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Chemical Attributes of an Oxisol Under Different Agricultural Uses in the Brazilian Semiarid Region

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Abstract

Different soil managements evidence soil properties, contributing positively or negatively to its quality. A study was conducted in the city of Martins, Rio Grande do Norte (RN) state, in four cultivated areas: corn intercropped with beans (CICB), cassava monocrop (CAMO), bean monocrop (BEMO) and native forest (NF, considered as the original soil condition). This study aimed to evaluate changes in the chemical properties of an Oxisol in function of different agricultural uses (N, P, K^+, Ca^{2+}, Mg^{2+}, $Na1^+$, Al^{3+}, pH, EC, H+Al, BS, V, CEC, t, m, OM and ESP) and the distinction of environments using multivariate analysis. The sampling was performed up to 30 cm deep. Soil pH values were kept close to 5.5, except for the area with corn intercropped with beans, whose values were higher than 7.0. Corn intercropped with beans had the highest concentrations of K^+, Na^+ and Ca^{2+} on the soil, with a direct impact on base sum. Different uses modified soil chemical properties. Corn intercropped with beans differs from the other treatments due to the addition of solid waste to the soil. Principal component analyses showed pH and exchangeable bases are the most sensitive indicators of environment separation.

Keywords: soil management, soil quality, crops

1. Introduction

Different soil uses reflect soil properties, contributing positively or negatively to its quality. Thus, management actions should aim to increase production but at the same time ensure the sustainability of resources.

The soil use must be based on soil suitability using appropriate management practices to local circumstances (Kämpf and Curi, 2012).

The study of soil quality is relevant for taking into account agricultural sustainability and environmental quality (Vezzani & Mielniczuk, 2009).

Accordingly, the soil chemical properties are important monitoring tools considering the different soil managements (Cavalcante et al., 2007). In addition, monitoring such attributes is important to adjust soil management practices (Bhatti et al., 1991). This study's hypothesis is that different agricultural uses and soil managements can change soil chemical properties. Therefore, the objective was to evaluate changes in the chemical attributes of an Oxisol under different agricultural uses and the distinction of environments using multivariate analysis.

2. Materials and Methods

The research was conducted in the Bela Vista ranch in the city of Martins, Rio Grande do Norte (RN) state, a semiarid region of the Brazilian Northeast region. It is located under the coordinates 06º05′16″ S and 37º54′39″ W. The altitude is 700 m. Climate is rainy tropical (according to the Köppen classification, Aw). The average rainfall is 1,133.8 mm and the average annual temperature is 25 °C.

The unit defined for the study covers an area in which ten families develop subsistence activities, including livestock, cultivation of fruits, forages, monoculture and intercropped grazing. There is also a native forest preservation area.

Four areas using different management systems were evaluated. They corresponded to the treatments of corn intercropped with beans (CICB), cassava monocrop (CAMO), bean monocrop (BEMO) and native forest (NF).

The native forest area is characterized by sub-evergreen vegetation with relatively thin and dense tree trunks and plants with broad leaves, a typical condition of rainy tropical climate zones. Among the most frequent species, there are goiabinha (*Psiium firmum*), pitomba (*Talisia esculenta*), pacara earpod tree (*Enterolobium contortisiliquum*), camunzé (*Pithecolobium polycephalum*), hawthorn (*Sideroxylon obtusifolium*), inharé (*Helicostylis tomentosa*), jatoba (*Hymenaea courbaril*), cumaru (*Dipteryx odorata*), *Mimosa sepiaria*, and diesel tree (*Copaifera langsdorffii*).

The area of corn intercropped with beans (CICB) was prepared using plowing and disking before the rainy season without pesticides and chemical fertilizers by removing the vegetation cover that remained from off-season crops. Particularly in this treatment, waste deposition from organic sources and construction works on the surface contributed to soil fertility.

The cassava monocrop (CAMO) was performed in an area cleared in 2003. Since then, soil preparation takes place through plowing and harrowing.

The bean monocrop (BEMO) was performed in a cleared area in the same period mentioned above, with preparation by disking plus the addition of cattle manure.

The soil was classified as a dystrophic Yellow Oxisol (Santos et al., 2013). The particle size analysis is shown in Table 1.

Table 1. Particle size analysis: Particle density (Pd), organic matter (OM) and textural classification of a dystrophic Yellow Oxisol under different agricultural uses: native forest (NF), cassava monocrop (CAMO), bean monocrop (BEMO) and corn intercropped with beans (CICB) in Martins, Rio Grande do Norte, Brazil

Managements	Particle size distribution					Pd	OM	Textural classification (SBCS*)
	Coarse sand	Thin sand	Total sand	Silt	Clay			
	g kg^{-1}					g cm^{-3}	g kg^{-1}	
NF	0.38	0.13	0.52	0.08	0.40	2.53	13.26	Sandy clay
CAMO	0.33	0.15	0.48	0.11	0.41	2.52	19.50	Sandy clay
BEMO	0.28	0.28	0.53	0.10	0.37	2.55	32.50	Sandy clay
CICB	0.43	0.15	0.58	0.09	0.33	2.52	21.80	Sandy clay loam

Note. * SBCS: Brazilian Society of Soil Science.

Soil samples were collected at four representative points of each area at 0.00-0.30 m deep. Three replications, totaling 48 samples, were taken to proceed with the chemical characterization of the areas (Donagema et al., 2011).

The mean values for soil chemical properties under different agricultural uses were interpreted through descriptive analysis by using multivariate statistical analysis tools, through principal component analysis by using the GENES software. Interpretation of the values of chemical attributes was as recommended by the manual for correctives and fertilizers for Minas Gerais (Ribeiro et al., 1999).

Soil chemical properties were measured with different units. Data standardization was necessary since variance is influenced by the measurement units of the attributes. Therefore, data were centralized and normalized to a null mean and a variance of one to ensure that attributes also contributed to the multivariable models used.

The correlation matrix was set after data standardization to verify the percentage and the degree of importance of correlations. Values higher than or equal to 0.7 were considered.

3. Results and Discussion

In the evaluation of soil chemical attributes, the highest values of nitrogen were obtained for the cassava monocrop. Corn intercropped with beans using a conventional cultivation with the addition of solid waste from organic sources and construction works represented the area with the lowest concentration of this nutrient.

Intercropped corn demands high nitrogen levels (at the grain filling stage, for example), thus drawing more nitrogen from the soil and justifying its lower concentration in the system.

On the other hand, cassava adapts easily to soil and weather conditions if compared with corn. Unlike this crop, it demands low concentration of nitrogen so that it has lower energy dependence on that nutrient (Salla et al., 2010).

Soil pH values (water) were kept close to 5.5, except for the area with corn intercropped with beans, which was higher than 7.0. The pH higher than the other treatments may be a result of the waste added to the surface, which influenced this attribute. Such condition directly reflects the availability of Al^{3+} and potential acidity.

Marinho et al. (2016) studied physicochemical attributes in function of different agricultural uses to analyze their impact on the soil. According to the authors, pH values were approximately 7.1-7.9 both in native forest and other agricultural uses (cajarana orchard area, collective no-tillage area using mixed cultures, colluvium area and agro-ecologic area) regardless of depth (0-5 and 5-10 cm).

Corrêa et al. (2009) characterized chemically soils from areas under different uses and found the soil pH in the range 6.0-6.7 at the 0-10 cm layer for uses related to production systems (such as fruit production, grazing and short cycle crops). The lowest value was observed for native forest. Furthermore, pH values in all layers decreased until up to 60 cm deep.

Upon studying changes in a humic Cambisol, Almeida et al. (2005) also found pH values higher in agricultural systems compared to native forests.

K^+, Na^+ and Ca^{2+} showed the same pattern in corn intercropped with beans so that this agricultural use provided the highest soil concentrations of all these nutrients, directly affecting base sum results. The presence of these nutrients at higher concentrations is attributed to the solid waste deposited over the soil surface.

The exception was the ion magnesium, which had the lowest value for the mentioned management. High pH values (usually above 6.0), such as those observed in this treatment, as well as the excess of calcium influence negatively the availability of magnesium and hinder its uptake by plants.

For corn intercropped with beans in a no-tillage system, Corrêa et al. (2009) found soil uses associated with production systems also had higher levels of K^+ and Ca^{2+}, and Mg^{2+} and P, as observed in this study. In general, the higher quantities of nutrients are due to the intensive fertilization, for example, which characterizes the no-tillage system, as well as liming.

Upon evaluating the chemical attributes of an Oxisol with millet cover crops and corn intercropped with Brachiaria, Silveira et al. (2010) found Ca^{2+} and Mg^{2+} contents up to 20 cm deep increased between two crop years regardless of the cover crop used.

Moreira et al. (2005) studying a dark dystrophic Red Oxisol cultivated with alfalfa, concluded that the increase in the K/(Ca+Mg) ratio favored the decrease of Ca and Mg contents. In addition, the increase in pH to more than 7 was influenced by the waste material applied over the soil surface.

The addition of plant residues on the soil surface causes the pH values to be in the range of alkalinity, which is directly related to the unavailability of exchangeable Al^{3+} (Amaral et al., 2000; Miyazawa et al., 1993; Pavinato & Rosolem, 2008). However, the use of heavy machinery in conventional farming, such as plows and harrows, and also the inadequate soil preparation make it susceptible to erosion and favor the depletion of the soil and the fertility (Table 2).

The cassava monocrop had the highest values for electrical conductivity, followed by native forest, bean monocrop and intercropping, which was approximately five times lower than the highest value. The increase in soil electrical conductivity is expected especially when performing either a mineral or an organic fertilization, or liming, for example (Nascimento et al., 2014).

Organic matter contents were marked in native forest with values around 35 g kg^{-1}, which were closer to those of the bean monoculture. As for cassava monoculture and corn intercropped with beans, the values were very close to each other, being lower than those mentioned above.

Nascimento et al. (2014) evaluated the chemical attributes of eight soils submitted to different uses in no-tillage and agro-ecological production systems up to 20 cm deep and observed differences between the uses. The highest organic carbon contents were found for native forest plots, indicating that the intensive use of the soil in production activities tends to decrease these values.

The replacement of natural environments for cultivated environments results, according to Corrêa et al. (2009), in changes in the soil chemical properties, which are dependent on management practices as well as on the culture itself.

The decrease in the carbon stock of natural systems is a response to the implementation of man-driven agricultural activities (Silva et al., 2010), which compromise the sustainability of agricultural systems in view of the importance of the presence of organic matter regarding different soil characteristics.

However, other practices such as the supply of phytomass to the soil due to the use of cover crops increase the production of fodder and help to maintain a balanced environment in the soil regarding its physical, chemical and biological characteristics (Loss et al., 2016).

Table 2. Descriptive statistics for the chemical attributes Nitrogen (N), Hydrogenionic potential (pH on water), Electrical conductivity (EC), Organic matter (OM), Phosphorus (P), Potassium (K^+), Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Aluminum (Al^{3+}), Potential acidity (H+Al), Base sum (BS), Effective cation exchange capacity (t), Potential cation exchange capacity (CEC), Base saturation (V), Aluminum saturation (m) and Exchangeable sodium percentage (ESP) of a dystrophic Yellow Oxisol under different agricultural uses: native forest (NF), cassava monocrop (CAMO), bean monocrop (BEMO) and corn intercropped with beans + addition of solid waste (CICB) in Martins, Rio Grande do Norte, Brazil

Chemical attributes	Managements	Descriptive analysis					
		Mean	Min	Max	s^2	s	CV (%)
N (g kg^{-1})	NF	1.55	1.31	1.87	0.06	0.24	15.22
	CAMO	1.60	1.49	1.75	0.01	0.11	7.07
	BEMO	1.22	1.00	1.42	0.05	0.22	17.88
	CICB	0.98	0.44	1.26	0.14	0.38	38.84
pH (water)	NF	5.54	5.05	5.98	0.17	0.41	7.42
	CAMO	5.76	5.22	6.88	0.58	0.76	13.25
	BEMO	5.03	4.78	5.25	0.04	0.20	3.95
	CICB	7.46	7.36	7.59	0.01	0.10	1.28
EC (dS m^{-1})	NF	0.56	0.49	0.76	0.02	0.13	23.47
	CAMO	0.87	0.56	1.21	0.12	0.35	40.27
	BEMO	0.46	0.33	0.52	0.01	0.09	19.17
	CICB	0.19	0.14	0.24	0.00	0.04	21.94
OM (g kg^{-1})	NF	34.90	30.20	37.80	10.70	3.27	9.38
	CAMO	19.50	10.50	26.03	50.28	7.09	36.36
	BEMO	32.50	16.08	42.18	136.29	11.67	35.92
	CICB	21.81	18.62	25.50	9.07	3.01	13.81
P (mg dm^{-3})	NF	22.13	15.61	30.37	39.18	6.26	28.28
	CAMO	23.76	19.87	28.64	14.26	3.78	15.89
	BEMO	6.93	5.21	8.85	2.30	1.52	21.88
	CICB	59.11	27.43	86.67	590.69	24.30	41.12
K (mg dm^{-3})	NF	45.85	28.01	59.18	200.65	14.17	30.90
	CAMO	56.15	41.17	73.03	172.00	13.11	23.36
	BEMO	26.62	20.73	32.51	23.45	4.84	18.19
	CICB	190.18	124.08	231.26	2,227.43	47.20	24.82
Na^+ (mg dm^{-3})	NF	5.87	5.53	6.20	0.07	0.27	4.66
	CAMO	7.71	5.53	9.56	3.04	1.74	22.62
	BEMO	4.86	4.52	5.20	0.08	0.28	5.71
	CICB	36.85	28.62	47.39	61.40	7.84	21.27
Ca^{2+} ($cmol_c$ dm^{-3})	NF	1.76	0.90	2.57	0.47	0.68	38.78
	CAMO	2.75	1.27	4.35	1.67	1.29	47.05
	BEMO	1.04	0.77	1.30	0.05	0.22	21.09
	CICB	14.57	11.65	17.38	5.48	2.34	16.06
Mg^{2+} ($cmol_c$ dm^{-3})	NF	1.81	1.10	2.38	0.29	0.54	29.56
	CAMO	2.09	1.57	2.57	0.18	0.43	20.54
	BEMO	1.68	0.87	2.53	0.68	0.83	49.39
	CICB	0.82	0.64	1.12	0.05	0.22	26.69
Al^{3+} ($cmol_c$ dm^{-3})	NF	0.42	0.13	1.00	0.16	0.40	95.30
	CAMO	0.25	0.00	0.47	0.04	0.19	77.91
	BEMO	0.91	0.67	1.13	0.04	0.21	23.16
	CICB	0.00	0.00	0.00	0.00	0.00	0.00

(H+Al) ($cmol_c\ dm^{-3}$)	NF	9.95	7.95	11.83	2.51	1.59	15.94
	CAMO	10.31	6.24	12.46	7.77	2.79	27.05
	BEMO	11.98	10.97	12.73	0.64	0,80	6.70
	CICB	0.00	0.00	0.00	0.00	0.00	0.00
BS ($cmol_c\ dm^{-3}$)	NF	3.71	298	4.36	0.32	0.57	15.32
	CAMO	5.01	2.98	6.79	2.76	1.66	33.16
	BEMO	2.80	2.02	3.61	0.49	0.70	25.02
	CICB	16.03	13.09	19.25	6.36	2.52	15.73
t ($cmol_c\ dm^{-3}$)	NF	4.14	3.97	4.54	0.07	0.27	6.59
	CAMO	5.26	3.45	6.79	2.18	1.48	28.04
	BEMO	3.71	2.69	4.74	0.83	0.91	24.57
	CICB	16.03	13.09	19.25	6.36	2.52	15.73
CEC ($cmol_c\ dm^{-3}$)	NF	13.66	11.78	14.81	1.77	1.33	9.75
	CAMO	15.32	13.04	18.28	5.59	2.36	15.43
	BEMO	14.78	12.99	15.62	1.46	1.21	8.17
	CICB	16.03	13.09	19.25	6.36	2.52	15.73
V (%)	NF	27.00	20.00	32.00	28.00	5.29	19.60
	CAMO	33.50	22.00	52.00	169.00	13.00	38.81
	BEMO	18.75	16.00	23.00	11.58	3.40	18.15
	CICB	100.00	100.00	100.00	0.00	0.00	0.00
m (%)	NF	10.50	3.00	25.00	103.00	10.15	96.66
	CAMO	5.75	0.00	13.00	29.58	5.44	94.59
	BEMO	24.75	24.00	25.00	0.25	0.50	2.02
	CICB	0.00	0.00	0.00	0.00	0.00	0.00
ESP (%)	NF	0.19	0.17	0.23	0.00	0.03	14.25
	CAMO	0.22	0.15	0.30	0.00	0.06	28.51
	BEMO	0.15	0.13	0.16	0.00	0.01	8.90
	CICB	1.34	0.78	2.00	0.25	0.50	37.54

Note. Min: Minimum; Max: maximum; s^2: variation; s: standard deviation; CV: Coefficient of variation (%).

The correlation matrix obtained by the principal component analysis (PCA) shows a positive correlation between base sum and exchangeable bases, except for magnesium, which showed a negative correlation. The positive correlation between P, K^+, Na^+ and Ca^{2+} is due to the increased pH, which releases these nutrients, and the unavailability of Al^{3+} in the soil, hence the lower potential acidity (H+Al) and aluminum saturation (m), which may be explained by a negative correlation between these elements.

Carneiro et al. (2009) and Alleoni et al. (2005), studying an Oxisol, obtained similar results according to which the increased pH raised the levels of exchangeable bases and decreased soil acidity.

Table 3. Correlation matrix for the chemical attributes Nitrogen (N), hydrogenionic potential (pH on water), Electrical conductivity (EC), organic matter (OM), Phosphorus (P), Potassium (K^+), Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Aluminum (Al^{3+}), Potential acidity (H + Al), Base sum (BS), Effective cation exchange capacity (t), Potential cation exchange capacity (CEC), Base saturation (V), Aluminum saturation (m), Exchangeable sodium percentage (ESP) of a dysprophic Yellow Oxisol under different agricultural uses: native forest (NF), cassava monocrop (CAMO), bean monocrop (BEMO) and corn intercropped with beans + addition of solid waste (CICB) in Martins, Rio Grande do Norte, Brazil

	N	pH	EC	OM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	(H+Al)	BS	t	CEC	V	m	ESP
N	1.00																
pH	-0.62	1.00															
CE	0.92	-0.60	1.00														
MO	-0.52	-0.23	-0.27	1.00													
P	-0.58	1.00	-0.58	-0.31	1.00												
K^+	-0.72	0.99	-0.69	-0.12	0.98	1.00											
Na^+	-0.78	0.97	-0.74	-0.04	0.96	1.00	1.00										
Ca^{2+}	-0.76	0.98	-0.72	-0.06	0.97	1.00	1.00	1.00									
Mg^{2+}	0.93	-0.83	0.94	-0.16	-0.80	-0.89	-0.92	-0.91	1.00								
Al^{3+}	0.15	-0.87	0.16	0.61	-0.89	-0.80	-0.73	-0.76	0.45	1.00							
(H+Al)	0.72	-0.99	0.72	0.16	-0.98	-1.00	-0.99	-0.99	0.90	0.79	1.00						
SB	-0.74	0.99	-0.69	-0.08	0.97	1.00	1.00	1.00	-0.89	-0.78	-0.99	1.00					
T	-0.77	0.98	-0.71	-0.05	0.96	1.00	1.00	1.00	-0.91	-0.75	-0.99	1.00	1.00				
CTC	-0.63	0.71	-0.33	0.35	0.65	0.73	0.75	0.75	-0.58	-0.52	-0.67	0.76	0.76	1.00			
V	-0.72	0.99	-0.68	-0.11	0.98	1.00	1.00	1.00	-0.89	-0.79	-1.00	1.00	1.00	0.74	1.00		
M	0.10	-0.84	0.11	0.64	-0.87	-0.76	-0.70	-0.72	0.40	1.00	0.75	-0.74	-0.72	-0.49	-0.76	1.00	
PST	-0.79	0.97	-0.75	-0.04	0.96	0.99	1.00	1.00	-0.93	-0.72	-0.99	1.00	1.00	0.73	0.99	-0.69	1.00

Note. N: nitrogen; pH: hydrogenionic potential; EC: electrical conductivity; OM: organic matter; P: phosphorus; K^+: potassium; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Al^{3+}: aluminum; (H+Al): potential acidity; BA: base sum; t: effective cation exchange capacity; CEC: potential cation exchange capacity; V: base saturation; m: aluminum saturation; ESP: exchangeable sodium percentage.

The percentage of explanation for seventeen soil chemical attributes are presented in Table 4, with accumulated explanation of 94.95% for the first two principal components (PC1 and PC2).

Table 4. Eigenvalues, percentage of explanation and percentage of accumulated explanation of soil chemical attributes

Principal components (PC)	Eigenvalues	Explanation (%)	Accumulated Explanation (%)
1	13.46	79.15	79.15
2	2.69	15.79	94.94

The highest positive weights in CP1 refer to pH and exchangeable cations, while the high negative values are represented by potential acidity (H+Al) and nitrogen (N) in the soil. In the CP2, organic matter (OM), aluminum (Al) and aluminum acidity (m) were responsible for the differentiation of agricultural uses (Table 5). This highlights the importance of maintaining plant residues such as an OM source responsible for the decrease of exchangeable Al (Vance et al., 1995; Meurer, 2007), as well as the increase of pH and base release.

Souza et al. (2015), studying the attributes of a eutrophic Cambisol under a native forest, a cajarana orchard, a traditional farming area and a colluvium area, pointed pH and potential acidity as important parameters for distinguishing these areas with different agricultural uses in the Rio Grande do Norte semi-arid.

Table 5. Eigenvalues of soil chemical attributes analyzed together with principal components

Soil chemical attributes	Principal components	
	1	2
Nitrogen (N)	-0.203	-0.407
Hydrogenionic potential (pH)	0.269	-0.100
Electrical conductivity (EC)	-0.192	-0.341
Organic Matter (OM)	-0.025	0.557
Phosphorus (P)	0.265	-0.137
Potassium (K^+)	0.272	-0.022
Sodium (Na^{2+})	0.272	0.037
Calcium (Ca^{2+})	0.273	0.018
Magnesium (Mg^{2+})	-0.246	-0.224
Aluminum (Al^{3+})	-0.211	0.383
Potential acidity (H+Al)	-0.272	0.022
Base sum (BS)	0.272	-0.002
Effective cation exchange capacity (t)	0.272	0.023
Potential cation exchange capacity (CEC)	0.201	0.105
Base saturation (V)	0.273	-0.017
Aluminum saturation (m)	-0.201	0.408
Exchangeable sodium percentage (ESP)	0.272	0.044

Figure 1 corresponds to the scores for the two first principal components (PC1 and PC2) of soil chemical attributes in relation to different agricultural uses. Three groups were formed: the first group consisted of native forest (NF) and cassava monocrop (CAMO), with the greatest similarity; the second group was formed by the bean monocrop (BEMO); and the third group was formed by corn intercropped with beans in a conventional tillage (CICB).

The greater distance of CICB from the other groups was due to the practices adopted, notably the addition of waste from organic sources and construction works, which favored the decrease of acidity, a characteristic inherent to the soil under study (Goedert & Oliveira, 2007), with increase in exchangeable bases and change in soil chemical properties.

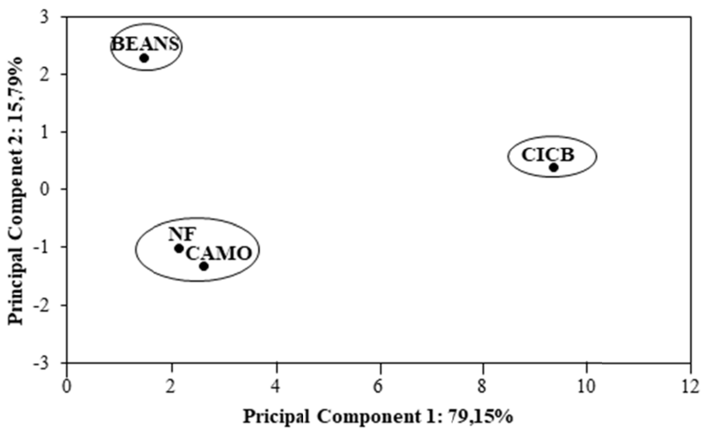

Figure 1. Graphical representation of scores for different agricultural uses: native forest (NF), cassava monocrop (CAMO), bean monocrop (BEMO), corn intercropped with beans + addition of solid waste (CICB) of the first two principal components obtained with soil chemical properties

4. Conclusions

Corn intercropped with beans, cassava monoculture and bean monoculture changed the soil chemical properties when compared to the native forest.

Corn intercropped with beans in a conventional tillage provided improved chemical properties, especially due to soil management with solid waste addition to the surface.

The principal component analyses showed pH, Na^+, Ca^{2+}, K^+, N and acidity were potential indicators of environments separation. The pH and the bases were the most sensitive.

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