine the Ca, Mn, Zn and Cu contents. The leaves were picked from productive branches located in the medium third portion of the plants. The sampled leaves were washed in distilled water, dried at 70°C until attaining constant weight, ground in a Willey type mill and submitted to digestion in a nitric-perchloric acid mixture. The nutrient contents were determined by atomic absorption spectrophotometry.

The root systems of the plants were evaluated 34 months after planting. Root samples of one plant per plot were collected using a hole probe with a 1,9 cm diameter. Cylindrical soil samples were taken 15 and 30 cm from the plant trunk, in the four quadrants, at soil depths of 0-20 and 20-40 cm. Sixteen soil samples were taken for each plot.

The roots were manually collected, washed, dried with a paper towel, weighed and colored with safranine at 1%. The colored roots were passed through a foliar area meter (Delta-T Area measurement System – Area Metter MK2). The values obtained were used for further estimation of the root length using the formula L=A/2R, where L is the length of the root (cm/dm^3 of soil), A is the result obtained from passing the roots through the Area Meter (cm^2) and R is the mean root radius (cm). The mean radius was estimated by the formula R=2V/A, where V is the volume of the root (cm^3) measured by the displacement of water in a graduate test tube (ROSSIELLO et al., 1995). With these data the specific root length (root length/root fresh matter) and the specific root surface (root surface/root fresh matter) were calculated. For each soil layer (0-20 and 20-40 cm), the values obtained were extrapolated to the 500 dm^3 occupied by the root system, considering a useful area of 2,5 m^2/plant.

The data obtained were submitted to variance and regression analysis. The choice of regression models was initially based on the coefficient of determination (R^2), where the one with the highest R^2 was chosen. The coefficients of the models, based on the mean square of the residual variance up to the level of 10% probability, were tested by the "*F*" test, *F*= [(t^2*Mean Square of the Residual Independent of the Regression)/(Mean Square of the Residual of the Variance Analysis/number of Repetitions)].

3 RESULTS AND DISCUSSION

Twenty-three months after planting, the variety IAC 99, previously considered moderately tolerant to aluminum (BRACCINI et al., 1998b, 2000a), presented square root based quadratic responses to limestone application for plant height and internode number, with maximum points at doses 0,54 and 0,25 LR, respectively, which were related to 16 and 29% of Al saturation in the top soil layer (Figures 1a and 1c). The number of plagiotropic branches did not vary with the lime doses (v= $\overline{Y}$ = 44.7; Figure 1b).

For the same variety, 34 months after planting, root fresh weight, root length and root surface in the top layer (0-20 cm) gave similar responses, with maximum points between the doses 0.34 and 0.35 LR, which were related to the 24 and 25% Al saturations, respectively (Figure 2a, 2b and 2c). In the lower soil layer, 34 months after planting, the root length and root surface of the variety IAC 99 presented cubic responses to the limestone doses, with maximum points at 0.36 LR and minimum at 1.22 LR for the two traits. These points corresponded, respectively, to 60 and 50% Al saturations (Figure 3b and 3c). In the 0-40 cm layer, the results for total fresh matter production, root length and root surface were similar to the top soil layer, with maximum points at the doses 0.33; 0.34 and 0.34 LR, respectively (Figure 4a, 4b and 4c).

In the variety IAC 99 there was a relation between shoot development 23 months after planting and root system development at 34 months. The limestone doses that promoted the greatest plant height and number of internodes were close to those that promoted maximum root development. At the maximum points of the regression curves plant height and internode number increased 19 and 25 %, respectively, in relation to these values at dose zero.

The variety IAC 15 showed no response, in plant height and internode number, to the limestone doses. However, it presented a cubic response for the number of plagiotropic branches, with minimum and maximum points at the doses 0.23 and 1.1 LR, respectively, which were related to a 31 and 4 % Al saturation in the top soil layer (Figure 1b). This variety also showed maximum root length in the lower soil layer with a dose of 0.82 LR, which was related to a 53% Al saturation (Figure 3b).

The variety IAC 15's moderate tolerance to Al, reported by Braccini et al. (1998b, 2000a), was not confirmed. However, the increase in limestone doses resulted in thinner and longer roots, detected by the linear increase in specific root length and specific root surface in the top soil layer and in both layers together (0-40 cm) (Figures 2d, 2e, 4d and 4e).

Plant height, number of plagiotropic branches and internode number of the variety UFV 3880, previously classified as Al sensitive (BRACCINI et al., 1998b, 2000a), showed no response to lime application (Figure 1a, 1b and 1c). The same results were obtained for 23-month-old coffee plants, variety Mundo Novo, grown in the dystrophic Red Latosol, in which plant height and internode number were not correlated with increasing lime doses and lime associated with gypsum (CORRÊA, 1992).

However, the root system of the variety UFV 3880 proved very sensitive to high Al concentrations in the soil, presenting reduced root development in the absence of liming. This variety presented responses to lime application for root length in both soil layers. The maximum points in the top and lower soil layers occurred at doses 0.84 and 0.79 LR, respectively, which were related to 7 and 54 % of Al saturation (Figures 2b and 3b). When the two layers (0-40) were analyzed together, the maximum point for total root length occurred at the dose of 0.82 LR (Figure 4b). Considering the layers 0-20, 20-40 and 0-40 cm, the doses corresponding to the maximum points promoted increases of 147, 181 and 147% in root length, in relation to dose zero.

The maximum root surface point of the variety UFV 3880, in the 20-40 cm layer, occurred at 0.74 LR (Figure 2c), whereas in the 0-40 cm layer it occurred at 0.80 LR, decreasing afterwards (Figure 4c). The specific root surface (cm^2/g FM) increased with lime doses in both soil layers. In the top layer the increase reached 0.80 LR (Figure 2e), which was related to 8 % of Al saturation. The increase in the lower layer (20-40 cm) reached 0.84 LR (Figure 3e), related to 53% of Al saturation; and in the soil profile (0-40 cm) the increase reached 0.84 LR (Figure 4e). This indicates that roots become thinner in the presence of lime, attaining an optimum value in a narrow liming range. According to these results, the

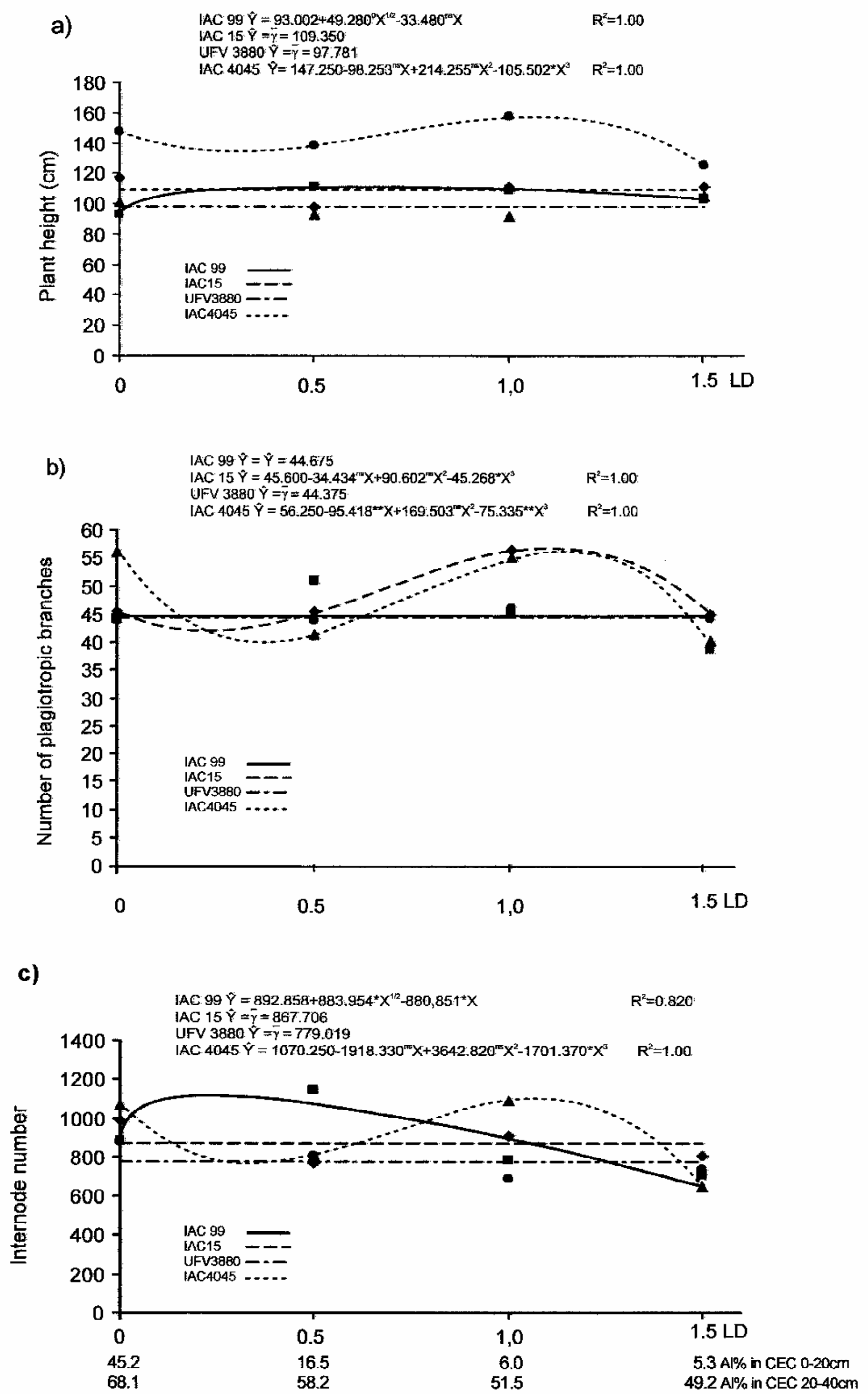

Figure 1 – Coffee-tree 'IAC 15´, 'IAC 4045´ and 'UFV 3880´ plant height (cm-a), plagiotropic branche number (b) and internode number (c) as function of limestone (LD), 23 months after planting.

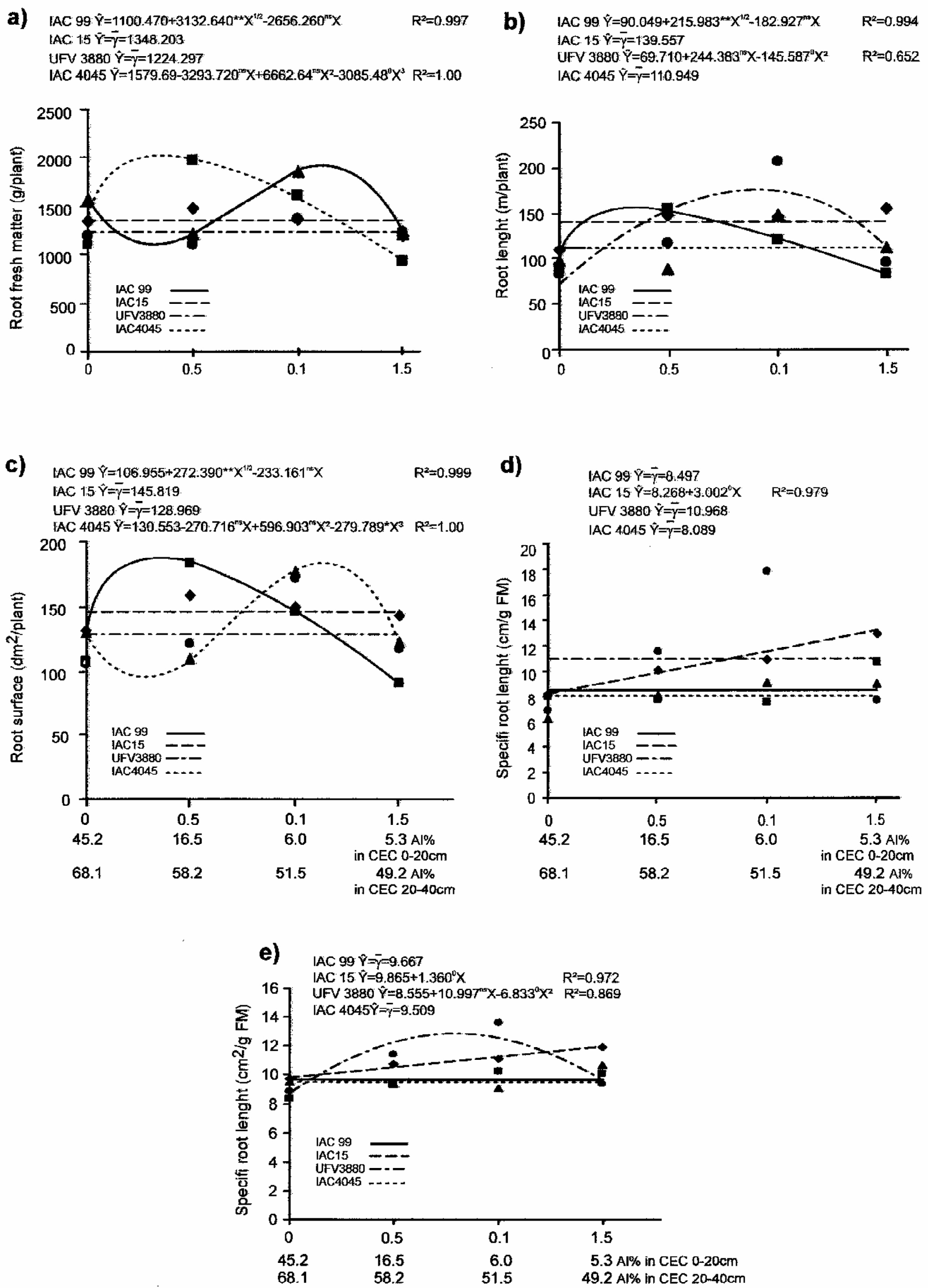

Figure 2 – Coffee-tree 'IAC 15´, 'IAC 4045´ and 'UFV 3880´ root fresh matter (g/plant – a), root length (m/plant – b), root surface (dm2/plant – c), specific root length (cm/g of root fresh matter – d), and specific root surface (cm2/g – e) allocated in the 0-20 soil layer, as function of limestone dose, 34 months after planting.

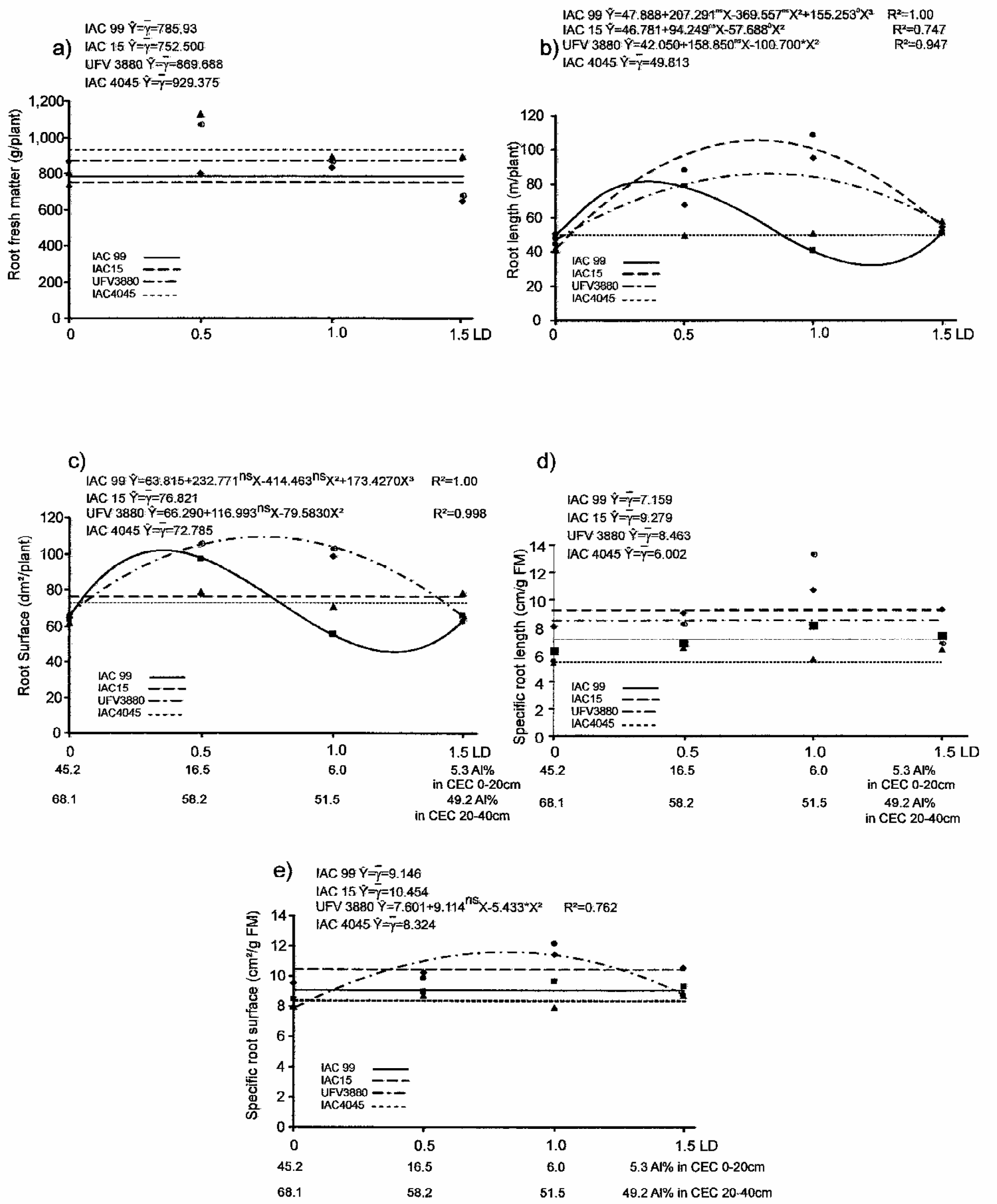

Figure 3 – Coffee-tree ‘IAC 15´, ‘IAC 4045´ and ‘UFV 3880´ root fresh matter (g/plant – a), root length (m/plant – b), root surface (dm^2/plant – c), specific root length (cm/g of root fresh matter – d), and specific root surface (cm^2/g – e) allocated in 20-40 cm soil layer (0-20 cm), as function of limestone dose (LD), 34 months after planting.

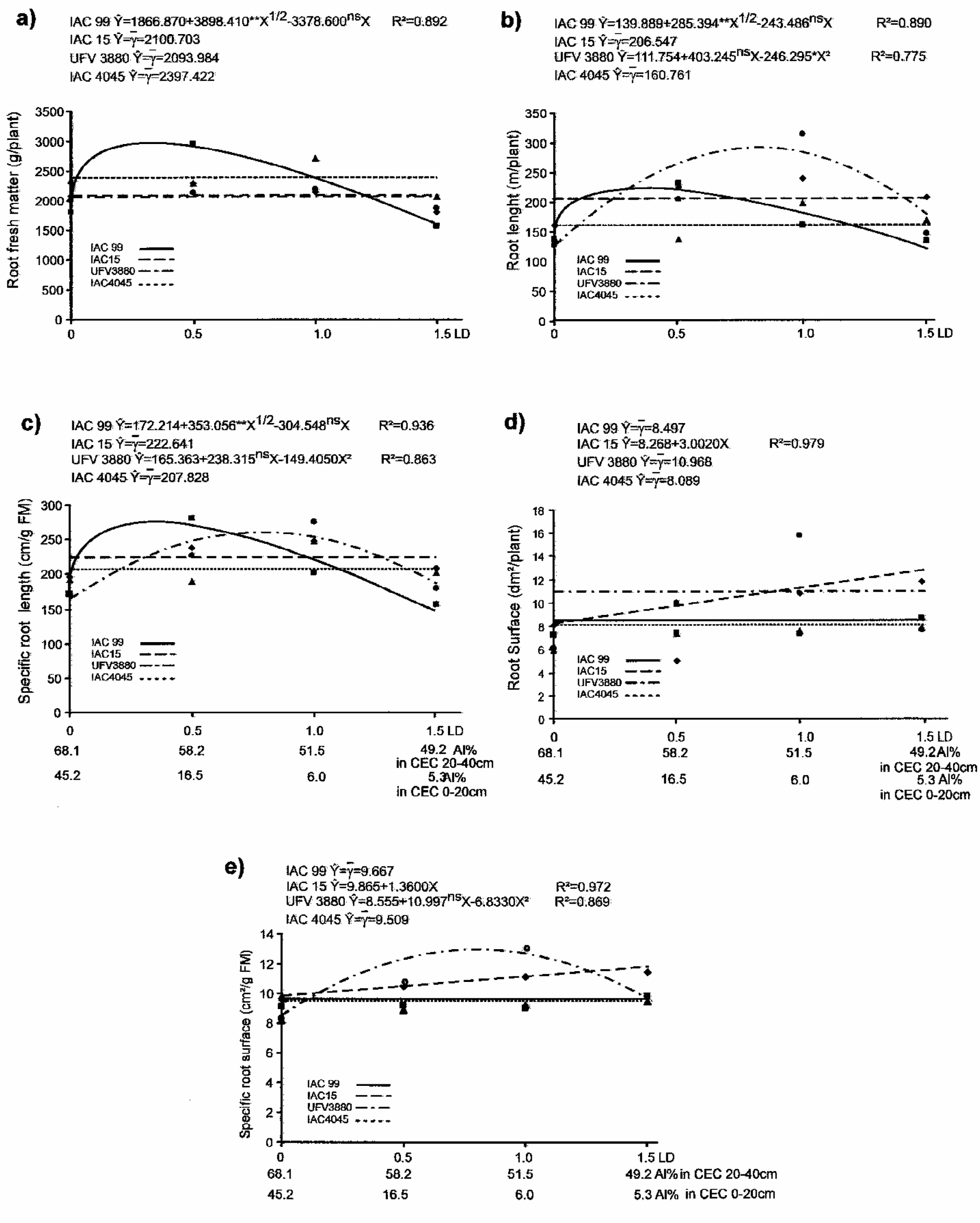

Figure 4 – Coffee-tree 'IAC 99´ 'IAC 15´, 'IAC 4045´ and 'UFV 3880´ root fresh matter (g/plant – a), root length (m/plant – b), root surface (dm^2/plant – c), specific root length (cm/g of root fresh matter – d), and specific root surface (cm^2/g – e) allocated in 0-40 cm soil layer (0-20 cm), as function of limestone dose (LD), 34 months after planting.

leaf Ca concentrations for this variety presented a quadratic response ($\hat{Y}$=0.820+0.670^{ns}X-0.400*X^2; R^2=0.997) to the treatments, with the maximum point at 0.84 LR, almost coinciding with the results obtained for root length, root surface and root specific surface.

At 23 months, the plant height, number of plagiotropic branches and internode number of the variety IAC 4045 showed cubic responses to lime application. Minimum and maximum points of plant height occurred at the doses 0.29 and 1.06 LR, respectively; the number of plagiotropic branches at 0.37 and 1.12 LR, and internode number at 0.35 and 1.08 LR (Figures 1a, 1b and 1c). For these traits, the Al saturation referred to minimum points at 27, 23 and 24%, and to maximum points at 4 % for the three characteristics.

The root fresh weight and root surface of the variety IAC 4045, in the top soil layer (0-20cm), showed cubic responses to lime application. Root fresh weight minimum and maximum points occurred at doses 0.32 and 1.12 LR, and root surface at 0.28 and 1.14 LR (Figures 2a and 2c). The points of reduced shoot and root development were closer to the highest foliar tissue Mn concentrations, with values approaching 520 mg/kg ($\hat{Y}$=479.025+445.976^{ns}X-1330.780*X^2+680.481*X^3; R^2=1.00), a concentration that exceeds by far the sufficiency range (77-141 mg/Kg) suggested for the region (MARTINEZ et al., 2003). The best shoot and root development took place in the lowest leaf Mn concentrations, showing that, despite this variety's classification as Al tolerant (BRACCINI et al., 2000b), it is likely to be more sensitive to Mn than the other ones. It is important to highlight that the pH attained with low lime doses could favor Mn availability in the soil.

Augusto (2000) reported that, in the path analysis of six coffee varieties with different spacings, plant height was the vegetative trait determinant of the first harvest production whereas, in the second harvest, using 2.5 m spacing between lines, the yield variation was explained by plant height, number of plagiotropic branches and stem diameter, with R^2=0.96. Thus, it would be expected that the varieties that showed growth response to liming would also show yield response. In this case, it should be considered that the variety UFV 3880, previously classified as Al sensitive, showed plant height variations that did not fit the tested regression models.

On the other hand, Rodrigues et al. (2001) reported no variations in the stem length of six-month-old plants of the varieties IAC 99 and IAC 4045 growing in soil columns with the superficial layer properly limed and fertilized, even when the subsurface presented high Al saturation. In that work, the authors verified that the root distribution through the soil column was affected by Al saturation only for the most sensitive variety, IAC 99. However, Braccini (2000) reported that uniform liming throughout a soil column, with pH 5.4 and m% 12.7, impaired the initial growth of the coffee varieties IAC 99 and IAC 4045 by restricting Cu and Zn absorption.

At 34 months, the leaf Mn concentrations were above the sufficiency range (77-141 mg/kg) suggested for the region (MARTINEZ et al., 2003). The lime doses did not affect the Mn levels in the varieties IAC 99 ($\hat{Y}=\bar{Y}$ = 445.5) and IAC 15 ($\hat{Y}=\bar{Y}$ =439.3), whereas the varieties UFV 3880 and IAC 4045 showed cubic responses for this trait (=391.6-766.1^{ns}X+1443^{ns}X^2-640.9*X^3; R^2=1.00-=479.0+446.0^{ns}X-1331.0*X^2+680.5*X^3; R^2=1.00). The leaf Zn levels had no variety response to the lime doses and were below the sufficiency range of 13-30mg/kg (MARTINEZ et al., 2003) for all varieties, ranging from $\hat{Y}=\bar{Y}$ = 7.8 for UFV 3880 to $\hat{Y}=\bar{Y}$ =9.4 for IAC 4045. The variety IAC 99 showed a linear decrease of leaf Cu concentration in response to the application of lime doses (=19.4-3.0^{0}X; R^2=0.99). There was no response for the other varieties. Also, the Cu concentrations observed were below the sufficiency range, between 26 and 72 mg/kg, considered suitable for the region, according to Martinez et al. (2003).

4 CONCLUSIONS

In field conditions, the shoot development of the variety UFV 3880, previously classified as Al sensitive, was not affected by liming levels, but the root system development was. Poor root development occurred in the absence of liming and the best development was observed at limestone doses from 0,74 to 0,84 LR.

The variety IAC 99, previously classified as moderately tolerant to Al, in field conditions presented the best shoot development at limestone doses from 0.25 to 0.54 LR, and the best root development at doses from 0.33 and 0.40 LR

There was a linear increase in root length and root specific surface (cm^2/g) with the increase of the lime doses, which caused root thinning and elongation in the variety IAC 15, suggesting that this variety is more sensitive to soil Al saturation than the other tested varieties. This result does not confirm the previous classification made in a nutritive solution.

The variety IAC 4045, previously classified as Al tolerant, presented the best shoot and root development in liming ranging from 1.06 to 1.14 LR. It seems that other soil constraints, like Mn content, can impair its development.

Root and shoot development of the studied varieties was not impaired by 30% Al saturation in the arable soil layer (00-20 cm). In higher saturations, aluminum restricted the specific root surface of coffee plants.

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