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Agro-industrial organic fertilizers for bell pepper (*Capsicum annuum* L.) growth and nutrition

Fertilizantes orgánicos agroindustriales para el crecimiento y la nutrición del pimiento (*Capsicum annuum* L.)

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Abstract

Agro-industrial wastes can be transformed into low-cost agricultural inputs while mitigating environmental risks associated with improper disposal. Bell pepper (*Capsicum annuum* L.) is a vegetable of high economic importance, widely consumed in Brazil and worldwide. This study evaluated the effect of organic fertilizers derived from agro-industrial wastes on bell pepper cultivation in two soil types: Dystrophic Yellow Oxisol and Quartizarenic Neosol. Two fertilizers were tested: PSSD, made with spent mushroom substrate from oil palm waste combined with compost from the dairy industry, and SSSD, produced with spent mushroom substrate from sisal waste combined with the same compost. Fertilizer doses ranged from 0 to 60 t ha^{-1}, alongside a chemical fertilizer treatment (60 N, 300 P, 240 K kg ha^{-1}). Plant growth parameters, including height, stem diameter, number of leaves, flowers, fruits, and biomass, were assessed. Nutrient concentrations (N, P, K, Ca, Mg, S) were measured at flowering (45 days after transplanting). Although chemical fertilization improved initial plant development, it resulted in lower fruit yields. Organic fertilizers, particularly PSSD and SSSD at 60 t ha^{-1}, significantly increased plant biomass and nutrient content, enhancing fruit yield by 62 % compared to chemical fertilization in Quartizarenic Neosol. Organic fertilization with these materials, starting at 30 t ha^{-1}, promoted greater dry matter accumulation and productivity. Overall, the study demonstrates the potential of PSSD and SSSD as sustainable fertilizers for bell pepper production, especially in sandy soils such as Quartizarenic Neosol.

Keywords: *Agave sisalana*, *Elaeis guineas*, *Pleurotus ostreatus*, plant growth and nutrition, spent mushroom substrate.

Resumen

Los residuos agroindustriales pueden transformarse en insumos agrícolas de bajo costo, mitigando los riesgos ambientales asociados con su disposición inadecuada. El pimiento (*Capsicum annuum* L.) es una hortaliza de alta relevancia económica, ampliamente consumida en Brasil y a nivel mundial. Este estudio evaluó el efecto de fertilizantes orgánicos derivados de residuos agroindustriales en el cultivo de pimiento en dos tipos de suelo: latossolo amarillo distrófico y neosol cuartzarénico. Se probaron dos fertilizantes: PSSD, elaborado con sustrato poscultivo de hongos a partir de residuos de palma de aceite combinado con compost de la industria láctea, y SSSD, con sustrato poscultivo de hongos a partir de residuos de sisal combinado con el mismo compost. Las dosis de fertilizante oscilaron entre 0 y 60 t ha^{-1}, junto con un tratamiento de fertilización química (60 N, 300 P, 240 K kg ha^{-1}). Se evaluaron parámetros de crecimiento vegetal como altura, diámetro del tallo, número de hojas, flores, frutos y biomasa. Las concentraciones de nutrientes (N, P, K, Ca, Mg, S) se midieron durante la floración (45 días después del trasplante). Aunque la fertilización química mejoró el desarrollo inicial de las plantas, resultó en menor rendimiento de frutos. Los fertilizantes orgánicos, particularmente PSSD y SSSD a 60 t ha^{-1}, incrementaron significativamente la biomasa vegetal y el contenido de nutrientes, mejorando el rendimiento de los frutos en un 62 % en comparación con la fertilización química en neosol cuartzarénico. La fertilización orgánica con estos materiales, comenzando a partir de 30 t ha^{-1}, resultó en un volumen mayor de materia seca y una mayor productividad. El estudio demuestra el potencial de los fertilizantes PSSD y SSSD para la producción sostenible de pimiento, especialmente en suelos arenosos como el neosol cuartzarénico.

Palabras clave: *Agave sisalana*, crecimiento y nutrición vegetal, *Elaeis guineensis*, *Pleurotus ostreatus*, sustrato poscultivo de hongos.

Introduction

Bell pepper (*Capsicum annuum* L.), like most vegetables, has high nutrient requirements, which can be met through chemical and organic fertilizers (Shehata *et al*., 2018). The interest in organically produced foods, especially vegetables, has increased with consumer´s growing awareness of the health and environmental risks associated with chemical inputs in agriculture. Achieving high yields and ensuring food safety require efficient plant production systems that promote not only a greater number and weight of fruits but also improved fruit quality (Conti *et al*., 2014).

Bell peppers are the third most cultivated solanaceous crop in the world and are amongst the ten most cultivated vegetables in Brazil, holding significant socioeconomic importance and prominence in family farming systems and the agro-industry (Lopes *et al*., 2018).

The use of by-products from agro-industrial activities is an important practice aimed at reducing fertilizer costs. In addition to increasing crop productivity, this approach is an effective option for reusing agro-industrial wastes, thereby preventing their inadequate disposal in the environment (Mendes *et al*., 2020). Various agricultural residues can be used in the formulation of substrates and fertilizers, which makes it a promising solution for the reuse of these materials (Singh *et al*., 2020), including spent mushroom substrates (Zhu *et al*., 2018) and wastes from dairy industries (Oliveira, 2020). Bell pepper cultivation in pots under protected environments, such as greenhouses, has been gaining popularity among producers.

Therefore, cultivating bell peppers under these conditions with organic soil amendments may represent an economically viable alternative for producers, while ensuring an organically grown horticultural crop with high added value. Considering the abundance of solid wastes from spent mushroom substrates and dairy industries, our hypothesis is that formulations with these wastes as organic amendments for bell pepper production constitute a viable fertilization technology for this crop. This study aimed at evaluating bell pepper production in pots using different sources and doses of organic fertilizers formulated from agro-industrial wastes.

Materials and methods

Two experiments were conducted under greenhouse conditions at the geographical coordinates 12º40'19" S, 39º06'23" W, using pots filled with soil. Each experiment was carried out with a different soil type: Dystrophic Yellow Oxisol (LAd) and Quartzarenic Neosol (NQ), and amended with different organic fertilizers.

The experiment with LAd soil was conducted from February to May 2020 under greenhouse conditions, with temperatures ranging from 25.3 °C to 42.1 °C (average 31.3 °C). The experiment with QN soil took place from July to November of 2020, with temperatures ranging from 31.4 °C to 39.6 °C (average 32.5 °C).

The first experiment was conducted using LAd soil, collected at a depth of 0 - 20 cm in the experimental field of the Federal University of Recôncavo da Bahia, city of Cruz das Almas, Bahia, Brazil. The soil's chemical and physical characteristics were as follows: pH (H_2O) = 6.6; organic matter (OM) = 20 g dm^{-3}; P (Mehlich 1) = 3.55 mg dm^{-3}; K^+ = 3.0 mg dm^{-3}; Ca^{2+} = 2.2 $cmol_c$ dm^{-3}; Mg^{2+} = 1.0 $cmol_c$ dm^{-3}; (H+Al) = 1.5 $cmol_c$ dm^{-3}; base saturation (BS) = 3.21 $cmol_c$ dm^{-3}; effective cation exchange capacity (CEC) = 3.21 $cmol_c$ dm^{-3}; potential CEC = 4.71 $cmol_c$ dm^{-3}; V = 68.14 %; sand = 777 g kg^{-1}; silt = 32 g kg^{-1}; and clay = 191 g kg^{-1}.

The second experiment was conducted using QN soil, collected at a depth of 0 - 20 cm in the municipality of Conceição do Coité (11º46'07" S, 39º16'29" W), in the state of Bahia, Brazil. This soil had the following chemical and physical characteristics: pH (H_2O) = 5.15; OM = 1.04 g dm^{-3}; P (Mehlich 1) = 6.4 mg dm^{-3}; K^+ = 14 mg dm^{-3}; Ca^{2+} = 1.50 $cmol_c$ dm^{-3}; Mg^{2+} = 0.34 $cmol_c$ dm^{-3}; (H+Al) = 2.2 $cmol_c$ dm^{-3}; BS = 1.88 $cmol_c$ dm^{-3}; effective CEC = 1.88 $cmol_c$ dm^{-3}; potential CEC = 4.08 $cmol_c$ dm^{-3}; V = 46.1 %; Zn^{2+} = 3.14 mg dm^{-3}; Fe^{2+} = 114.5 mg dm^{-3}; Mn^{2+} = 13.7 mg dm^{-3}; Cu^{2+} = 0.89 mg dm^{-3}; B = 0.17 mg dm^{-3}; sand = 790 g kg^{-1}; silt = 78 g kg^{-1}; and clay = 132g kg^{-1}.

Bell pepper (*Capsicum annuum* L., var *Cascadura Ikeda*) seeds were sown in 128-cell polystyrene trays, measuring 18.5 cm x 19.0 cm x 11.0 cm in width, length, and depth, respectively, with each cell having a volume of 50 ml. Two seeds were sown per cell using inert vermiculite as the substrate. 30 days after sowing, when the plantlets reached approximately 10 cm in height, they were transplanted into pots with a capacity of 3.8 L of soil. Plants were watered once daily with deionized water to maintain uniform moisture in the substrate, avoiding visible water deficit and waterlogging. Irrigation was not standardized to pot field capacity, and leachate was not intentionally produced. The same schedule was applied to all treatments (Supplement figure 1).

To formulate the fertilizers, spent mushroom substrate (SMS) from the cultivation of *Pleurotus ostreatus* was used. The SMS was produced using residues from the decortication of *Agave sisalana* leaves for fiber production (Carmo *et al*., 2021) and from palm oil production using *Elaeis guineensis* (Silva *et al*., 2020) (Supplement figure 2). The spent mushroom substrate (mycelial block) remaining after edible-mushroom cultivation (A); the organic fertilizer PSSD, formulated with oil-palm (*Elaeis guineensis*) residue plus compost from the dairy industry (B); organic fertilizer SSSD, formulated with sisal (*Agave sisalana*) residue plus compost from the dairy industry (C); organic compost from the dairy industry (D); as well as the transplanting of bell pepper seedlings (*Capsicum annuum*) (E–F) are shown in Supplement figure 2.

Both organic fertilizers (SSSD and PSSD) were formulated with a mixture of spent mushroom substrate from oil palm (PSS) or sisal (SSS) with organic compost from the dairy industry (D) at a 75:25 volume ratio (v/v) of PSS or SSS and D, respectively, based on the recommendations of Carmo *et al.* (2021).

The experimental design followed a 2 x 5 factorial scheme, consisting of two organic fertilizers (SSSD and PSSD) and five doses (0 t ha^{-1}, 15 t ha^{-1}, 30 t ha^{-1}, 45 t ha^{-1}, 60 t ha^{-1}), and an additional control treatment with chemical fertilization (CC). Treatments were arranged in a completely randomized design, with ten replicates and one plant per pot.

The chemical characterization of the spent substrates used to formulate the fertilizers (Table 1) was performed according to the methodologies described in the *Manual of Official Methods for Mineral and Organic Fertilizers and Correctives* (*Manual de Métodos Oficiais de Fertilizantes Minerais e Orgânicos e Corretivos*) (Alcarde, 2009), and the chemical characterization of the organic compost from the dairy industry was described by Oliveira (2020).

The pH in CaCl2 0.01 M was determined by potentiometry, and density was measured as mass per volume (m/v). Average humidity at 60 °C - 65 °C, average humidity at 110 °C, and total humidity were quantified gravimetrically. Organic carbon (OC) content was evaluated by oxidation with dichromate followed by titration, while total nitrogen was determined via sulfuric digestion using the Kjeldahl method. Phosphorus (P_2O_5) was quantified spectrophotometrically using vanadate-molybdate solution, and potassium (K_2O) and sodium (Na) concentrations were determined by flame photometry. Sulfur (S) was measured gravimetrically after precipitation with barium sulfate. The contents of calcium (Ca), magnesium, copper (Cu), manganese (Mn), zinc (Zn), and iron (Fe) were determined in HCl extracts through atomic absorption spectrophotometry, and boron (B) was analyzed by spectrophotometry using azomethine-H.

Table 1. Chemical characterization of the agro-industrial wastes used to formulate organic fertilizers for bell pepper (*Capsicum annuum* L.) production

Attribute	Unit	Palm oil WB	Palm oil DB	Sisal WB	Sisal DB	Organic compost WB	Organic compost DB
pH $CaCl_2$ 0.01	Mol L^{-1}	6.5	-	7.2	-	8.5	-
Density (organic waste)	g cm^{-3}	0.2	-	0.2	-	0.5	-
Humidity (organic waste) 65 °C	(%)	1.3	-	2.5	-	7.7	-
Humidity (organic waste) 110 °C	(%)	6.4	-	4.7	-	0.5	-
Total humidity	(%)	7.8	-	7.2	-	8.2	-
Total organic matter (combustion)	(%)	62	62.9	49.4	50.7	37.1	40.2
Organic carbon	(%)	33.1	33.5	26.2	26.9	19.3	20.9
Total mineral residue (TMT)	(%)	30.1	30.5	43.3	44.4	54.5	59.1
Mineral residue (MR)	(%)	16.2	16.5	25.4	26	19.1	20.7
Insoluble mineral residue (IMR)	(%)	13.8	14	17.8	18.3	35.4	38.4
Total nitrogen	(%)	2.4	2.5	2.2	-	2.7	2.9
Total phosphorus (P_2O_5)	(%)	1	1	0.3	0.3	1.1	1.1
Total potassium (K_2O)	(%)	1.2	1.2	1.3	1.4	1.5	1.6
Total calcium (Ca)	(%)	5.6	5.7	9.1	9.3	5.1	5.4
Total magnesium (Mg)	(%)	0.6	0.6	0.6	0.6	0.7	0.7
Total sulphide (S)	(%)	0.2	0.2	0.1	0.1	0.2	0.2
C/N ratio	-	13	-	13	-	7	-
Total copper (Cu)	(mg kg^{-1})	37	38	12	12	30	33
Total manganese (Mn)	(mg kg^{-1})	434	440	175	180	540	260
Total zinc (Zn)	(mg kg^{-1})	135	137	119	122	332	360
Total iron (Fe)	(mg kg^{-1})	5863	5944	4867	4994	7841	8496
Total boron (B)	(mg kg^{-1})	10	10	16	16	12	13
Total sodium (Na)	(mg kg^{-1})	2316	2348	2190	2247	25368	27487

WB = wet base, DB = dry base (65 °C).

The C/N ratio was calculated from the measured carbon and nitrogen contents. Total organic matter, insoluble mineral residue (IMR), mineral residue (MR), and total mineral residue (TMR) were determined by combustion in a muffle furnace.

In both soil experiments, physiological analyses of the plants were performed for 120 days. Plant growth and production were evaluated using the following parameters: plant height (PH), measured with a millimeter ruler; stem diameter (SD), determined with a pachymeter; number of leaves (NL); number of flower buds (Nb); number of flowers (NF); number of fruits (NFr); fruit weight (WFr); and chlorophyll a, b, and total chlorophyl (Cl-A, Cl-B, Cl-T). At 45 days after transplanting (DAT), corresponding to the beginning of flowering, five plants were collected from the treatments with doses of 30 t ha^{-1}, 45 t ha^{-1}, and 60 t ha^{-1}, as well as from the additional chemical treatment, for nutritional analysis of N, P, K, Ca, Mg and S, following the methodology described by Jones (2001) for determining nutrients in plant biomass.

Plants from each treatment were harvested and dried in a forced-air oven at 45 °C, to obtain the dry weight of shoots (ADW, including leaves and stems) and roots (RDW). The dried samples were ground in a Wiley mill, passed through a 20-mesh sieve, and stored in plastic bags. Approximately 0.1 g of the leaf dry mass was subjected to acid digestion using a mixture of 3.5 ml of concentrated sulfuric acid (H_2SO_4) and 3 ml of 30 % hydrogen peroxide (H_2O_2), as described by Jones (2001). The digested material was diluted with distilled water to a final volume of 100 ml to obtain the extract used for the determination of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) concentrations.

Plant nitrogen (N) content was determined using the phenol-hypochlorite spectrophotometric method (Weatherburn, 1967), phosphorus (P) content by the molybdovanadate spectrophotometric method, and potassium (K) content by flame photometry (Faithfull, 2002). Total plant dry weight was calculated based on the total dry weight of roots, stems, and leaves. To evaluate fruit yield, fruits were harvested, measured with a millimeter ruler, and weighed using a previously calibrated analytical balance. The harvest index (HI) was calculated as the ratio between the dry weight of the fruits, which are the economically important part of the plant, and the total plant dry weight.

Data were subjected to analysis of variance (ANOVA), using the statistical software R. When significant differences were detected, means were compared using the Scott-Knott test at a 5 % probability ($p < 0.05$). Regression analysis was also performed.

Results and discussion

Across both experiments, a significant interaction between fertilizer source and dose ($p < 0.05$) was observed for key growth traits, resulting in increases in chlorophyll a, b, and total chlorophyll, as well as shoot biomass. In the Yellow Oxisol (LAd), both PSSD and SSSD enhanced shoot dry weight, reaching maximum values of 1.14 g $plant^{-1}$ (PSSD at 53 t ha^{-1}) and 1.08 g $plant^{-1}$ (SSSD at 36 t ha^{-1}). Stem diameter also showed a linear increase over time (PSSD > SSSD). In the Quartizarenic Neosol (QN), the organic formulations resulted in higher fruit yield and harvest index at the end of the cycle, with doses of 45 t ha^{-1} - 60 t ha^{-1} achieving gains of up to 62 % compared to the chemical control and delaying plant senescence. Overall, both PSSD and SSSD provided superior final performance, likely due to the gradual release of nutrients and improved soil conditions.

Experiment 1 - Bell pepper growth in a Yellow Oxisol

There was a significant interaction ($p < 0.05$) between the organic fertilizer formulations and application doses for the variables 'plant height', 'number of leaves', 'above-ground plant dry weight', and the values of chlorophyll *a*, *b*, and total. For the variable 'stem diameter', there was an individual effect of the doses, and for the variables 'number of flowers' and 'flower buds' there were no significant differences ($p > 0.05$).

Stem diameter increased linearly over time and showed a system interaction, with SSSD showing a steeper growth response than PSSD ($p < 0.05$) (Figure 1B). The final mean SD was higher in SSSD (0.50 cm $plant^{-1}$) compared to PSSD 0.46 cm $plant^{-1}$).

There was a significant interaction between the source and the dose of the organic fertilizers, with a quadratic response ($p < 0.05$) for shoot dry weight. Plants grown in LAd soil with PSSD at a dose of 53 t ha^{-1} showed a higher mean shoot dry weight value (1.14 g $plant^{-1}$), compared to plants grown with SSSD at a dose of 36 t ha^{-1} and with a mean of 1.08 g $plant^{-1}$, and to the treatment with chemical fertilization (0.78 g $plant^{-1}$) (Figure 1C).

The increase in chlorophyll content is attributed to higher nitrogen accumulation in the leaves (Table 2). Bell pepper plants with higher a, b, and total chlorophyll values also showed a greater number of leaves and above-ground plant dry weight, indicating greater plant biomass (Figure 1). Other studies have shown that the chlorophyll index serves as an important indicator of the nitrogen nutritional status of plants (Silva *et al.*, 2017).

Godoy *et al.* (2003) and Padilla *et al.* (2018) evaluated the use of chlorophyll measurements and the different chlorophyll responses to increased

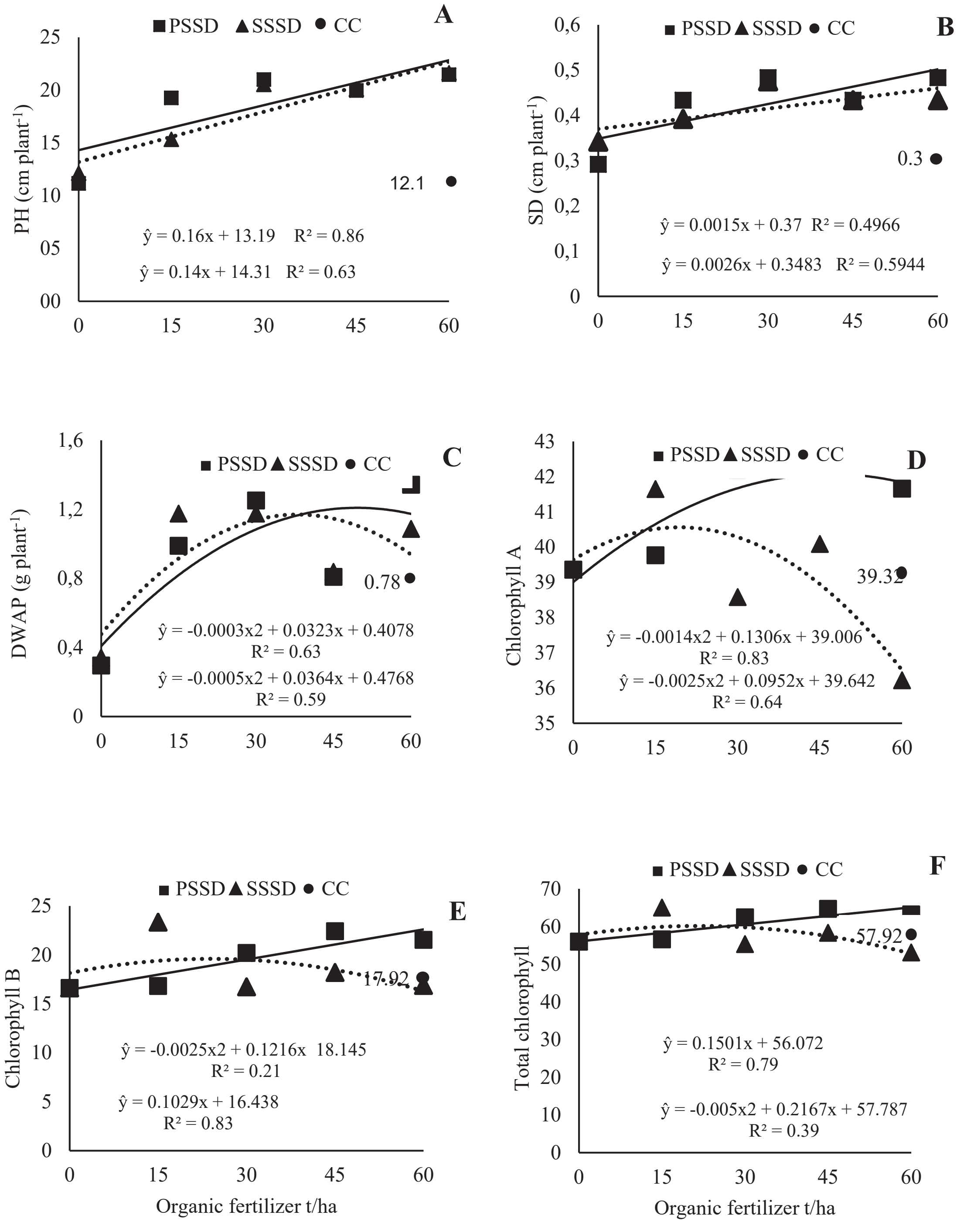


Figure 1. Average plant height (PH) (A), stem diameter (SD) (B), dry weight of the aerial parts (DWAP) (C), chlorophyll a (Cl-A) (D), chlorophyll b (Cl-B) (E), and total chlorophyll (Cl-T) (F) of bell pepper plants (*Capsicum annuum* var. Casca Dura Ikeda), 45 days after transplantation (DAT).
Note. Plants were cultivated in Dystrophic Yellow Oxisol (LAd) soil fertilized with different doses of SSSD (formulated with sisal residues and organic compost from the dairy industry) and PSSD (composed of a mixture of oil palm residues and organic compost from the dairy industry), as well as an additional treatment with chemical fertilization.

nitrogen supply in bell peppers and sweet peppers, and concluded that these measurements can serve as a good indicator for nitrogen fertilization management in the cultivars they studied. When determined at the time of nitrogen fertilization management, chlorophyll measurements can help adjust N levels according to the plants' requirements, thereby increasing the efficiency of N application.

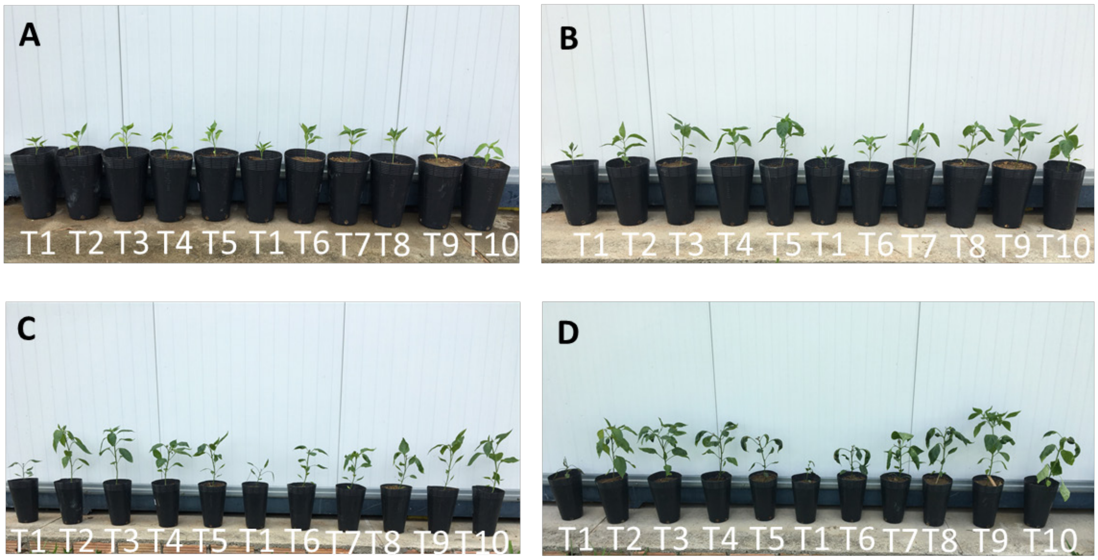


Figure 2. Bell pepper plants (*Capsicum annuum* var. Casca Dura Ikeda) at 15 (A), 30 (B), 45 (C), and 60 (D) days after transplantation (DAT).
Note. Plants were cultivated in a Dystrophic Yellow Oxisol (LAd) soil fertilized with different doses of SSSD (formulated with sisal residues and organic compost from the dairy industry): T1 = 0 t ha^{-1}, T2 = 15 t ha^{-1}, T3 = 30 t ha^{-1}, T4 = 45 t ha^{-1}, and T5 = 60 t ha^{-1}; and PSSD (composed of a mixture of oil palm residues and organic compost from the dairy industry): T6 = 15 t ha^{-1}, T7 = 30 t ha^{-1}, T8 = 45 t ha^{-1}, and T9 = 60 t ha^{-1}, plus an additional treatment with chemical fertilization (T10).

Experiment 2 – Bell pepper growth in a Quartizarenic Neosol

Variations in plant height were observed among the different organic fertilizers at the concentration of 60 t ha^{-1}, with the organic amendment SSSD showing superior performance compared to PSSD. However, the treatment with chemical fertilizer resulted in higher values for all variables, regardless of the fertilizer dose or source. The greater average plant height observed in plants grown in soil amended with SSSP compared to those amended with PSSD may be related to the nutrient availability in the soil, which depends on the type of the organic amendment (Table 1).

The chemical characterization of SSSD showed higher moisture and organic matter contents, as well as greater concentrations of macronutrients such as phosphorus, potassium, and calcium, and micronutrients such as copper and zinc, along with lower sodium levels when compared to organic residues [COP (organic compost from tree pruning + cattle and goat manure) and CLU (organic compost from urban wastes)]. Moreira *et al.* (2018) found that these attributes promoted the increasing growth of *Caesalpinia pulcherrima*. In the present study, oil palm residue contributed to increased bell pepper productivity due to its role in plant nutrition, thereby influencing plant growth and development, increasing plant productivity and fruit quality (Shehata *et al.*, 2018).

Plant growth varies depending on the chemical characteristics of the organic wastes used as crop fertilizers, like the compounds derived from fungal metabolism (Abreu *et al.*, 2020; Siqueira *et al.*, 2019). Soil amendment of these agro-industrial wastes used as organic fertilizer contributed to an increase in soil pH and, consequently, a decrease in the availability of essential nutrients for plants. When the chemical composition of crop fertilizers is not favorable for plant development, nutritional imbalances may occur, limiting plant development due to competition for nutrient uptake in the roots (Lima *et al.*, 2018). Thus, in this study, plants grown with chemical fertilization exhibited greater development, but lower fruit yield (Figure 3).

The LAd soil promoted an increase in shoot dry weight, which may be attributed to its properties such as texture, organic matter content, and water retention capacity, favoring a gradual water supply for plants for a longer period of time (Moreira *et al.*, 2018). It can be inferred that the higher bell pepper yield observed when cultivated in NQ soil using SSSD and PSSD may be related to the presence of primary minerals and greater water infiltration (Oliveira, 2008), as well as the incorporation of residues in the substrate, which enhanced water and nutrient retention, preserving their availability to plants and consequently improving fruit yield. Both soil classes presented low nutrient contents; however, the addition of organic residues in the substrate improved fertility, resulting in a positive plant response, as evidenced by increased biomass accumulation and fruit yield (Figure 3).

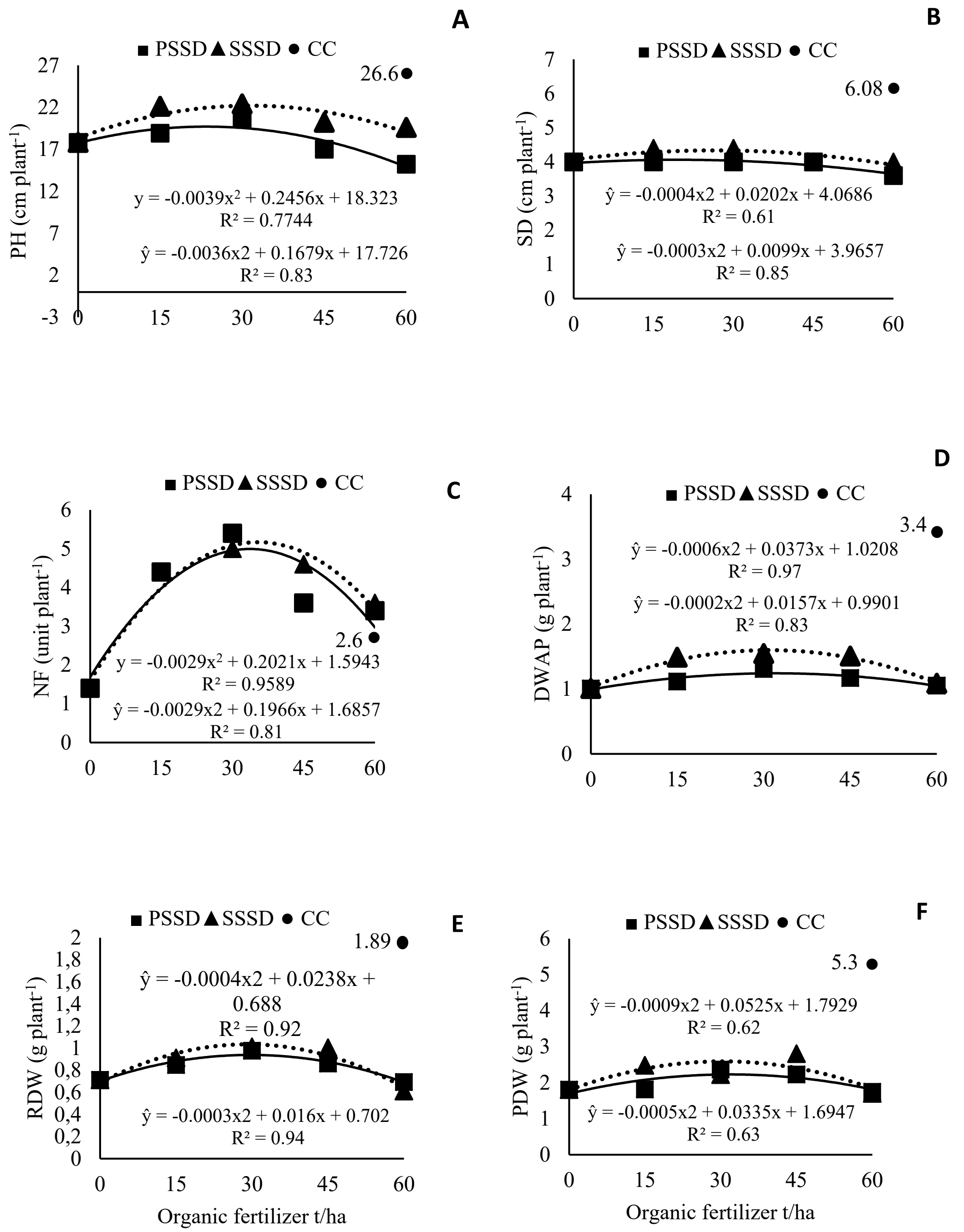


Figure 3. Plant height (PH) (A), stem diameter (SD) (B), number of flowers (NF) (C), dry weight of the aerial parts (DWAP) (D), root dry weight (RDW) (E), and total plant dry weight (PDW) (F) of bell pepper plants (*Capsicum annuum* var. Casca Dura Ikeda), 45 days after transplantation (DAT).
Note. Plants were cultivated in Quartizarenic Neosol (QN) soil fertilized with different doses of SSSD (formulated with sisal residues and organic compost from the dairy industry) and PSSD (composed of a mixture of oil palm residues and organic compost from the dairy industry), as well as an additional treatment with chemical fertilization.

Different doses of PSSD and SSSD significantly influenced the yield components of bell pepper ($p < 0.05$). During the crop cycle, up to 60 days after sowing, there was an increase in the physiological indexes evaluated with increasing doses of organic fertilizers, with higher values observed for the chemical fertilizer, which was used as a control treatment. The greater development under chemical fertilization is attributed to the higher availability of nutrients for plant absorption. However, after this stage of bell pepper development, the plants grown in soil amended with the formulated organic fertilizers showed a considerable increase in the physiological indexes. This result can be attributed to the slower and more gradual mineralization process that reduces volatilization and denitrification, leaching, and nutrient immobilization by soil microorganisms (Figure 5). In addition, it was observed that the plants with chemical fertilization began to exhibit senescence symptoms, such as leaf yellowing and leaf fall at 90 DAT (Figure 4F), as reflected in the average LDW value (0.26 g plant^{-1}) at 120 DAT (Figure 4D).

Other studies have reported that fertilization with *P. ostreatus* spent substrate (PSS) provides a wide variety of nutrients, although many of them are not immediately available to the plants and are released gradually through mineralization (Roy *et al.*, 2015). This is particularly true for nitrogen, phosphorus, and potassium (Hackett, 2015; Lou *et al.*, 2015; Zhu *et al.*, 2018). However, the combination of PSS with organic or mineral fertilizers has been associated with a significant increase in mineral N in the soil (Lou *et al.*, 2017).

This slow nutrient release from SSSD and PSSD allowed the values of PH, SD, NL, FRDW, DWAP, RDW, and TDW to increase after 45 DAT, as a result of the doses of these organic composts added to the soil (Figure 5). According to Lou *et al.* (2017), after evaluating the variability in the composition of PSS after continuous cultivation and the composting process, as well as the effects on mineral N transformation in the soil, it was observed that the application of PSS significantly increased the mineral N content in the soil. Moreover, Lou *et al.* (2015) reported that the combined application of PSS with other organic nutrient sources alters soil characteristics and promotes immobilization, thereby reducing its leaching.

Plant responses to fertilization vary according to the type and proportion of the organic matter and the soil type (Moreira *et al.*, 2018; Amalfitano *et al.*, 2017). Therefore, the types and proportions of organic fertilizers must meet the nutritional requirements of the crop. In this study, plants grown with 60 t ha^{-1} of PSSD showed the highest accumulation of N, P, K, and Mg in the aboveground parts, differing statistically from the other doses and the control with chemical fertilization. The dose of 45 t ha^{-1} of PSSD promoted the greatest accumulation of S in the aerial parts of the plants, but it did not differ significantly from the chemical treatment (Table 1).

Similarly, plants grown in soil with SSSD at a dose of 60 t ha^{-1} exhibited the highest accumulation of N, P, and Ca, while no significant differences were observed among the doses for K and Mg accumulation. For S accumulation in the aerial parts, the dose of 30 t ha^{-1} resulted in the highest mean value, which is different from the other treatments, but not from the treatment with chemical fertilization (Table 2).

Marcussi (2005) also reported that K (39.9 g kg^{-1}) was the mineral element that accumulated the most in bell pepper fruits, followed by N (28.3 g kg^{-1}), Ca (12.8 g kg^{-1}), Mg (5.9 g kg^{-1}), S (4.1 g kg^{-1}), and P (3.7 g kg^{-1}). Albuquerque *et al.* (2012) found in their study the following order of nutrient accumulation: N (32.69 g kg^{-1}) > K (13.32 g kg^{-1}) > Mg (11.06 g kg^{-1}) > Ca (4.88 g kg^{-1}) > P (3.38 g kg^{-1}) > S (2.71 g kg^{-1}) in the leaves, and K (26.00 g kg^{-1}) > N (25.92 g kg^{-1}) > P (3.75 g kg^{-1}) > Ca (3.45 g kg^{-1}) > S (1.99 g kg^{-1}) > Mg (1.76 g kg^{-1}) in the fruits. Finally, Ogunlade *et al.* (2013) reported the following order of nutrient accumulation (100 g kg^{-1}) in *Capsicum annum*: P (154.66 g kg^{-1}) > K (89.25 g kg^{-1}) > Ca (80.42 g kg^{-1}) > Mg (27.52 g kg^{-1}).

According to Peixoto (2020), the harvest index (HI) is a key factor in crop production and is defined as the ratio between plant yield (dry weight of fruits) and the efficiency of conversion of synthesized materials into fruits, which represent the commercial part of the plant. This index reflects the allocation of dry matter to the commercial product, which in our study corresponds to bell pepper fruits, and the total dry matter produced by the plant, providing an indicator of the optimal harvest time and, consequently, higher economic productivity. At 90 DAT, the highest harvest index was obtained in the treatment with 43 t ha^{-1} of PSSD, with an average of 0.83 g plant^{-1}, and 45 t ha^{-1} of SSSD, with an average of 1.11 g plant^{-1} (Figure 6).

Increasing amounts of organic fertilizer influenced the accumulation of dry matter in branches, leaves, stems, fruits, and roots of the plants. There was an increase in the allocation of dry matter to the aerial parts, and during the physiological maturation, a decrease in the leaf area was observed due to the greater translocation of assimilates to other organs of the plant (Almeida *et al.*, 2021).

Fertilization with PSSD and SSSD at a dose of 30 t ha^{-1} promoted an increase in the fruit dry weight of bell pepper plants, with values ranging from 4.77 g plant^{-1} to 6.01 g plant^{-1} (Figure 4G). The 60 t ha^{-1} dose of these organic fertilizers resulted in a 62 % increase in fruit production compared to the treatment with chemical fertilization. These results are in line with previous findings in the literature. Mohd Hanafi *et al.* (2018), in a review on the beneficial uses of SSP combined with organic sources, concluded that it can be incorporated into organic fertilizer formulations, offering the additional benefits of reducing production costs and minimizing the environmental impact associated with its accumulation. Thus, the use of agro-industrial residues for the formulation of organic fertilizers can play an important role in agriculture, by ensuring sustainable production and reducing the inadequate disposal of these materials in the soil. Therefore, formulations based on PSSD and SSSD are viable options for bell pepper cultivation. However, small variations in plant development and yield were observed depending on the agro-industrial residue type and the applied dose, indicating the need for further research under field conditions.

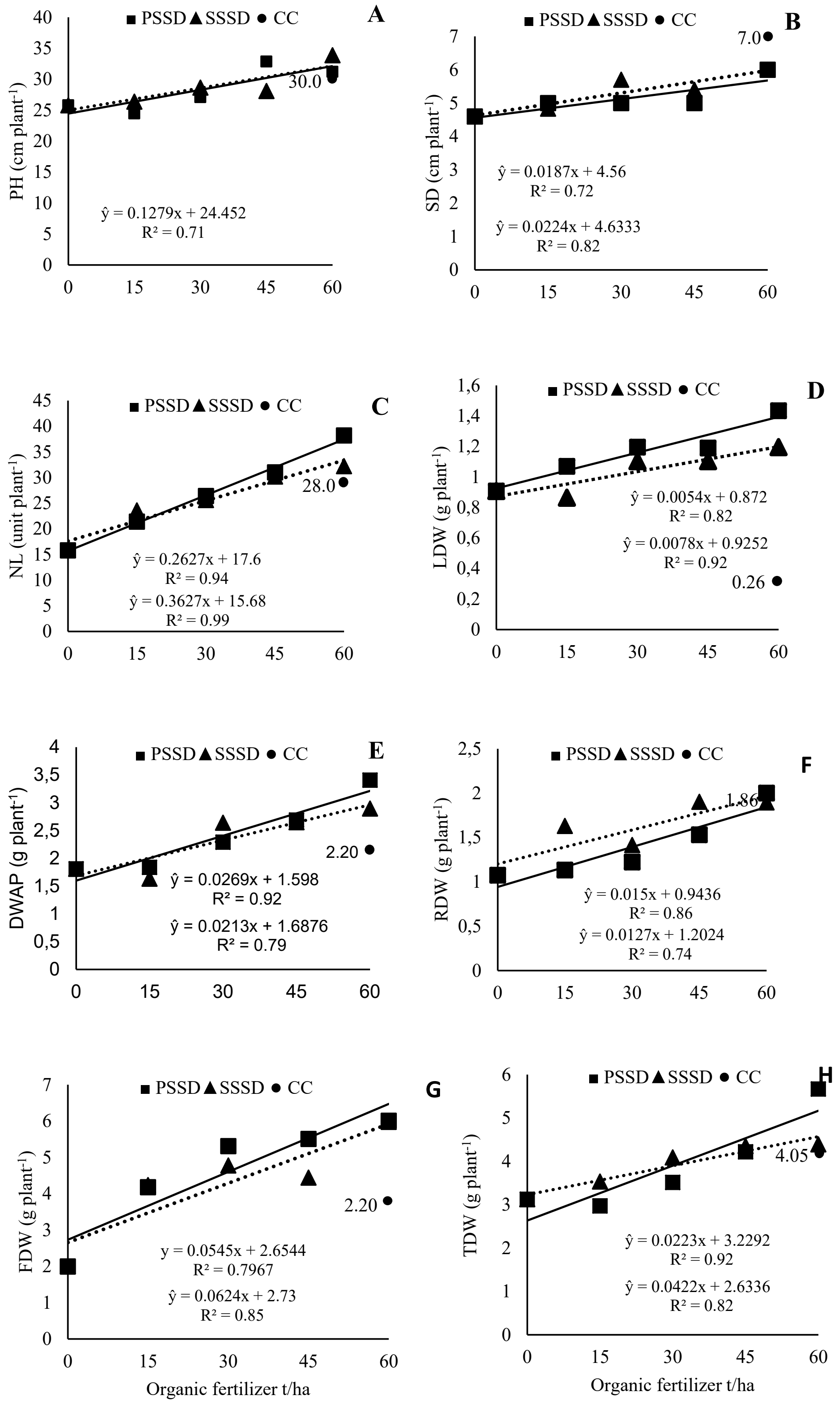


Figure 4. Plant height (PH) (A), stem diameter (SD) (B), number of leaves (NL) (C), leaf dry weight (LDW) (D), dry weight of the aerial parts (DWAP) (E), root dry weight (RDW) (F), fruit dry weight (FDW) (G), and total plant dry weight (TDW) (H) of bell pepper plants (*Capsicum annuum* L. var. Casca Dura Ikeda), 120 days after transplantation (DAT).

Note. Plants were cultivated in Quartizarenic Neosol (QN) soil fertilized with different doses of SSSD (formulated with sisal residues and organic compost from the dairy industry), and PSSD (composed of a mixture of oil palm residues and organic compost from the dairy industry), as well as an additional treatment with chemical fertilization.

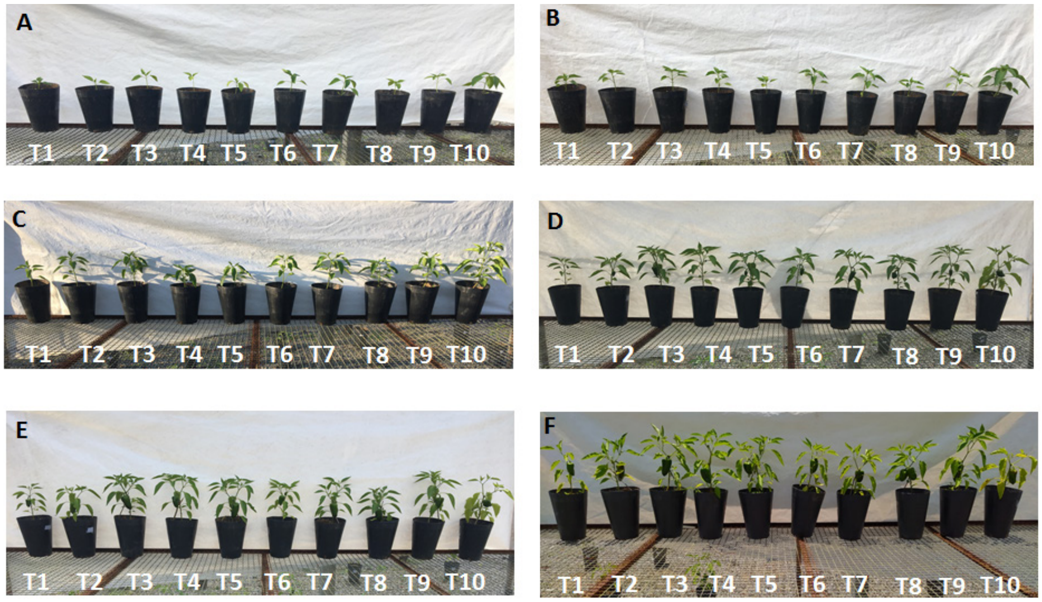


Figure 5. Bell pepper plants (*Capsicum annuum* var. Casca Dura Ikeda) at 15 (A), 30 (B), 45 (C), 60 (D), 75 (E), and 90 (F) days after transplantation (DAT). Note. Plants were cultivated in Quartizarenic Neosol (QN) soil fertilized with different doses of SSSD (formulated with sisal residues and organic compost from the dairy industry): T1 = 0 t ha^{-1}, T2 = 15 t ha^{-1}, T3 = 30 t ha^{-1}, T4 = 45 t ha^{-1}, and T5 = 60 t ha^{-1}; and PSSD (composed of a mixture of oil palm residues and organic compost from the dairy industry): T6 = 15 t ha^{-1}, T7 = 30 t ha^{-1}, T8 = 45 t ha^{-1}, and T9 = 60 t ha^{-1}; plus and an additional treatment with chemical fertilization (T10).

Table 2. Macronutrient content in dry matter of the aerial parts of *Capsicum annuum* L. at 45 days after transplantation (flowering period)

Fertilizer	Dose	N	P	K	Ca	Mg	S
	t ha^{-1}	t ha^{-1}	t ha^{-1}	g Kg^{-1}	g Kg^{-1}	g Kg^{-1}	g Kg^{-1}
PSSD	30	21.00b	6.12a	43.75b	11.15a	3.49c	2.68a
PSSD	45	24.38b	6.10a	53.75a	11.62a	3.97b	3.06a
PSSD	60	29.29a	6.26a	60.00a	13.08a	4.40a	2.12b
SSSD	30	24.83b	6.40a	45.00b	11.58a	3.55c	2.69a
SSSD	45	24.63b	4.67b	48.33b	10.42a	3.60c	2.37b
SSSD	60	32.95a	5.64a	42.50b	11.50a	3.83c	2.22b
Ad. Treat.	-	19,41b	4.12b	35.83b	8.63a	2.54d	2.69a
CV (%)		12.6	5.6	10.3	11.4	5.6	12.5

Note. Plants were cultivated in Quartizarenic Neosol (QN) soil fertilized with different doses of SSSD (formulated with sisal waste and organic compost from the dairy industry) and PSSD (composed of a mixture of oil palm residues and organic compost from the dairy industry), and with an additional chemical fertilization treatment. Ad. Treat = Additional treatment.

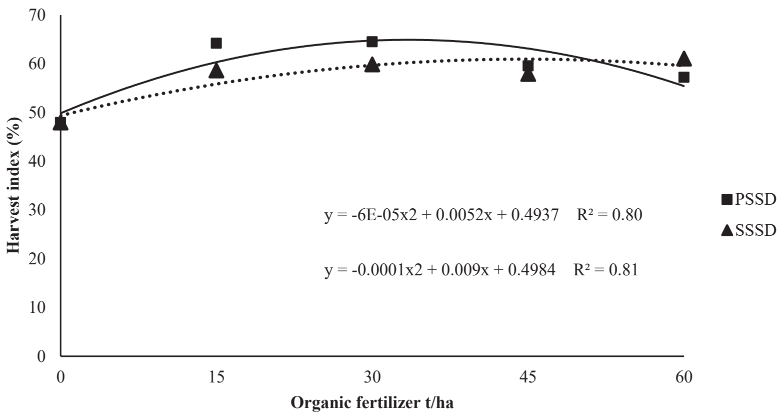


Figure 6. Harvest index (HI) of bell pepper plants (*Capsicum annuum* var. Casca Dura Ikeda) at 90 days after transplantation (DAT).
Note. Plants were cultivated in Quartizarenic Neosol (QN) soil fertilized with different doses of SSSD (formulated with sisal residues and organic compost from the dairy industry) and PSSD (composed of a mixture of oil palm residues and organic compost from the dairy industry).

Conclusion

Organic fertilizers formulated from agro-industrial residues —SSSD (sisal residue + compost from the dairy industry) and PSSD (oil palm residue + compost from the dairy industry)—proved effective for bell pepper cultivation, supporting plant growth, nutrition uptake, and fruit production, and serving as viable alternatives or complements to mineral fertilization.

Organic formulations exhibited soil class–dependent effects. In the Dystrophic Yellow Oxisol, they promoted greater shoot biomass accumulation and vegetative vigor, whereas in the Quartzarenic Neosol, the more gradual nutrient release sustained growth and increased yield. These findings reinforce the potential of agro-industrial residues for use in horticultural fertilization and highlight the need for field-scale validation to optimize application rates and management practices.

References

Abreu, C. G.; Costa, L. M. A. S.; Collela, C. F.; Castro, C. P.; Zied, D. C. and Dias, E. S. (2020). Spent mushroom substrate Agaricus bisporus in the production of pepper seedlings. *Scientia Agraria Paranaensis*, *19*(2), 161-167. https://doi.org/10.18188/sap.v19i2.23812

Albuquerque, F. S.; Silva, E. F. F.; Bezerra Neto, E.; Souza, A. E. R. and Santos, A. N. (2012). Mineral nutrients in fertigated sweet pepper under irrigation depths and potassium doses. *Horticultura Brasileira*, 30(4), 681-687. https://doi.org/10.1590/S0102-05362012000400019

Alcarde, J. C. (2009). *Manual de análise de fertilizantes*. FEALQ.

Almeida, A. T.; Peixoto, C. P.; Vieira, E. L.; Oliveira, E. R.; Santos, C. A. C.; Santos, J. M; Castro, A. M. P. B. and Pereira, V. S. (2021). Índices biométricos de genótipos de amendoim produzido por agricultores do Recôncavo da Bahia. *Brazilian Journal of Development*, 7(5), 49578-49598. https://doi.org/10.34117/bjdv.v7i5.29937

Amalfitano, C.; Del Vacchio, L.; Somma, S.; Cucinello, A. and Caruso, G. (2017). Effects of cultural cycle and nutrient solution electrical conductivity on plant growth, yield and fruit quality of 'Friariello' pepper grown in hydroponics. *Horticultural Science*, 44(2), 91-98. https://doi.org/10.17221/172/2015-HORTSCI

Carmo, C. O.; Rodrigues, M. S.; Silva, F.; Irineu, T. G. M. and Soares, A. C. F. (2021). Spent mushroom substrate of *Pleurotus ostreatus* kummer increases basil biomass and essential oil yield. *Revista Caatinga*, 34(3), 548-558. https://doi.org/10.1590/1983-21252021v34n306rc

Conti, S.; Villari, G.; Faugno, S.; Melchionna, G.; Somma, S. and Caruso, G. (2014). Effects of organic vs. conventional farming system on yield and quality of strawberry grown as an annual or biennial crop in southern Italy. *Scientia Horticulturae*, *180*, 63-71. https://doi.org/10.1016/j.scienta.2014.10.015

Faithfull, N. T. (2002). *Methods in agricultural chemical analysis: A practical handbook*. CABI Publishing.

Godoy, L. J. G.; Villas Bôas, R. L. and Büll, L. T. (2003). Use of chlorophyll meter readings in the management of nitrogen fertilization in bell pepper plants. *Revista Brasileira de Ciência do Solo*, 27(6), 1049-1056. https://doi.org/10.1590/S0100-06832003000600009

Gougoulias, C.; Clark, J. M. and Shaw, L. J. (2014). The role of soil microbes in the global carbon cycle: tracking the below-ground microbial processing of plant-derived carbon for manipulating carbon dynamics in agricultural systems. *Journal of the Science of Food and Agriculture*, 94(12), 2362-2371. https://doi.org/10.1002/jsfa.6577

Hackett, R. (2015). Spent mushroom compost as a nitrogen source for spring barley. *Nutrient Cycling in Agroecosystems*, *102*, 253-263. https://doi.org/10.1007/s10705-015-9696-3

Jones, J. J. B. (2001). *Laboratory guide for conducting soil tests and plant analysis* (1st ed.). CRC Press. https://doi.org/10.1201/9781420025293

Lima, N. S.; Silva, E. F. F.; Menezes, D; Camara, T. R. and Willadino, L. G. (2018). Fruit yield and nutritional characteristics of sweet pepper grown under salt stress in hydroponic system. *Revista Caatinga*, 31(2), 297-305. https://doi.org/10.1590/1983-21252018v31n205rc

Lopes, R. X.; Zied, D. C.; Martos, E. T.; Souza, R. J.; Silva, R. and Dias, E. S. (2015). Application of spent *Agaricus subrufescens* compost in integrated production of seedlings and plants of tomato. *International Journal of Recycling Organic Waste in Agriculture*, 4(3), 211-218. https://doi.org/10.1007/s40093-015-0101-7

Lopes, S. M.; Alcantra, E.; Rezende, R. M. and Freitas, A. S. (2018). Pepper fruits evaluation submitted to bagging in organic farming. *Revista da Universidade Vale do Rio Verde*, 16(1), 4922. https://doi.org/10.5892/ruvrd.v16i1.4922

Lou, Z.; Sun, Y.; Zhou, X.; Baig, S. A.; Hu, B. and Xu, X. (2017). Composition variability of spent mushroom substrates during continuous cultivation, composting process, and their effects on mineral nitrogen transformation in soil. *Geoderma*, 307, 30-37. https://doi.org/10.1016/j.geoderma.2017.07.033

Lou, Z.; Zhu, J.; Wang, Z.; Baig, S. A.; Fang, L.; Hu, B. and Xu, X. (2015). Release characteristics and control of nitrogen, phosphate, organic matter from spent mushroom compost amended soil in a column experiment. *Process Safety and Environmental Protection*, *98*, 417-423. https://doi.org/10.1016/j.psep.2015.10.003

Marcussi, F. F. N. (2005). Fertigation application and macronutrients concentrations in plant of bell pepper. *Engenharia Agrícola*, *25*(3), 642-650. https://www.scielo.br/j/eagri/a/HF5gXkBq5hyD6cHpDpknjrq/?format=html&lang=pt

Mendes, K. L. F.; Vieira, H.; Pereira Jr, E. B.; Moreira, J. N.; Vale, K. S.; Caiana, C. R. A.; Bezerra Neto, F. C.; Medeiros, A. C. and Maracajá, P. B. (2020). Produção de pimentão cultivado com pó de pedra e esterco em região semiárida. *Research, Society and Development*, 9(7), e487974360. https://doi.org/10.33448/rsd-v9i.4360

Mohd Hanafi, F. H.; Rezania, S.; Mat Taib, S.; Md Din, M. F.; Yamauchi, M.; Sakamoto, M.; Hara, H.; Park, J. and Ebrahimi, S. S. (2018). Environmentally sustainable applications of agro-based spent mushroom substrate (SMS): An overview. *Journal of Material Cycles and Waste Management*, *20*, 1383-1396. https://doi.org/10.1007/s10163-018-0739-0

Moreira, F. M.; Nóbrega, R. S. A.; Santos, R. P.; Silva, C. C. and Nóbrega, J. C. A. (2018). Cultivation of *Caesalpinia pulcherrima* L. SW. in regional substrates. *Revista Árvore*, 42(2), e420212. https://doi.org/10.1590/1806-90882018000200012

Ogunlade, I.; Alebiosu, A. A. and Osasona, A. I. (2013). Proximate, mineral composition, antioxidant activity, and total phenolic content of some pepper varieties (*Capsicum species*).

International Journal of Biological and Chemical Sciences, 6(5), 2221-2227. https://doi.org/10.4314/ijbcs.v6i5.28

Oliveira, E. C. (2020). *Viabilidade do uso de material de descarte da indústria láctea como componente de substrato e sua relação com inoculantes na produção de mudas de leucena* [Master's thesis]. Universidade Federal do Recôncavo da Bahia. https://www.ufrb.edu.br/pgcienciasagrarias/images/DISSERTA%C3%87%C3%83O_-_PPGMA_-_PPGCAG_-_Elielva_Cardoso_de_Oliveira.pdf

Oliveira, J. B. (2008). *Pedologia aplicada* (3ª ed.). FEALQ.

Padilla, F. M.; Souza, R.; Peña-Fleitas, M. T.; Gallardo, M.; Giménez, C and Thompson, R. B. (2018). Different responses of various chlorophyll meters to increasing nitrogen supply in sweet pepper. *Frontiers in Plant Science*, *9*, 1752. https://doi.org/10.3389/fpls.2018.01752

Peixoto, C. P. (2020). *Princípios de fisiologia vegetal: teoria e prática*. PoD Editora.

Roy, S.; Barman, S.; Chakraborty, U. and Chakraborty, B. (2015). Evaluation of spent mushroom substrate as biofertilizer for growth improvement of *Capsicum annuum* L. *Journal of Applied Biology & Biotechnology*, 3(3), 22-27. https://doi.org/10.7324/JABB.2015.3305

Shehata, S. A.; El-Mogy, M. M. and Mohamed, H. F. Y. (2018). Postharvest quality and nutrient contents of long sweet pepper enhanced by supplementary potassium foliar application. *International Journal of Vegetable Science*, *25*(2), 196-209. https://doi.org/10.1080/19315260.2018.1523816

Silva, G. C. C.; Puiatti, M.; Cecon, P. R. and Freitas, A. R. J. (2017). Growth, yield and nitrate accumulation in fruits of cucumber fertilized with sources of nitrogen fertilizers. *Agrária - Revista Brasileira de Ciências Agrárias*, *12*(2), 179-184. https://doi.org/10.5039/agraria.v12i2a5441

Silva, R. M.; Carmo, C. O.; Oliveira, T. A. S.; Figueirêdo, V. R.; Duarte, E. A. A. and Soares, A. C. F. (2020). Biological efficiency and nutritional value of *Pleurotus ostreatus* cultivated in agroindustrial wastes of palm oil fruits and cocoa almonds. *Arquivos do Instituto Biológico*, *87*, e0852018. https://doi.org/10.1590/1808-1657000852018

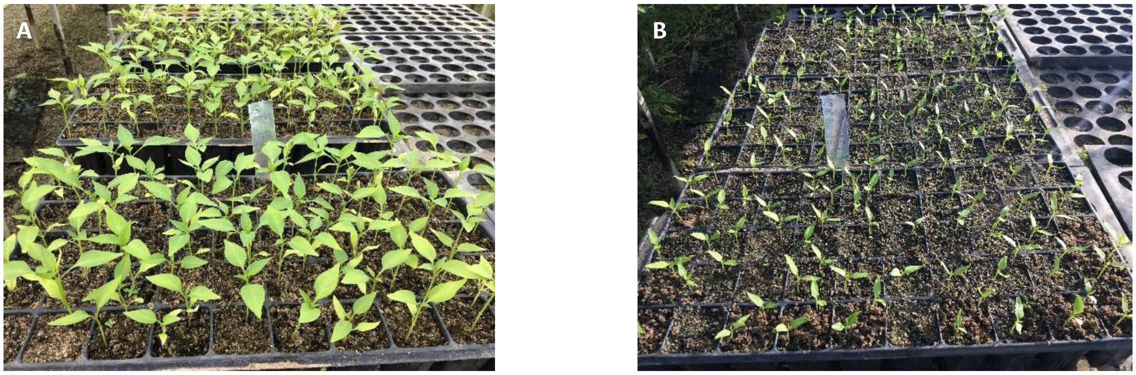
Singh, C.; Pathak, P.; Chaudhary, N.; Rathi, A.; Dehariya, P. and Vyas, D. (2020). Mushrooms and mushroom composts in integrated farm management. *Research Journal of Agricultural Sciences*, *11*(6), 1436-1443. https://www.researchgate.net/publication/345669937_Mushrooms_and_Mushroom_Composts_in_Integrated_Farm_Management

Siqueira, O. A. P. A.; Martins, O. G. and Andrade, M. C. N. (2019). Straw from different sorghum varieties in the formulation of new compounds for the cultivation of *Pleurotus ostreatus*. *Revista em Agronegócio e Meio Ambiente*, *12*(1), 273-285. https://doi.org/10.17765/2176-9168.2019v12n1p273-285

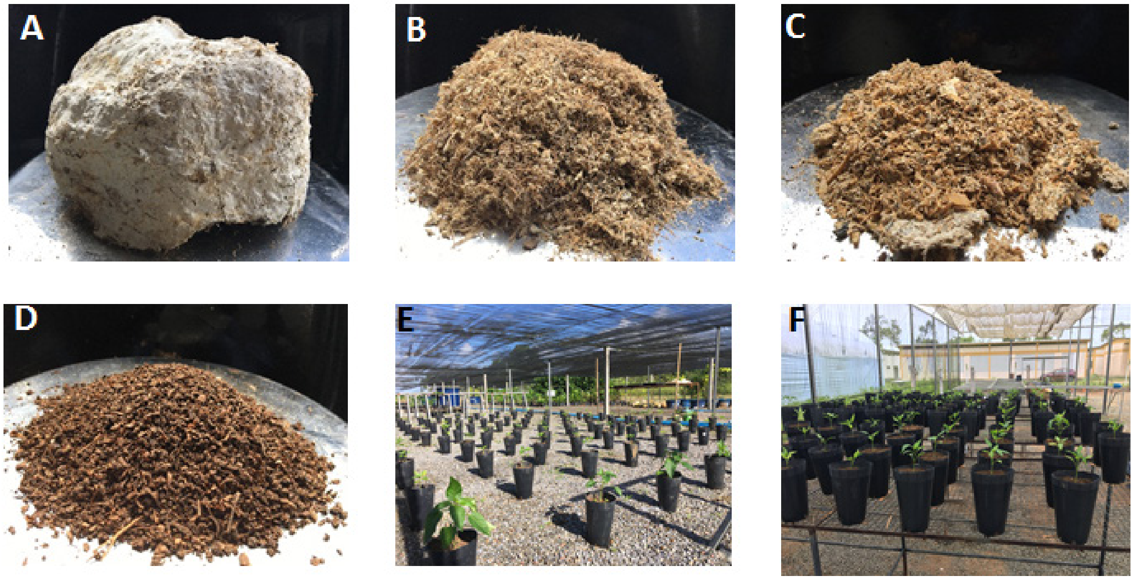
Weatherburn, M. W. (1967). Phenol-hypochlorite reaction for determination of ammonia. *Analytical Chemistry*, *39*, 971-974. https://doi.org/10.1021/ac60252a045

Zhu, H.; Zhao, S.; Yang, J.; Meng, L.; Luo, Y.; Hong, B.; Cui, W.; Wang, M. and Liu, W. (2018). Growth, nutrient uptake, and foliar gas exchange in pepper cultured with un-composted fresh spent mushroom residue. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 47(1), 227-236. https://doi.org/10.15835/nbha47111307

Supplemental material



Supplement figure 1. Plantlets of *Capsicum annum* L. var. Casca Dura Ikeda grown in a greenhouse, 15 (A) and 30 (B) days after sowing.



Supplement figure 2. Mycelial block after edible mushroom production (A); after-cultivation substrate formulated with *Elaeis guineensis* (B); after-cultivation substrate formulated with *Agave sisalana* (C); organic compost from the dairy industry (D); and transplantation of bell pepper plants (E, F).