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# Solid bio-compost as a nutrient source for family farming

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ABSTRACT

This study aimed to demonstrate the importance of goat manure, sawdust, and green waste (lettuce, potatoes, carrots, and cabbage) as nutrient sources for soil and crops in family farming. Macro and micronutrient concentrations were determined. Two bio-composts were formed, one with a mixture of goat manure, sawdust and agricultural waste and the other without manure only sawdust and agricultural waste. The physicochemical properties of the soil, residues, and bio-compost were measured. Sawdust had high total organic carbon (TOC) and low total nitrogen (TN), P, K, Ca, and Mg levels, whereas goat manure had high TOC, TN, K, Ca, Mg, and P levels. The soil treated with the solid bio-composts (with and without goat manure) had significant effects, with the pH value reaching 7.0, suggesting that the bio-composts were safe for agricultural use. The manure bio-compost was rich in TOC, TN, P, Ca, and K macronutrients but poor in Mg. The manure-free bio-compost had high TOC and TN levels. However, both bio-composts had low C:N ratios. Finally, the experiments revealed high Fe and Mn and low Cu and Zn concentrations. These results clearly revealed that growth of maximum plant height (71 cm) were significantly influenced by bio-compost and suggest that the levels of TOC, TN, P, K, Ca, Mg, Fe, Mn, Cu, and Zn were reliable and thus do not present restrictions for agricultural use.

## 1. Introduction

Sustainable practices can benefit from organic solid waste because it is biodegradable and can be converted into organic manure through composting methods, depending on the form and primary source of the waste [1]. Proper waste management can ensure better living standards by partially or completely eliminating synthetic inputs to fill the gap between food production and population growth [2]. The economics of agricultural production, environmental quality, and soil fertility can benefit from the use of inputs such as clean water irrigation, organic fertilizers, and crop protection techniques [3,4].

Fertile soils are crucial for natural ecosystem sustainability. Management processes are essential for soil development and performance assessment [5]. The Amazon rainforest soil often has low fertility and is highly acidic. Despite the region's large floristic diversity, it presents considerable agricultural constraints [6]. Organic matter plays a crucial role in maintaining soil texture owing to its advantages, such as water retention ability, micro biomass, and nutrient cycling [7,8]. Organic matter is a source of nutrients for plant growth and improves root zone drainage and aeration [9].

There are several requirements for crop yield, such as the potential of the soil to supply essential macronutrients and micronutrients. The physical, biological, and chemical properties of soil can be improved sustainably depending on the properties of organic matter. Accordingly, the quality of croplands can be measured in terms of agricultural economic value [10]. Solid bio-composting is an alternative for achieving soil cover recovery based on specific soil deficiencies. It helps to maintain organic matter and impacts nutrient release and decomposition enabling the development of large agricultural landscapes [11].

The process applied to turn goat manure and sawdust into compost is an alternative to simply disposing of these wastes since it minimizes environmental impact and enables sustainable measures to prepare soil cover for crop cultivation [12,13]. The use of solid waste for bio-composting in agricultural practices has sparked widespread interest

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owing to its low cost [14]. Brazil has one of the largest goat herds in the world (in the Northeast Region), is one of the primary Northeastern livestock activities, and has experienced steady growth through family farming [15].

Nutrient recovery using sawdust, green waste, and animal manure can significantly decrease inorganic fertilizer import costs and dramatically reduce the environmental impact of current waste disposal options. Tons of manure are produced by cattle, sheep, goats, and pigs and can be disposed of by composting to provide nutrient-rich substrate with ideal TN, C, C:N ratio, $NO_3$–N, $NH^{4}$-N, EC, pH, and microbial respiration properties [13,44] for agricultural production.

Family farms have resorted to composting as a strategy to increase crop yields. This practice improves the income of farmers because of its low cost and makes their crops sustainable [16]. The research was carried out in the rural community of Tomé-Açu, an area with intense agricultural activities, such as agroforestry systems, agriculture, ranching, and timber harvesting that generate large amounts of organic waste [17]. This study aimed to evaluate the potential of bio-compost to improve the quality of soil for crops and produce high-quality organic products.

## 2. Materials and methods

### 2.1. Study site

The study area was in the Tomé-Açu district, northeastern Pará State, Brazil (Fig. 1), 200 km from Belém City. This district has a longstanding tradition in agriculture, particularly black pepper cultivation, with notably high yields [18]. It is also known for its extensive area of crops intercropped with agroforestry species.

The soils in Tomé-Açu have low fertility for agriculture. However, the district is globally known for its agricultural expansion after Japanese immigrants established a black pepper (*Piper nigrum*) monoculture in the region [18]. Currently, local agriculture is economically reinforced by palm oil crops [19] and agroforestry systems, including *Euterpe oleracea, Theobroma grandiflorum*, and *Theobroma cacao* [20].

The climate is hot and humid (82–88% humidity). The mean annual temperature is 27.9 °C. The annual rainfall ranges from 2144 to 2581 mm, marked by a rainy season (from December to May) and a drier season (from June to November) [21].

Tomé-Açu's geology consists of laterite sediments (from the Ipixuna Formation), quaternary sediments, and alluvial deposits (directly related to the geomorphology unit of the Capim and Gurupi River plains) [21]. In the Acará and Acará-Miri River valleys, one may find the formation of quaternary floodplains and terraces [20]. Yellow latosols, red latosols, yellow argisols, gleysols, and neosols have been observed in this region [21].

The local vegetation comprises secondary forests and shrublands resulting from agricultural and livestock activities. Forests in the site can be referred to as dense tropical submontane, low evergreen, dense tropical, low evergreen, lowland, dense tropical evergreen, and alluvial. These forests are well-developed despite the underlying infertile soil [21].

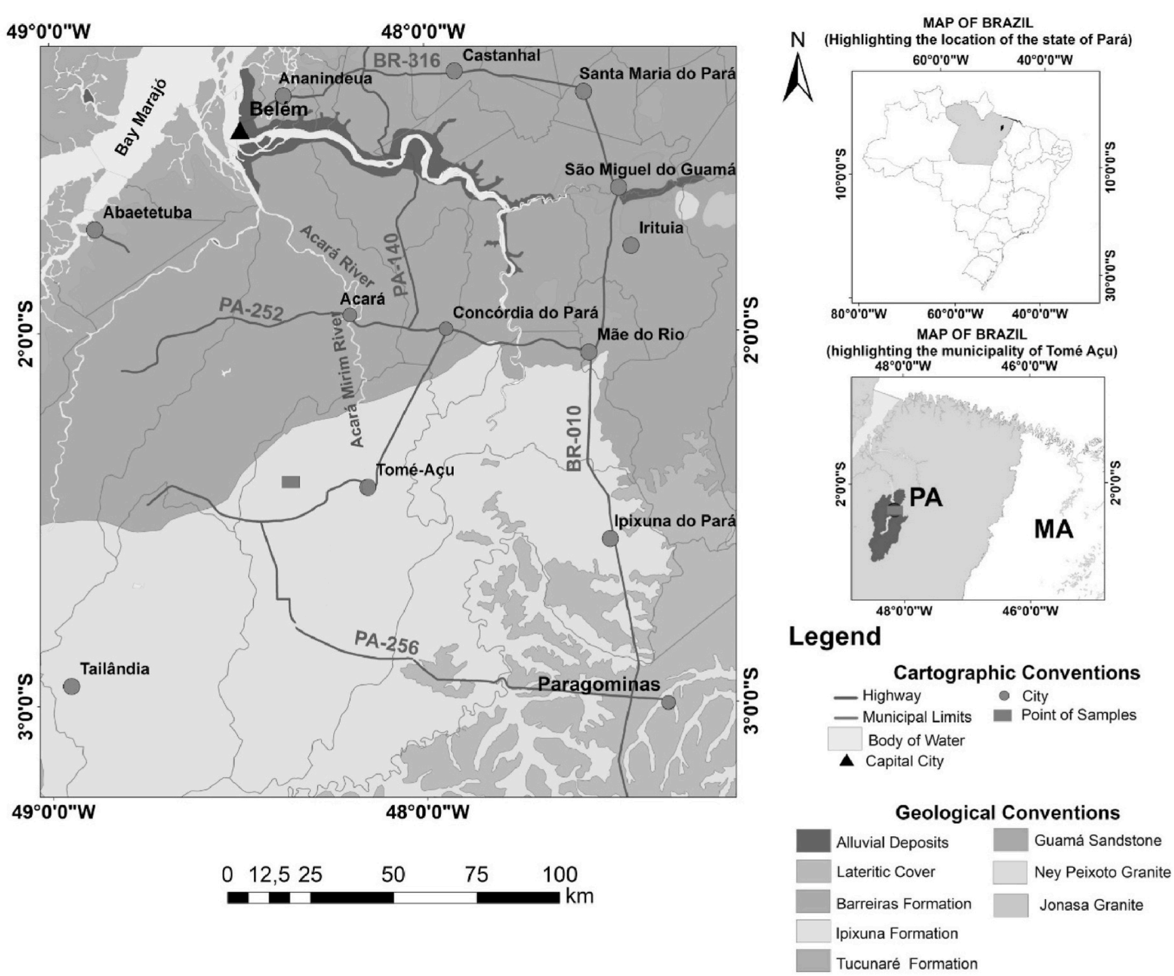


**Fig. 1.** Location map for the municipality of Tomé-Açu (Fonte CPRM).

### 2.2. Sampling and composting process

Samples of goat manure, sawdust, green waste (lettuce, potatoes, carrots, and cabbage), and cow milk were collected from local farms. An aliquot of 100 g of soil dry matter, goat manure, and sawdust was used for physicochemical analysis and nutritional (macro and micronutrient) assessments.

Soil samples from the region were collected from inactive cultivation areas at a soil layer of 0–20 cm for analysis soil composition for use in experiments with the bio-composts. The collection was carried out with a Dutch auger at five different points (P1, P2, P3, P4, and P5) set 50 m from each other. Collected samples were packed in plastic bags and subjected to natural drying. The samples were then separated for granulometric fractionation and chemical analysis.

The materials used in the bins were ground and passed through sieves (2 mm) with the following mixtures: 50% sawdust + 30% goat manure + 20% agricultural waste (lettuce, potatoes, carrots, and cabbage) with water and cow milk (3:1, v:v). The waste mass was composed of 7.5 kg sawdust +4.5 kg goat manure +3 kg green waste and was transferred to the compost bins (COM-1B, COM-2B, and COM-3B). Two other compost bins (COM-B) were assembled in the same proportion (3:1, v:v) but without the addition of manure, with only sawdust + green waste + water + whey, arranged in layers.

Five anaerobic mini compost bins were produced. Each bin was assembled using two polypropylene plastic containers (nontoxic 30 kg of polymer material). Container-1 contained waste from the biodegradation and maturation phases, which resulted in an organic compound (solid bio-compost). Container-2 had liquid waste (liquid bio-compost), which was used to moisten the organic compound in Container 1. Composting was performed at the Federal Rural University of the Amazon, Tomé-Açu campus. The goat manure + sawdust + green waste (lettuce, potatoes, carrots, and cabbage) + cow's milk mixture was produced in such a manner that the C:N ratio remained close to 30:1.

Water and cow milk was added to the samples until 60% moisture (wet basis) was attained in each compost mixture. The composts were covered with banana leaves to retain moisture and prevent excessive heat loss. The moisture content was maintained at 50–60% by adding liquid waste (liquid bio-compost) during the active-composting process. The accumulated gas was released once daily. The mixtures were stirred at 5-day intervals to maintain porosity. The process lasted for 100 days.

Temperature, room temperature, pH, and moisture measurements were obtained daily at random depths inside the mini-compost bins with a digital device used to assess in-process composting until the maturation phase. Samples of the finished compost compounds (solid bio-composts) were left to dry until attaining a constant weight and were subjected to physicochemical and chemical analyses for macro-and micronutrient determination. After chemical analysis, the solid bio-composts were applied to the unused cultivation area.

In a ~350 $m^2$ area, the soil was prepared to grow (*H. costaricensis*) dragon fruit. Eight hundred grams of the experimental solid bio-composts (with and without goat manure) was applied to each hole grow *Hylocereus costaricensis*. The soil was then cultivated with cladoids (~45 cm of *Hylocereus costaricensis*). In another area measuring ~50 $m^2$, 500 m away from the area where the bio-compost was applied, 30 g of chemical fertilizer was applied to grow the same species. Solid bio-compounds and chemical fertilizers were then applied to the crops every two months in the same amounts in grams.

### 2.3. Physicochemical and chemical analyses

Granulometric, mineralogical, and chemical measurements were taken of the soil, sawdust, goat manure, and compost (solid bio-compost) samples. Granulometric soil fractionation was performed using the pipette method at the Soil Analysis Laboratory of Museu Paraense Emilio Goeldi, Brazil. Mineralogical measurements were determined using an X-Ray Diffractogram (XRD) in a Bruker diffractometer (model D2 Phaser) equipped with the copper anode (λCu Kα = 1.54184 Å), voltage/current generator operating at 30 kV and 10 mA (300 W), and Lynxeye detector. Diffractograms of the sample were obtained by setting the 2θ reading values ranging from 5° to 75°. XRD analysis was performed at a step value of 0.02022 (2θ) and step time of 0.200 s. Diffractograms were analyzed using EVA and X'Pert High Score software \t LAMIGA Laboratory of the Federal University of Pará.

The pH was determined in a 1 mol $L^{-1}$ KCl suspension (soil/solution) and measured using a digital pH meter. Total organic carbon was measured using the Walkley–Black method through wet digestion in $K_2Cr_2O_7$ and concentrated $H_2SO_4$. TOC was digested in a digester pre-heated to 150 °C for 30 min after cooling and titrated to $Cr_2O_7^{2-}$ excess in ferrous ammonium sulfate. Total nitrogen was determined using the Kjeldahl method [22].

Exchangeable cations were obtained with 1 mol $L^{-1}$ KCl and analyzed using atomic absorption spectrometry ($Ca^{2+}$ and $Mg^{2+}$) and flame photometry ($Na^+$ and $K^+$). $Al^{3+}$ was analyzed by titration with NaOH. $H^+$ and $Al^{3+}$ was obtained in calcium acetate 0.5 mol $L^{-1}$ calcium acetate at pH 7.0 and measured through titration in NaOH to determine soil acidity. Phosphorus present in the soil was extracted using Mehlich-1 extraction and measured using the ascorbic acid method. Macro and micronutrient contents (Fe, Mn, Zn, and Cu) were determined using the method recommended in ISO standard 11466 (aqua regia digestion) and analyzed using atomic absorption spectroscopy (AAS) at the Chemical Analysis Laboratory of Museu Paraense Emilio Goeldi, Brazil.

Regression analysis (Statistica v. 6.0) was performed to determine the correlation between and the significance level ($r^2$; $p < 0.05$) of the following elements: composting temperature, room temperature, pH, and macro and micronutrients.

## 3. Results

### 3.1. Mineralogical and chemical characterization

Tomé-Açu is rich in sandy-clay soil (52.5% sand, 38.6% clay, and 8.9% silt, on average). Its mineralogical composition primarily involves quartz and kaolinite (Fig. 2a and b) and to a lesser extent goethite and hematite, neither of which were identified through X-ray diffraction. The prevalence of quartz and kaolinite indicates soil origin: laterite sediments in the Barreiras and Ipixuna formations [21]. The soil in the district had an acidic pH (average of 4.8) and kaolinite acidity of 5.5.

The organic matter content in the soil ranged from 0.6 to 3.1%. Total organic carbon (TOC) (1.2% ± 0.30) and total nitrogen (TN 0.09% ± 0.01) showed the highest concentrations among the macronutrients assessed. Phosphor (4.43 mg/kg ± 1.43) presented the lowest concentration values, followed by Na, K, Ca, and Mg < 1 $cmol_c$ $Kg^{-1}$ (Table 1). In contrast, $Al^{3+}$ ranged from 0.98 to 1.37 $cmol_c$ $Kg^{-1}$ and impacted the low Ca, K, and Mg levels. Cation exchange (CEC) ranged from 2.82 to 13.46 $cmol_c$ $Kg^{-1}$.

### 3.2. Chemical composition of samples

The chemical compositions of the raw materials are listed in Table 2. Total organic carbon (TOC) levels were higher in sawdust (54.87%, on average) but were lower for N, P, K, Ca, and Mg (<0.8%). Goat manure presented low TOC concentrations (20.27%, on average) and high TN concentrations (2.01%, on average), in addition to K, Ca, Mg, and P.

### 3.3. Physicochemical and chemical properties

The physical properties and chemical compositions of the compounds are shown in Table 2. The mean values recorded for the composting temperatures (COM-1B, COM-2B, and COM-3B) applied to the goat manure/sawdust mixture and the control (COM-B) without manure addition are shown in Fig. 3. Composting temperatures ranged from 36 to 43 °C in the mesophilic phase. These values were higher than the

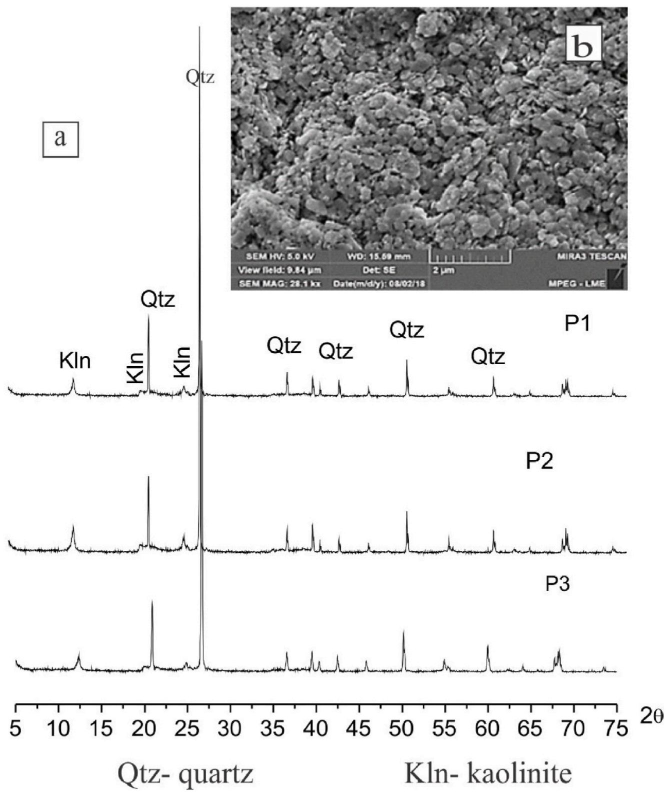


**Fig. 2.** (a) Total sample of X-ray diffractograms showing the principal minerals and (b) SEM image showing kaolinite layers in Tomé-Açu soils.

ambient temperature but similar to those observed for composts (COM-1B, COM-2B, COM-3B, and COM-B) that attained maximum temperatures in the thermophilic phase. The maximum temperature was 43–50 °C within 11–25 days and remained at 50 °C between days 20 and 24. After 24 days, the temperature decreased until it reached 26–27 °C.

The control compost bin e (COM-B), without goat manure, presented a temperature variation similar to that of the compost bins with goat manure, although with a lower temperature range of 34–39 °C (COM-B). After 25 d, the temperature decreased until it reached 26 °C (ambient temperature) on day 40.

The temperatures for the compost bins with and without manure were positively and significantly correlated ($r^2 = 0.98$; $p < 0.0001$, Table 4). When correlated with ambient temperature, they presented significant differences and were not statistically correlated ($r^2 = 0.3$; $p > 0.5$).

The pH values in goat manure compost samples initially ranged from 4.5 to 5.5 in the mesophilic phase (Fig. 4) due to ammonium loss caused by volatilization and nitrification. The pH ranged from 6.0 to 7.0 in the control compost (COM-B). The organic compound levels in all the composts in the thermophilic phase increased and reached a mean pH of ~7.0 ± 0.31 in all composts in the thermophilic phase. The finished compounds were stabilized at pH 7.5, 40 days after biodegradation.

The solid bio-compost (sawdust mixed with goat manure and green waste) had TOC levels ranging from 19.08 to 23.82% (21.25%, on average). Total nitrogen (TN) levels ranged from 1.45 to 3.10% (3.00% on average), whereas the C:N ratio reached 9.75 on average. The finished compound (bio-compost, COM-B) without goat manure presented TOC and TN levels of 21.70 and 1.50%, respectively. The C:N ratios ranged from 6.88 to 15.88 (Table 2). Total organic carbon (TOC) was not significantly correlated with temperature or pH in either experiment, whereas TN was positively correlated with temperature ($r^2 = 0.99$; $p = 0.002$) and negatively correlated with pH ($r^2 = 0.96$; $p =$

**Table 2**
Physical-chemical parameters and chemical composition of goat manure, sawdust and solid biocompost (dry weight base) of composting.

| | Goat manure | Sawdust | Biofertilizer with goat manure | Biofertilizer without manure |
|---|---|---|---|---|
| pH | N.a | N.a | 7.50 | 7.00 |
| C/N | 10.08 | | 9.75 | 14.47 |
| TOC (%) | 20.27 | 54.87 | 21.25 | 21.7 |
| TN (%) | 2.01 | 0.10 | 2.18 | 1.50 |
| P (%) | 0.57 | 0.02 | 3.30 | 1.30 |
| K (%) | 1.12 | 0.01 | 1.51 | 1.74 |
| Ca (%) | 0.38 | 0.31 | 3.74 | 3.21 |
| Mg (%) | 0.47 | 0.71 | 4.12 | 0.71 |
| Fe (μg $g^{-1}$) | N.a | N.a | 8834 | 10872 |
| Cu (μg $g^{-1}$) | N.a | N.a | 143 | 141 |
| Zn (μg $g^{-1}$) | N.a | N.a | 462 | 482 |
| Mn (μg $g^{-1}$) | N.a | N.a | 1073 | 1176 |

N.a: not analyzed, TOC: Total Organic Carbon, C/N ratio: Carbon/Nitrogen ratio.

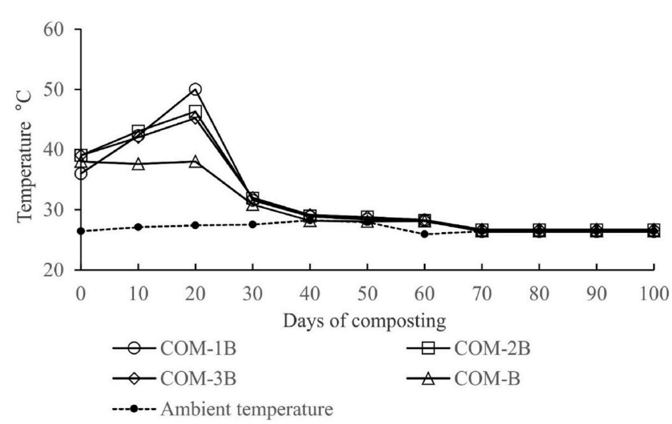


**Fig. 3.** Distribution of temperature values (°C) achieved in the compost bins during the composting process, and the ambient temperature values.

**Table 1**
Physical-chemical parameters and chemical composition of soils in Tomé-Açu.

| Sample | pH | TOC | TN | P | Al | K | Ca | Mg | CTC | C/N |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | mg/Kg | cmolc/Kg | | | | | |
| P1 | 4.89 | 1.38 | 0.11 | 5.30 | 1.17 | 0.04 | 0.83 | 0.17 | 6.71 | 12.50 |
| P2 | 4.75 | 1.45 | 0.09 | 2.81 | 1.22 | 0.03 | 0.63 | 0.15 | 6.18 | 16.11 |
| P3 | 4.77 | 1.51 | 0.08 | 4.24 | 1.32 | 0.03 | 0.58 | 0.17 | 12.16 | 18.87 |
| P4 | 4.91 | 0.83 | 0.08 | 3.14 | 1.27 | 0.04 | 0.57 | 0.28 | 3.57 | 10.37 |
| P5 | 4.95 | 0.87 | 0.10 | 6.70 | 1.20 | 0.04 | 0.71 | 0.23 | 3.46 | 8.70 |
| Average SD | 4.85 ± 0.07 | 1.20 ± 0.30 | 0.09 ± 0.01 | 4.43 ± 1.43 | 1.23 ± 0.05 | 0.034 ± 0.01 | 0.66 ± 0.01 | 0.20 ± 0.05 | 6.42 ± 3.16 | 13.31 ± 3.72 |

TOC: Total Organic Carbon; C/N ratio: Carbon/Nitrogen; SD: Standard deviation.

**Table 3**
Chemical composition of green residues and cow's milk in regions of Brazil and the world.

| Green waste | TOC | TN | P | K | Mg | Ca | Fe | Zn | Mn | Cu | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cabbage (*Brassica oleracea* var. *capitata*) | | * | 58[b] | 328[b] | 18[b] | 44[b] | 0.5[b] | 0.3[b] | 0.25[b] | 0.9[b] | [38] |
| | | | 26[b] | 170[b] | 12[b] | 40[b] | 0.47[b] | 0.18[b] | | | [39] |
| | | 2.86[a] | 0.41[a] | 2.54[a] | 0.71[a] | 0.58[a] | 61[c] | 0.12[c] | 45[c] | 3.5[c] | [40] |
| Carrot (*Daucus carota* L.) | | 3.06[a] | 28[b] | 315[b] | 11[b] | 23[b] | 0.2[b] | 0.2[b] | 0.05[b] | 0.05[b] | [38] |
| | | | 35[b] | 320[b] | 12[b] | 33[b] | 0.30[b] | 0.24[b] | – | – | [39] |
| | | | 0.98[a] | 4.25[a] | 0.3[a] | 2.54[a] | 319[c] | 43[c] | 311[c] | 21[c] | [40] |
| Lettuce (*Lactuca sativa* L.) | | * | 19[b] | 136[b] | 6[b] | 14[b] | 0.3[b] | 0.2[b] | 0.12[b] | 0.02[b] | [38] |
| | | | 33[b] | 238[b] | 13[b] | 35[b] | 1.24[b] | 0.2[b] | 0.179[b] | – | [39] |
| | | 51.5[c] | 0.12[c] | 0.73[c] | 0.06[b] | 0.14[b] | 235[c] | 6.8[c] | 11.6[c] | 1.88[c] | [41] |
| Potato (*Solanum tuberosum* L.) | | * | 39[b] | 302[b] | 15[b] | 4[b] | 0.4[b] | 0.2[b] | 0.1[b] | 0.09[b] | [38] |
| | | | 57[b] | 421[b] | 23[b] | 12[b] | 0.78[b] | 0.29[b] | 0.153[b] | – | [39] |
| Green waste (vegetables) | 15.30[a] | 2.90[a] | 0.18[b] | 0.95[a] | – | – | 145[c] | 64[c] | – | 1.32[c] | [26] |
| Cow milk | | * | 0.82[b] | 133[b] | 10[b] | 123[b] | 145[b] | 0.4[b] | 0.02[b] | 0.02[b] | [38] |
| | | | 0.230[d] | 0.143[d] | 0.011[d] | 0.117[d] | 400[e] | 4.000[e] | 30[e] | 120[e] | [39] |

TOC: Total Organic Carbon, TN: Total Nitrogen, P: Phosphorous, K: Potassium, Mg: Magnesium, Ca: Calcium, Fe: Iron, Zn: Zinc, Mn: Manganese and Cu: Copper in.
[a] (%).
[b] (mg g).
[c] (mg $kg^{-1}$).
[d] (g mL).
[e] (μg L).

**Table 4**
Regression coefficients for the relationship between physico-chemical parameters and concentration of TN, P, Ca, Mg, K elements and C/N ratio.

| Physical-chemical parameters and elements | Slope | Intercept | $r^2$ | *p-Value* |
|---|---|---|---|---|
| Temperature COM-B | | | | |
| COM-1B | −7.779 | 1.287 | 0.987 | 0.00001 |
| COM-2B | −7.081 | 1.683 | 0.982 | 0.00001 |
| COM-3B | −9.311 | 1.352 | 0.978 | 0.00002 |
| Ambient temperature | 24.361 | 0.099 | 0.267 | 0.572 |
| Temperature COM-B1 | | | | |
| COM-2B | 0.621 | 0.984 | 0.992 | 0.00000 |
| COM-3B | −1.211 | 1.058 | 0.995 | 0.00000 |
| Ambient temperature | 24.573 | 0.089 | 0.330 | 0.468 |
| Temperature | | | | |
| TN | −3.872 | 0.141 | 0.989 | 0.002 |
| C/N | 61.518 | −1.301 | 0.997 | 0.0002 |
| P | −8.166 | 0.284 | 0.979 | 0.001 |
| Ca | 0.184 | 0.080 | 0.260 | 0.379 |
| Mg | 0.178 | 0.014 | 0.200 | 0.450 |
| K | 3.289 | −0.042 | 0.102 | 0.598 |
| pH | | | | |
| TN | 6.833 | −0.571 | 0.968 | 0.002 |
| C/N | 4.262 | 0.118 | 0.994 | 0.0002 |

NT: Total Nitrogen, C/N ratio: Carbon/Nitrogen ratio.

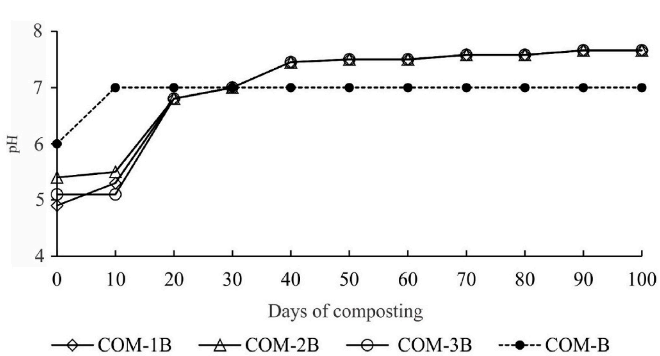


**Fig. 4.** pH values during the composting process for organic composts with and without goat manure in the compost bins.

0.002, Table 4). The C:N ratio was negatively correlated with temperature and positively correlated with pH ($r^2 = 0.99$, $p = 0.0002$, Table 4).

The phosphorus concentration in the goat manure bio-composts ranged from 2.81 to 6.08% (3.30%, on average), Ca ranged from 2.7 to 4.96% (3.63%, on average), and K ranged from 0.77 to 1.94% (1.51%, on average). Magnesium exhibited the lowest variation, ranging from 0.63 to 0.91% (0.87%, on average), as shown in Fig. 5. These values were higher than those recorded for the control (Table 2). Among the macronutrients (P, Ca, and Mg), Phosphorus presented the best positive correlation to temperature ($r^2 = 0.97$; $p = 0.001$, Table 4) among the set of elements assessed (P, Ca, and Mg).

The micronutrient concentrations of the solid bio-composts are listed in Table 2. The highest concentrations of Fe and Mn were recorded in both experiments: the manure bio-compost reached 8834 μg $g^{-1}$ and 1073 μg $g^{-1}$ on average. However, the control without manure showed 10872 μg $g^{-1}$ and 1176 μg $g^{-1}$ on average. Finally, Cu and Zn showed values < 490 μg $g^{-1}$ in both bio-composts (Table 2).

### 3.4. Chemical composition of the soil with biocompost

The chemical composition of the soil treated with the solid bio-composts (with and without goat manure) had significant effects. Ninety days after the application of organic fertilization, both showed a pH value of 7 and increased concentrations of TOC (4.77 and 3.60%), TN (0.32 and 0.17%), P (816.21 and 39.08 mg/kg), and K (91.88 and 317.09 mg/Kg), respectively. These values were significant when compared with those of the soil before treatment (Table 1).

Over 150 days, the *Hylocereus costaricensis* cladoids planted in the soil with biocompost, clearly revealed maximum vegetative growth in

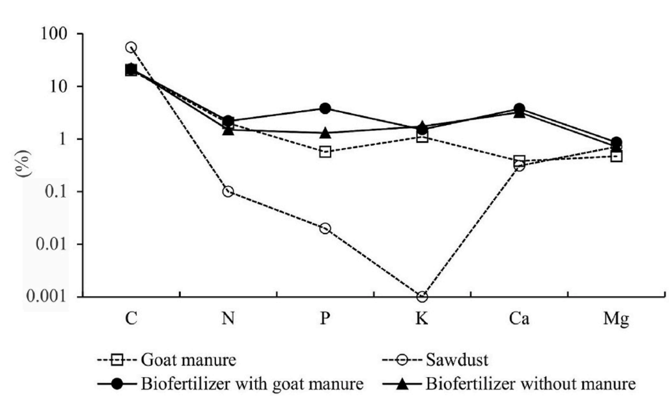


**Fig. 5.** Macronutrient composition in the organic wastes (raw material) and the organic compounds (dry-base biocompost) produced.

term of plant height an average of (71 ± 30 cm, Table 5). The data presented were significantly influenced by different combinations of bio-compost. An average plant height of (28 ± 7 cm) was observed without manure. Seedlings with chemical fertilization (N, P, K) had an average of plant height (38 ± 18 cm, Table 5).

## 4. Discussion

### *4.1. Changes in temperature, pH and macro and micronutrients during the composting process*

Tomé-Açu is rich in sandy clays. Kaolinite and quartz are the prevailing minerals in this soil, which corresponds to a chemical composition poor in macro-and micronutrients. Low CEC and high $Al^{3+}$ saturation are typical features of acidic Amazonian soils [21]. This indicates poor ion exchange. Tropical soils are primarily acidic due to CEC and soil pH [21].

There was a rapid rise in temperature from the beginning of the mesophilic phase to the thermophilic phase in both experiments. The temperature increase in the thermophilic phase was attributed to the following factors: heat-induced breathing, sugar decomposition, and starch and protein production by microorganisms [26]. These factors are the consequence of intense biodegradation of the most easily biodegradable organic matter fractions [25,26]. The high temperatures recorded in the composting system are similar to those found in goat manure [25,33] and rice straw [27] in sawdust [17] and sewage [28]. This was due to rapid disintegration of easily biodegradable organic fractions in the biocompost.

The green waste and cow's milk were not chemically analyzed to determine their macro-and micronutrient composition but had significantly impacts in this study. Green waste is rich in macro-and micronutrients, whereas milk is rich in Ca and P (Table 3). These materials were used to promote the growth of microbial populations, which accelerated the decomposition of organic matter during composting. In both treatments, the temperatures inside the compost bins were similar and had high positive correlations with levels of significance of $p < 0.0001$. The experiments, with and without manure, showed low correlations for pH measurements but a good level of significance ($r^2 = 0.50$; $p < 0.05$).

It was assumed that the amount of organic matter in the sawdust, green waste, and goat manure compost mixtures gradually decreased throughout the composting process owing to intense microbial activity and high temperatures, which stimulated the hydrolysis of some polysaccharides and resulted in rapid organic matter degradation [7,29]. Acid formation and polysaccharide decomposition occur during the bio-oxidation phase of organic matter degradation [23,24]. Such a decrease in the amount of organic matter can be attributed to manure and green waste mineralization since sawdust with high C:N ratio and lignin content are slow to degrade [28,30].

The maintenance of temperature during the composting process ensures organic matter stability and suppresses pathogenic microorganisms capable of infecting organic compounds with bacteria [7,28]. The temperature was maintained within the ideal range for composting (50–60 °C), indicating that the compounds were safe for agricultural use [27,28].

Goat manure, green waste, and cow's milk accelerated microorganism activity in compost with sawdust [43]. The finished organic compounds (solid bio-compost) presented pH values suitable for agriculture. Furthermore, they were within the pH range (6–8.5) obtained for this organic compounds [23,31].

The high TOC levels in sawdust were caused by the presence of lignin in the wood [30,32,33]. The relative increase recorded in the levels of K, Ca, Mg and TN found in goat manure is explained by the decrease in TOC in sawdust compounds [34].

The TOC value (54.87%) in sawdust presumably decreased during the composting process (Table 2) owing to microbial activity. Sawdust and green waste have high TOC contents. Carbon is used as an energy source by microorganisms that accumulate cell metabolic processes during composting [27]. The green waste provided most of the C absorbed by the microorganisms and converted into $CO_2$, which helped reduce the C:N ratio (7.08 and 14.47) in the finished compound [32]. Likewise, TN values may also increase owing to nitrogen-fixing bacteria that start acting at the end of the composting process [27,33].

The results of this study are within the range of the C:N < 20 ratios. This value is considered reliable and represents no restrictions for agricultural use [27,34]. It indicates the maturity of the finished compound [35]. Moreover, the accumulation of macronutrients (N, P, K, Ca, and Mg) and micronutrients (Fe, Mn, and Zn) in the finished compound and the low Cu level also indicate the maturity of the compound [27]. Metals such as Zn, Cu, Mn, and Fe are absorbed by plants during fertilization. Therefore, they are useful to trace elements for crop growth [27,29]. Potassium plays a crucial role in plant growth. It elongates the roots, improves protein synthesis, encourages enzymatic reactions, and improves photosynthetic processes and crop development [27].

The high Fe, Mn, Zn, and Cu levels in the soil were similar to those reported by Banegas et al. [28], who worked with anaerobic and aerobic composting and highlighted Fe and Zn accumulation during the composting process. These authors also mentioned that the low Cu concentration in the compost indicates compound maturity and biostability, which could be correlated with metal and nutrient accumulation. Iron accumulation is caused by moisture, carbon loss, and high temperatures during the bio-compost production process.

### *4.2. Effect of biocompost on plant growth*

The physicochemical parameters and chemical composition obtained in the experiments with and/or without manure were stable during the maturation period, indicating that during the composting process, the enrichment of macronutrients (TOC, N, Mg, Ca, and P) and micronutrients (Fe, Mn, Zn, and Cu) was provided by the green waste, and cow's milk because sawdust is nutrient-poor (Tables 2 and 3). The bio-compost with goat manure accounted for the largest share of N and K (80% on average). In the bio-compost without manure, the macro and micronutrients were obtained from green waste and cow's milk. Macro and micronutrients from bio-compost with and/or without manure were positively correlated ($r^2 = 98$; $p < 0.0001$). Based on these results, it can be concluded that the use of sawdust with goat manure alone is insufficient to produce high-quality bio-compost.

This study also confirmed that sawdust and goat manure, associated with green waste and cow's milk and developed under appropriate conditions, provided for the growth of microbial populations and increased the decomposition of organic matter, producing a high-quality bio-compost for use in agriculture [43]. The *Hylocereus costaricensis* cladoids planted in the soil in 150 days with biocompost showed the highest growth than planted with chemical fertilizers (N, P, K). The increased vegetative growth in this treatment might also be attributed due to the increased biological nitrogen fixation, better organic nitrogen

**Table 5**
Biometric monitoring of the maximum growth of Hylocereus costaricensis cladoids planted in soil with biocompost, chemical compound (N, P, K) and without treatment.

| Accompaniment (measurements cm) | Biocompost with manure (cm) | Biocompost without manure (cm) | Chemical compost (cm) | White (untreated) (cm) |
|---|---|---|---|---|
| Measure-1 | 26.7 | 18.3 | 18.0 | 6.8 |
| Measure-2 | 80.7 | 30.1 | 46.2 | 21.5 |
| Measure-3 | 95.9 | 34.9 | 59.5 | 36.7 |
| Measure-4 | 80.9 | 28.2 | 30.0 | 12.9 |
| Average | 71.0 | 27.8 | 38.4 | 19.5 |
| SD | 30.41 | 6.98 | 18.9 | 12.97 |

utilization, better development of root system and the possible synthesis of plant growth regulators like cytokinin's with the combined application of bio-compost [48].

Incorporation of bio-compost must have led to better mobilization of bound macro and micronutrients and improvement in the physical condition of the soil facilitating deeper penetration of the roots and higher nutrient extraction from the soil. This in turn might have enabled the to greater plant height [45–47], indicating that bio-composts are safe for agriculture and the nutrient-rich bio-compost with pH (≥7) can effectively ameliorate soils of an acidic nature.

The results recorded for macro and micronutrients of the soil fertilized with solid bio-compost suggest that the chemical composition of the poor soil in the region studied was beneficially altered to decrease acidity and toxicity, confirming that the bio-compost was of excellent quality. This change made the soil nutritionally fertile for crop development [36]. The use of this compound suggested that there was nutritional transfer [37,38,42].

## 5. Conclusion

The results confirmed that the period of experimentation bio-compost improve the physic-chemical properties of soil and can both become nutrient providers for plants. The bio-composts presented N, P, K, Mg, Zn, Cu, Fe, and Mn levels higher than those of the raw materials (sawdust and goat manure). Therefore, the final product absorbed the macro-and micronutrients required for soil recovery. Such outcomes make bio-compost suitable for agriculture due to its nutritional availability. Additionally, they make it possible to treat aluminum toxicity, a limiting factor for other substances.

## Declaration of competing interest

We, the authors, declare that no other people have met the authorship criteria but are not listed. We further confirm that the order of the authors listed in the manuscript has been approved by all of us and there are no conflict of interest.

## Data availability

Data will be made available on request.

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