ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.25, n.11, p.764-771, 2021
agriambi
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v25n11p764-771

Characterization of soils cultivated with cassava under different managements[1]

Caracterização de solos cultivados com mandioca sob diferentes manejos

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HIGHLIGHTS:

The predominant textural class in the different areas cultivated with cassava is sandy clay loam.
Cassava agricultural areas with different managements have low fertility and organic matter concentration.
The chemical attributes of the soil were the most significant to distinguish the different areas cultivated with cassava.

ABSTRACT: Although cassava is an undemanding crop in terms of soil chemical fertility, the scarcity of nutrients affects crop productivity, and it is common to cultivate it in soils with low natural fertility, as occurs in Coastal Tablelands. In this context, the present study aimed to evaluate the physical and chemical attributes of soils cultivated with cassava under different managements. The study was carried out in the municipality of São Felipe, located in the landscape unit of Coastal Tablelands, Bahia state, Brazil. Fifteen properties were selected to evaluate the characteristics of soils cultivated with cassava under different types of management. Soil sampling was carried out during the months of October and November 2018, a dry period in the region. The medium-textured soil was predominant in the different areas of management of cassava cultivation. Most areas showed pH below the recommended range for cassava (5.5 to 6.5), base saturation below 50% and low phosphorus, potassium, calcium, and magnesium contents, according to the crop's nutritional needs. The first two principal components explained 84.65% of the total variance. Thus, it was possible to verify that the diversity of management of cassava production areas results in high or very high variability of soil chemical attributes. The attributes pH, P, Al, H + Al, V, CEC and OM are the most representative in the distinction of soils of the cassava cultivation areas evaluated.

Key words: *Manihot esculenta* Crantz, mineral fertilization, organic fertilization, agricultural practices

RESUMO: Embora a mandioca seja uma cultura pouco exigente em termos de fertilidade química do solo, a escassez de nutrientes afeta a produtividade da cultura, sendo comum o seu cultivo em solos de baixa fertilidade natural, como ocorre nos Tabuleiros Costeiros. Nesse contexto, o presente estudo teve como objetivo avaliar os atributos físicos e químicos de solos cultivados com mandioca sob diferentes manejos. O estudo foi realizado no município de São Felipe, inserido na unidade paisagística Tabuleiros Costeiros, Bahia, Brasil. Quinze propriedades foram selecionadas para avaliar as características dos solos cultivados com mandioca sob diferentes manejos. As coletas de solo foram realizadas durante os meses de outubro e novembro de 2018, período de seca na região. A textura média do solo foi predominante nas diferentes áreas de manejo de cultivo de mandioca. A maioria das áreas apresentou pH abaixo da faixa recomendada para mandioca (5,5 a 6,5), saturação por base abaixo de 50% e baixo teor de fósforo, potássio, cálcio e magnésio, de acordo com as necessidades nutricionais da cultura. Os dois primeiros componentes principais explicaram 84,65% da variância. Assim, foi possível verificar que a diversidade de manejo das áreas de produção de mandioca resulta em alta ou muito alta variabilidade dos atributos químicos do solo. Os atributos pH, P, Al, H + Al, V, CEC e MO são os mais representativos na distinção dos solos das áreas de cultivo de mandioca avaliadas.

Palavras-chave: *Manihot esculenta* Crantz, adubação mineral, adubação orgânica, práticas agrícolas

• Ref. 246208 – Received 05 Dec, 2020
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• Accepted 01 May, 2021 • Published 30 May, 2021
Edited by: Hans Raj Gheyi

Introduction

Although cassava is an undemanding crop in terms of soil chemical fertility, the shortage of nutrients affects crop productivity, as root yields are directly related to the availability of nutrients in the soil (Borges et al., 2020).

According to Souza et al. (2009), the planting of cassava should be carried out, preferably, in deep soils of medium texture, in order to promote a good root development, with soil pH within the range from 5.5 to 6.5 and base saturation greater than 50%. However, cassava produces well in acidic and low-fertility soils, provided that they are improved by liming and fertilization (Araújo et al., 2019).

The cultivation of cassava is widespread in the Coastal Tablelands, a landscape unit where there is predominance of Oxisols and Ultisols, both with low natural fertility and natural cohesion, but Oxisols have problems with phosphorus fixation, while Ultisols have high susceptibility to erosion (Marques et al., 2014).

Souza et al. (2009) reported that these soils provide satisfactory conditions for the cultivation of cassava, as long as they are improved by liming and fertilization (organic and mineral). In addition, cassava has a high yield potential with the correction of soil fertility (Rós et al., 2020). However, only a small portion of producers apply fertilizers to their cassava crops and correct soil acidity, but their use is recommended to increment soil fertility (Rós et al., 2013; 2020).

These precautions are related to the fact that the cassava crop removes many nutrients from the soil and provides little recycling of these, in addition to low initial growth, which exposes the soil to erosion; these facts are aggravated when cassava is cultivated in soils with low nutrient availability (Fialho et al., 2017).

In this context, the present study aimed to evaluate the physical and chemical attributes of soils cultivated with cassava under different managements.

Material and Methods

The study was carried out in the municipality of São Felipe, Bahia state, Brazil, located in the landscape unit of Coastal Tablelands, with territorial extension of 222,408 km², at the following geographical coordinates: 12° 50’ 50” S latitude; 39° 05’ 22” W longitude; and altitude of 195 m.

The climate varies between humid and dry sub-humid with average annual temperature of 23.8 °C and average annual precipitation of 800 to 1100 mm, and the predominant soils are Oxisols (Moreira et al., 2020). During soil collection the average temperature was 24.5 °C, with an relative air humidity of 79% and precipitation of 0.08 mm, data that were monitored by a meteorological station in a neighboring municipality by the National Institute of Meteorology (INMET, 2018).

Fifteen farms were selected to evaluate the characteristics of soils cultivated with cassava under different managements. Soil sampling was carried out during the months of October and November 2018, a dry period in the region.

For that, four soil samples were collected from the 0 to 0.20 m layer, with the aid of a Dutch auger, and mixed to obtain a composite sample per area. The cultivation areas were smaller than one hectare.

During soil sampling, more detailed information was obtained from the producers on crop management in each of the 15 cultivation areas evaluated (Table 1).

Particle-size analysis and textural class were determined in the Soil Physics Laboratory of the Universidade Federal do Recôncavo da Bahia, Brazil, by the pipette method using 1 mol L^{-1} NaOH as dispersant (Teixeira et al., 2017).

The chemical attributes of the soil analyzed were: pH in water; electrical conductivity of saturation extract (EC); P - phosphorus (Mehlich-1); K - potassium (Mehlich-1); Ca - calcium; Mg - magnesium; Na - sodium, all extracted with 1 mol L^{-1} KCl; SB - sum of bases; Al - aluminum, extracted with 1 mol L^{-1} KCl; H + Al - potential acidity, extracted with calcium acetate buffered at pH 7; CEC - cation exchange

Table 1. Description of the cultivation areas of cassava cultivars under different agricultural managements, where soil samples were collected for characterization

Area	Cassava cultivar	Fertilizer used	Agricultural managements [1]
1	‘Salangó’ (S1)	Chicken manure	Crop rotation with *Arachis hypogaea*
	‘Cigana’ (C1)	Chicken manure	Crop rotation with *Arachis hypogaea*
2	‘Salangó’ (S2)	Cattle manure	Crop rotation with *Dioscorea rotundata*
	‘Cigana’ (C3)	Cattle manure	Crop rotation with *Dioscorea rotundata*
3	‘Salangó’ (S3)	Mineral fertilization	Area for the cultivation of cassava only
4	‘Cigana’ (C2)	Chicken manure and Cattle manure	Area for the cultivation of cassava only
5	‘Platina’ (P1)	Cattle manure	Intercropping with orange tree
	‘Graveto’ (G1)	Cattle manure	Intercropping with orange tree
6	‘Platina’ (P2)	Mineral fertilization, castor cake and flour mill residue	Crop rotation with *Arachis hypogaea*
7	‘Platina’ (P3)	Chicken manure	Area for the cultivation of cassava only
8	‘Eucalipto’ (E1)	Mineral fertilization and cattle manure	Crop rotation with *Dioscorea rotundata*
9	‘Eucalipto’ (E3)	Mineral fertilization and cattle manure	Intercropping with orange tree
	‘Graveto’ (G3)	Mineral fertilization and cattle manure	Intercropping with orange tree
	‘Milagrosa’ (M3)	Mineral fertilization and cattle manure	Intercropping with orange tree
10	‘Eucalipto’ (E2)	Cattle manure	Crop rotation with *Arachis hypogaea*
11	‘Correnteza’ (CT)	Chicken manure	Crop rotation with *Dioscorea rotundata*
12	‘Graveto’ (G2)	Mineral fertilization, cattle manure and castor cake	Intercropping with orange tree
13	‘Milagrosa’ (M1)	Mineral fertilization and flour mill residue	Crop rotation with *Arachis hypogaea*
14	‘Milagrosa’ (M2)	Cattle manure and flour mill residue	Crop rotation with *Arachis hypogaea*
15	‘Cidade Rica’ (CR)	Mineral fertilization	Crop rotation with *Arachis hypogaea*

[1] There was no correction of soil acidity before planting

capacity; V - base saturation; and OM - organic matter by the Walkley-Black method. The analyses were carried out by the Soil and Plant Nutrition Laboratory of Embrapa Mandioca e Fruticultura, according to Teixeira et al. (2017).

The micronutrients copper (Cu), iron (Fe), zinc (Zn) and manganese (Mn) (Mehlich-1) were determined in the Laboratory of Water, Soil and Plant Analysis of Universidade Federal Rural do Semi-Árido – UFERSA (Teixeira et al., 2017).

The analytical results of the soils were initially analyzed by descriptive statistics, considering the mean, coefficient of variation (CV), minimum and maximum. The CV was classified as low (CV ≤ 10%), medium (10 < CV < 20%), high (20 ≤ CV < 30%) and very high (CV ≥ 30%) (Zonta et al., 2014). Data normality was assessed by the Shapiro-Wilk test ($p \leq 0.05$).

Pearson's correlation matrix was used to verify whether the variables analyzed had sufficient minimum correlations to justify their use in the multivariate analysis matrix. For this, 21 variables were analyzed in a total of 15 soil samples. Then, the data were subjected to cluster analysis, adopting the method of average distances, from the Euclidean distance, to describe the similarity between the groups.

The data were standardized and subjected to principal component analysis (PCA), considering only the variables that had eigenvectors above 0.60. Variables with low explanation in the principal components (PCs) were removed from the database and a new analysis was performed. The Kaiser criterion was adopted to define the number of PCs that indicated the greatest explanation of variance, that is, only components with eigenvalues greater than one and accumulated variance greater than or equal to 70% (Hongyu et al., 2015) were kept in the system.

All analyses were performed in R software version 3.5.2 through the Hmisc (Pearson's Correlation analysis), FactoMineR (cluster analysis) and factoextra (PCA) packages.

Results and Discussion

From the 15 areas evaluated, 13 had medium-textured soil, with predominance of the clayey textural class in 12 areas, sandy clay loam texture, and one area with sandy loam texture (Table 2). The textural class of the soils of the two remaining areas was sandy clay, which, despite being considered as clayey texture, had clay contents (366 and 388 g kg^{-1}) very close to the limit of separation from the sandy clay loam class (350 g kg^{-1}) (Teixeira et al., 2017).

This result, along with the sand concentrations (589 and 569 g kg^{-1}), does not characterize great disagreement from the recommendation of Souza et al. (2009), that is, cassava cultivation should be carried out in medium-textured soils, since soils with high clay content hamper root growth. In addition to the physical impediment, high clay concentrations confer greater possibility of waterlogging and rotting of the roots, besides greater difficulty for harvesting, especially if the producer needs to harvest cassava in the dry season (Souza et al., 2009; Fialho et al., 2017).

Studies conducted by Portela et al. (2001) in Oxisols of the Bahia Coastal Tablelands cultivated with cassava, in the municipality of Cruz das Alma, Bahia state – Brazil, found medium-textured soil at 0.10 m deep, with 727 g kg^{-1} of sand, 28 g kg^{-1} of silt and 245 g kg^{-1} of clay, and clayey soil at a depth of 0.30 m, containing 648 g kg^{-1} of sand, 31 g kg^{-1} of silt and 321 g kg^{-1} of clay. Biratu et al. (2018) also studied the effect of the use of manure and NPK fertilizer on the cultivation of cassava in medium-textured soil, with yield ranging from 19 to 30 t ha^{-1} of fresh root depending on the dose of fertilizer. Oliveira et al. (2015b), in area under cassava cultivation in the municipality of Humaitá, Amazonas, Brazil, found higher silt concentrations in the soil (272.0, 573.2 and 145.9 g kg^{-1} for clay, silt and sand, respectively), diverging from the present study. Therefore, cassava has been grown in different soil textures,

Table 2. Particle-size analysis, chemical attributes and micronutrient concentrations of soils of 15 areas cultivated with cassava

Soil attributes	Areas/Managements(1)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sand	627	754	614	657	639	589	660	734	755	707	769	694	569	695	762
Silt	81	25	78	47	82	45	100	21	8	51	27	48	43	32	52
Clay	292*	221*	308*	296*	279*	366**	240*	245*	237*	242*	204*	258*	388**	273*	186***
pH(2)	5	7.4	4.3	5.3	6.5	4.6	4.7	4.7	5	6	5.4	5.1	5	4.9	5.7
EC	0.148	0.193	0.212	0.159	0.238	0.214	0.204	0.219	0.196	0.255	0.158	0.198	0.212	0.181	0.224
P	1	69	4	10	48	36	21	13	9	17	47	16	29	2	12
K	0.04	0.08	0.06	0.18	0.31	0.31	0.08	0.12	0.09	0.17	0.12	0.12	0.22	0.22	0.12
Ca	0.73	2.63	0.47	0.81	2.87	0.65	0.99	0.69	1.41	2.05	0.92	1.06	1.25	0.61	1.49
Mg	0.4	0.38	0.27	0.46	0.68	0.29	0.62	0.27	0.37	0.47	0.26	0.33	0.32	0.39	0.43
Na	0.02	0.02	0.02	0.03	0.04	0.02	0.05	0.03	0.03	0.03	0.01	0.02	0.02	0.03	0.04
Al	0.4	0	0.7	0.2	0	0.6	0.6	0.6	0.4	0	0.1	0.3	0.4	0.5	0
H + Al	3.08	0	4.51	2.86	1.43	3.63	3.74	3.08	3.3	1.98	2.64	3.19	3.3	3.52	1.98
SB	1.2	3.12	0.81	1.48	3.9	1.27	1.74	1.11	1.9	2.72	1.32	1.53	1.81	1.26	2.07
CEC	4.28	3.12	5.32	4.34	5.33	4.9	5.48	4.19	5.2	4.7	3.96	4.72	5.11	4.78	4.05
V	28	100	15	34	73	26	32	26	37	58	33	32	35	26	51
OM	7.9	10	11.9	10	15	11	11	11	15	11.9	8.9	10	10.8	13.9	10
Cu	0	0.045	0.015	0	0.083	0	0	0	0	0	0.173	0	0	0	0
Fe	0.589	1.612	0.646	0.851	1.455	0.347	0.647	0.47	0.475	0.332	0.563	0.331	0.196	0.363	0.371
Zn	3.116	2.096	5.425	2.327	2.842	4.088	3.937	3.334	3.782	1.838	2.375	3.883	4.271	5.293	1.868
Mn	0.268	0.791	0.189	0.34	0.246	0.529	0.411	0.25	0.297	0.34	0.6	0.363	0.233	0.249	0.3

(1) For details of management see Table 1. (2) Sand (g kg^{-1}); Silt (g kg^{-1}); Clay (g kg^{-1}); pH – Hydrogen potential in water; EC – Electrical conductivity of saturation extract (dS m^{-1}); P – Phosphorus (mg dm^{-3}); K – Potassium (cmol$_c$ dm^{-3}); Ca – Calcium (cmol$_c$ dm^{-3}); Mg – Magnesium (cmol$_c$ dm^{-3}); Na – Sodium (cmol$_c$ dm^{-3}); SB – Sum of bases (cmol$_c$ dm^{-3}); Al – Aluminum (cmol$_c$ dm^{-3}); H + Al – Potential acidity (cmol$_c$ dm^{-3}); CEC – Cation exchange capacity (cmol$_c$ dm^{-3}); V – Base saturation (%); OM – Organic matter (g kg^{-1}); Cu – Copper (mg dm^{-3}); Fe – Iron (mg dm^{-3}); Zn – Zinc (mg dm^{-3}); and Mn – Manganese (mg dm^{-3}); * - Sandy clay loam texture; ** - Sandy clay texture; *** – Sandy loam texture

including in a transition area between Entisols and Ultisols (Rós et al., 2020).

As for the chemical attributes, it can be observed in Table 2 that the soils of most areas showed pH below the range recommended for cassava crop (5.5 to 6.5) and base saturation (V) below 50% (Souza et al., 2009). According to the interpretation of class presented by Ribeiro et al. (1999), 73% of the soils of the areas studied had medium potential acidity (H + Al) (2.51 to 5.00 $cmol_c\ dm^{-3}$).

According to Howeler (2002), most cassava cultivars tolerate electrical conductivity of saturation extract (EC) of up to 0.5 $dS\ m^{-1}$. Studies conducted by Cruz et al. (2017) demonstrated that soil salinity greater than 3.6 $dS\ m^{-1}$ reduced carbon assimilation, stomatal conductance, transpiration, and the instantaneous water use efficiency in cassava cultivation. Besides that, the harvest index was reduced by 50% with the highest salt concentration (6.8 $dS\ m^{-1}$). Cruz et al. (2018), also report that the increase in salinity to 6.8 $dS\ m^{-1}$ in cassava hampered the absorption of phosphorus, potassium, magnesium, and sulfur, except nitrogen. Therefore, the soils of all areas had EC within the tolerable range for cassava and without reducing the absorption of nutrients, that is, below this value.

In relation to available phosphorus (P), it can be classified as high for soils of 53% of the areas, because its concentration was higher than 15 $mg\ dm^{-3}$; in the soils of the other areas, the P concentrations were classified as very low (< 2 $mg\ dm^{-3}$), low (2 to 4 $mg\ dm^{-3}$) and medium (4 to 15 $mg\ dm^{-3}$) (Howeler, 2002). The results obtained corroborate the information presented by Souza et al. (2009), who stated that Brazilian soils are generally low in this nutrient. However, Aliyu et al. (2019) argued that these problems related to low phosphorus concentration can be overcome through an efficient association with arbuscular mycorrhizal fungal inoculants in cassava.

As usually occurs in areas of small cassava farmers, who use little fertilization and grow successive crops in the same area, potassium (K) concentrations for most soils of the areas were classified as very low (< 0.10 $cmol_c\ dm^{-3}$) and low (0.10 to 0.15 $cmol_c\ dm^{-3}$) (Howeler, 2002). The soils of areas 5 and 6 had concentrations considered high for the crop (> 0.25 $cmol_c\ dm^{-3}$), whereas the concentrations were medium (0.15 to 0.25 $cmol_c\ dm^{-3}$) in the soils of areas 4, 10, 13 and 14.

Calcium (Ca) and magnesium (Mg) concentrations were classified as low (0.25 to 1.00 $cmol_c\ dm^{-3}$ for Ca and 0.2 to 0.4 $cmol_c\ dm^{-3}$ for Mg) to medium (1.0 to 5.0 $cmol_c\ dm^{-3}$ for Ca and 0.4 to 1.0 $cmol_c\ dm^{-3}$ for Mg) for the soils of all areas (Howeler, 2002). The low concentrations of calcium and magnesium must be associated with the absence of liming, as reported by all producers. Fialho et al. (2017) describe that the application of limestone, in addition to correcting acidity and neutralizing toxic aluminum, provides these nutrients for plants. According to Howeler (2002), calcium plays an important role in the regulating supply of water in the plant, while Mg is a basic component of chlorophyll and, as such, is essential for photosynthesis. The deficiency of these nutrients can cause reduced growth of roots and aerial part and chlorosis (Howeler, 2002). According to Rós et al. (2020), the application of the limestone dose of 2.5 $t\ ha^{-1}$ increased the pH from 4.86 to 5.46, Ca, Mg, sum of bases, and base saturation of the soil, but did not increase the productivity of cassava cultivar IAC 576-70.

The sum of bases (SB) was considered low (0.61 to 1.80 $cmol_c\ dm^{-3}$) in the soils of most areas, being medium (1.81 to 3.60 $cmol_c\ dm^{-3}$) in the soils of areas 2, 9, 10 and 15 and high (3.61 to 6.00 $cmol_c\ dm^{-3}$) in the soils of area 5. These results demonstrate the importance of correcting soil acidity before cultivation, as recommended by Howeler (2002), Souza et al. (2009) and Fialho et al. (2017). Soil acidification leads to the replacement of exchangeable base cations (Ca^{2+}, Mg^{2+}, K^+) with H^+ and Al^{3+}, and the dissolution of minerals containing Al, Mn and Fe, causing nutrient imbalance (Rahman et al., 2018).

Organic matter (OM) was classified as low (7.1 to 20.0 $g\ kg^{-1}$) in the soils of all areas evaluated (Ribeiro et al., 1999). Fialho et al. (2017) highlight the importance of organic fertilization, as it provides nutrients for the crop and acts as a soil conditioner, promoting improvements in structure and aeration. Thus, it is observed that, in general, the soils of the different areas showed low fertility and concentrations of OM. This need for low amounts of agrochemicals for production and high yield of carbohydrate sources per hectare compared to sugarcane and beet makes cassava cultivation a basic crop among farmers (Souza et al., 2007; Sánchez et al., 2017). In addition, it has drought- and salt-tolerant genotypes and can be grown in marginal soils (Oliveira et al., 2015a; Sánchez et al., 2017; Oliveira et al., 2018).

Regarding micronutrients (Table 2), the soils of the areas were classified as of low concentrations of copper (Cu < 0.4 $mg\ dm^{-3}$) and manganese (Mn < 1.9 $mg\ dm^{-3}$) and high concentration of zinc (Zn > 1.6 $mg\ dm^{-3}$) (Souza et al., 2009). As for iron, the soils of most areas were classified as of very low concentration (Fe < 1 $mg\ dm^{-3}$); only the soils of areas 2 and 5 were classified as of low concentration (1 to 10 $mg\ dm^{-3}$). According to Souza et al. (2009), there are few results of research on micronutrients for cassava crop. However, values above 0.8 $mg\ dm^{-3}$ for copper, 5 $mg\ dm^{-3}$ for manganese and 1.6 $mg\ dm^{-3}$ for zinc can be considered as critical levels.

Descriptive statistical analysis for the analytical data of the soils of the evaluated areas (Table 3) showed very high variability by the coefficient of variation (CV) (CV ≥ 30%) for most soil attributes, low (CV ≤ 10%) for sand, medium (10 < CV < 20%) for pH, EC, CEC and OM, and high variability (20 < CV < 30%) for clay. Oliveira et al. (2015b) observed coefficients of variation for soil texture of 20.7, 13.3 and 45.2% for clay, silt and sand, respectively, in area under cassava cultivation in Humaitá, Amazonas, Brazil. Gbadegesin et al. (2011) studied soils cultivated with cassava in the coastal zone of Nigeria and found very high variability for most of the evaluated attributes, such as: silt (42.33%), clay (60.48%), EC (38.98%)), P (64.57%), Ca (30.05%), Mg (37.72%), K (53.03%), Al (31.41%), H (77.19%); SB (21.37%), CEC (23.68%) and OM (29.69%); average for Na (18.63%); and low for sand (4.30%) and pH (4.52%). The authors stressed that the soils could be made productive in terms of crop cultivation if proper management systems such as liming and fertilizer application are applied.

In the present study, high variability in soil attributes was already expected due to the lack of technical assistance,

Table 3. Descriptive statistical analysis for the soil attributes of the areas cultivated with cassava

Attributes	Unit	Mean	CV (%)	Minimum	Maximum	Shapiro-Wilk
Sand	g kg^{-1}	682	9.6	569	769	0.941^{ns}
Silt	g kg^{-1}	49	52.9	8	100	0.947^{ns}
Clay	g kg^{-1}	269	20.6	186	388	0.944**
pH[(1)]	-	5.3	15.3	4.3	7.4	0.875*
EC	dS m^{-1}	0.201	14.9	0.148	0.255	0.966^{ns}
P	mg dm^{-3}	22.3	88.8	1	69	0.884^{ns}
K	$cmol_c$ dm^{-3}	0.15	56.5	0.04	0.31	0.902^{ns}
Ca	$cmol_c$ dm^{-3}	1.24	59.4	0.47	2.87	0.847*
Mg	$cmol_c$ dm^{-3}	0.40	31.2	0.26	0.68	0.887^{ns}
Na	$cmol_c$ dm^{-3}	0.03	37.8	0.01	0.05	0.904^{ns}
Al	$cmol_c$ dm^{-3}	0.32	79.4	0.0	0.7	0.891^{ns}
H + Al	$cmol_c$ dm^{-3}	2.82	39.0	0.00	4.51	0.909^{ns}
SB	$cmol_c$ dm^{-3}	1.82	46.2	0.81	3.90	0.867*
CEC	$cmol_c$ dm^{-3}	4.63	13.9	3.12	5.48	0.941^{ns}
V	%	40.4	54.3	15	100	0.803**
OM	g kg^{-1}	11.2	18.2	7.9	15.0	0.909^{ns}
Cu	mg dm^{-3}	0.021	228.4	0	0.173	0.526**
Fe	mg dm^{-3}	0.617	66.2	0.196	1.612	0.779**
Zn	mg dm^{-3}	3.365	34.3	1.838	5.425	0.939^{ns}
Mn	mg dm^{-3}	0.360	45.4	0.189	0.791	0.826**

[(1)]pH – Hydrogen potential in water; EC – Electrical conductivity of saturation extract; P – Phosphorus; K – Potassium; Ca – Calcium; Mg – Magnesium; Na – Sodium; SB – Sum of bases; Al – Aluminum; H + Al – Potential acidity; CEC – Cation exchange capacity; V – Base saturation; OM – Organic matter; Cu – Copper; Fe – Iron; Zn – Zinc; Mn – Manganese; CV - Coefficient of variation; ns, *, ** - Not significant, significant at $p \leq 0.05$ and at $p \leq 0.01$ by Shapiro-Wilk test, respectively

reported by farmers. The areas were fertilized and, possibly, with no regularity in the distribution and types of fertilizers and their repetition over time, besides the fact that soil analysis is not adopted by small cassava farmers.

Some soil attributes of the areas (Table 3) showed non-normal distribution, by the Shapiro-Wilk test, such as clay, pH, Ca, SB, V, Cu, Fe and Mn, while the others showed normal distribution. As a result, in the case of using univariate statistical analysis, the data should be transformed previously. However, the non-normal distribution of some attributes does not interfere with the multivariate statistical procedures used in the present study.

The Pearson's correlation matrix for the chemical attributes of the soils of the evaluated areas showed a strong positive correlation of pH with P, Ca, SB and V, and negative correlation of pH with Al, H + Al and CEC (Table 4). P was positively correlated with Ca, SB and V, and negatively correlated with H + Al. Ca showed a positive correlation with Mg, SB and V, and negative correlation with Al and H + Al. There was a strong positive correlation of H + Al with CEC and Al and a negative correlation with SB and V. The OM variable was correlated only with CEC, in this case positively.

The correlation between pH and most of the attributes evaluated can be attributed to its action as conditioner of the general state of the soil due to the cause and effect relationships with other chemical, physical and biological attributes. When in excess, acidity can cause changes in soil chemistry and fertility, such as the availability of toxic elements (Mn, Fe, H and Al) for plants and unavailability of macronutrients, such as P, K, Ca and Mg (Rahman et al., 2018).

The results of the principal component analysis (PCA) show that the first two PCs explained 84.65% of the total variance, effectively summarizing the total sampling variance (Table 5). PC1 showed an eigenvalue of 6.32 and explained 63.21% of the total variance. The variables that most contributed to the formation of PC1 were pH, P, Ca, Al, H + Al, SB and V. PC2 showed an eigenvalue of 2.14 and was explained by the variables Mg, CEC and OM, representing 21.44% of the total variation.

It is possible to observe the separation of three groups of soils/areas based on the degree of similarity, as follows: a) Group 1 – formed by 73% of the soils of the sampled cultivation areas (1, 3, 4, 6, 7, 8, 9, 11, 12, 13 and 14); b) Group 2 – formed by the soils of areas 5, 10 and 15; and c) Group 3 – formed only by the soil of area 2 (Figure 1).

Table 4. Pearson's correlation matrix between chemical attributes of the soils cultivated with cassava

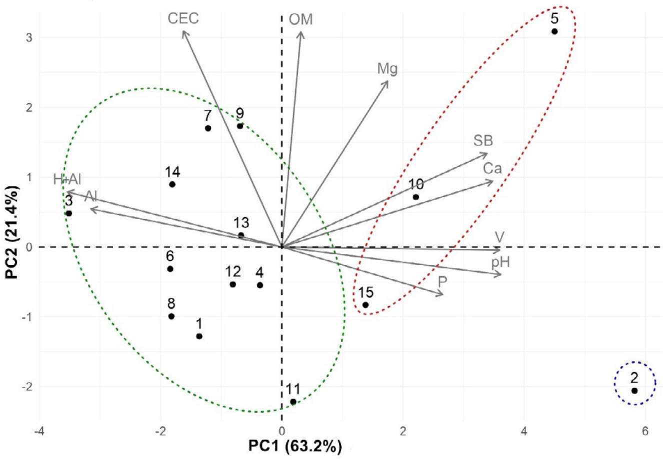
Attributes	pH	EC	P	K	Ca	Mg	Na	Al	H+Al	SB	CEC	V	OM
pH	1.00												
EC	0.18	1.00											
P	**0.70**	0.12	1.00										
K	0.09	0.36	0.28	1.00									
Ca	**0.90**	0.46	**0.64**	0.21	1.00								
Mg	0.39	0.26	0.11	0.23	**0.55**	1.00							
Na	0.05	0.42	-0.20	0.10	0.25	**0.80**	1.00						
Al	**-0.86**	-0.12	-0.48	-0.12	**-0.76**	-0.35	-0.03	1.00					
H+Al	**-0.98**	-0.17	**-0.68**	-0.07	**-0.86**	-0.32	-0.05	**0.85**	1.00				
SB	**0.86**	0.48	**0.61**	0.32	**0.98**	**0.66**	0.36	**-0.74**	**-0.81**	1.00			
CEC	**-0.55**	0.34	-0.37	0.30	-0.18	0.32	0.38	0.50	**0.65**	-0.08	1.00		
V	**0.98**	0.29	**0.72**	0.10	**0.94**	0.43	0.15	**-0.77**	**-0.96**	**0.90**	-0.46	1.00	
OM	0.02	0.48	-0.07	0.43	0.31	0.34	0.41	0.08	0.07	0.37	0.59	0.10	1.00

Correlations in bold are significant at $p \leq 0.05$; [(1)]pH – Hydrogen potential in water; EC – Electrical conductivity of saturation extract; P – Phosphorus; K – Potassium; Ca – Calcium; Mg – Magnesium; Na – Sodium; SB – Sum of bases; Al – Aluminum; H + Al – Potential acidity; CEC – Cation exchange capacity; V – Base saturation; OM – Organic matter

Table 5. Eigenvalues and accumulated variance obtained from the first two principal component (PC1 and PC2), from soil attributes of the areas cultivated with cassava

Soil attributes	PC1	PC2
	Eigenvectors	
pH	**0.985** [(1)]	-0.108
P	**0.724**	-0.186
Ca	**0.948**	0.257
Mg	0.474	**0.653**
Al	**-0.859**	0.147
H + Al	**-0.966**	0.213
SB	**0.923**	0.366
CEC	-0.455	**0.836**
V	**0.980**	-0.011
OM	0.088	**0.838**
Eigenvalues	6.32	2.14
Explained variance (%)	63.21	21.44
Cumulative variance (%)	63.21	84.65

[(1)] Variables with higher correlation (in bold) were selected within each component



PC – Principal components; PC1 explained 63.21% of the total variance and PC2 21.44% of the total variance; Ellipses correspond to the separation of the groups indicated by the cluster analysis; For details of management see Table 1

Figure 1. Biplot diagram of the principal components integrating the areas cultivated with cassava and the soil attributes

The soils of the areas of group 1 (Figure 1) differed from the others because they had high values of Al and H + Al and low values of pH, V and P, attributes that showed higher correlation with PC1. Group 2 (Figure 1) stood out as its soils showed higher values of Ca, SB, Mg and OM, and the latter two attributes were more correlated with PC2. Group 3 (Figure 1), formed only by the soil of area 2, stood out in terms of P, pH and V, in addition to the absence of Al and H + Al.

PC1 may be interpreted as the component that explains the chemical fertility of soils. Then, areas 2 and 10 were considered those with the most fertile soils. Both soils were fertilized with cattle manure. On the other hand, the other areas (mainly area 3) are those with lowest levels of soil fertility (Figure 1).

PC2 explains the level of organic matter (OM) and the cation exchange capacity (CEC) of the soils. Areas 5, 7 and 9 are separated from the others (mainly from area 11), due to the higher content of OM and CEC. The proximity of OM and CEC vectors (Figure 1) suggests the positive correlation between both variables, indicating that soil CEC is dependent on OM levels, which is common in tropical soils. It highlights the importance of OM maintenance for increasing the production capacity of these soils.

Based on the studied variables, PCA was useful to show that areas 3 and 11 can be considered as those with the worst soils for cassava cultivation. The low content of OM in area 3 must be associated with successive cultivation cycles of cassava and with application of chemical fertilizers only. In the area 11, chicken manure was used instead of cattle manure, which was applied in the other areas. According to Silva et al. (2014), chicken manure decomposition was faster than that of cattle manure, which can explain the lowest OM level of the soil in the area 11.

Most of the soils of the areas of group 1 had pH classified as very acidic (5.0-5.5) and extremely acidic (< 5.0) and V below 50%, being characterized as soils of low fertility (Figure 1). Values of pH below 5.0 promote the replacement of Ca, Mg and K by H and Al and the solubility of elements that can be toxic to plants, such as Al, Mn and Fe, and removal of basic cations from the exchange complex, such as Na (Rahman et al., 2018). These toxic elements can cause reduced growth of roots and shoots, leaf chlorosis, and small but not deformed young leaves (Howeler, 2002).

Group 2 (Figure 1), formed by areas 5, 10 and 15, showed soils with pH within the ideal range for cassava crop (5.7-6.5) and V of 51-73%, being characterized as fertile, but in the following descending order: 5 > 10 > 15. The soil of area 5 had the highest concentrations of OM (15.0 g kg^{-1}), Ca (2.87 $cmol_c$ dm^{-3}), Mg (0.68 $cmol_c$ dm^{-3}) and SB (3.90 $cmol_c$ dm^{-3}), being the only soil to show SB classified as high (3.61 to 6.00 $cmol_c$ dm^{-3}) (Souza et al., 2007).

These characteristics are probably associated with the use of organic fertilization and conservation practices, since the addition of organic fertilizers improves soil fertility by increasing the pH, with a consequent increase in the cation exchange capacity, and by the release of nutrients (Rós et al., 2013). In addition, conservation practices, such as crop rotation and intercropping, favor the improvement of soil quality, representing a promising alternative for better crop management (Cong et al., 2015; Zhang et al., 2021).

Group 3 (Figure 1), formed only by area 2, was characterized by having soil with alkaline pH (7.4), V equivalent to 100% and considerable concentration of P (69 mg dm^{-3}) classified by Howeler (2002) as high P concentration (>15 mg dm^{-3}). P availability varies according to pH, with higher availability of this nutrient in soils with pH between 6.0 and 7.0 (Souza et al., 2007). In addition, it showed medium concentration of Ca (2.63 $cmol_c$ dm^{-3}), absence of Al and H + Al, low SB (3.12 $cmol_c$ dm^{-3}) and low CEC (3.12 $cmol_c$ dm^{-3}).

The high concentrations of phosphorus in the aforementioned area may be associated with the pH value, since the availability of P varies with the pH, with the maximum availability of nutrients that can occur at almost neutral pH (Souza et al., 2007; Penn & Camberato, 2019). In contrast, Howeler (2002) described that soils with high pH can lead to low absorption of micronutrients by the cassava crop.

Conclusions

1. In cassava agricultural areas under different managements, medium-textured soils predominate.

2. The diversity of management of cassava production areas results in high or very high variability of soil chemical attributes.

3. The attributes pH, P, Al, H + Al, V, CEC and OM are the most representative in the distinction of soils of the cassava cultivation areas evaluated.

Acknowledgements

We thank the Fundação de Amparo à Pesquisa do Estado da Bahia - FAPESB, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES, the Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq and the Universidade Federal do Recôncavo da Bahia for the financial support over the years.

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