Clay and organic compost as quality conditioners of a sandy soil in the brazilian semiarid

Argila e composto orgânico como condicionadores de qualidade de um solo arenoso no semiárido brasileiro

Arcilla y compost orgánico como acondicionadores de calidad de un suelo arenoso en el semiárido brasileño

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ABSTRACT

Due to natural and anthropic pressures of semiarid regions, like sandy texture, organic matter (OM) deficiency, water scarcity and inadequate management, we carried out an experiment under greenhouse conditions, to evaluate the effects of clay and OM addition on the quality of a sandy soil of the Brazilian semiarid. The experiment lasted 75 days, testing four clay contents (10 and 31% natural soils, 15% by clay addition to a sandy soil and 26% by mixing clay subsoil to a sandy topsoil) in the absence and presence of organic compost (7.5g.kg\(^{-1}\)). For biological parameters, sorghum plants were used for biometric and mineral composition analysis, in addition to assessing microbial activity (BSR, MBC, and qCO\(_2\)). The results showed significant differences in soil microporosity and total porosity; the field capacity and permanent wilting point correlated linearly with clay content and OM addition; potential and exchangeable soil acidity decreased significantly in the presence of compost. Sorghum plants showed higher values of biometric attributes and lower levels of nutrients in the presence of compost. The microbial activity did not show significant differences in terms of clay content or compost addition. The cluster analysis correlated the mixed soils (26%) to the lowest clay content soil (10%), and the clay addition (15%) to the highest clay content soil (31%), showing potential as soil conditioner in association with compost, as it might promote changes in the soil quality properties of semiarid regions.

Keywords: claying, amendments, soil quality, degraded soils, biological indicators.

RESUMO

Devido a pressões naturais e antrópicas de regiões semiáridas, como textura arenosa, deficiência de matéria orgânica (OM), escassez de água e manejo inadequado, realizamos um experimento em condições de estufa para avaliar os efeitos da argila e da adição de OM na qualidade de um solo arenoso do semiárido brasileiro. O experimento durou 75 dias, testando quatro teores de argila (10 e 31% de solos naturais, 15% por adição de argila a um solo arenoso e 26% por mistura de subsolo argiloso a um solo arenoso) na ausência e presença de composto orgânico (7.5g.kg\(-1\)). Para os parâmetros biológicos, foram utilizadas plantas de sorgo para análise da composição biométrica e mineral, além da avaliação da atividade microbiana (BSR, MBC e qCO\(_2\)). Os resultados mostraram diferenças significativas na microporosidade do solo e na porosidade total; a capacidade de campo e o ponto de murchamento permanente correlacionados linearmente com o conteúdo de argila e a adição de OM; a acidez potencial e permútável do solo diminuiu significativamente na presença de composto. Plantas de sorgo apresentaram maior valor de atributos
biométricos e menores níveis de nutrientes na presença de composto. A atividade microbiana não apresentou diferenças significativas em termos de teor de argila ou adição de composto. A análise de aglomerado correlacionou os solos mistos (26 %) com o solo com menor teor de argila (10 %) e a adição de argila (15 %) com o solo com maior teor de argila (31 %), mostrando potencial como condicionador de solo em associação com o composto, uma vez que pode promover alterações nas propriedades de qualidade do solo das regiões semiáridas.

**Palavras-chave:** argila, alterações, qualidade do solo, solos degradados, indicadores biológicos.

**RESUMEN**

Debido a presiones naturales y antrópicas de regiones semiáridas, como textura arenosa, deficiencia de materia orgánica (OM), escasez de agua y manejo inadecuado, se llevó a cabo un experimento en condiciones de invernadero, para evaluar los efectos de la adición de arcilla y OM en la calidad de un suelo arenoso del semiárido brasileño. El experimento duró 75 días, probando cuatro contenidos de arcilla (10 y 31% suelos naturales, 15% por adición de arcilla a un suelo arenoso y 26% por mezcla de subsuelo arcilloso a un suelo arenoso) en ausencia y presencia de compuestorgánico (7.5g.kg-1). Para los parámetros biológicos, se utilizaron plantas de sorgo para el análisis biométrico y de composición mineral, además de evaluar la actividad microbiana (BSR, MBC y qCO2). Los resultados mostraron diferencias significativas en la microporosidad del suelo y la porosidad total; la capacidad de campo y el punto de marchitamiento permanente se correlacionaron linealmente con el contenido de arcilla y la adición de OM; la acidez potencial e intercambiabl del suelo disminuyó significativamente en presencia de compuesto. Las plantas de sorgo mostraron valores más altos de atributos biométricos y niveles más bajos de nutrientes en presencia de compuesto. La actividad microbiana no mostró diferencias significativas en términos de contenido de arcilla o adición de compuesto. El análisis de conglomerados correlacionó los suelos mixtos (26%) con el suelo de menor contenido de arcilla (10%), y la adición de arcilla (15%) con el suelo de mayor contenido de arcilla (31%), mostrando potencial como acondicionador del suelo en asociación con el compuesto, ya que podría promover cambios en las propiedades de calidad del suelo de las regiones semiáridas.

**Palabras clave:** arcillas, enmiendas, calidad del suelo, suelos degradados, indicadores biológicos.

**1 INTRODUCTION**

Soil quality and its ecosystems services result from the interaction of intrinsic and extrinsic factors, such as soil structure, biodiversity, climatic
conditions, and agricultural management (ZORNOZA et al., 2015). Organic matter (OM) content and soil physical characteristics, such as density and porosity, stand out as soil quality indicators due to the interactions with mineral and biological components (TAHIR; MARSCHNER, 2016).

The OM formation and its dynamics are influenced by organic exudation and decomposition, in addition to soil texture (COLEMAN et al., 2014). It tends to bind more strongly and for longer time to clays due to their greater cation exchange capacity (CEC) and specific surface area, according to their mineralogical diversity (SINGH et al., 2017), especially associated to the type and clay content. Clays can protect the soil organic carbon from microbial activity through chemical and physical barriers, forming organo-mineral complexes with organic carbon or by its occlusion into aggregates (HAN et al., 2016).

Soils in arid and semiarid regions are highly vulnerable due to shortage and low levels of OM, which increases greenhouse gas emissions, impairs soil aggregation, favors nutrient leaching, and decreases water retention (RAMANKUTTY et al., 2018). In Brazil, Giongo et al. (2018) described the limiting characteristics of the northeastern semiarid, such as low quantity and poorly distributed rainfall, high temperatures and variation in soil types, besides poor-C soils. The Brazilian northeastern semiarid is among the regions with the most vulnerable soils in view of climate change and projections of aridity intensification (VIEIRA et al., 2015), with serious socioeconomic and environmental implications, which compromise ecosystem services and food security, then becoming dependent on practices that improve soil quality.

Studies have shown that clay addition to soil, either in the upper horizons or by the inversion of deeper clayey horizons, can improve their chemical and physical conditions (SHI; MARSCHNER, 2013). Ortega et al. (2020) increased the fertility of degraded soils, by adding different types of zeolite and organic correctives, associated with native plants and, more recently, were found lower CO₂ emissions in the field, 15 years after kaolinite addition (GROVER et al., 2020). It is inferred that the addition of clay and OM would act as soil conditioners, as they increase the soil cation exchange capacity, specific surface area and
influence its porosity, improving water retention and nutrient adsorption, which could boost soil quality permanently in the face of constant semiarid environmental constraints.

Thus, the research aimed to I) evaluate the influence of clay and OM addition, alone and in conjunction, in the physical and chemical attributes of a sandy soil of a tropical semiarid region; II) evaluate the response of biological indicators (forage sorghum and microbial activity) by the clay and OM addition and III) determine the most efficient clay addition strategy, between direct clay incorporation into the soil or the inversion of deeper clayey horizon.

2 MATERIALS AND METHODS
2.1 SOIL SAMPLING AND EXPERIMENT SET UP

Soil samples of a typical Eutrophic Yellow Argisol (Brazilian soil classification, equivalent to Ultisols by the Soil Taxonomy) were collected in the municipality of Pacajus, Ceará State, northeastern Brazil, at 0-30 cm (10 %, 3 % and 86 % of clay, silt and sand, respectively) and at 30-60 cm depth. Part of the subsoil samples (30-60 cm depth) was mixed with the upper soil (0-30 cm), then obtained a soil with 26 %, 6 % and 67 % of clay, silt and sand, respectively.

Samples of a typical Eutrophic Red-Yellow Argisol (Brazilian soil classification, equivalent to Ultisols by the Soil Taxonomy) were also collected in Fortaleza, Ceará (3°44'44.2"S 38°34'56.7"W), at 30-60 cm (31 %, 6 % and 60% of clay, silt and sand, respectively). Some particularities in certain soils of the Coastal Tablelands in northeastern Brazil is the parent material being developed from sediments with high degree of weathering and, thus, present similarity in the clay fraction, with predominance of kaolinite in the different horizons. It is worth pointing out that this characteristic is not limited only to Brazilian soils (Mota et al. 2021).

 Were considered four different clay contents to the establishment of the treatments, as follows: Pacajus soil (0-30 cm), 10 % clay; Mixed Pacajus soil (0-30 cm) + (30-60 cm), totaling 26 % clay; Fortaleza soil (30-60 cm), 31 % clay; and Pacajus soil (0-30 cm) + 5 % added clay, totaling 15 % clay.
The experimental design was completely randomized, with a 4x2 factorial scheme (4 clay contents x presence and absence of organic compost), totaling eight treatments, distributed in 64 pots (3 kg each). The soils containing 10, 15, 26, and 31 % clay were assembled in pots in the absence of organic compost and referred as 10NC, 15NC, 26NC, and 31NC treatments. The treatments 10AC, 15AC, 26AC, and 31AC were assembled with the same clay content with the addition of 7.5 g kg\(^{-1}\) of organic compost (AC). This dose corresponded to 15 t ha\(^{-1}\) of manure for the sorghum (*Sorghum bicolor* [L.] Moench) cultivation in sandy soils (AQUINO et al., 1993), used for the determination of biological parameters. The characterization of organic compost, based on earthworm humus is shown in table 1. The experiment was conducted under greenhouse conditions in Fortaleza, Brazil.

<table>
<thead>
<tr>
<th></th>
<th>g kg(^{-1})</th>
<th>cmol kg(^{-1})</th>
<th>mg kg(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>97.81</td>
<td>4.88</td>
<td>13.69</td>
</tr>
<tr>
<td>MO</td>
<td>186.62</td>
<td>3.12</td>
<td>615.33</td>
</tr>
<tr>
<td>N</td>
<td>12.37</td>
<td>0.36</td>
<td>130.39</td>
</tr>
<tr>
<td>P</td>
<td>4.69</td>
<td>0.71</td>
<td>111.78</td>
</tr>
</tbody>
</table>

Source: Prepared by the Authors

Soils were moistened with distilled water by capillarity for 20 days, then six seeds of forage sorghum (*Sorghum bicolor* [L.] Moench) were planted per pot. Thinning was done 20 days after planting, leaving three plants per pot, irrigated daily with distilled water, at a rate close to the field capacity (450 mL per pot).

### 2.2 Chemical and physical soil characterization

The chemical soil characterization (table 2) was done at the beginning and at the end of the incubation period, following the methodologies described by Teixeira et al. (2017). Briefly, pH was determined in water (1: 2.5); electrical conductivity in saturation extract; total P extracted with Mehlich-1 solution and determined spectrophotometrically; exchangeable bases (Ca\(^{2+}\), Mg\(^{2+}\), K\(^{+}\), and Na\(^{+}\)) extracted with ammonium acetate solution pH 7.0, determined by flame photometry (K\(^{+}\) and Na\(^{+}\)) and atomic absorption (AA spectrometer, Thermo Scientific iCE 3000 Series) (Ca\(^{2+}\) and Mg\(^{2+}\)); potential acidity (H + Al) was
extracted with calcium acetate pH 7.0 and titrated with 0.0606 N NaOH, while exchangeable aluminum was extracted with potassium chloride and titrated with 0.025 N NaOH. Organic carbon was determined by the Walkley-Black method (Gessesse and Khamzina 2018).

Table 2 Selected properties of the soils [sampled\(^{a}\) and assembled\(^{b}\)] used in the experiments

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Units</th>
<th>Soils (according to clay content - %)</th>
<th>10(^{a})</th>
<th>15(^{b})</th>
<th>26(^{b})</th>
<th>31 (^{a})</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td>3.9</td>
<td>4.9</td>
<td>3.7</td>
<td>5.0</td>
</tr>
<tr>
<td>EC(^{†})</td>
<td>dS m(^{-1})</td>
<td></td>
<td>0.0013</td>
<td>0.0037</td>
<td>0.0011</td>
<td>0.0012</td>
</tr>
<tr>
<td>SB</td>
<td></td>
<td></td>
<td>0.76</td>
<td>1.26</td>
<td>1.11</td>
<td>5.5</td>
</tr>
<tr>
<td>t</td>
<td>cmol(_c)kg(^{-1})</td>
<td></td>
<td>0.74</td>
<td>2.15</td>
<td>1.91</td>
<td>3.68</td>
</tr>
<tr>
<td>T</td>
<td>cmol(_c)kg(^{-1})</td>
<td></td>
<td>4.34</td>
<td>2.65</td>
<td>6.11</td>
<td>7.76</td>
</tr>
<tr>
<td>H(^{+})Al</td>
<td></td>
<td></td>
<td>3.8</td>
<td>1.5</td>
<td>5.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Al</td>
<td></td>
<td></td>
<td>0.20</td>
<td>1.00</td>
<td>1.20</td>
<td>0.12</td>
</tr>
<tr>
<td>P</td>
<td>g kg(^{-1})</td>
<td></td>
<td>1.66</td>
<td>1.45</td>
<td>1.23</td>
<td>3.94</td>
</tr>
<tr>
<td>OC</td>
<td>g kg(^{-1})</td>
<td></td>
<td>0.94</td>
<td>0.53</td>
<td>0.47</td>
<td>4.74</td>
</tr>
<tr>
<td>V</td>
<td>%</td>
<td></td>
<td>73.0</td>
<td>53.6</td>
<td>37.3</td>
<td>96.7</td>
</tr>
</tbody>
</table>

\(^{†}\)Electrical conductivity in the saturation extract; (SB) sum of bases; (t) effective CEC; (T) total CEC; (H\(^{+}\)Al) potential acidity; (Al) exchangeable acidity; (P) phosphorous; (OC) organic carbon, (V) base saturation. Source: Prepared by the Authors

The soil density was obtained by the volumetric method. Total porosity, microporosity and macroporosity were obtained after saturation for 24 hours to 6 kPa tension table, weighed after water level stabilization and after 24 hours drying in an oven at 105 °C. Microporosity was obtained as a function of moisture in g / g of soil and the density of dry soil. Macroporosity was obtained by the difference between total porosity and microporosity. Field capacity (FC) and permanent wilting point (PWP) were obtained at 33 kPa and 1500 kPa, respectively.

2.3 PLANT ANALYSIS

The length and diameter of the forage sorghum stem were measured, as well as the length and width of the largest leaf to calculate the leaf area, according to Mokhtarpour et al. (2010) at 35 and 75 days after planting. At the same frequency, the relative chlorophyll index of two plants per pot was measured, totaling 16 readings per pot, using a chlorophyll meter SPAD 502 (Minolta, Osaka, Japan).
At the end of the experiment, the shoots were collected to determine the dry biomass in a forced circulation oven at 65 °C for drying to constant weight. Then, leaves and stems were ground in a Willey mill, for the material acid digestion according to Mendonça and Matos (2005). The N content was determined by distillation and titration of the digested extract by sulfuric solubilization. The contents of P, K, Ca, Mg, Fe, Cu, Zn and Mn were extracted via dry digestion, in an electric muffle at 500 °C, the ashes diluted in HCl 1N and determined by atomic absorption spectrophotometry (Silva 2009), except P, that was determined colorimetrically.

2.4 SOIL MICROBIAL ACTIVITY

At the end of the experiment soil samples were collected for basal soil respiration (BSR), determined as the amount of C released in the form of C-CO$_2$ (ALEF; NANNIPIERI, 1995), at a total of seven readings. The fumigation-extraction method was used to obtain the carbon of the microbial biomass (MBC) (VANCE et al, 1987), using 0.33 as a correction factor for Brazilian soils according to Silva et al. (2007). The $q$CO$_2$ was calculated from the C-CO$_2$ accumulated during the seven readings at the end of the experiment and the MBC (ANDERSON; DOMSCH, 1993).

2.5 STATISTICAL ANALYSIS

The data were submitted to analysis of variance (ANOVA) and the means were compared by the Tukey test at 5% probability. Regression analysis was performed for clay contents. Pearson’s correlation, Principal Component Analysis and Cluster Analysis were performed for the studied parameters in the software SAS University Version, Microsoft Excel 2007, and SigmaPlot 12.0.

3 RESULTS

3.1 SOIL CHARACTERIZATION

Microporosity was significantly influenced by clay content, varying from 22% to 30.8% for 10NC and 31AC treatments, respectively. The interaction
between soil particles and organic compost also affected microporosity and total porosity. Figure 1 shows the positive relationship between microporosity and clay content, increasing water retention, in interaction with the organic compost. ANOVA also showed a significant effect of clay content on FC and PWP, regardless the presence of the compost. However, the FC and PWP values did not adjust to the linear and quadratic regression models in the absence of organic compost (figure 2).

Figure 1 Microporosity in the presence (A) and absence (B) of compost in soils with different clay contents (sampled and assembled).

* Statistical significance at the level of 5% probability. Source: Prepared by the Authors
Soil acidity was significantly influenced by the clay contents and presence of compost and their interaction. The pH averages differed significantly between treatments, ranging from 4.16 to 5.89, referring to 26NC and 31AC treatments, respectively. The treatments with 15% clay did not differ significantly from the 10% clay in terms of H+Al, Al^{3+}, SB, t, and V. Figure 3 shows that the adjustment to the simple linear regression model occurred in the absence of organic compost, suggesting a buffering effect of the OM on these attributes.

The OC and N averages did not differ significantly in terms of clay contents, unlike P. Only N was not significantly affected by the compost. It was observed that, despite the greater availability of soil charges in 31 AC and NC treatments (total CEC), there was no significant OC retention. The phosphorus (P) differed significantly between the clay contents, and the highest and lowest P values were found with 31 % and 26 % clay treatments, respectively, while 10 and 15 % clay treatments did not differ from each other.
Figure 3 Potential acidity (H+Al), exchangeable acidity (Al) and total CEC (T) in the absence of compost in soils with different clay contents (sampled and assembled).

* Statistical significance at the level of 5% probability. Source: Prepared by the Authors

3.2 PLANT RESPONSES

All biometric attributes were significantly affected by the clay content and by the organic compost, except for the stem diameter (figure 4). As for the mineral attributes, the averages of Ca, Fe, Cu, and Mn were not influenced by the clay content and the presence of compost, except for Fe (table 3).

Table 3 Analysis of variance of mineral attributes of forage sorghum cultivated in treatments with different clay contents and presence and absence of organic compost

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>0.0056</td>
<td>0.003*</td>
<td>0.005*</td>
<td>0.08*</td>
<td>2.6823</td>
<td>0.0038</td>
<td>0.18*</td>
<td>1.43</td>
</tr>
<tr>
<td>Compost</td>
<td>0.0004</td>
<td>0.006*</td>
<td>0.032*</td>
<td>0.488*</td>
<td>11.979*</td>
<td>0.0036</td>
<td>0.513*</td>
<td>1.098</td>
</tr>
<tr>
<td>CxC</td>
<td>0.0031</td>
<td>0.0002</td>
<td>0.005*</td>
<td>0.077*</td>
<td>5.0779</td>
<td>0.0048</td>
<td>0.1015</td>
<td>1.456</td>
</tr>
<tr>
<td>Residual</td>
<td>0.0024</td>
<td>0.0007</td>
<td>0.0003</td>
<td>0.0221</td>
<td>1.9613</td>
<td>0.0032</td>
<td>0.0142</td>
<td>0.924</td>
</tr>
<tr>
<td>CV</td>
<td>13.2</td>
<td>15.2</td>
<td>7.1</td>
<td>10.5</td>
<td>132.9</td>
<td>51.7</td>
<td>25.88</td>
<td>39.2</td>
</tr>
</tbody>
</table>

Calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn). Clay= clay contents, Compost= addition or not of organic compost, CxC= clay contents x compost interaction, CV= coefficient of variation. *Significant by F test at 5%.

Source: Prepared by the Authors
Figure 4 Averages, standard error, and statistical significance of stem diameter (SD) \([p<0.0001]\), culm length (CL) \([p<0.0001]\), leaf length (LL) \([p<0.0001]\) and leaf width (LW) \([p<0.0001]\) of forage sorghum (Sorghum bicolor [L.] Moench) planted in soils with different clay contents.

Bars with the same pattern and equal letters do not differ significantly in terms of clay content. * Significant difference at the level of 5% probability for the presence and absence of organic compost, ns = not significant. Source: Prepared by the Authors

SD \([p=0.581]\), CL\([p<0.0001]\), LL\([p<0.0001]\), LW\([p<0.0001]\).

There was no significant difference in the dry mass (DM) of the plants from 15 and 31 % clay, as well as between 31 and 10 % clay (5.49, 4.89 and 4.31 g, respectively), while the plants with 26% clay showed the lowest DM averages (2.16g). The chlorophyll content did not differ among plants with 10 and 15 % clay. The plants with 10% clay treatments stood out in the P accumulation (22.2 g kg\(^{-1}\)), while 26 % clay plants accumulated more N and less P (3.45 g kg\(^{-1}\) and 19.35 g kg\(^{-1}\), respectively).

Pearson’s correlation between the main physical and chemical soil attributes and the main biometric and mineral plant attributes is shown in table 4. The leaf area (LA) was positively correlated with pH, soil P and base saturation (V), suggesting an effect of pH on the availability of nutrients in plant development, where the highest pH and LA values were in plants with 31 % clay. Plant N negatively correlated with soil P, V, LA, and DM, which was benefited by the compost, whose addition to the soils may have stimulated the soil N mobilization in the biomass, decreasing its concentrations over time. The highest plant N values were obtained with 26 % clay, where the plants had the least
development. Plant P correlated positively with soil P and LA, due to the P increase with the compost addition.

Table 4 Pearson’s correlation matrix for soil physical-chemical, biometric, and mineral attributes of forage sorghum, under different clay contents in the presence and absence of organic compost

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Ps</th>
<th>SB</th>
<th>T</th>
<th>V</th>
<th>MIC</th>
<th>CC</th>
<th>LA</th>
<th>DM</th>
<th>Np</th>
<th>Pp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat</td>
<td>0.371</td>
<td>0.051</td>
<td>0.606</td>
<td>0.752</td>
<td>0.148</td>
<td>0.872</td>
<td>0.164</td>
<td>-0.133</td>
<td>-0.125</td>
<td>-0.040</td>
<td>-0.157</td>
</tr>
<tr>
<td></td>
<td>0.366</td>
<td>0.903</td>
<td>0.112</td>
<td>0.031</td>
<td>0.726</td>
<td>0.0047</td>
<td>0.698</td>
<td>0.753</td>
<td>0.768</td>
<td>0.923</td>
<td>0.710</td>
</tr>
<tr>
<td>pH</td>
<td>0.532</td>
<td>0.895</td>
<td>0.349</td>
<td>0.840</td>
<td>0.397</td>
<td>0.367</td>
<td>0.766</td>
<td>0.517</td>
<td>-0.533</td>
<td>0.575</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.174</td>
<td>0.002</td>
<td>0.397</td>
<td>0.0090</td>
<td>0.330</td>
<td>0.371</td>
<td>0.026*</td>
<td>0.189</td>
<td>0.174</td>
<td>0.136</td>
<td></td>
</tr>
<tr>
<td>Ps</td>
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Attributes: pH, P in the soil (Ps), sum of bases (SB), total CEC (T), base saturation (V), microporosity (MIC), chlorophyll content (CC), leaf area (LA), dry matter (DM), plant N (Np) and plant P (Pp). Upper line refers to Pearson's correlation coefficient and lower line to statistical significance at the level of 5% probability. * Statistical significance at the level of 5% probability. Source: Prepared by the Authors

3.3 SOIL MICROBIAL ACTIVITY

The microbial activity did not show any significant differences regarding clay contents and the presence of compost for BSR, MBC, and qCO₂, as well as Pearson's correlation between microbial activity, soil physical-chemical attributes and the dry mass of the plants.

_Multivariate analysis of soil, sorghum, and microbial activity attributes_

It was necessary the use of three components (C1, C2 and C3) to explained 75.86 % of the variability. Most of the soil attributes and the MBC correlated positively with C1. The 26NC treatment correlated positively with C2, which concentrated the attributes related to soil acidity. Figure 5 shows the dendrogram of the cluster analysis, which distances the treatment with 26% clay (subsoil inversion) from the others, due to the influence of acidity on the performance of the analyses, while the treatment with the addition of clay at 15% approaches performance of the 31% clay soil, with better results.

Figure 5 Dendrogram of the Cluster Analysis of treatments with sandy soils, under the influence of different clay contents and the presence and absence of organic compost.

Treatments with different clay contents and addition of organic compost (10AC, 15AC, 26AC, 31AC) and with no addition of organic compost (10NC, 15NC, 26NC, 31NC). Source: Prepared by the Authors
4 DISCUSSION

Microporosity was the physical attribute most influenced by the clay content along the 75 days of the experiment. As already mentioned, kaolinite is predominant in the clay fraction of Brazilian Coastal Tablelands, and its laminar shape facilitates its adjustment between the particles (LIMA et al., 2004). The clay could be transported by irrigation water then settled in the pores, increasing microporosity, reducing percolation, and enhancing water retention by adsorption, as stated by Ismail and Ozawa (2007). The increase in water retention by adding clay to a sandy soil was also observed by Tahir and Marschner (2016) and Singh et al. (2019). The influence of the compost in the total porosity is due to the connection between OM and soil particles, through the charges available on the surface, forming organo-mineral complexes and aggregates, increasing porosity (MINASNY; MCBRATNEY, 2018), also influencing the FC and PWP. The increase in microporosity and, consequently, in the capillary pores volume, increase the specific surface area, providing a greater area for water adsorption, enhancing water retention even under a tension of 1500 kPa as reported in the literature (WIECHETECK et al., 2020).

The 26 AC and NC treatments (26% clay) are considered chemically poor, whose pH value was the lowest among the four soils used, as well as the lowest V value and OC and showed the highest H+Al and Al\(^{3+}\) (Table 3). Thus, it can be assumed that the high acidity found in those treatments, typically from Coastal Tablelands (LIMA et al., 2004), remained in the soils that came from this area. Soil acidity affects the nutrient availability for plants and microbiota, in addition to interfering in the physical soil quality (BRONICK; LAL, 2005). The results observed in 26 AC and NC treatments suggests that the added clay content was not satisfactory to improve the soil charges availability, caused by the small surface area and low CEC of kaolinite (SINGH et al., 2019).

Due to lower pH values, there was a lack of exchangeable cations, as they were less available in the soil solution because of low solubilization, being lost by leaching, reflected in the low EC and SB. In less acidic soils, cations dominate the bonds with the negative charges present on the clay surfaces, increasing the
SB, CEC, and V values, generally observed in treatments with higher clay content, as stated by Goulding (2016).

The interaction between OC and clay has been addressed in several studies, since the clay surface charges, and OC association contribute to the chemical protection against microbial degradation of OM (SHI; MARSCHNER, 2013; SINGH et al., 2017). Given the low CEC of kaolinite (GROVER et al., 2020) the amount of clay was not enough to promote a significant retention of OC and N during the period of this experiment.

Tahir and Marschner (2016) found an increase in soil P with clay addition compared to a sandy soil. In the present study, the higher clay content (31 %) was significantly more effective in retaining P than the other levels, but it is also possible to infer that the P availability was influenced by the low pH in 26 AC and NC treatments (26 % clay), since the P solubilization is reduced in more acidic soils (MAATHUIS, 2009; DELGADO; GÓMEZ, 2016), although the compost addition significantly increased the P content.

It was observed that the amount of clay did not determine the development of plants, but the soil chemical conditions. Treatments with 26% clay, which showed high acidity and low base saturation and CEC, had the least development of sorghum. The results differ from Ismail and Ozawa (2007) and Song et al. (2020), who observed an improvement in the biometric attributes of cucumber and maize under clay addition, due to increases in the soil hydraulic properties as stated by the authors. Although there was a linear increase in the FC and PWP, the present study did not show any significant difference regarding the water availability capacity, considering the difference between these variables (MINASNY; MCBRATNEY, 2018), inferring that the soil chemical variables affected most the biometric attributes, confirmed by the Pearson´s correlation.

The compost addition increased the soil nutrients and significantly the P and N in soil, which benefited the plants investment in biomass (LARCHER, 2000). This explains the larger sizes of plants with compost and the low concentration of N in plants, which also affected the chlorophyll content. The chlorophyll content is dependent on N in the soil, and with compost addition, the
plants initially invested N in biomass. However, in the absence or replacement of compost, the chlorophyll content was affected by the low N assimilation by plants, inducing a negative correlation between dry mass and chlorophyll content.

The soil chemical conditions were poorer for treatments without compost, especially for treatments with 26% clay, indicating that they must have stimulated the low investment in biomass and the higher concentration of plant nutrients to maintain the soil deficiencies, spending N in the chlorophyll formation (LARCHER, 2000). This would explain the higher N concentration and smaller plants sizes in the 26 AC and NC treatments. Low P availability affected photosynthesis, due to its importance in the energy supply (inorganic P) and in the formation of carbon fixing compounds (MAATHUIS, 2009), reflecting in the low values of leaf area and dry mass, especially in the absence of compost.

None of analyzes showed statistical significance for clay or organic compost regarding microbial activity. Shi and Marschner (2013) also found no significant differences in the basal soil respiration (BSR) of sandy soils with clay addition (10 % and 30 %), and the carbon of the microbial biomass (MBC) was affected by the 30 % clay after 14 and 28 days of the experiment, suggesting that the incubation period of seven days in our study could have been insufficient to obtain significant differences. Yazdanpanah et al. (2016) found significant differences in BSR and MBC of soils with different clay contents and the addition of organic residues. Several factors can affect microbial activity, such as the soil nutrients availability (SPOHN, 2015; VINHAL-FREITAS et al., 2017), soil texture and pH (PAUL, 2016; WIESMEIER et al., 2019) and water availability (ZHANG; MARSCHNER, 2016). In the current study, the pH significantly affected the soil chemical conditions, which in turn may have influenced the microbiological community composition and its OM decomposition kinetics (PAUL, 2016). In addition, the clay type may also have affected BSR, as the low SSA and CEC common in kaolinite soils, limit the protection offered to OC against degradation, increasing the C-CO₂ release (SINGH et al., 2019).

Due to the low activity of kaolinite regarding its advanced stage of weathering (GROVER et al., 2020; MOTA et al., 2021), the interaction between
clay and organic compost may have contributed to the better performance of the soils (clay) considering the physical and chemical attributes. The losses caused by the 26 AC and NC treatments (26% clay) due to soil acidity might be minimized possibly due to the interaction of OM and Al³⁺, forming organo-mineral complexes (WIESMEIER et al., 2019). The removal of Al³⁺ and H⁺ decreases competition with exchangeable cations for negative charges on the clays and OM surfaces (DELGADO; GÓMEZ, 2016).

The compost addition to 15 AC treatments may have masked the low effect of added clay, approaching the 10 AC and 15 AC treatments. However, surprisingly, the 15 NC treatment was alike to 31 NC treatment. It is possible that during the process of getting 15% clay content, may have exposed some binding sites to the maximum and promoted a loss of acidic cations, allowing a performance like 31% clay treatments.

5 CONCLUSIONS

The results showed that the clay contents used in the experiment did not have significant effects on the soil chemical parameters since kaolinite is a low activity clay. However, in association with organic compost, there was an improvement in attributes such as microporosity, Al³⁺, sum of bases and CEC. The microbial activity was not influenced by the clay content and the presence of compost during the studied period.

It was evident that the direct clay addition to a sandy soil (15% clay treatments) was more efficient than the mixed horizons (26% clay treatments), advising that the chemical conditions of the soil/horizon of clay origin were relevant in the biological soil parameters, despite the clay content. Thus, the direct clay incorporation into the soil, associated with compost, was more effective in enhancing soil attributes, but still requiring more studies to assess soil quality in long term.
REFERENCES


