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# Changes in soil fertility and mineral nutrition of mango orchards in São Francisco Valley, Brazil

João P. S. da Silva[1], Clístenes W. A. do Nascimento[1], Davi J. Silva[2], Karina P. V. da Cunha[3] & Caroline M. Biondi[1]

[1] Universidade Federal Rural de Pernambuco, Departamento de Agronomia, Rua Dom Manoel de Medeiros, s/n, Dois Irmãos, CEP 52171-900, Recife-PE, Brasil. E-mail: jprsp@yahoo.com.br; clistenes@depa.ufrpe.br; carolinebiondi@yahoo.com
[2] Embrapa Semiárido, BR 428, km 152, Zona Rural, CEP 56302-970, Petrolina-PE, Brasil. Caixa Postal 23. E-mail: davi@cpatsa.embrapa.br
[3] Universidade Federal do Rio Grande do Norte, Centro de Tecnologia, Departamento de Engenharia Civil, Av. Senador Salgado Filho, 3000, Lagoa Nova, CEP 59072-970, Natal-RN, Brasil. E-mail: cunhakpv@yahoo.com.br

## ABSTRACT

This research aimed to analyse the soil fertility changes and macronutrient concentration in mango plantations in Petrolina, Pernambuco, Brazil. Samples of soil were collected at depths of 0-20 and 20-40 cm, and leaves of mango trees during vegetative growth were collected from 11 areas with different cultivation time spans (6, 7, 8, 9, 10, 11, 14, 16, 17, 19, and 26 years). Nearby areas under natural vegetation were sampled for reference. The chemical characteristics of soil evaluated were: pH; P, K, Ca, Mg; exchangeable Na and Al; H + Al; organic matter; sum of bases; base saturation; and total cation exchange capacity. The mango leaves were analysed for N, P, K, Ca, and Mg. The agricultural management practices adopted by the mango-producing companies promoted changes in soil fertility when compared with the reference areas. The concentrations of organic matter tended to increase in the crop areas. The organic matter caused increases in CEC and nutrient retention. High P values were observed in soils and plants owing to the excessive use of fertilizers. This may cause nutritional imbalance and contamination of water sources. The contents of N, P, K in the leaves of mango trees were nutritionally adequate.

**Key words:** *Mangifera indica*, mineral fertilizers, soil organic matter

# *Alterações na fertilidade dos solos e teores foliares de nutrientes em cultivos de mangueira no Vale do São Francisco*

## RESUMO

Esta pesquisa objetivou avaliar as alterações na fertilidade do solo e nos teores de macronutrientes nas folhas em áreas cultivadas com mangueira em Petrolina-PE. Foram coletadas amostras de solo nas profundidades de 0-20 e 20-40 cm e de folhas da mangueira na fase vegetativa em onze áreas com diferentes tempos de cultivo (6, 7, 8, 9, 10, 11, 14, 16, 17, 19 e 26 anos). Áreas de vegetação nativa adjacentes às áreas cultivadas foram utilizadas para efeito de comparação. As propriedades químicas dos solos avaliadas foram: pH, P, K, Ca, Mg, Na e Al trocáveis, H+Al, matéria orgânica, SB, V e CTC total. Os macronutrientes avaliados nas folhas foram: N, P, K, Ca e Mg. Os manejos agrícolas adotados pelas empresas promoveram alterações na fertilidade dos solos quando comparados com os solos das áreas de referência. Os teores de matéria orgânica tendem a aumentar nas áreas de cultivo. A MO causou aumento na CTC e retenção de nutrientes. Altos valores de P foram observados em solos e plantas devido ao uso excessivo de fertilizantes; isto pode causar desequilíbrio nutricional e contaminação das fontes de água. Os teores de N, P e K nas folhas das árvores de manga foram nutricionalmente adequados.

**Palavras-chave:** *Mangifera indica*, fertilizantes minerais, matéria orgânica do solo

## Introduction

Fruit farming, as one of the most important segments of Brazilian agribusiness due to high added value and significant use of manpower, is an important alternative for the advancement of Brazilian exportation of agricultural products (SOBER, 2009). Among the fruits, mangos (*Mangifera indica* L.) stand out in both internal and external markets, due to their high commercial value (Albuquerque et al., 1999).

The removal of native vegetation for planting of crops may promote modifications in the chemical properties of the soil, mainly in the topsoil, due to the addition of fertilizers and pesticides and due to agricultural operations. These changes may improve the properties of the soil, and may also accelerate the process of degradation, depending on the type of soil, the plant species, the management system, and the time of cultivation (Maia & Ribeiro, 2004; Costa, 2009). According to Silva & Araújo (2005), the continuous application of mineral fertilizers, without periodic evaluation of the residual effect of the applied fertilizers, in addition to contributing to the increase of the salinity of the irrigated soils, may also cause changes in the chemical properties of soil, and therefore in its nutrient balance. Little research has been done with long-term experiments related to the influence on soil properties.

An understanding of changes in the chemical properties of the soil caused by soil management may provide information for the adoption of practices that will allow for an increase in crop productivity while minimizing environmental damage (Corrêa et al., 2001).

Thus, due to the importance of the mango crop for Brazil, mainly in the Northeast region, this study had the objective of evaluating changes in soil fertility and in leaf nutrient contents of areas with mango crops in in the municipality of Petrolina, Pernambuco State, Brazil.

## Material and Methods

The soils and plant materials used for the analysis were collected from areas planted with mango crops (mostly Tommy Atkins cultivar), located in the municipality of Petrolina-PE, Brazil. The research areas comprised eight agricultural companies that are mainly geared towards the exportation of mangos (AM Export, Andorinha, EBFT, Fazenda Alphavale, Copafruit, Agrobrás, Frutex, and UPA). These areas exhibit different histories of fertilization and liming. In general, the fertilizing program annually provides 40 L plant$^{-1}$ of organic matter from animal sources. The doses and sources of N vary among the companies, with ammonium sulfate being the most commonly used source, with doses varying between 300 and 500 g plant$^{-1}$. The most used source of K is potassium sulfate (doses varying between 100 and 800 g plant$^{-1}$). For P, the doses average 1000 g plant$^{-1}$ of simple superphosphate. Plant spacings are 8 x 5 and 10 x 10 m. The chemical correction of the soils is carried out by using lime and gypsum. Irrigation is performed daily by all the companies, using the micro-sprinkler method. To control pests and diseases, all of the companies follow the integrated fruit production (IFP) program.

The samples, all of them of sandy soils, were collected in mango areas with 11 cultivation times (6, 7, 8, 9, 10, 11, 14, 16, 17, 19, and 26 years), in two distinct situations: the cultivated area and the reference area (Caatinga biome with minimal human interference). Samples were taken at two depths (0-20 cm and 20-40 cm) in the projection area of the canopy. The areas were divided into three equal parcels from which 15 points were selected in order to form the composite sample. To evaluate the plants nutritional status, four leaves were collected per plant at the average height of the canopy. The samples were placed in a paper bag and kept under refrigeration until being transported to the laboratory.

The soil samples were air dried and passed through a 2 mm sieve. The chemical attributes analysed were pH in water (1:2.5); $K^+$ and $Na^+$; exchangeable $Ca^{2+}$ and $Mg^{2+}$; exchangeable $Al^{3+}$; H+Al; available phosphorous; and organic carbon (Embrapa, 1999). Values for the sum of bases (SB), potential (T) and effective (t) cation exchange capacities, base saturation (V), and Al saturation (m) were calculated.

The total N in leaves was measured by Kjeldahl method. The other elements were determined in extracts of digestion in a microwave oven using the 3051A method (USEPA, 1998). P was determined by colorimetry, K by flame photometry, and Ca and Mg by atomic absorption spectrophotometry (Embrapa, 1999).

The statistical analysis was performed in a 2x2 split plot arrangement [two environments (main plot) and two depths (sub plot)] with three replications, for a total of 132 experimental units. For the chemical analysis of plants, 10 cultivation times were considered with three replicates, for a total of 30 experimental units. The statistical analysis was based on analysis of variance, correlation analysis, and a Tukey's test ($P < 0.05$), using the Statistical Analysis System software (SAS, 1999).

## Results and Discussion

The pH of the cultivated soil was greater than the pH of the soil with native forest (Table 1), except in the areas with 6 and 9 years of cultivation time. This increase in pH with cropping is favored by agricultural practices, mainly liming. Borges & Kiehl (1997) found pH values that were higher in planted areas due to application of limestone. The area with 6 years of cultivation, at a depth of 20-40 cm, and the area with 11 years of cultivation, at both depths, showed reduced pH in the cultivated area (CA) compared to the reference area (RA). In these areas, which belong to the same company, the application of ammonium fertilizers may explain these results.

The concentrations of organic matter (OM) at a depth of 0-20 cm differed ($P < 0.05$) for the majority of the evaluated areas (Table 1). Only the areas with 7, 10, and 26 years of cultivation presented OM amounts that were greater than those of the reference area. An increase in the OM content with crops was also reported by Costa (2009), who analyzed soils with different cultivation times for grapes in the same region. The agricultural practices adopted in the respective areas, such as the use of mulch in the area with 7 years of cultivation and the application of organic fertilizers in the other two areas, it could

**Table 1.** Chemical attributes (pH, OM, P, Al and H+Al) of soils with different periods, in cultivated areas (CA) and reference areas (RA) at depths of 0-20 and 20-40 cm

| Cultivation Time (years) | pH (1:2,5) | | OM $g\ kg^{-1}$ | | P $mg\ dm^{-3}$ | | Al | | H+Al | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $cmol_c\ dm^{-3}$ | | | |
| | CA | RA | CA | RA | CA | RA | CA | RA | CA | RA |
| Depth 0-20 cm | | | | | | | | | | |
| 6 | 6.5aA | 6.5aA | 9.89aA | 9.38aA | 147.28aA | 2.35bA | 0.10aA | 0.00bA | 1.23bA | 1.76aB |
| 7 | 7.0aB | 5.5bA | 14.20aA | 5.01bA | 131.95aA | 2.32bA | 0.00bA | 0.12aB | 0.86bA | 1.93aA |
| 8 | 7.5aA | 5.1bA | 14.29aA | 9.55aA | 291.03aA | 4.81bA | 0.00bA | 0.28aA | 0.53bA | 3.41aA |
| 9 | 7.3aA | 7.0aA | 8.31aA | 7.26aA | 72.81aA | 24.27aA | 0.00aA | 0.00aA | 0.72aA | 0.69aA |
| 10 | 7.4aA | 4.9bA | 11.00aA | 6.50bA | 88.74aA | 6.84aA | 0.00bA | 0.33aB | 0.58bA | 2.44aA |
| 11 | 6.9bA | 7.3aA | 15.22aA | 11.41aA | 116.02aA | 42.08bA | 0.00aA | 0.00aA | 1.09aA | 0.91aA |
| 14 | 7.1aA | 5.6bA | 10.19bA | 69.16aA | 112.80aA | 5.99bA | 0.00bA | 0.12aA | 1.04bA | 7.70aA |
| 16 | 7.4aA | 5.6bA | 11.24bA | 69.16aA | 121.66aA | 5.99bA | 0.00bA | 0.12aB | 0.78bA | 7.70aA |
| 17 | 7.0aA | 5.5bA | 10.60aA | 8.25aA | 67.98aA | 5.34bA | 0.03aA | 0.12aA | 0.79bA | 2.36aA |
| 19 | 7.8aA | 6.4bB | 13.63aA | 11.27aA | 133.63aA | 11.56bA | 0.00aA | 0.03aA | 0.58bA | 2.01aA |
| 26 | 7.7aA | 4.8bA | 14.94aA | 9.71bA | 248.75aA | 8.20bA | 0.00bA | 0.53aB | 0.49bA | 3.87aB |
| Depth 20-40 cm | | | | | | | | | | |
| 6 | 6.1bA | 6.4aB | 7.37aA | 9.85aA | 115.08aA | 2.80bA | 0.00aB | 0.03aA | 1.51bA | 2.06aA |
| 7 | 7.3aA | 5.2bB | 7.87aB | 2.52bB | 76.40aA | 1.24bB | 0.00bA | 0.28aA | 0.64bA | 1.43aB |
| 8 | 7.7aA | 5.0bA | 8.24aB | 4.58aB | 131.68aA | 2.26bA | 0.00bA | 0.33aA | 0.36bA | 1.93aB |
| 9 | 7.1aA | 6.7bB | 4.34bB | 5.27aB | 21.00aA | 9.52aB | 0.00aA | 0.00aA | 0.75aA | 0.80aA |
| 10 | 7.3aA | 4.9bA | 5.48aB | 5.54aB | 52.51aA | 5.83aA | 0.00bA | 0.43aA | 0.53bA | 2.50aA |
| 11 | 6.6bA | 7.3aA | 7.33bB | 11.37aA | 75.68aA | 31.16aB | 0.07aA | 0.00aA | 1.17aA | 0.94bA |
| 14 | 6.9aA | 5.4bB | 7.10bA | 35.18aB | 110.95aA | 3.51bB | 0.00bA | 0.17aA | 0.87bA | 7.10aB |
| 16 | 7.0aB | 5.4bB | 4.71bB | 35.18aB | 62.20aA | 3.52bB | 0.00bA | 0.17aA | 0.82bA | 7.10aB |
| 17 | 6.7aA | 5.4bA | 4.96bB | 7.61aB | 20.87aA | 4.67bA | 0.03aA | 0.10aA | 0.90bA | 2.25aA |
| 19 | 7.7aA | 6.5aA | 7.43aB | 7.96aB | 70.37aA | 4.79bB | 0.00aA | 0.03aA | 0.56bA | 1.87aA |
| 26 | 7.6aA | 4.6bB | 8.41aB | 7.64aB | 142.52aA | 4.00bB | 0.00bA | 1.02aA | 0.72bA | 4.28aA |

Means followed by same lowercase letters in the horizontal (between CA and RA) and capital letters in the vertical (between 0-20 and 20-40 cm) do not differ statistically by Tukey test ($P < 0.05$)

explain this result since such practices increase the organic matter concentration in soil (Lourenço et al., 2001).

In the areas with 14 and 16 years of cultivation (at both depths) and in the areas with 9, 11 and 17 years of cultivation (at the depth of 20-40 cm) the amounts of OM were significantly greater in the RA, which could be explained by the fact that organic matter is better preserved by virtue of not moving in the soil, by a greater diversity of plant species, and by greater recycling of carbon due to the continual replacement of organic plant matter (Almeida et al., 2005). Similarly, Sanches et al. (1999) verified greater amounts of OM in the forest areas at a depth of 20-40 cm than in an area with citrus fruit crops. Santos & Ribeiro (2002) observed a reduction in the amount of organic carbon in the soil profile with mango crops, in comparison to the profile of soil with native vegetation, in the São Francisco River Valley region. The authors attributed this fact to the likely small doses of OM applied and the greater humidity and movement of the soils under irrigated cultivation. Only the areas with 7 years of cultivation presented OM amounts in the CA that were greater than those of the RA, at a depth of 20-40 cm, due to the very low content of OM in these soils in the 'Caatinga'.

In general, the OM content of the soil in 0-20 cm depth was greater than that in  20-40 cm depth, both for the CA and for the RA (Table 1), with the exception of the CA with 6 and 14 years of cultivation and the RA with 6 and 11 years of cultivation. These results corroborate the findings of Corrêa et al. (2001), who detected a reduction of the OM content with increasing depth, both in forest soil and in the soil under sugar cane cultivation.

The OM content in the soil of the CA is considered low (Faria et al., 2007). It may be that the sandy soils of the São Francisco River Valley region provide low protection for organic matter, and along with the climatic conditions of the region, they may imprint the soils with greater ease of OM oxidation (Silva & Resck, 1997). Therefore, the organic fertilization adopted by the majority of the evaluated areas is of great importance.

The greatest amounts of P were found in cultivated areas (Table 1). These values were very high, taking into account the critical level of P for mango trees (40 mg $dm^{-3}$) (IPA, 2008). Similar results were found by Sanches et al. (1999) and Araujo et al. (2000). Costa (2009) found amounts of P that were significantly greater than those in the present study; this can be explained by the more intense use of phosphate fertilizers in the cultivation of grapes. These elevated amounts of P may be attributed to the practices of mineral fertilization adopted. These fertilizers are applied on a semester basis. Differences in the P concentration between depths were observed only for the RA. This result is likely to be due to the sandy texture of the soils, which facilitates the downward P movement in the soil profile.

The increase in the amounts of K in the areas under cultivation resulted from the application of fertilizers (Table 2). The reduction of the amount of K in soils with a 16 and 17 years may be explained by the fact that fertilizers are normally applied during the production while the soil samples were collected at the time of vegetative growth. The K levels in the area with 11 years of cultivation cannot be explained by agricultural management, as the amounts of K found in the area were 5 times greater than the value considered to be very high (>0.40 $cmol_c\ dm^{-3}$) (Faria et al., 2007). For the majority of the cultivated areas there were no significant differences in the amount of K between depths. This is explained by the movement of K to the subsurface due to the daily irrigation practices employed by all farms.

**Table 2.** Chemical attributes (Ca, Mg, Na e K) of soils with different periods, in cultivated areas (CA) and reference areas (RA) at depths of 0-20 and 20-40 cm

| Cultivation Time (years) | Ca | | Mg | | Na | | K | |
|---|---|---|---|---|---|---|---|---|
| | $cmol_c\ dm^{-3}$ | | | | | | | |
| | CA | RA | CA | RA | CA | RA | CA | RA |
| | Depth 0-20 cm | | | | | | | |
| 6 | 2.88bA | 5.70aA | 1.30bA | 2.20aA | 0.11aA | 0.05aA | 0.57aA | 0.40aA |
| 7 | 4.10aA | 0.62bA | 1.42aA | 0.52bA | 0.11aA | 0.04aA | 0.15aA | 0.03bA |
| 8 | 4.98aA | 0.95bA | 1.08aA | 0.53bA | 0.08aA | 0.03bA | 0.43aA | 0.09bA |
| 9 | 2.97aA | 2.37bA | 1.03aA | 0.65aA | 0.06aA | 0.04aA | 0.21aA | 0.16bA |
| 10 | 3.63aA | 0.77bA | 1.22aA | 0.75bA | 0.02aA | 0.05aA | 0.21aA | 0.11bA |
| 11 | 4.10aA | 4.52aB | 1.28bB | 2.02aA | 0.10aA | 0.10aA | 0.56bA | 2.18aA |
| 14 | 3.57bA | 7.45aA | 0.73bA | 1.80aA | 0.01aA | 0.10aA | 0.22aA | 0.33aA |
| 16 | 4.22bA | 7.45aA | 0.63bA | 1.80aA | 0.03aA | 0.10aA | 0.22bA | 0.33aA |
| 17 | 3.17aA | 2.75aA | 1.03aA | 1.00aA | 0.06aA | 0.07aA | 0.24aA | 0.26aA |
| 19 | 4.58aA | 3.53aA | 1.30aA | 0.70bA | 0.23aA | 0.09bA | 0.36aA | 0.21bA |
| 26 | 5.37aA | 1.25bA | 1.43aA | 0.90aA | 0.05aA | 0.03aA | 0.31aA | 0.20bA |
| | Depth 20-40 cm | | | | | | | |
| 6 | 2.48bA | 5.67aA | 1.32bA | 2.47aA | 0.06aA | 0.05aA | 0.45aA | 0.41aA |
| 7 | 2.78aA | 0.00bB | 0.62aB | 0.35aA | 0.08aA | 0.05aA | 0.10aB | 0.02bB |
| 8 | 3.55aA | 0.35bA | 0.82aA | 0.38bA | 0.05aB | 0.06aA | 0.23aB | 0.07bB |
| 9 | 1.68aB | 1.55bB | 0.72aA | 0.55aA | 0.12aA | 0.03aA | 0.17aA | 0.14bB |
| 10 | 2.42aA | 0.73bA | 0.85aA | 0.30bB | 0.10aA | 0.04aA | 0.19aA | 0.10bA |
| 11 | 3.25bA | 5.23aA | 1.43bA | 2.33aA | 0.15aA | 0.08aA | 0.52bA | 1.93aA |
| 14 | 3.02aA | 5.12aB | 0.77bA | 1.55aA | 0.03aA | 0.10aA | 0.29aA | 0.24aB |
| 16 | 2.20bB | 5.12aB | 0.75bA | 1.55aA | 0.03aA | 0.10aA | 0.23aA | 0.24aB |
| 17 | 1.80bB | 2.67aA | 0.88aA | 1.02aA | 0.08aA | 0.07aA | 0.18bA | 0.26aA |
| 19 | 2.78bA | 3.32aA | 1.02aA | 0.83aA | 0.07aB | 0.06aA | 0.33aA | 0.18bB |
| 26 | 3.45aA | 0.85bB | 1.08aA | 0.87aA | 0.03aA | 0.09aA | 0.27aA | 0.17aA |

Means followed by same lowercase letters in the horizontal (between CA and RA) and capital letters in the same vertical (between 0-20 and 20-40 cm) do not differ statistically by Tukey test (P <0.05).

The areas with 7, 8, 9, 10, and 26 years presented an increase in the sum of bases (SB) in relation to the reference areas (Table 3), which is explained by the addition of fertilizers and lime to soils. There was a reduction of SB with an increase in depth. According to Araujo et al. (2000), the quality of the soil for plant growth is related to the proportion of bases in the soil exchange complex. Base saturation (V%) was significantly greater in the CA than in the RA.

**Table 3.** Chemical attributes (sum of bases, CECtotal e base saturation) of soils with different periods, in cultivated areas (CA) and reference areas (RA) at depths of 0-20 and 20-40 cm

| Cultivation Time (years) | SB | | $CEC_{total}$ | | V | |
|---|---|---|---|---|---|---|
| | $cmol_c\ dm^{-3}$ | | | | % | |
| | CA | RA | CA | RA | CA | RA |
| | Depth 0-20 cm | | | | | |
| 6 | 4.86bA | 8.35aA | 6.09bA | 10.11aB | 79.59aA | 82.58aA |
| 7 | 5.77aA | 1.21bA | 6.63aA | 3.14bA | 87.28aA | 38.59bA |
| 8 | 6.57aA | 1.60bA | 7.10aA | 5.00bA | 92.50aA | 31.71bA |
| 9 | 4.27aA | 3.22bA | 4.99aA | 3.91bA | 85.70aA | 82.46aA |
| 10 | 5.09aA | 1.68bA | 5.67aA | 4.12aA | 89.50aA | 40.83bA |
| 11 | 6.04bA | 8.81aB | 7.14aA | 9.71aB | 84.79bA | 90.66aA |
| 14 | 4.52bA | 9.68aA | 5.56bA | 17.38aA | 81.36aA | 55.70bA |
| 16 | 5.11bA | 9.68aA | 5.89bA | 17.38aA | 86.46aA | 55.71bA |
| 17 | 4.50aA | 4.08aA | 5.29bA | 6.44aA | 85.02aA | 63.30bA |
| 19 | 6.47aA | 4.54aA | 7.05aA | 6.54aA | 91.59aA | 69.32bA |
| 26 | 7.16aA | 2.38bA | 7.65aA | 6.25aA | 93.76aA | 37.93bA |
| | Depth 20-40 cm | | | | | |
| 6 | 4.31bA | 8.59aA | 5.82bA | 10.65aA | 73.98bA | 80.64aB |
| 7 | 3.58aB | 0.41bB | 4.22aB | 1.84bB | 84.83aA | 22.31bB |
| 8 | 4.64aA | 0.87bB | 5.01aA | 2.79bB | 92.32aA | 31.00bA |
| 9 | 2.70aB | 2.27bB | 3.45aB | 3.07aB | 78.38aB | 74.03aB |
| 10 | 3.55aA | 1.18bB | 4.08aA | 3.68aB | 87.07aA | 31.98bB |
| 11 | 5.36bA | 9.57aA | 6.54bA | 10.50aA | 81.87bA | 91.11aA |
| 14 | 4.10bA | 7.01aB | 4.97bA | 14.10aB | 81.33aA | 49.69bB |
| 16 | 3.21bB | 7.01aB | 4.02bB | 14.10aB | 79.59aA | 49.69bB |
| 17 | 2.95bB | 4.02aA | 3.85bB | 6.26aA | 76.60aB | 64.07bA |
| 19 | 4.20aB | 4.39aA | 4.75bB | 6.25aA | 88.39aA | 70.12bA |
| 26 | 4.84aA | 1.97bA | 5.56aA | 6.26aA | 87.09aA | 31.53bA |

Means followed by same lowercase letters in the horizontal (between CA and RA) and capital letters in the same vertical (between 0-20 and 20-40 cm) do not differ statistically by Tukey test (P <0.05)

The total and potential CEC have well-differentiated behaviors between the CA and RA environments (Table 3). The areas with 7, 8, and 9 years of cultivation time, at a depth of 0-20 cm, and the areas with 7 and 8 years of cultivation time, at a depth of 20-40 cm, showed higher values in the CA in comparison to the RA. The areas with 6, 14, 16, and 17 years of cultivation and the area with 19 years, at the subsurface layer (20-40 cm) presented the inverse situation, with higher values in the RA than in the CA, which could be explained by the greater amounts of OM and of H+Al, in accordance with the results obtained by Araujo et al. (2000), Sanches et al. (1999), and Corrêa et al. (2001). According to Sanchez (1981), one of the factors that determine this difference is the reduction of the amount of OM in the soil of the cultivation area, with a consequent reduction of the exchange sites. For Brams (1971), the decrease of the CEC could be attributed to the changes in the quantity of OM and the pH, mainly in the areas with long periods of cultivation. Regarding the effect of depth, there were statistically significant differences in the two environments for the majority of the studied areas, with a reduction of CEC values in the majority of the CT as the depth increases. This reduction is mainly due to the decrease in the amount of OM with increasing depth (Brams, 1971; Sanches et al., 1999).

The OM contents presented positive and significant correlations in the cultivated areas, especially with Ca (Tables 4 and 5). In the RA there were positive correlations with H+Al, Ca, Mg, SB, and total and effective CEC as well as a negative correlation with m% at a depth of 20-40 cm. The high positive correlation between OM and CEC shows the participation of OM in the increase of CEC in the soil. The OM has an

**Table 4.** Linear correlation between soil chemical properties in cultivated areas (CA) and reference areas (RA) at two depths of 0-20 cm

| | Areas | pH | MO | P | H+AL | Ca | Mg | Al | K |
|---|---|---|---|---|---|---|---|---|---|
| MO | CA | 0.14$^{ns}$ | - | 0.44* | 0.03$^{ns}$ | 0.79** | 0.28$^{ns}$ | -0.28$^{ns}$ | 0.29$^{ns}$ |
| | RA | -0.11$^{ns}$ | - | -0.17$^{ns}$ | 0.92** | 0.80** | 0.50** | -0.11$^{ns}$ | -0.01$^{ns}$ |
| P | CA | 0.19$^{ns}$ | 0.44* | - | -0.06$^{ns}$ | 0.54** | 0.15$^{ns}$ | -0.07$^{ns}$ | 0.19$^{ns}$ |
| | RA | 0.73** | -0.17$^{ns}$ | - | -0.41* | 0.06$^{ns}$ | 0.21$^{ns}$ | -0.35* | 0.83** |
| SB | CA | 0.38* | 0.82** | 0.54** | -0.22$^{ns}$ | 0.93** | 0.47** | -0.24$^{ns}$ | 0.35* |
| | RA | 0.46** | 0.70** | 0.24$^{ns}$ | 0.47** | 0.97** | 0.91** | -0.51** | 0.51** |
| $CEC_T$ | CA | 0.16$^{ns}$ | 0.84** | 0.54** | 0.04$^{ns}$ | 0.88** | 0.45** | -0.15$^{ns}$ | 0.44* |
| | RA | 0.09$^{ns}$ | 0.92** | -0.04$^{ns}$ | 0.80** | 0.94** | 0.77** | -0.23$^{ns}$ | 0.24$^{ns}$ |
| $CEC_{ef}$ | CA | 0.37* | 0.81** | 0.54** | -0.21$^{ns}$ | 0.92** | 0.48** | -0.22$^{ns}$ | 0.36* |
| | RA | 0.43* | 0.71** | 0.23$^{ns}$ | 0.49** | 0.97** | 0.91** | -0.47** | 0.51** |
| V | CA | 0.81** | 0.34* | 0.25$^{ns}$ | -0.90** | 0.59** | 0.33$^{ns}$ | -0.43* | -0.05$^{ns}$ |
| | RA | 0.94** | -0.04$^{ns}$ | 0.64** | -0.38* | 0.48** | 0.54** | -0.78** | 0.59** |
| m | CA | -0.57** | -0.29$^{ns}$ | -0.08$^{ns}$ | 0.37* | -0.41* | 0.14$^{ns}$ | 0.99** | 0.34* |
| | RA | -0.79** | -0.33$^{ns}$ | -0.34* | 0.01$^{ns}$ | -0.71** | -0.55** | 0.91** | -0.36* |

*,** and ns: Significant at 5 and 1% probability level by t test and not significant, respectively

**Table 5.** Linear correlation between soil chemical properties in cultivated areas (CA) and reference areas (RA) at two depth of 20-40 cm

| | Areas | pH | MO | P | H+AL | Ca | Mg | Al | K |
|---|---|---|---|---|---|---|---|---|---|
| MO | CA | 0.30$^{ns}$ | - | 0.72** | 0.01$^{ns}$ | 0.87** | 0.21$^{ns}$ | -0.01$^{ns}$ | 0.36* |
| | RA | -0.05$^{ns}$ | - | -0.05$^{ns}$ | 0.89** | 0.67** | 0.45** | -0.16$^{ns}$ | 0.06$^{ns}$ |
| P | CA | 0.15$^{ns}$ | 0.72** | - | 0.09$^{ns}$ | 0.71** | 0.27$^{ns}$ | -0.14$^{ns}$ | 0.28$^{ns}$ |
| | RA | 0.67** | -0.05$^{ns}$ | - | -0.34* | 0.33$^{ns}$ | 0.45** | -0.30$^{ns}$ | 0.94** |
| SB | CA | 0.14$^{ns}$ | 0.85** | 0.71** | 0.15$^{ns}$ | 0.90** | 0.48** | 0.24$^{ns}$ | 0.63** |
| | RA | 0.60** | 0.57** | 0.49** | 0.27$^{ns}$ | 0.98** | 0.95** | -0.51** | 0.67** |
| $CEC_t$ | CA | -0.13$^{ns}$ | 0.77** | 0.67** | 0.43* | 0.79** | 0.57** | 0.31$^{ns}$ | 0.76** |
| | RA | 0.22$^{ns}$ | 0.87** | 0.18$^{ns}$ | 0.71** | 0.91** | 0.80** | -0.24$^{ns}$ | 0.38* |
| $CEC_{ef}$ | CA | 0.13$^{ns}$ | 0.84** | 0.70** | 0.16$^{ns}$ | 0.90** | 0.48** | 0.26$^{ns}$ | 0.64** |
| | RA | 0.56** | 0.59** | 0.48** | 0.31$^{ns}$ | 0.97** | 0.96** | -0.43* | 0.67** |
| V | CA | 0.87** | 0.48** | 0.33$^{ns}$ | -0.80** | 0.59** | -0.10$^{ns}$ | -0.16$^{ns}$ | -0.15$^{ns}$ |
| | RA | 0.90** | 0.07$^{ns}$ | 0.60** | -0.29$^{ns}$ | 0.71** | 0.69** | -0.70** | 0.64** |
| m | CA | -0.33$^{ns}$ | -0.06$^{ns}$ | -0.18$^{ns}$ | 0.25$^{ns}$ | -0.02$^{ns}$ | 0.18$^{ns}$ | 0.94** | 0.34* |
| | RA | -0.72** | -0.43* | -0.35* | -0.10$^{ns}$ | -0.81** | -0.62** | 0.74** | -0.39* |

*,** and ns: Significant at 5 and 1% probability level by t test and not significant, respectively

important role in the nutrient cycle, in addition to contributing towards increasing the CEC of tropical soils (Barreto et al., 2003).

The correlation between OM and P was significant at the depth of 0-20 cm and highly significant at the depth of 20-40 cm in the CA (Tables 4 and 5). This indicates that P moved towards the deeper layers, possibly due to the low P adsorption capacity of sandy soils (Galvão et al., 2008).

The amounts of nutrients in leaves followed the order: Ca>N>K>Mg>P (Table 6). These results are similar to those of Medeiros et al. (2005) and are different from the findings of Galli et al. (2009), who found amounts of nutrients in the order of N>Ca>K>P>S>Mg when analyzing mango leaves in the vegetative phase.

The amounts of N in the leaves appear to be excessive for the areas of 6, 9, and 11 years of cultivation, according to the values established by Quaggio (1996). Only two areas (7 and 16 years) had N contents that were within the range of an adequate amount. The high values found in the majority of the areas were due to plants being in the vegetative stage and due to the agricultural practice of organic fertilizing adopted by the majority of companies. According to Galli et al. (2009), the concentration of N is high in the vegetative period and decreases in the subsequent phases. It is worth highlighting that these variations in the amounts of N may occur from one year to the next, and the age of the plant may also influence N concentration, as indicated by Klein (1980) in apple orchards.

Excess N causes problems for the crop, such as excessive vegetative growth, difficulty in floral differentiation, a loss of fruit production and quality due to internal collapse, and an increase in susceptibility to disease (Pinto et al., 2009). Pinto (2000) reported that in Brazil, mango orchards with an amount of leaf N higher than 12 g kg$^{-1}$ can pose greater incidence of fruits with green peel coloration, which decreases the market value of the fruit.

**Table 6.** Concentrations of maronutrients in mango leaves, grown in Northeast Brazil in different cultivation time (CT)

| CT years | N | Ca | Mg | K | P |
|---|---|---|---|---|---|
| | g kg$^{-1}$ | | | | |
| 6 | 16.58 | 16.34 | 1.81 | 17.98 | 3.03 |
| 7 | 14.00 | 14.79 | 2.16 | 10.90 | 2.32 |
| 9 | 17.95 | 17.89 | 2.24 | 12.44 | 2.79 |
| 10 | 15.21 | 23.64 | 2.22 | 11.17 | 1.93 |
| 11 | 16.44 | 19.73 | 2.15 | 10.57 | 1.94 |
| 14 | 14.77 | 16.68 | 1.97 | 10.37 | 1.70 |
| 16 | 12.61 | 20.73 | 2.07 | 10.50 | 1.53 |
| 17 | 14.25 | 17.18 | 2.19 | 11.77 | 1.91 |
| 19 | 15.92 | 12.09 | 1.80 | 13.77 | 2.59 |
| 26 | 15.19 | 18.61 | 1.78 | 11.57 | 2.13 |
| | *Range Levels | | | | |
| Deficient | <8.0 | <15.0 | <1.0 | <2.5 | <0.5 |
| Appropriate | 12.0-14.0 | 20.0-35.0 | 2.5-5.0 | 5.0-10.0 | 0.8-1.6 |
| Excessive | >16.0 | >50.0 | >8.0 | >12.0 | >2.5 |

*Source: Quaggio (1996).

In the areas with cultivation times of 10 and 16 years, the amounts of calcium were within the range of adequate values (Table 6), while in the areas with 7 and 19 years, the amounts were below the range of values considered deficient (Quaggio, 1996). In the other areas, Ca concentrations were found to be between the deficient and adequate ranges. These low amounts in the leaves found in the majority of the areas are explained by the fact that the plants were in the vegetative phase of growth, since the amounts of Ca increase in the fruit formation phase (Avilan, 1971).

It was shown that the N/Ca ratio was greater than 0.5 in all of the evaluated areas, varying from 0.61 to 1.32. These high ratios make the fruits of monoembryonic varieties apt to develop physiological disorders such as internal collapse of the fruit (Silva et al., 2008). Young & Miner (1961) described the use of the N/Ca ratio as an indicator of the incidence of "soft nose" (softening of the pulp), suggesting 0.5 as the upper limit of the ratio. Assis et al. (2004) and Silva et al. (2008) found similar results.

It was shown that in all of the studied areas, Mg levels were below the adequate range (Table 6), yet this amount was above the deficient range. Low values of Mg in the leaves of mango trees were also found by Assis et al. (2004), Rozane et al. (2007) and Galli et al. (2009). This element is part of the chlorophyll molecule and is an activator of various enzymes, in addition to being essential for the absorption of P. However, its absorption is inhibited by high concentrations of K in the plant (Magalhães & Borges, 2000), which could have occurred in the plants in this study, since large amounts of K were found in the leaves.

The areas with 6, 9 and 19 years of cultivation presented leaf K concentrations above the excessive range, while the other areas showed values above the adequate range but below of the excessive amount. These high values are the consequence of the application of potassium fertilizers used by the majority of the companies. As with N, the elevated amounts of K were also influenced by the phenological state of the plant. Medeiros et al. (2005) reported that the amounts of K during flowering were frequently higher than during other phenological phases of the mango crop.

In the areas with 6, 9, and 19 years of cultivation, the concentrations of P were above the threshold considered to be excessive, whereas they had values between the adequate and excessive ranges in the other areas. Similar results were found by Galli et al. (2009). The high amounts found were the result of applied fertilizers, as shown by the high amounts also found in the soils of the cultivated areas (Table 1). This clearly indicates that the practice of economical and more environmentally-sustainable fertilizing should be considered for the cultivation of mango crops in this region.

## Conclusions

The agricultural management practices adopted by the mango-producing companies promoted changes in the fertility of the soils when compared with the soils of the reference areas.

The concentration of organic matter tended to increase in the crop areas. The OM caused increases in CEC and nutrient retention.

High P concentrations were observed in soils and plants owing to the use of excessive doses of fertilizers.

The concentration of N, P, K in the leaves of mango trees were nutritionally adequate. On the other hand the concentration of Ca and Mg were less than those required by the crop.

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