# Composts from bovine rumen and chicken litter improve soil fertility and promote the growth of pepper (Capsicum chinense Jacq.)

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# Abstract

Organic waste from agricultural activities has the potential for reuse when treated and applied to the soil as organic fertilizers. This study investigated the effects of composted bovine ruminal content (CBR) and composted chicken litter (CCL) on the soil attributes, growth, and nutrition of *Capsicum chinense* Jacq. plants. The experiment was conducted at the Federal University of Piauí, Teresina, using a randomized block design with four replications in a 3×2 + 2 factorial scheme. Treatments included doses of 30, 60, and 90 Mg $ha^{-1}$ of CBR and CCL and two additional treatments (mineral fertilization, NPK; unfertilized soil, CK). The monitored variables included soil biological and chemical attributes, plant nutritional status, biometry, and dry matter. Results indicate that organic compost has the potential to improve soil attributes, such as pH, organic carbon, nitrogen, phosphorus, potassium, calcium, sodium, microbial biomass carbon, and soil respiration. Moreover, plant variables were positively affected by CBR and CCL, with a linear increase in response to CBR and a quadratic increase due to CCL. Nutrient concentrations in the leaves increased with compost application, except for iron. Therefore, CBR and CCL have the potential to improve soil chemical and microbiological attributes as well as support the development and nutritional status of *Capsicum chinense* Jacq. plants, suggesting that the use of organic waste as a fertilizer is a sustainable cultivation strategy.


# Introduction

Agriculture is an essential activity for maintaining human society as it is responsible for the production of food and raw materials for the industry. However, the global population has increased over the years, with an estimated 10.1 billion inhabitants by 2050, and food production has intensified, raising production costs due to the increased use of agricultural inputs such as mineral fertilizers (United Nations 2019; Allam et al. 2022). In addition, the generation of waste in production chains (998 million tons per year) has compromised environmental sustainability because of the inadequate disposal of organic materials that can be reused in agricultural areas (Obi et al. 2016; Urra et al. 2019; Trombetta et al. 2020).

Organic waste resulting from agricultural activities is an important source of nutrients for plants and can be used as organic fertilizers to improve soil quality, with the aim of increasing agricultural productivity and reducing production costs. According to Sayara et al. (2020), the application of organic waste to the soil can improve soil fertility because these materials are composed of a variety of essential nutrients for plant growth, such as nitrogen, phosphorus, and potassium. Furthermore, according to Eckhardt et al. (2021)d dtke et al. (2021), the use of organic waste can mitigate environmental impacts and reduce the dependence of farmers on chemical fertilizers.

Recent investigations indicate that the use of agricultural and livestock residues increases the levels of macro-and micronutrients, total organic carbon, pH, and soil microbial biomass, enhancing microbial activity (Frazão et al. 2019; Bhunia, Bhowmik, Mallick, & Mukherjee 2021; Sankar et al. 2022). However, the use of organic residues as fertilizers is limited by the risk of soil contamination due to heavy metal loads or pathogenic bacteria. Therefore, composting has been used as an effective technology for waste management and utilization in agriculture (Bhunia, Bhowmik, Mallick, & Mukherjee 2021).

Crop productivity and quality are directly related to the quality of the soil in which plants are grown. Thus, the availability of nutrients in considerable amounts in the soil favors the productive performance of crops; otherwise, it becomes a limiting factor in lower quantities (Kalu et al. 2021). The use of composted organic residues as fertilizer can improve soil quality and increase productivity, as already observed in various prominent crops, such as maize (*Zea mays*), common bean (*Phaseolus vulgaris*), and bell pepper (*Capsicum annuum*) (De Sousa et al. 2018; Bhunia, Bhowmik, Mallick, Debsarcar et al. 2021; Mendes et al. 2021; Sankar et al. 2022).

Pepper (*Capsicum* spp.), one of the main vegetables grown in Brazil (Acunha et al. 2017), is responsive to the application of organic composts. Previous studies have shown that the use of organic fertilizers significantly increases the growth and development of peppers and contributes to the nutritional status of the crop (Pereira et al. 2021; Jaaf et al. 2022). Among the pepper varieties, "biquinho" is a popular variety in Brazil and is gaining increasing popularity worldwide (Diel et al. 2020). Biquinho-type fruits are highly appreciated, mainly in the processed form as preserves, due to their aroma, crunchiness, and lack of pungency. This cultivar can also be used as ornamental pepper (Heinrich et al. 2015).

However, responses to the use of composted bovine ruminal content and chicken litter in soil properties where pepper is cultivated are still incipient, making it relevant to study the influence of these wastes on soil attributes and yield of the species. Therefore, in this study, the chemical and microbiological attributes of the soil, development, and nutritional status of yellow “biquinho” pepper (*Capsicum chinense*) in response to different doses of composted bovine ruminal content (CBR) and composted chicken litter (CCL) were evaluated.

# Materials and methods

### Location, characterization of soil and composts, and experimental design

The study was conducted in a protected environment (greenhouse) at the Center of Agricultural Sciences of the Federal University of Piauí, Teresina, Piaui State, Brazil (05°05’ S, 42°48’ W, 75 m), between November 2021 and February 2022. According to the Köppen classification, the region has an Aw climate (dry tropical with two distinct seasons: rainy summer and dry winter). The average annual temperature and rainfall in the region are 28°C and 1,325 mm, respectively (Bastos and Andrade Júnior 2019). The average climatic data for the experimental period are shown in Fig. 1.

The soil used in this study, a Dystrophic Yellow Argisol (PAd) (Argissolo Amarelo – Brazilian classification, Dos Santos 2018) without a history of agricultural use, was collected from the arable layer (0–20 cm) and characterized for chemical and physical attributes: pH ($H_20$) = 5.7; EC = 0.70 dS $m^{-1}$; P = 4.06 mg $dm^{-3}$; K = 0.06 $cmol_c$ $dm^{-3}$; Ca = 2.45 $cmol_c$ $dm^{-3}$; Mg = 0.50 $cmol_c$ $dm^{-3}$; Na = 0.07 $cmol_c$ $dm^{-3}$; Al

= 0.00 $cmol_c$ $dm^{-3}$; H + Al = 5.6 $cmol_c$ $dm^{-3}$; SB = 3.1 $cmol_c$ $dm^{-3}$; CTC = 8.7 $cmol_c$ $dm^{-3}$; V = 35.5%; Sand = 880 g $kg^{-1}$; Silt = 100 g $kg^{-1}$; Clay = 20 g $kg^{-1}$.

The organic residues (rumen content and chicken litter) used in the experiment were placed in 380 L perforated polyethylene boxes. These boxes were placed in 50% shade to avoid direct exposure to sunlight (Kiehl 2004). The residues were arranged in alternating layers, with sugarcane bagasse and bovine manure added at a 3:1:1 (v:v:v) ratio. The proportions of raw materials in the mixtures were designed to achieve a C:N ratio of 35–45, which is considered optimal for microbial growth that breaks down the materials into compost (Michel et al. 1996; Kumar et al. 2010). During the composting process (~ 120 days), several parameters, including temperature (27–59°C), moisture (40–60%), pH (9.4–6.6), and electrical conductivity (4.90–1.98 dS $m^{-1}$) were monitored weekly, and compost density (0.10 g $cm^{-3}$ for CBR; 0.15 g $cm^{-3}$ for CCL) was measured at the end of the process. After maturation, the compost samples were sent to the laboratory for chemical characterization (Table 1) following the methodology described by Teixeira et al. (2017).

Table 1
Chemical characterization of organic waste after 120 days of composting

| **Organic compost** | **pH** | **C** | **N** | **P** | **K** | **Ca** | **Mg** | **S** |
|---|---|---|---|---|---|---|---|---|
| | **($CaCl_2$)** | **%** | **———g $kg^{-1}$———** | | | | | |
| Rumen contents | 6.6 | 25.7 | 19.7 | 6.4 | 18.4 | 25.1 | 6.0 | 6.1 |
| Chicken litter | 7.8 | 11.4 | 10.9 | 16.9 | 26.0 | 158.2 | 13.2 | 3.1 |
| | EC | Zn | Mn | Fe | Cu | B | C:N | - |
| | dS $cm^{-1}$ | ———mg $kg^{-1}$——— | | | | | | |
| Rumen contents | 1.98 | 146 | 257 | 5,666 | 30 | 6.6 | 13.1 | - |
| Chicken litter | 4.17 | 317 | 500 | 2,724 | 61 | 21 | 10.5 | - |

EC: Electric conductivity

A randomized complete block design with four replications was adopted, in a factorial scheme with two additional treatments [(3×2) + 2]. The treatments referred to the dry-based doses of CBR and CCL, and two additional treatments were as follows: i) additional treatment 1 (mineral fertilization, NPK); ii) additional treatment 2 (unfertilized soil, CK); iii) 30 Mg $ha^{-1}$ of CBR; iv) 60 Mg $ha^{-1}$ of CBR; v) 90 Mg $ha^{-1}$ of CBR; vi) 30 Mg $ha^{-1}$ of CCL; vii) 60 Mg $ha^{-1}$ of CCL; viii) 90 Mg $ha^{-1}$ of CCL.

### Production of seedlings and preparation of treatments

In order to produce seedlings, seeds from the yellow "biquinho" pepper accession (BGC UFPI 205) were used, which were obtained from the *Capsicum* Active Germplasm Bank (BAGC) at the Federal University of Piauí. Seeds were sown per cell in a polystyrene tray with 128 cells filled with a commercial Basaplant® substrate, with two seeds sown per cell. Fifteen days after sowing (DAS), the seedlings were thinned out, leaving only the most vigorous plant in each cell.

Seedlings were transplanted at the six-leaf stage (~ 38 DAS) into pots (3.8 L) filled with the formulated treatments. The compost was mixed with soil and manually added to the pots according to defined doses. In Control Treatment 2, liming was performed by applying dolomitic limestone (PRNT = 90%). Mineral fertilization (NPK) was established according to the crop's needs (Ribeiro et al. 1999) using the following fertilizer sources: urea (45% N, 160 kg $ha^{-1}$ in split doses), simple superphosphate (18% $P_2O_5$; 600 kg $ha^{-1}$), and potassium chloride (58% $K_2O$; 120 kg $ha^{-1}$). The pots were regularly watered to maintain a moisture content close to 60% of field capacity.

### Evaluation of soil and plant attributes

Soil and plant samples were collected at the end of the cultivation period (~ 100 DAS). Soil chemical analysis included the quantification of total nitrogen (N), available phosphorus (P), exchangeable cations ($K^+$, $Ca^{2+}$, and $Na^+$), pH according to the methodology described by Silva (2009), electrical conductivity (EC) using the method described by Richards (1954), and total organic carbon (TOC) (Yeomans and Bremner 1988; Kirkels et al. 2014). Microbiological analyses of the soil included the determination of soil microbial biomass carbon (SMBC) using the irradiation-extraction method (Islam and Weil 1998), soil respiration (SR) by daily measurement of $CO_2$ release under aerobic incubation at 25°C for 7 days (Alef and Nannipieri 1995), metabolic quotient ($qCO_2$) calculated as the ratio of SR and SMBC (Anderson and Domsch 1993), and microbial quotient (*q*Mic), calculated as the ratio of SMBC to TOC, expressed as a percentage (%).

Plant parameters evaluated included plant height (PH, cm), measured from the base of the plant to the apex; relative chlorophyll index (RCI) measured by a portable electronic chlorophyll meter (ClorofiLOG Falker® CFL 1030) on the first complete leaf from the top of the branch; leaf area (LA; cm²), measured by the ImageJ® computer program; number of fruits per plant (NFP); shoot dry mass (SDM; g); and root dry mass (RDM; g), determined after drying in a forced air circulation oven at 65°C to obtain a constant weight. After drying, the leaves were ground using a Willye Model STAR FT-50 knife mill and sent to the laboratory for nutritional status analysis of the crop via chemical analysis of the plant tissue.

## Statistical analysis

Two-way ANOVA was used to test the effects of composted residues, compost doses, and their interactions on soil chemical and biological attributes, biometric parameters, and nutritional status of pepper plants. The normality of errors was indicated by the Shapiro-Wilk test, and variance homogeneity was assessed using Bartlett's K-squared test. Tukey's test ($p < 0.05$) was used for comparisons following ANOVA when appropriate. Principal component analysis (PCA) and heatmap were performed to categorize various characteristics (nutrient content in leaves, growth, and physiology) of pepper plants grown in soil under different doses of composted organic residues, illustrating the distinction between variables and the different treatments applied. All analyses were conducted using R v 4.1.3 (R Core Team 2022).

# Results

## Evaluation of soil attributes

The results demonstrated a significant interaction between the evaluated factors for pH, TOC, N, P, Ca, K, and Na, but not for EC (Supplementary Table S1). The highest EC values were observed with CCL application at a dose of 90 Mg $ha^{-1}$ (Supplementary Table S2).

The composts exhibited significant differences in pH at all doses applied to the soil. The CCL at doses of 30 and 60 Mg $ha^{-1}$ in relation to the CBR and at a dose of 90 Mg $ha^{-1}$, CBR stood out in relation to CCL (Table 2). There were no significant differences among the doses of CBR applied to the soil. However, with the application of CCL, the pH values were statistically similar at doses of 30 and 60 Mg $ha^{-1}$, but significantly lower at a dose of 90 Mg $ha^{-1}$.

Table 2
Mean values for significant interactions in the analysis of variance related to chemical properties of an Argisol under various organic compost and compost doses (Mg $ha^{-1}$)

| Organic compost | Doses of organic compost | | |
|---|---|---|---|
| | **30** | **60** | **90** |
| | pH | | |
| Rumen contents | 8.30 bA | 8.33 bA | 8.50 aA |
| Chicken litter | 8.68 aA | 8.80 aA | 8.15 bB |
| | TOC (g $kg^{-1}$) | | |
| Rumen contents | 14.03 aC | 17.43 aB | 20.09 aA |
| Chicken litter | 12.52 aA | 11.57 bA | 13.37 bA |
| | | N (g $kg^{-1}$) | |
| Rumen contents | 2.52 aA | 2.24 aB | 1.26 aC |
| Chicken litter | 1.54 bA | 1.26 bB | 1.05 aB |
| | P (mg $dm^3$) | | |
| Rumen contents | 1.27 bB | 1.27 bB | 2.13 bA |
| Chicken litter | 2.35 aC | 4.57 aB | 5.62 aA |
| | | K (mg $dm^3$) | |
| Rumen contents | 22.75 bB | 19.25 bB | 97.50 bA |
| Chicken litter | 60.25 aC | 51.25 aB | 252.25 aA |
| | Ca ($cmol_c$ $dm^{-3}$) | | |
| Rumen contents | 2.57 bC | 3.17 bB | 3.87 aA |
| Chicken litter | 3.48 aB | 3.54 aAB | 3.79 aA |
| | Na (mg $dm^3$) | | |
| Rumen contents | 58.50 bB | 61.25 bB | 95.5 bA |
| Chicken litter | 66.25 aC | 75.50 aB | 166.5 aA |

Means followed by the same letter, lowercase in the column (dose levels) and uppercase in the row (levels of compost) do not differ statistically by Tukey's test ($p < 0.05$)

An increase in organic fertilization increased the total organic carbon (TOC) concentration of the soil. The highest doses of CBR (60 and 90 Mg $ha^{-1}$) resulted in the highest TOC concentrations, with the highest dose (90 Mg $ha^{-1}$) having the highest TOC concentration. There was no significant difference in the TOC values among the CCL doses (Table 2).

CBR and CCL composts reduced the nitrogen concentration in the soil at different applied doses (Table 2). In the case of CBRC, there was a 12.5% reduction when the dose was increased from 30 to 60 Mg $ha^{-1}$. By increasing the dose from 30 to 90 Mg $ha^{-1}$, the reduction was 100%, indicating that the nitrogen concentration was completely reduced. There was a 77.8% reduction in N concentration between the doses of 60 and 90 Mg $ha^{-1}$. For CCL, doses of 30, 60, and 90 Mg $ha^{-1}$ resulted in reductions of 22.2%, 46.7%, and 20%, respectively. The greatest reduction occurred between the lowest and highest doses, followed by the reduction between the lowest and intermediate doses, and the lowest reduction occurred between the highest doses.

The highest contents of P, K, and Na were obtained with the highest compost dose (90 Mg $ha^{-1}$), which differed from the other applied doses (Table 2). The calcium (Ca) content presented similar results, except for doses of 30 and 60 Mg $ha^{-1}$ of CCL. The chicken litter had higher values than the CBR for all applications.

Analysis of soil microbiological attributes showed that compost promoted changes in SMBC and $qCO_2$, and doses influenced SMBC, SR, $qCO_2$, and *q*Mic (Supplementary Table S3). There was also an interaction (compost × dose) between SMBC and SR ($p < 0.05$). The SMBC, $qCO_2$, and *q*Mic values showed a significant difference ($p < 0.05$) between the doses and additional treatments (Fig. 2). In SR, the lowest dose of CBR (30 Mg $ha^{-1}$) was similar to both additional treatments, and the same dose of CCL differed only from the NPK treatment.

Increasing doses of CBR compost resulted in an increase in soil SMBC, with the best response observed at the highest dose (90 Mg $ha^{-1}$), which was statistically different from the lower doses ($p < 0.05$) (Fig. 2A). Similar results were observed with the application of the CCL compost. Comparing the composts, CBR stood out at all doses compared with CCL, with the highest improvement being promoted by CBR at the highest dose.

Regarding SR (Fig. 2B), doses of 60 and 90 Mg $ha^{-1}$ of CBR showed the highest values when compared to the lowest dose of compost, unlike the CCL doses, which responded similarly. Among the composts, the highest SR was observed when CBR was applied at a dose of 90 Mg $ha^{-1}$, which differed from the same dose of CCL. The composts were similar when applied at a dose of 60 Mg $ha^{-1}$, and the application of CCL at the lowest dose (30 Mg $ha^{-1}$) was superior to that of CBR.

The $qCO_2$ at a dose of 90 Mg $ha^{-1}$ of compost was lower than that at doses of 30 and 60 Mg $ha^{-1}$ ($p < 0.05$) (Fig. 2C). Among the composts, the lowest $qCO_2$ was observed with CBR application. As for *q*Mic

(Fig. 2D), a higher increase was observed when compost was added at a dose of 90 Mg $ha^{-1}$, which differed statistically from lower doses ($p < 0.05$) (30 and 60 Mg $ha^{-1}$).

## Plant evaluation

### *Morphophysiological and yield characteristics*

A significant interaction effect was observed between doses and composts for SDM, RCI, LA, and NFP variables, but only doses influenced RDM, and there was no influence of compost and dose factors on plant height (PH) (Supplementary material S4).

The plants responded differently to the addition of CBR and CCL. For CBR, the linear model best fit the dose response (Fig. 3), showing that the best response was observed with the highest dose of compost, which was significantly different from the other doses for SDM, RCI, LA, and NFP (Table 3). A linear increase in response to increasing doses of CBR was also observed for the RDM and PH variables (Fig. 3B and Fig. 3C).

In contrast, for CCL, the best response model was quadratic (Fig. 3). The SDM and LA of plants responded similarly to compost doses of 30 and 60 Mg $ha^{-1}$, where an increase in their values was observed, followed by a reduction when subjected to a higher dose (Fig. 3A and Fig. 3E). The maximum values of SDM (4.30 g $plant^{-1}$) and PH (432.52 $cm^2$ $plant^{-1}$) were observed at doses of 54.49 Mg $ha^{-1}$ and 57.69 Mg $ha^{-1}$, respectively.

No significant effect of applied CCL doses was observed for RCI (Fig. 3D) ($p > 0.05$) (Table 3), whereas the highest number of fruits per plant was obtained with the application of 73.92 Mg $ha^{-1}$ of CCL. For RDM (Fig. 3B), inflection of the curve was observed at a dose of 88 Mg $ha^{-1}$ of CCL, and for PH, a reduction in plant height was observed at a dose of 55.62 Mg $ha^{-1}$ of CCL (Fig. 3C).

Among the composts, CCL applied at a dose of 30 Mg $ha^{-1}$ obtained the highest SDM and RCI values. At a dose of 60 Mg $ha^{-1}$, both composts had similar values for these variables. However, at the highest dose (90 Mg $ha^{-1}$), CBR showed better results than CCL did. For AF and NFP, only ruminal compost residue showed better results at the highest dose (90 Mg $ha^{-1}$), which was significantly different from the lower doses of CCL (Table 3).

Table 3
Mean values of significant interactions in the analysis of variance related to the evaluation of pepper plants grown in an Argisol treated with different organic composts and compost doses (Mg $ha^{-1}$)

| Organic compost | Doses of organic compost | | |
|---|---|---|---|
| | 30 | 60 | 90 |
| | SDM (g $plant^{-1}$) | | |
| Rumen contents | 2.50 bC | 3.63 aB | 4.60 aA |
| Chicken litter | 3.91 aA | 3.95 aA | 2.93 bB |
| | RCI | | |
| Rumen contents | 51.71 bB | 53.92 aB | 64.20 aA |
| Chicken litter | 56.82 aA | 56.05 aA | 57.61 bA |
| | LA ($cm^2$ $plant^{-1}$) | | |
| Rumen contents | 182.57bC | 267.25 bB | 445.09 aA |
| Chicken litter | 367.71aAB | 414. 53 aA | 326.35 bB |
| | NFP | | |
| Rumen contents | 25.25 bC | 53.75 bB | 80.00 aA |
| Chicken litter | 48.50 aB | 64.00 aA | 65.50 bA |

Means followed by the same letter, lowercase in the column (dose levels) and uppercase in the row (levels of compost) do not differ statistically by Tukey's test ($p < 0.05$)

*Nutritional status of plants*

After the application of the composts, there was a significant increase ($p < 0.05$) in nutrient concentration in the leaves, with significant differences between doses and additional treatments, except for iron (Fe) content (Supplementary material S5). An interaction effect was observed only for zinc (Zn) and manganese (Mn) concentration. For nitrogen (N), potassium (K), magnesium (Mg), and copper (Cu), the factors showed significant individual effects. Only the compost factor significantly influenced the calcium (Ca) and sulfur (S) concentration, and the dose factor influenced the Fe concentration. There was no significant difference in the phosphorus (P) concentration.

Regarding Zn values, among the doses of CBR, the dose of 90 Mg $ha^{-1}$ showed the highest average (57.38 mg $kg^{-1}$), which was statistically different from the doses of 30 and 60 Mg $ha^{-1}$ (45.55 and 51.67 mg $kg^{-1}$, respectively). Regarding the application of dairy CCL, doses of 60 and 90 Mg $ha^{-1}$ responded similarly, with averages of 46.53 and 48.32 mg $kg^{-1}$, respectively, and were higher than the dose of 30 Mg $ha^{-1}$ (29.88 mg $kg^{-1}$) (Supplementary material S6). When analyzing the composts, CBR showed better results than CCL at the three levels of evaluated doses. Regarding Mn values, the dose of 30 Mg $ha^{-1}$ of CBR was superior (83.31 mg $kg^{-1}$) to the other doses and differed only from the dose of 60 Mg $ha^{-1}$ (68.52 mg $kg^{-1}$), unlike CCL, which had the highest average with the application of the highest dose (75.59 mg $kg^{-1}$), followed by the dose of 60 Mg $ha^{-1}$ (74.01 mg $kg^{-1}$), which differed from the dose of 30 Mg $ha^{-1}$ (45.71 mg $kg^{-1}$). When comparing the composts, a difference was observed only at a dose of 30 Mg $ha^{-1}$, with emphasis on a higher CBR content.

The results indicated that a dose of 90 Mg $ha^{-1}$ was the most efficient in improving N, K, Mg, Fe, and Cu concentration in the leaves, showing statistically significant differences compared to the other doses, except for K content (Supplementary material S5). CCL had higher nutrient concentration in the leaves compared to CBR, especially for N, K, Cu, and S, while Ca and Mg showed a significant increase after the application of composted ruminal content ($p < 0.05$).

*Multivariate analysis*

Principal component analysis (PCA) considered the nutrient concentrations in the leaves and the morphophysiological parameters of the different treatments. The two principal components represented 78.5% of the data variability, with 63.5% for PC1 and 15% for PC2 (Fig. 4A). A positive correlation was observed between the higher compost doses for morphophysiological parameters (PH, SDM, LA, RCI, NFP, and RDM) and the N, K, Cu, and Zn concentrations, which were highly correlated with each other. PCA also showed a clear positive correlation between the P, S, Mg, Ca, and Mn concentrations and the application of NPK.

The heatmap indicates the relative performance of pepper plants grown in soil with compost application compared to the control conditions (CK). According to the color scale, the darkest red color represents the highest values, whereas the darkest blue ranges represent the lowest values of the experimental conditions (Fig. 4B). The concentrations of N, K, Cu, and Zn in the leaves showed moderate trends in pepper plants grown in soil under CBR30 to CCL30 compared to plants under control treatments (CK and NPK) and CBR60, CBR90, CCL60, and CCL90. Fe concentration in pepper leaves increased with the application of higher compost doses (90 Mg $ha^{-1}$). The morphophysiological parameters (RDM, SDM, PH, NFP, and RCI) showed considerable variation between pepper plants under the CBR90 and control treatments, indicating a crop response to compost application.

# Discussion

## Evaluation of soil attributes

The observed changes in soil pH after the application of compost may be related to the complexation of $H^+$ ions due to the increase in organic matter content in the soil (De Souza et al. 2021). The reduction in pH observed at the highest CCL dosage may be associated with the release of organic acids that have not yet dissociated during organic matter decomposition (Ernani 2016).

The increase in soil organic matter content owing to the application of the composted residues evaluated in this study also increased the TOC concentration, and the best response was obtained at the doses of CBR with the highest C:N ratio presented by the compost (Table 1), providing a 45% increase in organic carbon compared to the CK treatment. A similar result was observed by Araújo et al. (2018) who used permanent application of organic residues in the soil. The addition of organic materials to soil has favored the accumulation of carbon, which is an important mechanism among conservation practices to minimize climate change and maintain sustainability in agricultural cultivation soils (Cui et al. 2021).

The reduction in nitrogen content with increasing compost doses can be explained by its high mobility in the soil and the large amount required by pepper crops (Silva 2009). When organic residues with a C:N ratio below 20:1 are incorporated into the soil, N is rapidly mineralized by microorganisms, because it is an immediate source of the microbial population (Batista et al. 2018). When N is available in the soil in a form assimilable by plants, it is quickly absorbed by the roots and exported to the leaves, which is associated with an increase in photosynthetic activity. It is then redistributed to the fruits, which are the main sink of the plant during the fruiting phase and depend on the nutrient supply for their metabolism (Sousa et al. 2015; Kiboi et al. 2019; Prado 2021).

The organic composts applied to the soil positively influenced the availability of nutrients, such as P, K, and Ca, as evidenced by the increase in their levels in response to the applied doses. CCL compost had the highest contribution because of the higher nutrient concentrations in the compost (Table 1). This effect has been observed in other studies, such as those by Cui et al. (2021) and Jaaf et al. (2022), which relate the increase in nutrient availability to the decomposition of the organic components of the compost.

The application of organic materials also stimulated soil microbial activity, as indicated by the higher values of SMBC observed with the application of CBR. This increase can be attributed to the higher carbon content in the compost, which provided a significant increase in SMBC compared with the NPK and CK treatments. Microbial biomass is important for the decomposition of organic materials and availability of energy and nutrients in the soil, and the addition of waste to the soil can enhance this microbiological activity. This has been observed in other studies, such as that of De Nascimento et al. (2022), who also observed an increase in SMBC with organic fertilization.

The results of the SR (Fig. 2) showed that the increase in microbial activity stimulated by the addition of organic residues is related to the presence of organic matter (Araújo and Monteiro 2007; Ferreira et al. 2018). The SR values found at a dose of 60 Mg $ha^{-1}$ for both composts were 30% higher than those of the additional treatments. Some soil management practices can directly affect soil microbial communities (Ferreira et al. 2015). Therefore, it is important to evaluate the efficiency of carbon use by soil microbial biomass because the oxidation of organic matter to $CO_2$ may not reveal microbial activity.

The low values of $qCO_2$ in the soil that received 60 Mg ha$^{-1}$ of organic compost (Fig. 2C) indicate greater efficiency in carbon use by soil microbial biomass, confirming that for biomass to be considered efficient, it should have a lower respiration rate (Dos Reis Junior 2007; Silva et al. 2021). In contrast, higher $qCO_2$ in the additional treatments (CK and NPK), especially in the treatment with only soil, indicated little use of C and loss in the form of $CO_2$. The observed increase in *q*Mic values, mainly at higher compost dosages, reflects the quality of the organic matter applied to the soil and efficiency of microbial activity (Silva et al. 2021).

## Plant evaluation

### *Morphophysiological and yield characteristics*

The addition of organic composts from CBR and CCL can improve the performance of pepper crops, resulting in increased dry matter production of shoots and roots, leaf area, chlorophyll index, and pepper plant yield. This effect can be explained by the increase in nutrient levels in the soil, especially nitrogen and phosphorus, which influence the photosynthetic activity, cell division, root development, and fruiting of plants.

In previous studies (Gomes et al. 2019; Kang et al. 2022) indicated that well-nourished plants perform better in terms of leaf area, chlorophyll index, and root system. Furthermore, organic fertilization may be more efficient in promoting plant growth and development, as shown in studies with other crops such as basil (*Ocimum basilicum* L.) (Paillat et al. 2022). However, it is important to note that the dose and quality of organic composts used should be carefully evaluated, taking into consideration crop, sustainability, and environmental preservation.

Based on studies conducted on pepper cultivation, it can be stated that a soil sodium content above 0.6 cmolc dm$^{-3}$ can be considered critical for proper crop development. This finding has been confirmed by various authors, including Liu et al. (2022) and Da Silva et al. (2021), who indicated that excess sodium in the soil can negatively affect nutrient absorption by plant roots, trigger ionic imbalances, and impair plant development. This can explain the quadratic effect observed in the morphophysiological variables of the plant with increasing doses of CCL and, therefore, the lack of availability of other elements at desirable levels for the crop.

### *Nutritional status of plants*

This study showed that the application of organic compost to pepper cultivation can influence nutrient uptake by plants. The application of these composts increased nitrogen and magnesium levels in pepper leaves, reaching ideal levels for the crop (30–45 and 3–12 g kg$^{-1}$, respectively), as reported by Silva (2009). However, the application of compost also increases potassium levels, which could hinder the absorption of other nutrients, such as calcium (Silva and Trevizam 2015).

Calcium values found in the leaves were lower than those necessary for the crop (15–35 g $kg^{-1}$), which may be explained by a reduction in soluble calcium availability in the soil due to the presence of other cations in greater concentrations, such as potassium (Prado 2021). Excessive accumulation of K in the soil can affect the availability and uptake of other essential nutrients for plants, leading to a nutritional imbalance that can harm agricultural production. This phenomenon may explain the relationship observed between increasing doses of organic composts and the quadratic effect on pepper morphophysiological variables, indicating the importance of proper management of soil fertilization to ensure healthy and sustainable plant growth.

The reduction in Mn concentration in pepper leaves after CBR application may be related to complex formation with organic matter in the soil, resulting in lower Mn availability for the plant, following a similar pattern to that observed in organic soils, as explained by Carvalho Filho et al. (2011). On the other hand, an increase in Zn concentration was observed with increasing doses of compost, especially with the use of CBR, remaining within the suitable range for pepper development (30–100 mg $kg^{-1}$). As for Cu, despite the increase in compost doses, the levels remained within the ideal and tolerable range for the plant (8–20 mg $kg^{-1}$). These results highlight the importance of the proper management of organic fertilizers to ensure balanced plant nutrition.

## Conclusions

The study analyzed the effects of applying organic composts to the soil-on-soil attributes, microbial activity, and nutrient availability for pepper cultivation. The results indicate that applying organic composts positively influenced nutrient availability, such as phosphorus, potassium, and calcium, as well as soil organic matter content and total organic carbon. Applying organic composts also increased soil microbial biomass, indicating that organic composts can enhance microbiological activity.

These findings suggest that adding organic composts to the soil is an effective practice for improving soil quality. Additionally, the type of compost and the dosage added to the soil should be considered when selecting the best compost for soil application. Further studies are needed to investigate the long-term effects of adding organic composts to the soil and their influence on crop productivity.

## Declarations

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# Declaration of interest statement

The authors report there are no competing interests to declare.

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# Figures

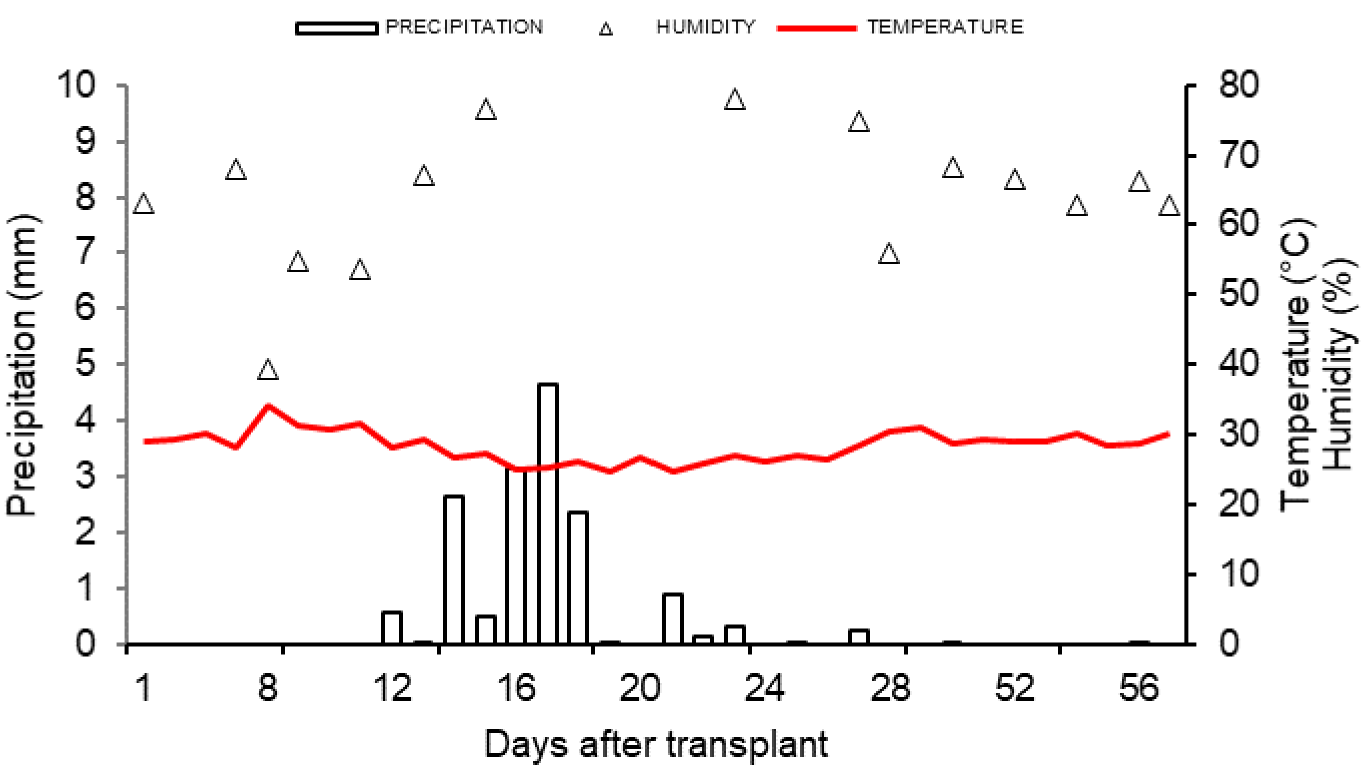
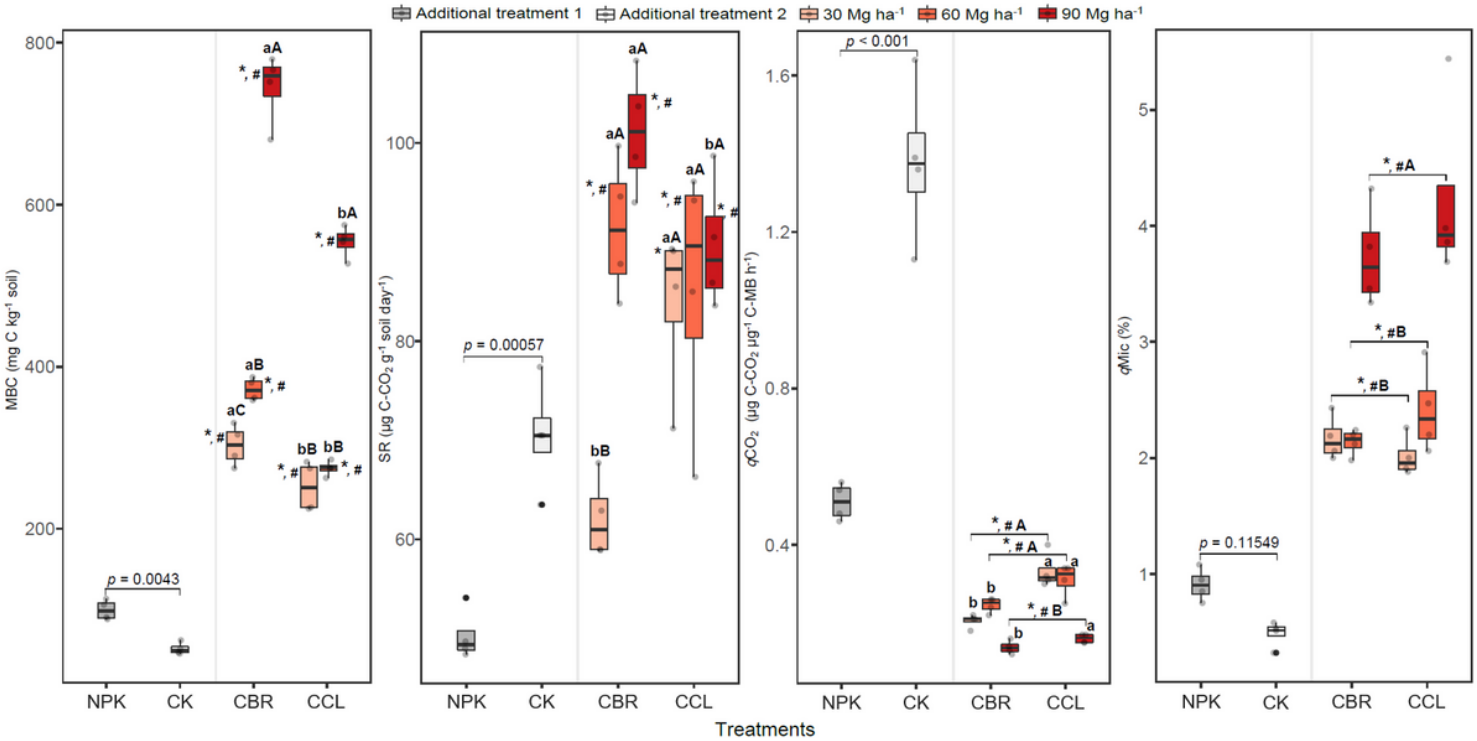


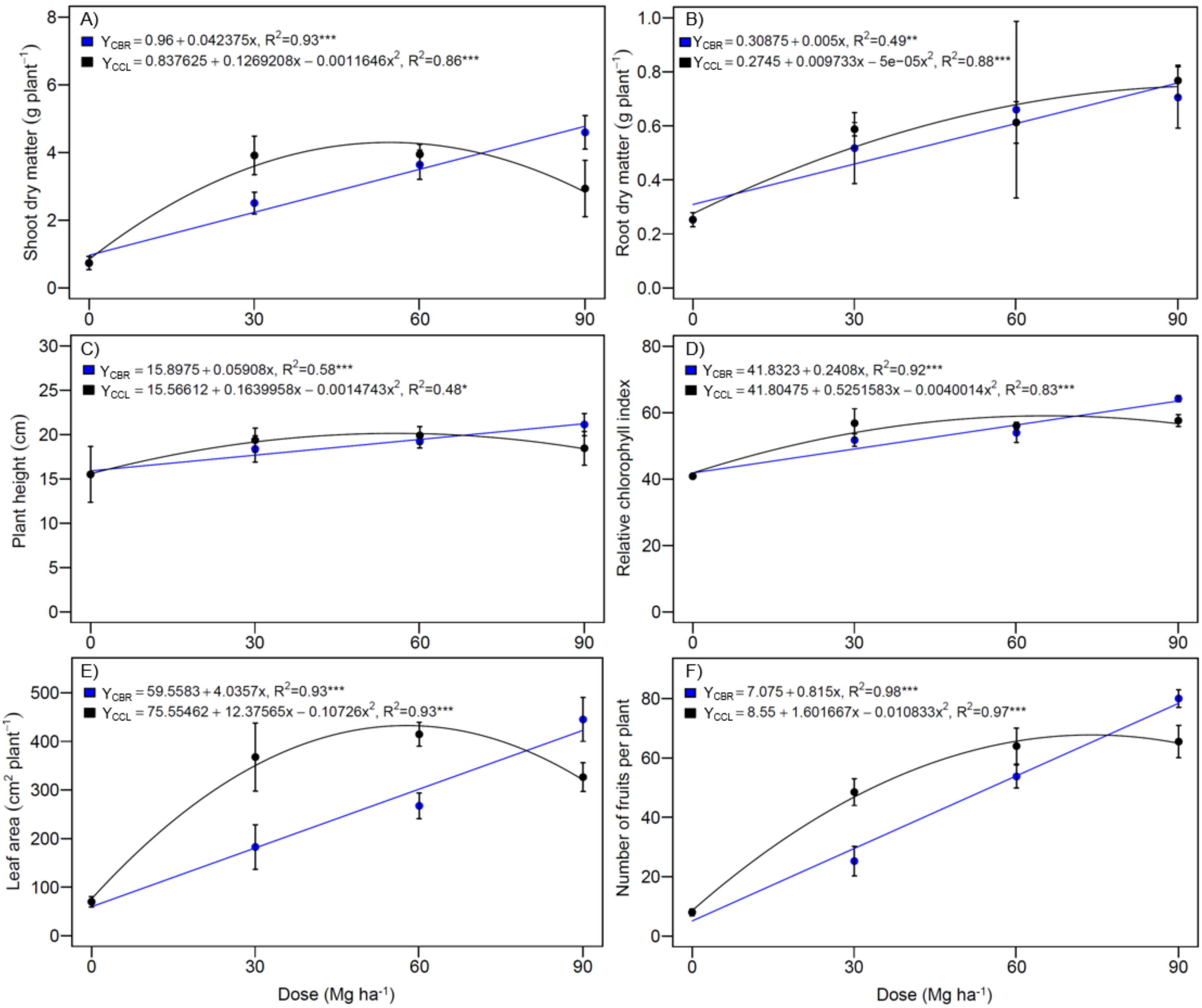

**Figure 1**

Graphic representation of average precipitation (mm), temperature (°C) and humidity (%), during the experimental period (December 16, 2021 to February 11, 2022). Source: INMET



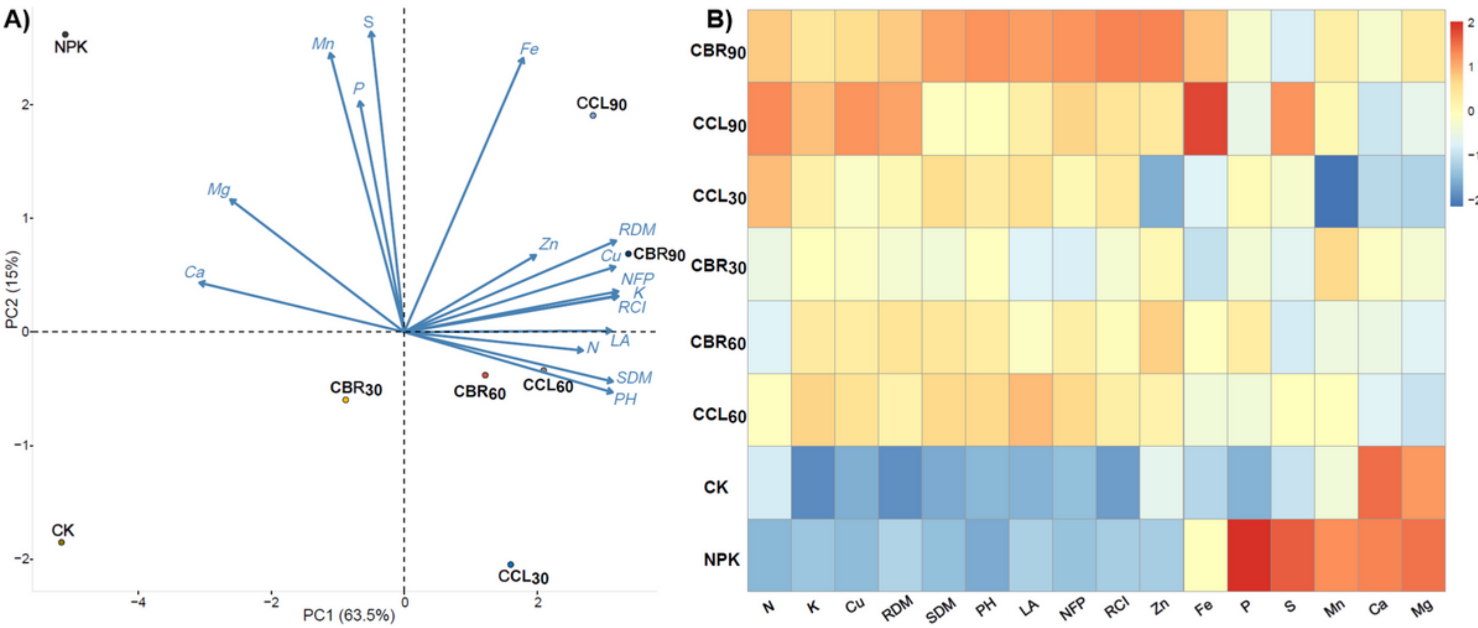

## Figure 2

Box plot with values of biological attributes of an Argisol subjected to different treatments. Uppercase letters compare dose factor levels within compost factor levels, and lowercase letters compare compost factor levels within dose factor levels by Tukey's test ($p < 0.05$). *Statistically lower average than the additional treatment 1 (CK) by Dunnett test at 5% probability. #Statistically superior average than the additional treatment 2 (NPK) by Dunnett test at 5% probability




## Figure 3

Shoot (A) and root dry matter weight (B), plant height (C), relative chlorophyll index (D), leaf area (E) and number of fruits per plant (F) according to different doses of organic compost in Argisol. CBR=composted bovine rumen content; CCL= composted chicken litter




## Figure 4

Principal component (A) and heat map (B) of leaf nutrient content and morphophysiological variables of pepper plants grown in Argisol under different treatments. CBR=composted bovine rumen content; CCL= composted chicken litter; 30, 60 e 90 Mg of compost per ha; RDM = root dry matter; SDM = Shoot dry matter weight; PH = plant height; LA = leaf area; NPF = number of fruits per plant; RCI = relative chlorophyll index

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