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‘Palmer’ Mango Yield as Affected by Soil Class and Pedon Physicochemical Characteristics

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Abstract

To evaluate the variation in ‘Palmer’ mango yield related to soil formation and soil physical and chemical properties, we studied a transect with 11 soil profiles, selected according to the altitude in a commercial orchard. Surface and subsurface diagnostic horizons were described up to two meters in depth. Soil depth, texture, structure, consistency, clay coating, cementation, and color of each horizon were morphologically determined. Undisturbed and disturbed samples were used to determine the soil total porosity, macroporosity, microporosity, density, saturated hydraulic conductivity, granulometry, total organic carbon, pH, sum of bases, and the contents of P, S, K, Na, Ca, Mg, Al, Fe, Mn, Cu, and Zn. The number of fruits (for production estimates), stem diameter, canopy area, and plant height were determined in four plants around each soil profile. Three classes of soil showed good suitability for mango cultivation: Argisol Red-Yellow Eutrophic typic, Cambisol Haplic Eutrophic Tb, and Latosol Red Yellow Eutrophic typic. The ‘Palmer’ mango yield was correlated with the K contents, sum of bases, and pH. The low yield was a result of the low K content associated with the presence of gravel.

Keywords: soil catena, soil horizon, *Mangifera indica* L.

1. Introduction

The mango tree (*Mangifera indica* L.) belongs to the family Anacardiaceae and is native to Asia, where 76% of world production is concentrated. India is the world’s largest mango producer followed by Thailand (FAOSTAT, 2018). Brazil is among the largest producers and exporters of the fruit, and occupied, in 2016, the sixth and seventh position in the world rankings of mango production and exportation, respectively (Carvalho et al., 2017). The Northeast and Southeast regions, represented by the states of Bahia, Pernambuco, São Paulo, and Minas Gerais, are the main mango producers in Brazil (Treichel et al., 2016; Carvalho et al., 2017).

The cultivation of mango in northern Minas Gerais State represents41% of the state’s production (IBGE, 2016). ‘Palmer’stands out as the predominant species, corresponding to 95% of the production in this region.The maintenance of its agricultural yield under irrigated systems is closely related to the chemical, physical, and biological attributes of the soil. These attributes are altered due to the continuous use of irrigation, fertilizers, pesticides, and machine traffic, which modify soil quality and, as a consequence, its productive potential (Corrêa et al., 2010).

Irrigation also changes several chemical attributes, such as pH, cation exchange cationic capacity and exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+), micronutrients, and soil organic matter. Hence, the agricultural production is affected (Assis et al., 2010). In irrigated semiarid areas, such as the north of Minas Gerais, the mango tree has the potential to produce high-quality fruits at any time of the year by the use of the floral induction technology (Oliveira, 2015). However, high productions are directly associated with the physical and chemical quality of the soil and crop management practices, such as proper fertilization and irrigation.

2. Method

2.1 Description of the Experimental Site

The study was carried out at Piranhas Farm belonging to the Gorutuba Project, in Janauba, MG, Brazil (15°45′09″ S and 43°20′34″ W, 500 m). The climate of the region is considered as AW (tropical with dry winter), according to the Köppen classification, with mean temperature above 18 °C in the coldest month. Mean annual climate elements values are: precipitation of 873.5 mm, temperature of 24.7 °C, and relative humidity of 65%. The study was performed in a 23-ha area cultivated with ‘Palmer’ mango for ten years and previously cultivated with banana.

The irrigation consisted of a micro-sprinkler system with a flow rate of 75 L h^{-1} and lateral lines of 45 m in length. Sprinklers were spaced 8 m between rows and 5 m between plants. The nutritional reposition was based on leaf and soil analyses and carried out twice a year, right after harvest and before flowering. Monoammonium phosphate (MAP), potassium chloride, magnesium sulfate, and ammonium sulfate were used as sources of phosphorus (P), potassium (K), magnesium (Mg), and nitrogen (N), respectively. Liquid organic matter and fulvic and humic acids were also applied via soil at each fertilization event. Floral induction was performed from the third year of cultivation onwards aiming at offseason production.

2.2 Experimental Design and Treatments

The experiment consisted of a completely randomized design (CRD) with 11 soil profiles distributed across 23 ha crop from January to December 2014. The soil profiles were aligned in four rows with three profiles per row (except one row with two profiles). The soil profile was used to evaluate soil morphology, soil physical and chemical properties. The sampling position follows the toposequence position of the crop the toposequence position of the crop: shoulder, backslope, and footslope. A 2 m-deep trench was drilled in each soil profile to allow soil classification and the identification and measurement of the diagnostic horizons and layers. Each soil profile has three horizons (A, B, C) sampled, with a total of 33 soil horizons analyzed by disturbed and undisturbed soil samples.

2.3 Evaluations

Soil color, depth, structure, texture, clay coating, consistency, and cementation were morphologically determined in each horizon (Santos et al., 2013).

The central portions of the horizons A, B, and C were used for determining the chemical and physical attributes of the soil whereas the BC horizon was used for soil characterization and classification. Undisturbed soil samples were collected using a volumetric ring (0.054 m height and 0.05 m internal diameter) to determine the soil total porosity (TP), microporosity, macroporosity, density (SD), and saturated hydraulic conductivity (K_{sat}) (Embrapa, 2011).

Disturbed soil samples were also taken from the same horizons and used for the evaluation of particle size distribution and chemical analysis for fertility purposes. The disturbed samples were air dried, ground, and sieved in a 2mm mesh size. The samples were homogenized and used for granulometry analysis and to determine soil particle density (PD) (Embrapa, 2011); total organic carbon (TOC) (Yeomans & Bremner, 1988); pH in water (1:2.5); extractable P;exchangeable S, K, Na, Al, Ca, and Mg; and the contents of the micronutrients Fe, Mn, Cu and Zn (Embrapa, 2011). The exchangeable Al was extracted using a 1 mol L^{-1} KCl solution and determined by titration with a 0.025 mol L^{-1} NaOH solution. Ca and Mg were determined in the same extract by atomic absorption spectrophotometry. P, Na, K, and the micronutrients were extracted with a Mehlich I solution (0.05 mol L^{-1} HCl + 0.0125 mol L^{-1} H_2SO_4). P was determined by colorimetry (660 mm wavelength); K and Na by flame photometry; micronutrients by atomic absorption spectrophotometry; and S by calorimetry.

Crop production characteristics, such as number of fruits per plant (used for production estimation), trunk diameter, canopy area, and plant height were evaluated in four plants (considered as plots) located around each trench. Since the mango tree yield stabilizes with plant age, management, and history of the area, the yield data of a single year was used.

2.4 Statistical Analysis

Soil data were subject to descriptive statistics and Pearson’s correlation analysis with the crop production characteristics. Data were subject to analysis of variance and means were compared by the Tukey’s test to differentiate the effect of the soil classes.

3. Results and Discussion

The soils were classified according to Santos et al. (2013a), and three classes were identified: Argisol Red-Yellow Eutrophic tipic (PVAe), Cambisol Haplic Eutrophic Tb (CXbe), and Latosol Red-Yellow Eutrophic tipic (LVAe) (Table 1). Cambisols and Latosols predominated in the 11 soil profiles evaluated and presented five classes each.

Table 1. Morphological description of the horizons in soil profiles cultivated with 'Palmer' mango in the semiarid region of Minas Gerais State, Brazil

Argisol Red-Yellow Eutrophic tipic1—PVAe1	
A	0-0.22 m, subangular blocky, silty, weak, slightly hard, strong, reddish-brown (5YR 4/4)
B	0.22-0.45 m, subangular blocky, very fine clayey, weak, slightly hard,strong,reddish-yellow (5YR 4/6)
BC	0.45-0.63 m, subangular blocky, clayey, weak, hard,strong,reddish-yellow (5YR 5/8)
C	0.63-2.0 m+, subangular blocky, clayey, weak, slightly hard, strong, reddish-yellow (5YR 6/6)
OBS: altitude 504.73 m asl, 3.20% declivity.	
Cambisol Haplic Eutrophic Tb1—CXbe1	
A	0-0.28 m, subangular blocky, medium, weak, slightly hard, moderate, dark reddish-brown (5YR 3/4)
Bi	0.28-0.55 m, subangular blocky, clayey, weak, hard, moderate, reddish-brown (5YR 4/4)
BC	0.55-0.68 m, subangular blocky, clayey, weak, hard, moderate, reddish-yellow (5YR 4/6)
C	0.68-2.0 m+, subangular blocky, clayey, weak, hard, moderate, reddish-yellow (5YR 4/6)
OBS: altitude 500.09 m asl, 4.42% declivity, presence of nodules and tortuous roots.	
Cambisol Haplic Eutrophic Tb2—CXbe2	
A	0-0.28 m, subangular blocky, clayey, weak, hard, moderate, brown (7.5YR 4/4)
Bi	0.28-0.39 m, subangular blocky, clayey, weak, hard, moderate, strong brown (7.5YR 5/6)
BC	0.39-0.48 m, subangular blocky, clayey, weak, slightly hard, moderate, strong brown (7.5YR 5/6)
C	0.48-2.0 m+, subangular blocky, clayey, weak, slightly hard, moderate, strong brown (7.5YR 5/8)
OBS: altitude 501.09 m asl, 1.37% declivity, presence of iron-manganese concretions.	
Cambisol Haplic Eutrophic Tb3—CXbe3	
A	0-0.20 m, subangular blocky, clayey, weak, hard, moderate,very dark gray (5YR 3/1)
Bi	0.20-0.40 m, subangular blocky, clayey, weak, very hard, moderate, dark reddish-brown (5YR 3/2)
BC	0.40-0.56 m, subangular blocky, clayey, weak, very hard, moderate, reddish-brown (5YR 5/3)
C	0.56-2.0 m+, subangular blocky, clayey, weak, hard, moderate, reddish-brown (5YR 5/4)
OBS: altitude 502.11 m asl, 3.15% declivity, presence of iron-manganese concretions and gravel.	
Cambisol Haplic Eutrophic Tb4—CXbe4	
A	0-0.29 m, subangular blocky, clayey, weak, hard, moderate, dark reddish-brown (5YR 3/2)
Bi	0.29-0.62 m, subangular blocky, clayey, moderate, hard, moderate, reddish-brown (5YR 5/3)
C	0.62-2.0 m+, subangular blocky, clayey,weak, hard, moderate, reddish-brown(5YR 5/4)
OBS: altitude 503.06 m asl, 0.53% declivity, presence of iron-manganese concretions and gravel.	
Cambisol Haplic Eutrophic Tb5—CXbe5	
A	0-0.18 m, subangular blocky, clayey, moderate, hard, moderate, dark brown (7.5YR 3/3)
Bi	0.18-0.43 m, subangular blocky, clayey, moderate, very hard, moderate, brown (7.5YR 4/3)
C	0.43-2.0 m+, subangular blocky, clayey, weak, hard, moderate, brown (7.5YR 4/4)
OBS: altitude 503.53 m asl, 0.75% declivity. Moderately drained, presence of hydromorphicreduction mottlingandiron-manganese concretions.	
Latosol Red-Yellow Eutrophic tipictípico 1—LVAe1	
A	0-0.30 m, subangular blocky, clayey, weak, hard, weak,very dark grayish-brown (10YR 3/2)
B	0.30-0.80 m, subangular blocky, clayey, weak, hard, strong, brown (10YR 4/3)
C	0.80-2.0 m+, subangular blocky, clayey, weak, hard, strong, dark yellowish-brown (10YR 4/4)
OBS: altitude 501.60 m asl, 0.64% declivity.	
Latosol Red-Yellow Eutrophic tipic2—LVAe2	
A	0-0.28 m, granular, clayey, weak, slightly hard, strong, very dark grayish-brown (10YR 3/2)
Bw	0.28-0.79 m, granular, clayey, weak, slightly hard, strong, yellowish-brown (10YR 5/6)
C	0.79-2.0 m+, granular, clayey, weak, hard,strong,yellowish-brown (10YR 5/6)
OBS: altitude 504.19 m asl, 5.33% declivity.	
Latosol Red-Yellow Eutrophic tipic3—LVAe3	
A	0-0.27 m, granular, clayey, weak, slightly hard,weak,dark brown (10YR 3/3)
Bi	0.27-1.30 m, granular, clayey, weak, hard, strong, dark yellowish-brown (10YR 3/4)
BC	1.30-1.50 m, granular, clayey, weak, hard, strong, dark yellowish-brown (10YR 4/4)
C	1.50-2.0 m+, granular, clayey, weak, hard, strong, dark yellowish-brown (10YR 4/4)
OBS: altitude 504.24 m asl, 0.08% declivity, presence of iron-manganese concretions.	

Latosol Red-Yellow Eutrophic tipic4—LVAe4	
A	0-0.15 m, granular, clayey, moderate, slightly hard,weak, dark brown (10YR 3/3)
B	0.15-0.40 m, subangular blocky, very fine clayey, weak, slightly hard, strong, dark yellowish-brown (10YR 4/4)
BC	0.40-0.60 m, subangular blocky, clayey, weak, slightly hard,strong, yellowish-brown (10YR 5/4)
C	0.60-2.0 m+, subangular blocky, clayey, weak, slightly hard,strong, yellowish-brown (10YR 5/8)
OBS: altitude 504.67 m asl, 1.52% declivity, presence of iron-manganese concretions.	
Latosol Red-Yellow Eutrophic tipic5—LVAe5	
A	0-0.18 m, granular, clayey, moderate, hard, weak, dark brown (10YR 3/3)
B	0.18-1.50 m, granular, clayey, weak, hard, strong, yellowish-brown (10YR 5/6)
C	1.50-2.0 m+, granular, clayey, weak, hard, strong, yellowish-brown (10YR 5/8)
OBS: altitude 506.80 m asl, 3.03% declivity.	

Note. Attributes described for each soil horizon: depth (m); structure; texture; clay coating; consistency; cementation, and color (dry).

CXbe1, CXbe2, and LVAe3 were observed in the lowest part of the landscape while the middle part was comprised exclusively by Cambisols (CXbe6, 7, 8). Latosols (LVAe4, 5, 10, 11) and PVAe9 were found in the highest portion of the landscape, with the prevalence of LVAe.

All soils in the area are derived from the weathering of meta-calcilutite and meta-calcarenite and present dominant clay levels (CODEMIG, 2012). Colluvial soils were observed in accumulation zones in the lower part of the landscape. This type of soil formation was predominantly calcareous and presented iron-manganese concretions. Cambisols (CXbe1, 6) occurred in the areas with the highest declivities.

The highest *solum* depth was observed in Latosol areas, with profiles presenting A + Bwhorizon up to 1.5 m thick. The lowest depth was verified in CXbe2 which showed a 0.39 m-thick A + Bi horizon. The subangular blocky structure prevailed in Argisols and Cambisols, with subangular blocky and granular structures in Latosols.

Soil moisture was similar in all profiles. Dry-soil consistency varied from slightly hard to hard; some Cambisol areas had a very hard consistency. Soil cementation was mainly weak (Latosols) and strong (Argisols) in the A, B, and C horizons. Moderate cementation was recorded in all Cambisol horizons. The clayey texture predominated in all horizons, except in the horizons A (CXbe1 and PVAe1) and B (LVAe4). The latter was classified as very clayey texture. Soil clay coating was mostly weak; some clay coating was found in Cambisols and some areas of the A horizon in Latosols. The fragmented clay coatings are evidence of a transition of cambic to argillic horizons in Cambisols (Skorupa et al., 2017), and to Latosols, showed weak to moderate clay skins that representing the flocculation and immobilization of colloidal material enhanced by calcium ion, from calcareous materials of soil formation (Pal et al., 2003).

Similar characteristics were observed in clayey and very clayey texture Latosols as well as in Cambisols originated from pelitic rocks of the Bambui group, in the Curvelo-MG region (Pereira et al., 2010); and in Argisol in Pici, Fortaleza-CE (Mionet. et al., 2012). Careful management of the CXbe5 region was necessary because of the presence of gravel and a bad drainage spot. Additionally, iron-manganese nodules and concretions were commonly found in most parts of this area, indicating a high concentration of Mn in the soil (Table 2).

The frequent iron-manganese concretions are related to the soil parent material. Therefore, ferriferous quartz and ferric lenses are commonly found in limestone developed soils in the north of Minas Gerais. They tend to increase in size with depth in Cambisols and to remain small in Latosols (CODEMIG, 2012). Mn high values may be associated with elevated pH values. However, in this study, the Mn high values did not impair the ‘Palmer’ mango production.

The exploratory analysis of the soil attributes in each horizon is illustrated in Table 2. The mean and median values were similar in more than 61% of the attributes, with a distribution close to the central value. Most of the coefficients of variation of the attributes in A, B, and C horizons were medium and high, according to Warrick and Nielsen (1980). This high variability is related to the different soil classes and slope. Despite the variability of the attributes, yield was not reduced because of the increased fertilization and floral induction performed.

It means that crop management strategy with high of fertilizers associated with plant growth regulator can overcome original soil restrictions.

Table 2. Descriptive statistics of soil attributes in the A, B, and C horizons of soils cultivated with 'Palmer' mango in the semiarid region of Minas Gerais State, Brazil

Attribute	Horizon A						Horizon B						Horizon C					
	Mean	Med	Max	Min	CV	W	Mean	Med	Max	Min	CV	W	Mean	Med	Max	Min	CV	W
pH	6.79	6.90	7.16	6.15	4.50	N	6.67	6.87	7.06	6.04	5.65	*	6.49	6.57	7.00	5.31	7.72	N
TOC	1.94	1.97	2.62	1.36	18.66	N	1.19	0.96	2.66	0.55	52.82	N	1.58	1.72	2.29	0.65	41.11	N
P	8.31	9.19	16.23	2.64	46.44	N	1.33	0.95	3.06	0.04	83.73	N	1.67	1.36	2.85	0.39	45.88	N
S	5.30	5.01	9.80	1.87	44.92	N	7.17	7.22	11.58	3.12	39.01	N	9.71	8.84	17.73	4.40	48.24	N
K	184.48	215.25	255.75	48.00	39.32	*	54.39	31.00	167.75	12.50	89.51	*	24.91	17.75	58.75	10.50	63.26	*
Na	0.28	0.23	0.87	0.16	72.79	*	0.22	0.19	0.45	0.15	38.05	*	0.39	0.34	0.99	0.23	53.46	*
Ca	3.55	3.33	4.49	2.55	16.35	N	3.31	3.30	5.29	1.24	36.72	N	3.76	3.48	6.65	2.08	37.53	N
Mg	1.06	1.05	1.35	0.81	17.44	N	0.65	0.71	1.12	0.26	43.32	N	0.62	0.59	1.19	0.12	67.90	N
Al	0.00	0.00	0.01	0.00	171.27	*	0.00	0.00	0.01	0.00	138.74	*	0.03	0.01	0.21	0.00	204.56	*
SB	5.36	5.22	7.31	3.88	16.92	N	4.32	4.57	6.53	2.23	28.98	N	4.82	4.94	7.97	2.54	31.95	N
Fe	28.97	19.47	56.82	9.95	63.52	*	37.53	28.24	93.95	18.07	57.98	*	54.27	50.53	91.15	23.64	46.48	N
Mn	34.47	12.01	83.00	5.94	93.18	*	14.43	14.76	25.59	6.00	43.85	N	8.50	7.57	13.98	4.60	35.12	N
Cu	1.03	1.07	1.56	0.37	34.36	N	0.59	0.61	1.23	-0.07	62.47	N	0.64	0.63	1.10	0.16	54.31	N
Zn	13.32	14.25	17.22	8.64	26.24	*	5.92	5.77	11.45	2.08	56.25	N	1.98	2.14	3.64	-0.42	57.79	N
Sand	25.50	28.22	34.74	6.75	34.47	*	21.70	21.93	26.11	15.76	13.03	N	20.76	20.59	27.91	13.22	19.92	N
Silt	34.72	30.55	56.80	24.63	30.41	*	27.40	30.14	37.61	6.20	32.11	*	28.59	29.08	36.50	18.41	17.81	N
Clay	39.78	39.10	47.15	33.30	10.81	N	50.90	47.05	74.60	41.80	19.09	*	50.66	51.60	61.00	42.50	10.46	N
PD	2.59	2.63	2.74	2.27	5.08	N	2.67	2.67	2.90	2.25	6.97	N	2.67	2.67	2.78	2.56	2.69	N
TP	0.44	0.44	0.53	0.34	12.23	N	0.43	0.42	0.49	0.34	11.09	N	0.45	0.46	0.51	0.41	6.14	N
Macro	0.11	0.13	0.20	0.03	44.75	N	0.09	0.09	0.13	0.01	40.69	N	0.10	0.09	0.14	0.06	22.73	N
Micro	0.33	0.33	0.35	0.30	5.20	N	0.34	0.33	0.38	0.30	7.13	N	0.35	0.35	0.41	0.27	10.67	N
SD	1.52	1.52	1.67	1.26	7.06	N	1.54	1.53	1.72	1.40	6.09	N	1.56	1.53	1.84	1.46	7.29	*
K_{sat}	24.24	18.57	53.51	2.29	85.94	*	22.41	14.39	47.49	7.95	57.45	N	34.54	35.73	42.35	13.80	23.99	*

Note. Med: median; Max: maximum; Min: minimum; CV: coefficient of variation (%); W: Shapiro-Wilk test (*, N: non-normal and normal distribution at 5%, respectively); pH in water; TOC: total organic carbon (dag kg^{-1}) ; P, S, K, Na, Fe, Mn, Cu, and Zn (mg dm^{-3}); Ca, Mg, Al, and sum of bases (SB) ($cmol_c$ dm^{-3}); sand, silt, and clay (%); soil total porosity (TP), macroporosity (Macro), and microporosity (Micro) (m^3 m^{-3}); soil density (SD) and particle density (PD) (g cm^{-3}); saturated hydraulic conductivity (K_{sat}) (cm h^{-1}).

Low (S), median (TOC, P, Fe, and Cu), good (Ca, Mg, and SB), very good (K), and high (pH, Mn, and Zn) values were recorded for the chemical attributes of the A horizon (Table 2), as described by Ribeiro et al. (1999). This good soil fertility is a consequence of the fertilization performed to high yields in mango trees. However, soil properties range indicate soil fertility variability, but without yield changes, due to high and very high macronutrients levels.

Most of the soil horizons show pH values near-ideal range (5.5-6.8, Embrapa, 2004) to the mango tree. Special management attention to avoid the unavailability of some cationic micronutrients, which could be harmful to the crop (Novais et al., 2007).

Despite the good nutrient management of the soil, low levels of P were observed in the A horizon (2.64 mg dm^{-3}) (Table 2) due to the tropical pedogenesis and intense weathering. As a result, Fe and Al oxides prevail in the soil and specifically adsorb P from the solution, thus making it unavailable to the plants (Novais et al., 2007).

Based on the visual diagnosis of the crop, the high Mn did not induce toxicity nor did it reduce the yield of 'Palmer' mango, this experiment did not find manganese toxicity symptoms by visual diagnosis, neither 'Palmer' mango yield decrease effect. According to Galliet al. (2009), most of the mango trees have a luxury absorption of Mn and show high levels of this element in the leaves, but no visual symptoms of toxicity are verified in the plants.

The texture of the soil was classified according to Santos et al. (2013b). The clayey texture was dominant in the soil morphological description and physical analysis (Tables 1 and 2) due to the limestone parent material, which favored the high levels of Ca and Mg and the formation of fertile soils. Therefore, complementary fertilization supported the approximate yields of 25 t ha^{-1} recorded in these soils.

A physically ideal soilfor plant growthhas adequate water retention, aeration, heat supply, and low resistance to root growth. At the same time, good aggregate stability and soil water infiltration are critical physical conditions for the environmental quality of agroecosystems (Costa et al., 2016).

A mean value of 0.44 m^3 $m^{-3}$was verified for TP in the soils studied (Table 2). An equal value was registered by Oliveira et al. (2015), in a fruit growing area in northern Minas Gerais. Conversely, Castro et al. (2009) recorded values of 0.56 and 0.54 m^3 m^{-3} in Red Latosol under pasture and savanna conditions, respectively. These differences may probably be a result of soil compaction caused by the traffic of people, animals, and agricultural machinery, which interfere with soil structure, increasing SD and reducing TP (Klaus & Timm, 2004; Becerra et al., 2010). In this study, the mean macroporosity value was 0.10 m^3 m^{-3}, similar to that registered in pastures (Carneiro et al., 2009). However, macroporosity in A (0.03 m^3 m^{-3}) and B (0.007 m^3 m^{-3}) horizons were very low in LVAe2 (Table 3), associated to intense machine traffic in the orchard, harm macropores keeping and compromising soil aeration and drainage because soil macroporosity is closely linked to soil hydraulic conductivity. However, macroporosity values were very low in the horizons A (0.03 m^3 m^{-3}) and B (0.007 m^3 m^{-3}) in LVAe2 (Table 3) probably due to the intensive use of agricultural machinery. As a consequence, the maintenance of macropores was impaired,and soil aeration and drainage was compromised since macroporosity is closely related to soil K_{sat}.

Table 3. Physical characterization of 11 soil profiles cultivated with 'Palmer' mango in the semiarid region of Minas Gerais State, Brazil. Total porosity (TP), macroporosity (Macro), microporosity (Micro), soil density (SD), and saturated hydraulic conductivity (K_{sat})

Soil	Horizon	TP	Macro	Micro	SD	K_{sat}
		------------------------- m^3 m^{-3}		--------------------------	g cm^{-3}	cm h^{-1}
PVAe	A	0.5015	0.1993	0.3022	1.26	42.49
	B	0.4059	0.0771	0.3288	1.56	14.39
	C	0.4355	0.0926	0.3429	1.55	41.77
CXbe1	A	0.5320	0.1837	0.3483	1.56	53.51
	B	0.3976	0.0664	0.3312	1.72	27.85
	C	0.4662	0.0913	0.3749	1.84	35.73
CXbe2	A	0.3962	0.0688	0.3274	1.67	52.46
	B	0.4668	0.1329	0.3339	1.50	13.90
	C	0.4290	0.0916	0.3374	1.53	34.37
CXbe3	A	0.4297	0.0895	0.3402	1.49	33.48
	B	0.3660	0.0583	0.3077	1.59	12.93
	C	0.4729	0.0616	0.4113	1.70	27.10
CXbe4	A	0.4710	0.1345	0.3366	1.63	3.75
	B	0.4854	0.1220	0.3634	1.40	13.73
	C	0.5058	0.1144	0.3914	1.52	42.35
CXbe5	A	0.4418	0.1269	0.3149	1.60	4.89
	B	0.4403	0.1022	0.3381	1.53	47.49
	C	0.4221	0.0892	0.3329	1.61	40.55
LVAe1	A	0.4558	0.1274	0.3284	1.50	18.57
	B	0.4209	0.1248	0.2961	1.57	32.74
	C	0.4118	0.1448	0.2670	1.46	32.07
LVAe2	A	0.3373	0.0335	0.3038	1.55	2.29
	B	0.3376	0.0073	0.3302	1.63	7.95
	C	0.4627	0.1220	0.3407	1.53	13.80
LVAe3	A	0.4085	0.0622	0.3463	1.52	42.32
	B	0.4213	0.0917	0.3297	1.48	12.75
	C	0.4568	0.1030	0.3537	1.50	34.07
LVAe4	A	0.4219	0.0880	0.3339	1.51	5.50
	B	0.4669	0.0903	0.3766	1.51	23.43
	C	0.4811	0.1215	0.3596	1.47	40.32
LVAe5	A	0.4882	0.1359	0.3523	1.49	7.41
	B	0.4766	0.1120	0.3646	1.41	39.34
	C	0.4574	0.0813	0.3760	1.50	37.79

Note. 'Palmer' mango yield was correlated with soil pH (0.599, $p < 0.05$), K content (0.834, $p < 0.01$), and SB (0.598, $p < 0.05$) in the A horizon.

Most chemical attributes showed lower mean values in the horizons B and C, as a result of the low management influence in the deeper layers of soil (Correa et al., 2010). The soil parent material increased the levels of Ca and Fe in depth, while S was translocated to the subsurface.

Regarding the two dominant soil classes in the area, differences among Cambisols were found for pH, sand, and clay; and differences among Latosols were identified for pH, Na, Mg, clay, and micropores (Table 4).

Table 4. Chemical and physical attributes of Cambisol and Latosol profiles cultivated with 'Palmer' mango in the semiarid region of Minas Gerais State, Brazil

Soil class	pH	Na	Mg	Sand	Silt	Clay	Micropores
		-------- $cmol_c\ dm^{-3}$ -------		-------------------- $g\ kg^{-1}$ --------------------			$m^3\ m^{-3}$
CXbe1	6.56b	0.36a	0.83a	268.0a	313.2a	418.8b	0.35a
CXbe2	6.85ab	0.34a	0.52a	232.9ab	323.4a	443.7b	0.33a
CXbe3	6.63b	0.44a	0.72a	238.2ab	310.3a	451.5ab	0.35a
CXbe4	6.07c	0.23a	0.93a	179.0b	304.0a	517.0a	0.36a
CXbe5	7.00a	0.23a	0.95a	252.7ab	295.5a	451.8ab	0.36a
CV (%)	1.86			12.50		5.63	
LVAe1	6.98a	0.28a	0.65bc	219.6a	382.1a	398.3b	0.30b
LVAe 2	6.86a	0.22ab	0.40c	213.2a	335.6a	451.2ab	0.32ab
LVAe 3	6.44ab	0.27a	0.45bc	248.2a	285.1a	466.7ab	0.34ab
LVAe 4	6.77a	0.22ab	1.14a	226.2a	235.5a	538.3a	0.35ab
LVAe 5	5.96a	0.20b	0.79ab	258.9a	240.4a	500.7ab	0.36a
CV (%)	3.92	9.36	18.58			10.27	6.61

Note. Means followed by the same letter in the column do not differ by the Tukey's test ($p < 0.05$).

No differences between soil classes were observed for trunk diameter and canopy area. However, differences were detected for plant height and yield. 'Palmer' mango yield varied from 19.66 to 31.35 t ha^{-1}, similarly to the 31.06 t ha^{-1} reported by Campos et al. (2008) in mango trees under different irrigation levels.

Table 5. Trunk diameter, plant height, canopy area, and yield in 'Palmer' mango cultivated in the semiarid region of Minas Gerais State, Brazil

Soil class	Trunk diameter	Plant height	Canopy area	Yield
	---------------------- m ---------------------		m^2	t ha^{-1}
PVAe	0.17a	2.58b	6.65a	29.70a
CXbe1	0.17a	2.99a	6.60a	22.01b
CXbe2	0.17a	3.33a	7.27a	22.84b
CXbe3	0.16a	2.59b	6.49a	19.66b
CXbe4	0.16a	2.55b	5.54a	25.99b
CXbe5	0.19a	3.14a	8.20a	29.01a
LVAe1	0.18a	3.28a	7.41a	22.70b
LVAe2	0.17a	2.75b	5.04a	25.58b
LVAe3	0.17a	2.65b	5.85a	31.35a
LVAe4	0.17a	2.78b	5.96a	30.53a
LVAe5	0.18a	2.80b	7.61a	21.67b

Note. Means followed by the same letter in the column do not differ by the Tukey's test ($p < 0.05$).

Due to cropping orchard time, size and plant shape is influenced mainly by pruning, which is frequent in the management system of 'Palmer' mango. This fact shows that this small variation in tree size is not a determinant factor of yield. None of the plant characteristics evaluated showed a positive correlation with yield. The diameter of the trunk was the only trait that significantly correlated with yield (0.349; $p < 0.05$).

The lowest yields were observed in Cambisol (CXbe1, 2, 3, 4) and Latosol (LVAe1, 5, 2) profiles. CXbe3was characterized by its low depth, presence of gravel, and the lowest K contents (50.83 mg dm^{-3}) in the profile.

These conditions impaired the development of the characteristic deep root system since mango trees require no physical or chemical impediment in the soil for full production. The importance of K is highlighted by Costa et al. (2011) in 'Tommy Atkins' mango fertilization.

The second lowest yield was identified in LVAe5. Although it is a deep soil (Table 1), LVAe5 presented low levels of K (33.17 mg dm^{-3}), S (7.42 mg dm^{-3}), and sum of bases (3.23 cmol$_c$ dm^{-3}), which directly influenced plant yield. CXbe1 and CXbe3 showed low chemical fertility, andsoil physical conditions were not the most favorable for mango cultivation since it presented iron-manganese concretions, gravel, and tortuous roots. However, the recorded low yields were higher than the national mean of 15.63 t ha^{-1}. These results indicate that although some soil profiles had low physicochemical quality, they are suitable for mango production (Poll et al. 2012).

The highest yields were identified in PVAe, CXbe5, LVAe3, and LVAe4. Adequate soil structure and depth were observed in Latosols (Table 1), in addition to the highest values of K (249.5 and 255.75 mg dm^{-3}) and SB (4.96 and 5.06 cmol$_c$ dm^{-3}) in the A horizons from LVAe3 and LVAe4, respectively. Even though CXbe5 had no physical limitation, flooding conditions were indicated by the moderate to imperfect drainage in the description of the soil profile.

Despite the differences among the distinct LVAe, a mean yield of 26.37 t ha^{-1} was recorded, whereas CXbe showed a mean yield of 23.90 t ha^{-1}.

4. Conclusions

Even under intensive production system, the eutrophic soils have high productive potential and suitability for the mango tree cultivation.

All soils presented iron-manganese concretions, but with no interference in the 'Palmer' mango yield.

The 'Palmer' mango yield is directly influenced by the soil K contents, SB, and pH, and it is impaired by the low effective depth and gravel presence in the soil profile.

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