Characterization of a compost made from chicken droppings and fish bones and application to tomato cultivation

Comment [MF1]: Fish bones consist of two parts, organic and inorganic material. The largest proportion of the inorganic fraction is hydroxyapatite. Ca 10 (PO4)6 (OH)2 is the chemical formula for hydroxyapatite and it accounts for approximately 65% of total bone mass. Hydroxyapatite has the molecular structure of apatite, with 39 % Ca, 18.5 % P, and 3.38 % OH, and an atomic ratio Ca/P of 1.67. In this research, it did not address the structure of the bone nor the effect of the presence of its components in the mixture used with the soil. Therefore, it must be indicated in the research whenever it is required.

Abstract

The effect of compost made from chicken droppings and fish bones on soil quality and tomato production was evaluated. The soil of Bokito (Central Region-Cameroon) was amended with four variants C1, C2, C3 and C4 of compost at 5%, 10%, and 15% compost/soil (m/m). The experimental device was completely randomized en bloc with 5 repetitions for each treatment. The physicochemical, biological and biochemical parameters of compost and amended soils, as well as tomato production were evaluated.

The highest concentrations of nitrogen, phosphorus and potassium were obtained with C3 (1.96g/Kg) and C2 (0.42 g/Kg; 0.08 g/Kg) respectively. The different compost variants had a C/N ratio between 21.88 (C1) and 30.27 (C2) and their pH was basic. They were rich in exchangeable ions (Mg^{2+}, Ca^{2+}, K^{+}, Na^{+}) and poor in heavy metals (Pb, Zn, Cu). A significant increase in the C/N ratio was noted in all the amended soils compared to the unamended soil. It varied from 12.50±0.10 (unamended soil) to 30.55±2.04 (C1 10%). Exchangeable ion concentrations (Mg^{2+}, Ca^{2+}, K^{+}, Na^{+}) were higher in amended soils. The bacterial biomass varied from 347 x 10^5UFC/g (C4) to 609 x10^5UFC/g (C2) values significantly higher than that of the unamended soil (100 x10^5UFC/g). The fungal biomass varied from 470 x10^5UFC/g (C1) to 781 x10^5UFC/g (C2) values significantly higher than that of the unamended soil (120 x10^5UFC/g). The 15% C2 component presented the highest cellulase and protease activities with values 3 and 9 times higher than the unamended soil respectively. The compost variants C2 and C1 (15%) were generally more productive with respective values of 85 and 69 fruits, the tomato amended with the chemical fertilizer having given 24 fruits.

Comment [MF2]: 10% refer to what?

Comment [MF3]: Duplicate phrase, please delete or rephrase it.

These results show that compost made from chicken droppings and fish bones could contribute to the development of green manure to enrich the soil, thus improving tomato production.

Keywords: Biofertilizer, Compost, Chicken droppings, Fishbones, Tomato

1. Introduction

Agricultural production is essential to sustaining human life. Sustainable agriculture must be able to maintain soil fertility, which is important for future generations; but the choices of agricultural inputs aimed at maintaining soil fertility while respecting the environment are often contested **(Bougnom et *al*., 2009)**. In agriculture, market gardening occupies an important place for human food. Considered a food sovereignty activity **(FAO, 2019)**, market gardening plays a key role in most nutrition and poverty reduction programs and contributes significantly to family incomes **(James, 2010)**. Native to South America, the tomato (*Lycopersicon esculentum* Mill.) is a fleshy fruit considered one of the most important vegetables in the human diet. It has become, over the years, an inescapable element of the gastronomy of several countries **(Blancard, 2009)**. Indeed, the tomato is one of the most cultivated vegetables in the world, ranking second in production after the potato **(Tuyen et *al*, 2016)**. The tomato is rich in vitamin E, C, β-carotene and lycopene, compounds that all have strong antioxidant power; it also has a balanced content of mineral elements (Zn, Mn, Ca^{2+}, Fe) **(Keatinge, 2012)**. It is therefore a perfect fruit to fight against free radicals, compounds responsible for the premature ageing of our cells. The main producing countries are China (56,308,910 tons), India (1,839,000 tons), the United States (1,303,8410 tons), Turkey (1,260,000 tons) and Egypt (7,943,000 tons) **(FAOSTAT, 2019)**.

Comment [MF4]: Is this amount per year?

In Cameroon, tomato yield has been assessed at 12.1 t/ha with a production of 1,279,853 tons **(FAOSTAT, 2019)**. With a consumption of fresh tomatoes of about 42 kg per person per year. Tomato is the most important vegetable in Cameroon in terms of quantity **(Rock Giguère, 2015)**. It benefits from a buoyant market linked to its growing integration into the food model and the extension of consumer outlets. Despite the substantial improvement in tomato production, it still faces many constraints **(Kenneth et *al*., 2018)**. In particular the parasitic pressure due to harmful insects and pathogens and especially the poor soils leads to a decrease in production.

To cope with the various production constraints, farmers have recourse to pesticides, herbicides and chemical fertilizers, but these have harmful consequences on the health of the farmer and the consumer and lead to the deterioration of the environment and the emergence of new pathogens that are increasingly resistant to pesticides. The misuse of agrochemicals causes the long-term accumulation of heavy metals in water and soil. These heavy metals are assimilated by plants and enter the food chain causing health problems in animals and humans **(Zwolak et *al*., 2019)**. Thus, to increase tomato production by reducing the use of synthetic chemical agricultural inputs, it is important to develop alternative methods by using biological inputs with the advantage of being substances that are not very toxic to humans and its environment. Previous studies have shown that the use of composts made from green waste and wood ash as biological inputs in soybean cultivation improves the physicochemical and microbiological parameters of the soil **(Bougnom et *al*., 2020)**. It has also been proven that compost made from household waste improve tomato growth parameters and protects it against diseases (**Btissam et *al*., 2010**). This is how we set ourselves the objective of evaluating the effect of compost made from chicken droppings and fish bones on the physicochemical, biological and biochemical properties of the soil, and the production of the tomato.

2. Materials and methods

2.1 Materials

2.1.1 Biological and soil material

Chicken droppings were obtained from a poultry farm in the Ngousso district (Yaoundé-Cameroon). The fish bones used were collected in Yaoundé from fish braisers in Ngoa-ekelle (Yaoundé-Cameroon). The soil used was sampled in a field in the Center Region, in the locality of Bokito (4°34'N, 11°7'E) (Cameroon). Tomato seeds of the Rio Grande variety were purchased at the Mfoundi market (Yaoundé-Cameroon). The NPK fertilizer (10-11-18) serving as a positive control was purchased at the Mfoundi market (Yaoundé-Cameroon).

Comment [MF5]: The type of fish should be mentioned?

Comment [MF6]: What does this abbreviation refer to?

2.2. Methods

2.2.1. Compost preparation

Chicken droppings and fish bones were dried at room temperature in an enclosed space at the University of Yaoundé 1 and then crushed using a mill. Depending on the mass/mass proportions of chicken droppings and fish bones, different droppings variants of the compost were obtained: 100% chicken droppings (C1), 75% chicken droppings + 25% fish bones (C2) , 50% chicken droppings + 50% fish bones (C3), 25% chicken droppings + 75% fish bones (C4). The different mixtures were introduced into buckets and covered throughout the composting period. Each variant of the compost was made in 5 repetitions and the buckets were placed in the greenhouse in a completely randomized block for a period of 122 days from December 23, 2021 to March 22, 2022. During the composting process, the compost were turned twice a month. Water was added once a month to maintain the humidity of the environment at 60% of the humidity level. The compost produced was used to amend the soil and some of the samples were taken and stored in a freezer at 4°C for physicochemical, biological and biochemical analyses.

Comment [MF7]: Are these weight or volume ratios?

2.2.2. Characterization of the compost produced and the compost soil mixture during tomato cultivation

2.2.2.1. pH measurement

Ten grams (10g) of compost were taken to which 50 mL of distilled water was added. The mixtures were stirred for 5 minutes and then allowed to stand for two hours. The pH was then measured using a pH meter brand HQ 11 D (HACH).

2.2.2.2. Measurement of electrical conductivity (EC)

The electrical conductivity was determined according to the ISO 11265 (1994) standard, which consists of extracting the sample with water in a proportion of 1/5; the purpose of this extraction is to dissolve the electrolytes. It is determined by conductimetry and expressed in (mS/cm). 20g of each compost sample was taken to which 100 ml of distilled water was added. The solutions were stirred for 30 minutes and then filtered. The specific electrical conductivity of the filtered extract is measured using a Hach brand HQ 14d conductivity meter.

2.2.2.3. Determination of total organic matter (MOT); total organic carbon and total nitrogen

- **Total organic matter (TOM)**

A sample of compost (50 g) was dried in an oven at 105°C, and then calcined at 550°C for 2 hours in an oven. The percentage of total organic matter (% MOT) or volatile solid was obtained by weighing the difference between the mass of the sample dried at 105°C and the mass of the sample after calcination **(Charnay, 2005)** according to this formula:

$$\% \text{MOT} = \frac{(\text{M1} - \text{M2}) \times 100}{\text{M1}}$$

M1: mass of the sample after passing through the oven (g); M2: mass of the sample after calcination (g); % MOT: percentage of dry matter contained in the sample.

- **Organic carbon**

The total organic carbon was determined according to the formula of **Giroux and Audesse (2004):**

$$\% \text{C} = \frac{\% \text{MOT}}{2}$$

- **Dosage of total nitrogen**

The total organic nitrogen content was determined by the Kjeldahl method. The mineralized sample is distilled with 40% soda in a BUCHI K-350 brand nitrogen still. The nitrogen vapours thus obtained are collected in an Erlenmeyer flask containing a pinkishcolored mixture composed of 20 ml of 3% boric acid and 3 drops of Tashiro's reagent. This mixture gradually turns yellowish-green in the case where the distilled sample contains nitrogen, as the sample drops from the distillation column are added. The solution obtained is dosed by titrimetry with 0.1 N sulfuric acid **(Eaton et *al*., 2005)**.

- **C/N ratio**

The C/N ratio of the composts was calculated from the organic carbon and nitrogen values obtained, it was determined according to the formula:

$$\frac{C}{N} = \frac{\text{Organic Carbon \%}}{\text{Total Nitrogen \%}}$$

2.2.2.4. Determination of concentrations of exchangeable cations (Mg^{2+}, Ca^{2+}, K^{+}, Na^{+}) and heavy metals (Pb, Zn, Cu).

The determination of the macroelements and microelements of the different variants of the compost and in the soil was made after the mineralization of the samples. The solutions were prepared by mixing 0.2 g of sample with 4 ml of sulfuric acid (H_2SO_4) 95%. These solutions were then incubated for 5 minutes in a HACH brand digital mineralizer, first at low temperature, then by gradually increasing the temperature to 440°C until the mixture cleared. During the incubation, between the 3rd and 4th minute (after boiling), 10 ml of hydrogen peroxide (H_2O_2) was gradually added using a syringe. The mineralized material thus obtained (5 ml) was reduced to 70 ml in a volumetric flask with distilled water. The Ca^{2+}, Mg^{2+}, Na^{+}, Pb, Zn, and Cu concentrations were then determined according to standard protocols **(Anonyme, 1992)** using a DR 3900 spectrophotometer.

2.2.2.5. Dosage of total phosphorus

The total phosphorus content was determined by the so-called “molybdovanadate” method **(Anonyme, 1992)**. 1 ml of molybdovanadate reagent is added to 25 ml of each previously mineralized sample. A control consisting of distilled water follows the same treatment. The reading of the optical density was done with the HACH brand DR/3900 spectrophotometer at the 650 nm wavelength. The values were expressed in mg/l.

2.2.2.6. Potassium assay

To 25 ml of a sample contained in a test tube, were successively added the contents of a capsule of reagent potassium 1 and potassium 2. The mixture was stoppered and homogenized. To the solution is clear, was added the contents of a capsule of potassium reagent 3. After 30 seconds of agitation, the solution obtained was transferred into a 25 ml cell. Another cuvette (the blank) was filled with 25 ml of sample. The reading of the optical density was made with the DR/3900 spectrophotometer at the wavelength of 650 nm. The result was expressed in mg/l.

2.2.2.7. Determination of biological and biochemical parameters of compost and amended soil

2.2.2.7.1. Enumeration of fungal flora

Analysis of the microflora was carried out using the suspension-dilution technique **(Rapilly, 1968)** on agar medium, Sabouraud dextrose agar (SDA) medium supplemented with an antibiotic (gentamicin). In a 250 mL Erlenmeyer flask containing 90 mL of sterile distilled water was aseptically added 10 g of dry compost soil mixture (after drying at 30°C overnight). This mixture was stirred using magnetic bars for 30 minutes to suspend the compost particles as well as the spores that were attached to it. The supernatant obtained constituted the crude extract and from this crude extract, a cascade dilution made it possible to obtain the following concentrations: 10^{-1}, 10^{-2}, 10^{-3}; 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7}, 10^{-8}. Using a sterile bent pipette, 0.1ml of each dilution was inoculated into Petri dishes containing the culture medium. Petri dishes were incubated at 26°C for three days. The fungal mass was determined in CFU/g of compost soil according to the formula:

$$N = \frac{\Sigma \text{colonies} \times \text{Fd1}}{\text{Vml} \times (\text{n1} + 0{,}1\text{n2})}$$

N: number of CFU per gram of soil; Σcolonies: sum of the colonies of the interpretable boxes; V: volume of solution deposited (1ml); n1: Number of boxes considered at the first dilution retained; n2: number of boxes considered at the second dilution used; Fd1: factor of the first dilution retained.

2.2.2.7.2 Enumeration of bacterial flora

The determination of the total bacterial flora was carried out using the suspension-dilution technique on nutrient agar added to an antifungal (0.5% nystatin). 5g of each sample were introduced into a 100ml Erlenmeyer flask containing 45ml of sterile physiological water (9g of NaCl/L in 1000ml of distilled water) and suspended using a magnetic stirrer for 30 minutes. The suspension was then decanted for 20 minutes, then the supernatant was removed. The supernatant obtained constituted the crude extract and from this crude extract, a cascade dilution made it possible to obtain the following concentrations: 10^{-1}, 10^{-2}, 10^{-3}; 10^{-4},

10^{-5}, 10^{-6}, 10^{-7}, 10^{-8}. Using a sterile bent pipette, 0.1ml of each dilution was inoculated into Petri dishes containing the culture medium. Petri dishes were incubated at 26°C for three days. Growing bacteria were solubilized in sterile distilled water and counted using a light microscope.

2.2.2.7.3. Enzymatic analyzes

• Cellulase activity

The cellulase activity was determined by the method described by **Tabatabaï et *al*., (1994)**. The enzymatic unit (U) is expressed in g of reducing sugars released per hour. The enzymatic activity (A) corresponds to U/g of compost soil.

• Protease activity

The protease activity was determined using the method described by **Tabatabaï et *al*., (1994)**. The enzyme unit (U) is expressed in mg of amino acid released over 2 hours. The enzymatic activity (A) corresponds to U/mg of compost soil.

2.2.2.8. Evaluation of the effect of compost on growth parameters and production of tomato

2.2.2.8.1. Tomato cultivation

Tomato cultivation was carried out in pots in a semi-controlled environment at the University of Yaoundé 1 (Cameroon) for 110 days with a frequency of watering twice a day (morning and evening) with water.

2.2.2.8.2. Nursery

The nursery (seeds of the Rio Grande tomato variety) was carried out in 4 trays containing 15kg of soil (earth + sand) sterilized for 21 days with a frequency of watering twice a day (morning and evening) with water.

2.2.2.8.3. Soil amendment

The previously sterilized soil was amended with:

- Compost soil pots: each component of the compost was mixed with the soil in the proportions 5%, 10%, and 15% compost/soil (m/m).
- Positive control (soil amended with NPK 10-11-18 fertilizer)
- Negative control (soil without amendment)

2.2.2.8.4. Transplantation

The tomato was grown in pots. Transplantation was done 30 days after sowing. The cultivation period was 110 days and the frequency of watering was twice a day with water.

2.2.2.8.5. Determination of tomato plant growth parameters and production

• Growth parameters

Leaf number, plant height, length, width and leaf area of each plant were determined weekly after transplanting for 42 days.

• Tomato yield

During tomato cultivation, the number of flowers and total fruits were determined according to the proportions of the compost soil mixture 70, 90 and 110 days after transplantation (DAT). The number of ripe fruits and the average mass of ripe fruits harvested were determined at 90 and 110 DAT.

2.2.2.9. Statistical analyzes

The results obtained were subjected to statistical analysis for the calculation of means, standard deviations and the search for significant differences, using the SPSS 22.1 software. The one-way ANOVA test coupled with Student-Newman-Keuls tests was used to assess the Least Significant Difference (LSD) at $P < 0.05$.

3.1. Results

3.1.1. Characteristics of the compost produced

The physicochemical characteristics of the different variants of compost C1, C2, C3 and C4 were determined. **Table I** below presents the characteristics of the different variants of the compost produced.

Table I: pH, EC, organic C, total N, C/N ratio, total P, concentrations of exchangeable ions (Mg^{2+}, Ca^{2+}, K^{+}, Na^{+}) and heavy metals (Pb, Zn, Cu) of compost variants C1, C2, C3 and C4.

Characteristics	Composts variants			
	C1	C2	C3	C4
pH	9,03±0,03^{a}	9,13±0,01^{b}	9,17±0,01^{c}	9,14±0,00^{bc}
EC (mS/cm)	0,43±0,03^{b}	0,49±0,00^{c}	0,40±0,02^{bc}	0,37±0,01^{a}
C (g/kg)	38,30±1,00^{a}	54,50±1,73^{c}	48,00±0,76^{b}	40,00±1,25^{a}
Total N (g/kg)	1,93±0,05^{c}	1,80±0,05^{b}	1,96±0,05^{d}	1,76±0,05^{a}
P (g/kg)	0,30±0,00^{a}	0,42±0,02^{c}	0,37±0,01^{b}	0,28±0,01^{a}
C/N ratio	21,88±1,05^{a}	30,27±1,32^{c}	24,40±1,15^{b}	22,64±1,25^{ab}
Mg^{2+} (g/kg)	0,08±0,00^{a}	1,06±0,11^{b}	0,06±0,00^{a}	0,04±0,00^{a}
Ca^{2+} (g/kg)	0,04±0,01^{a}	0,47±0,02^{c}	0,25±0,01^{b}	0,24±0,01^{b}
K^{+} (g/kg)	0,06±0,00^{b}	0,08±0,00^{c}	0,02±0,01^{a}	0,01±0,00^{a}
Na^{+} (g/kg)	6,70±0,20^{a}	14,66±1,52^{c}	8,76±0,05^{b}	6,633±0,11^{a}
Pb (mg/kg)	0,53±0,05^{a}	0,78±0,02^{c}	0,89±0,01^{d}	0,56±0,11^{b}
Zn (mg/kg)	0,04±0,00^{a}	0,23±0,01^{b}	0,04±0,01^{a}	0,07±0,01^{c}
Cu (mg/kg)	2,13±0,02^{c}	2,23±0,01^{c}	1,79±0,01^{b}	1,56±0,01^{a}

Results are presented as means ± standard deviations of 5 replicates. The values assigned by different letters on the same row are significantly different at the threshold ($P < 0.05$). C1 = 100% chicken droppings, C2 = 75% chicken droppings + 25% fish bone powder, C3 = 50% chicken droppings + 50% fish bone powder, C4 = 25% chicken droppings + 75% fish bone powder.

Comment [MF8]: Please explain this behavior… It is assumed that the increase in fish bones increases the percentage of P because they are rich in it!!

Comment [MF9]: Please explain this behaviour… It is assumed that the increase in fish bones increases the percentage of Ca because they are rich in it!!

From this table, it appears that the characteristics vary according to the component of the compost. pH 9.17±0.01; 9.14±0.00; and 9.13±0.01 respectively obtained with composts C3, C4 and C2 were significantly higher than the pH of compost C1 (9.03±0.03). The largest conductivity value was obtained with C2 (0.49±0.00 mS/cm) and the smallest with C4 (0.37±0.01mS/cm). Organic carbon concentrations were significantly higher for C2 (54.50±1.73g/kg) and C3 (48.00±0.76g/kg) compared to C1 (38.30±1.00g/kg) and C4 (40.00±1.25g/kg). The highest nitrogen concentration was obtained with C3 (1.96±0.05g/kg) and the lowest with C4 (1.76±0.05g/kg). The highest C/N ratio was obtained with C2 and C3 with respective values of 30.27±1.32 and 24.40±1.15. The highest Mg^{2+}, Ca^{2+}, K^{+}, Na^{+} concentrations were obtained with C2 with respective values of 1.06±0.11g/kg; 0.47±0.02g/kg; 0.08±0.00g/kg; 14.66±1.52g/kg. In all the components the Pb, Zn and Cu concentrations were generally low.

3.1.2. Characteristics of soil amended with compost

3.1.2.1. Values of pH, electrical conductivity (EC), organic carbon, total nitrogen and total phosphorus concentrations.

The values of pH, electrical conductivity (EC), organic carbon (C), total nitrogen (N) and total phosphorus (P) concentrations were determined in the compost soil mixtures. The results are shown in **Table II** below.

Table II: Values of pH, electrical conductivity (EC), organic carbon concentrations, total nitrogen, total phosphorus in composts/soil mixtures

Characteristics Compost/soil mixtures		pH	CE (mS/cm)	C (g/kg)	Total N (g/kg)	C/N ratio	P (g/kg)
	T-	$5,10\pm0,07^{a}$	$1,02\pm0,18^{b}$	$10,00\pm0,20^{a}$	$0,80\pm0,05^{a}$	$12,50\pm0,10^{a}$	$3,00\pm0,10^{a}$
	T+	$6,53\pm0,04^{c}$	$0,57\pm0,46^{a}$	$34,43\pm2,62^{e}$	$2,58\pm0,08^{e}$	$13,38\pm1,40^{a}$	$12,37\pm0,62^{e}$
C1	5%	$5,60\pm0,10^{b}$	$1,86\pm0,00^{d}$	$32,33\pm1,52^{d}$	$1,20\pm0,10^{b}$	$26,94\pm2,00^{d}$	$10,66\pm1,15^{d}$
	10%	$6,13\pm0,05^{c}$	$2,36\pm0,01^{e}$	$36,66\pm1,52^{f}$	$1,20\pm0,10^{b}$	$30,55\pm2,04^{f}$	$14,33\pm1,52^{h}$
	15%	$7,16\pm0,05^{d}$	$2,76\pm0,00^{f}$	$52,66\pm1,15^{f}$	$2,15\pm0,05^{c}$	$24,49\pm2,50^{c}$	$16,50\pm1,52^{i}$
C2	5%	$6,23\pm0,05^{c}$	$1,86\pm0,05^{d}$	$33,33\pm2,30^{d}$	$1,23\pm0,11^{b}$	$27,09\pm1,70^{d}$	$9,50\pm0,50^{c}$
	10%	$7,16\pm0,05^{d}$	$2,23\pm0,01^{e}$	$35,66\pm2,08^{f}$	$1,23\pm0,15^{b}$	$28,99\pm2,50^{e}$	$13,20\pm0,17^{g}$
	15%	$7,40\pm0,10^{e}$	$3,50\pm0,28^{g}$	$55,00\pm2,30^{h}$	$2,28\pm0,10^{d}$	$24,12\pm2,70^{c}$	$16,66\pm0,10^{h}$
C3	5%	$5,20\pm0,10^{a}$	$1,56\pm0,00^{c}$	$28,00\pm1,00^{b}$	$1,23\pm0,11^{b}$	$22,76\pm2,10^{b}$	$9,43\pm0,51^{c}$
	10%	$6,06\pm0,05^{c}$	$2,36\pm0,01^{e}$	$35,66\pm2,08^{f}$	$1,23\pm0,15^{b}$	$28,99\pm2,02^{e}$	$13,16\pm0,76^{h}$
	15%	$7,06\pm0,11^{d}$	$2,76\pm0,00^{f}$	$55,66\pm2,30^{g}$	$2,38\pm0,05^{d}$	$23,38\pm2,60^{b}$	$15,00\pm1,15^{i}$
C4	5%	$5,16\pm0,05^{a}$	$1,86\pm0,00^{d}$	$29,66\pm1,15^{c}$	$1,23\pm0,11^{b}$	$24,11\pm1,80^{c}$	$8,66\pm1,15^{b}$
	10%	$6,06\pm0,05^{c}$	$2,36\pm0,01^{e}$	$34,66\pm1,52^{e}$	$1,23\pm0,15^{b}$	$28,17\pm1,98^{d}$	$14,33\pm1,15^{f}$
	15%	$7,03\pm0,05^{d}$	$2,76\pm0,00^{f}$	$50,00\pm1,73^{g}$	$2,13\pm0,05^{c}$	$23,47\pm2,07^{b}$	$13,33\pm1,52^{f}$

Results are presented as means ± standard deviations of 5 replicates. The values assigned by different letters on the same row are significantly different at the threshold ($P < 0.05$). C1 = 100% chicken droppings, C2 = 75% chicken droppings + 25% fish bone powder, C3 = 50% chicken droppings + 50% fish bone powder, C4 = 25% chicken droppings + 75% fish bone powder, 5%, 10%, 15%: T^{+} =Soil amended with NPK, T^{-}=Unamended soil, 5%, 10%, 15% = compost soil proportions (m/m).

From this table, it appears that all the parameters evaluated varied according to the proportions of the variant mixtures of compost soil. Except the C3 and C4 mixtures (5%), all the mixtures gave pH significantly higher than the pH of the unamended soil. The highest pH was obtained with the C2 15% mixture (7.40±0.10) significantly higher than the pH of the unamended soil (5.10±0.07).

Electrical conductivity (EC) increased significantly during soil amendment. The highest EC was obtained with Variant C2 (15%) with a value of 3.50±0.28mS/cm significantly higher than the unamended soil (1.02±0.18mS/cm).

There is a significant increase in carbon concentration in all amended soils compared to unamended soil. The highest carbon concentrations were obtained with the C3 and C2 variants (15%) with respective values of 55.66 ±2.30g/kg and 55.00 ±2.30g/kg significantly higher than the soil unamended (10.00 ±0.20g/kg). Total nitrogen concentration varied and increased significantly in all amended soils. The highest concentrations were obtained with the C3 and C2 variants (15%) with respective values of 2.38 ±0.05g/kg and 2.28 ±0.10g/kg significantly higher than the unamended soil (0.80 ±0.05g/kg).

The C/N ratio varied according to the proportions of the compost soil mixtures. A significant increase in this ratio was noted in all amended soils compared to unamended soil. It varied from 12.50±0.10 (unamended soil) to 30.55±2.04 (C1 10%).

Phosphorus concentration increased significantly in all amended soils. The highest phosphorus concentrations were obtained with variants C2 and C1 (15%) with respective values of 16.66 ±0.10g/kg and 16.50 ±1.52g/kg significantly higher than the soil unamended (3.00 ±0.10g/kg).

3.1.2.2. Concentrations of exchangeable ions (Mg^{2+}, Ca^{2+}, K^+, Na^+) and heavy metals (Pb, Zn, Cu).

Concentrations of exchangeable ions (Mg^{2+}, Ca^{2+}, K^+, Na^+) and heavy metals (Pb, Zn, Cu) were determined in compost soil mixtures compared to unamended soil. **Table III** below presents the results obtained.

Table III: Concentrations of exchangeable ions (Mg^{2+}, Ca^{2+}, K^{+}, Na^{+}) and heavy metals (Pb, Zn, Cu) in composts/soil mixtures

Characteristics compost/soil mixtures		Mg^{2+} (g/kg)	Ca^{2+} (g/kg)	K^{+} (g/kg)	Na^{+} (g/kg)	Pb (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
	T	$0,30\pm0,01^{a}$	$3,00\pm0,01^{a}$	$0,20\pm0,07^{a}$	$0,40\pm0,00^{a}$	$0,15\pm0,01^{a}$	$0,01\pm0,00^{a}$	$0,11\pm0,00^{a}$
C1	5%	$2,13\pm0,11^{c}$	$12,66\pm1,15^{d}$	$0,66\pm0,11^{b}$	$1,69\pm0,18^{b}$	$0,19\pm0,01^{b}$	$0,02\pm0,00^{b}$	$0,13\pm0,00^{b}$
	10%	$2,93\pm0,11^{e}$	$14,66\pm1,15^{f}$	$1,06\pm0,05^{d}$	$2,09\pm0,00^{e}$	$0,38\pm0,02^{d}$	$0,03\pm0,00^{c}$	$0,16\pm0,00^{c}$
	15%	$3,88\pm0,28^{g}$	$14,00\pm1,73^{d}$	$1,33\pm0,15^{g}$	$2,56\pm0,11^{f}$	$0,47\pm0,11^{f}$	$0,03\pm0,00^{c}$	$0,16\pm0,00^{c}$
C2	5%	$1,86\pm0,11^{b}$	$10,66\pm1,15^{b}$	$0,73\pm0,05^{c}$	$1,81\pm0,02^{c}$	$0,22\pm0,98^{bc}$	$0,02\pm0,00^{b}$	$0,14\pm0,00^{b}$
	10%	$2,70\pm0,26^{d}$	$12,66\pm0,57^{d}$	$1,10\pm0,10^{e}$	$2,03\pm0,05^{d}$	$0,36\pm0,02^{d}$	$0,03\pm0,00^{c}$	$0,16\pm0,00^{c}$
	15%	$3,86\pm1,52^{g}$	$16,50\pm0,11^{h}$	$1,36\pm0,11^{g}$	$2,56\pm0,02^{f}$	$0,47\pm0,01^{f}$	$0,04\pm0,00^{d}$	$0,16\pm0,00^{c}$
C3	5%	$1,90\pm0,10^{b}$	$11,33\pm1,15^{c}$	$0,66\pm0,11^{b}$	$1,75\pm0,08^{c}$	$0,19\pm0,01^{b}$	$0,02\pm0,00^{b}$	$0,14\pm0,00^{b}$
	10%	$2,80\pm0,17^{d}$	$13,33\pm0,57^{e}$	$1,10\pm0,10^{e}$	$2,13\pm0,15^{e}$	$0,37\pm0,02^{d}$	$0,03\pm0,00^{c}$	$0,16\pm0,00^{c}$
	15%	$3,66\pm0,28^{f}$	$16,66\pm1,15^{h}$	$1,20\pm0,17^{h}$	$2,56\pm0,11^{f}$	$0,36\pm0,11^{c}$	$0,04\pm0,00^{d}$	$0,16\pm0,00^{c}$
C4	5%	$1,93\pm0,11^{b}$	$10,66\pm1,15^{b}$	$0,66\pm0,11^{b}$	$1,76\pm0,08^{c}$	$0,18\pm0,01^{b}$	$0,02\pm0,00^{b}$	$0,14\pm0,00^{b}$
	10%	$2,33\pm0,28^{c}$	$13,26\pm0,64^{e}$	$1,05\pm0,05^{d}$	$2,03\pm0,05^{d}$	$0,38\pm0,01^{d}$	$0,03\pm0,00^{c}$	$0,16\pm0,00^{c}$
	15%	$3,66\pm0,28^{f}$	$16,00\pm1,00^{g}$	$1,10\pm0,11^{e}$	$2,60\pm0,17^{f}$	$0,43\pm0,05^{e}$	$0,04\pm0,00^{d}$	$0,16\pm0,00^{c}$

Results are presented as means ± standard deviations of 5 replicates. The values assigned by different letters on the same row are significantly different at the threshold ($P < 0.05$). C1 = 100% chicken droppings, C2 = 75% chicken droppings + 25% fish bone powder, C3 = 50% chicken droppings + 50% fish bone powder, C4 = 25% chicken droppings + 75% fish bone powder, T=Unamended soil, 5%, 10%, 15% = compost soil mixtures (m/m).

From this table, it appears that the concentrations of exchangeable ions (Mg^{2+}, Ca^{2+}, K^{+}, Na^{+}) increased significantly in all the amended soils compared to the unamended soil. The highest Mg2+ concentrations were obtained with the C1 and C2 variants (15%) with respective values of 3.88±0.28g/kg and 3.86±1.52g/kg, significantly higher than the unamended soil (0.30 ±0.01g/kg). The highest Ca^{2+} concentrations were obtained with the C3 and C2 variants (15%) with respective values of 16.66±1.15g/kg and 16.50±1.11g/kg significantly higher than the soil unamended (3.00 ±0.01g/kg). The highest K^{+} concentrations were obtained with variants C2 and C1 (15%) with respective values of 1.36±0.11g/kg and 1.33±0.15g/kg significantly higher than the soil unamended (0.20 ±0.07g/kg). The highest Na^{+} concentrations were obtained with variants C4, C1, C2, and C3 (15%) with respective values of 2.60±0.17g/kg, 2.56±0.11g/kg, 2.56±0.02g/kg and 2.56±0.11g/kg significantly higher than unamended soil (0.40 ±0.08g/kg).

The concentrations of heavy metals (Pb, Zn, Cu) varied according to the proportions of the compost soil mixtures. A significant increase in these concentrations is noted in all amended soils. The highest lead (Pb) concentrations were obtained with variants C1 and C2 (15%) with respective values of 0.47±0.11mg/kg and 0.47±0.01mg/kg significantly higher than unamended soil (0.15 ±0.01mg/kg). Zinc (Zn) and copper (Cu) concentrations were generally low.

3.1.2.3. Microbial biomass and enzymatic activities in soils amended with compost

Total bacterial and fungal concentrations, cellulase and protease activities were determined in soils amended with different variants of 15% compost. **Table IV** presents the results obtained.

Table IV: Microbial biomass, cellulase and protease activities in soils amended with compost at 15% (m/m).

Parameters	15% m/m compost/soil mixtures				
	T	C1	C2	C3	C4
Total bacteria (x10^{5}UFC/g)	100,00±3,50^{a}	570,00±9,00^{d}	609,00±15,00^{e}	466,00±17,00^{c}	347,00±15,00^{b}
Total fungi (x10^{5}UFC/g)	120,10±5,35^{a}	470,00±8,66^{b}	781,00±23,00^{e}	638,00±23,00^{d}	482,00±20,00^{c}
Cellulase activity (U/g/h)	8,45±2,27^{a}	17,66±1,15^{c}	26,66±1,52^{e}	20,66±1,15^{d}	13,66±1,52^{b}
Protease activity (U/mg/h)	0,25±0,01^{a}	1,17±0,02^{c}	2,34±0,08^{e}	1,06±0,02^{b}	1,41±0,03^{d}

Results are presented as means ± standard deviations of 5 replicates. The values assigned by different letters on the same row are significantly different at the threshold ($P < 0.05$). C1 = 100% chicken droppings, C2 = 75% chicken droppings + 25% fish bone powder, C3 = 50% chicken droppings + 50% fish bone powder, C4 = 25% chicken droppings + 75% fish bone powder, T=Unamended soil, 5%, 10%, 15% = compost soil mixtures (m/m).

From this table, it appears that the bacterial concentrations varied from 347.00±15.00 x10^{5}UFC/g (C4) to 609.00±15.00 x10^{5}UFC/g (C2) values significantly higher than that of the soil unamended (100.00±3.50 x10^{5}UFC/g). The fungal biomass varied from 470.00±8.66 x10^{5}UFC/g (C1) to 781.00±23.00 x10^{5}UFC/g (C2) significantly higher than that of the unamended soil (120.10±5. 35). The 15% C2 component presented the highest cellulase and protease activities with values 3 and 9 times higher than the unamended soil respectively.

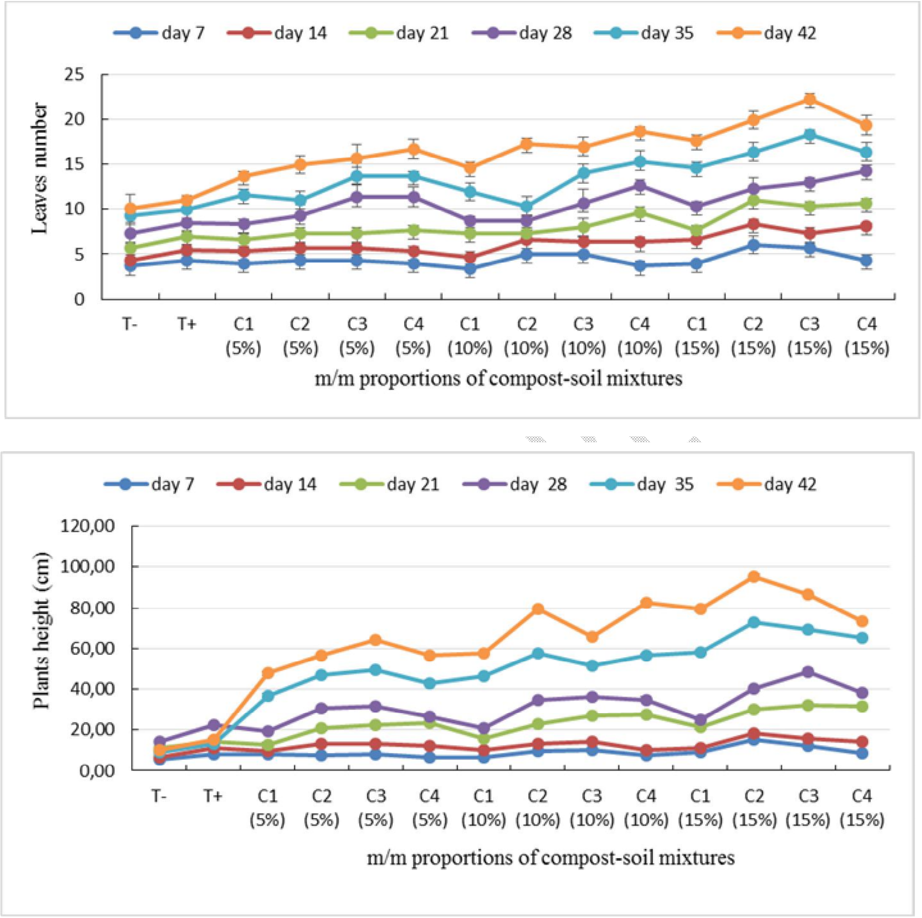
3.1.3. Evaluation of the effect of compost on tomato production

3.1.3.1. Effect of compost on growth parameters and production of tomato

- **Growth parameters**

The tomato plants were grown in pots in a compost soil mixture at different mass/mass concentrations. The number of leaves, the height of the plants and the surface of the leaves of each plant were determined weekly after transplanting for 42 days. The results are shown in

Figure 1.



Results are presented as means ± standard deviations of 5 replicates. C1 = 100% chicken droppings, C2 = 75% chicken droppings + 25% fish bone powder, C3 = 50% chicken droppings + 50% fish bone powder, C4 = 25% chicken droppings + 75% fish bone powder, 5%, 10%, 15%: T^+ *=Soil amended with NPK,* T^-*=Unamended soil, 5%, 10%, 15% = compost soil proportions (m/m).*

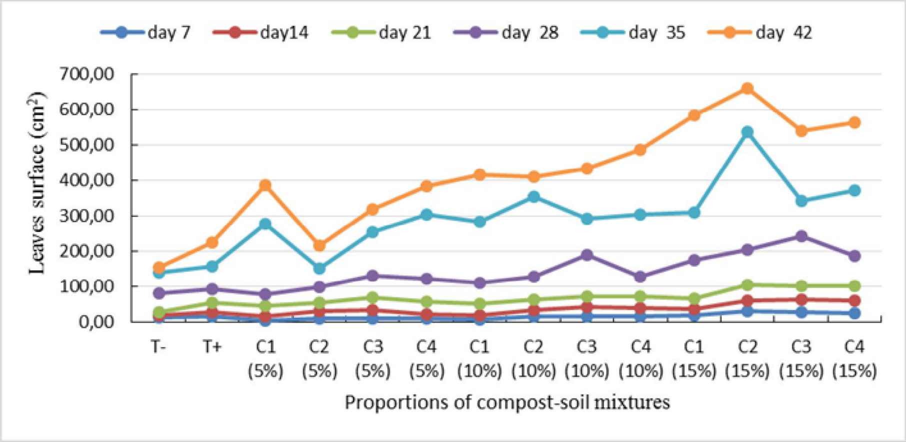
Figure 1: Variation in the number of leaves (A) and height (B) of tomato plants as a function of the proportion of compost soil mixtures and as a function of time.

It appears that the number of leaves varies according to the concentration of the compost soil mixture. On days 7, 14 and 21, the number of leaves of the tomato plants was significantly higher in the C2 mixture (15%) than in the non-almond (T-) and NPK-fertilized

(T+) soils. On day 28, the number of leaves is significantly higher in the C4 mixture (15%). On days 35 and 42 the number of leaves was significantly higher in the C3 pots (15%) with respective values of 18.33±0.57 leaves and 22.33±0.57 leaves than in the positive controls (10.00±1.00; 11.00±1.00 leaves) and negative controls (9.33±0.57; 10.10±0.58 leaves). **(Figure 1A)**

On days 7 and 14 the height of the tomato plants was significantly higher in the C2 mixture (15%) than in the non-almond (T-) and almond-based soils with chemical fertilizer (T+). On days 21 and 28, plant heights were significantly higher in the C3 mix (15%). On days 35 and 42 the heights of the plants were significantly higher in the C2 pots (15%) with respective values of 72.67±1.15 cm and 95.33±1.15 cm than in the positive controls (13.00±1.00; 15.33±0.58 cm) and negative (9.33±0.58; 10.33±1.53 cm). **(Figure 1B)**

The surface of the leaves of each plant were determined weekly after transplanting for 42 days. The results are shown in **Figure 2.**



Results are presented as means ± standard deviations of 5 replicates. C1 = 100% chicken droppings, C2 = 75% chicken droppings + 25% fish bone powder, C3 = 50% chicken droppings + 50% fish bone powder, C4 = 25% chicken droppings + 75% fish bone powder, 5%, 10%, 15%: T$^+$=Soil amended with NPK, T$^-$=Unamended soil, 5%, 10%, 15% = compost soil proportions (m/m).

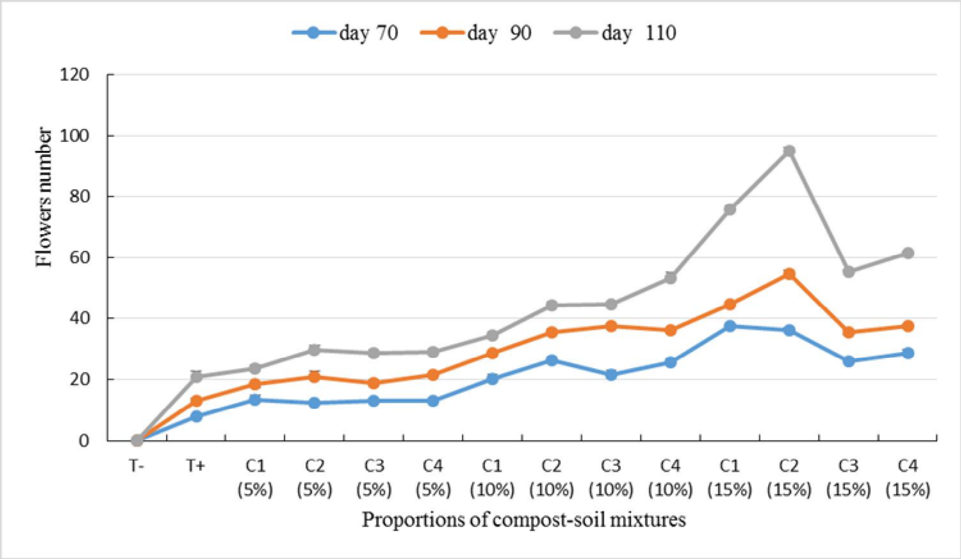
Figure 2: Variation in leaf surface of tomato plants as a function of the proportion of compost soil mixtures and as a function of time.

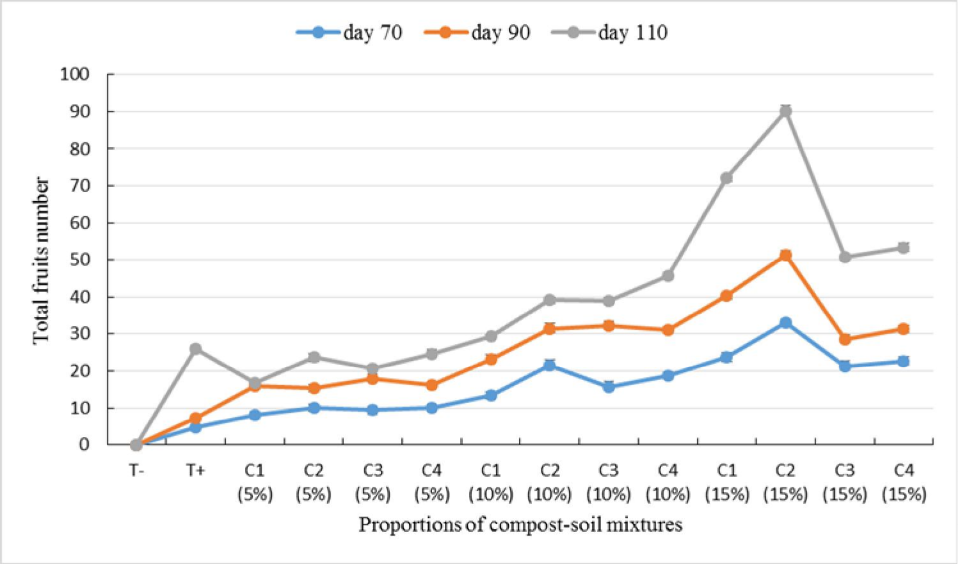
On day 7, leaf surface of tomato plants were significantly higher in the C2 mixture (15%) than in non-almond (T$^-$) and chemically fertilized (T$^+$) soils. On days 21, 35 and 42, plant leaf surface were significantly higher in C2 pots (15%) with respective values of

102.00±0.34cm; 535.30±0.75cm and 661.63±2.30cm than in the positive and negative controls **(Figure 2).**

- **Production**

The number of flowers and total fruits were determined at 70, 90 and 110 days after transplantation (DAT). The number of ripe fruits and their average mass were determined at 90 and 110 DAT. The results are shown in **Figure 3**.





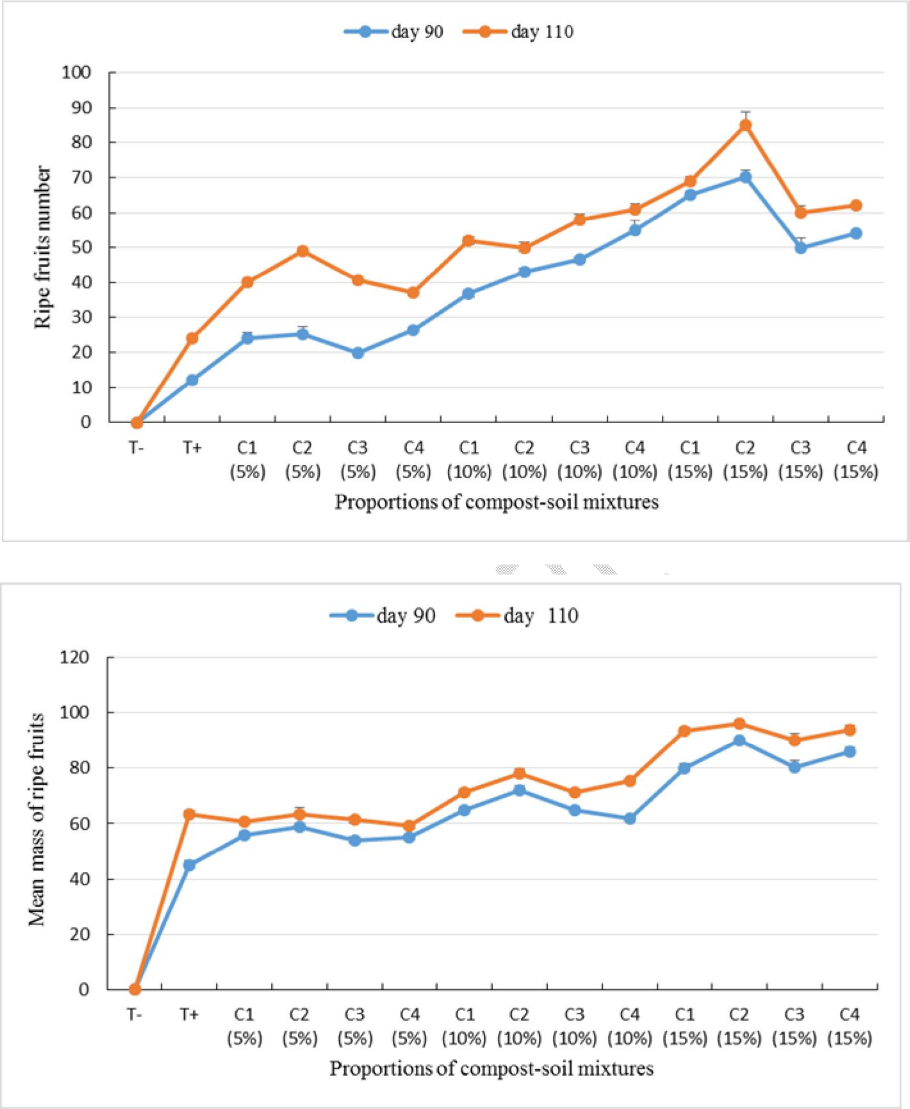
Results are presented as means ± standard deviations of 5 replicates. C1 = 100% chicken droppings, C2 = 75% chicken droppings + 25% fish bone powder, C3 = 50% chicken droppings + 50% fish bone powder, C4 = 25% chicken droppings + 75% fish bone powder, 5%, 10%, 15%: T^+=Soil amended with NPK, T^-=Unamended soil, 5%, 10%, 15% = compost soil proportions (m/m).

Figure 3: Variation in the number of flowers (A), total fruits (B) as a function of the proportion of compost soil mixtures and as a function of time.

From this figure, it appears that the negative control plants (non-almond soil) did not produce flowers. At 70, 90 and 110 DAT, plants in pots amended with compost gave a significantly higher number of flowers compared to the positive control (soil amended with NPK fertilizer). On day 110, compost C2 (15%) presented the highest number of flowers followed by compost C1 (15%) with respective values of 95.00 ±1.15 flowers and 76.00±1.85 flowers. The positive control produced 21.00±1.73 flowers **(Figure 3A)**.

The number of total fruit of the tomato plants was determined according to the proportions of the mixtures of the compost soil variants and according to the time 70, 90 and 110 days after transplantation (DAT). From this figure, it follows that the negative control plants (non-almond soil) did not produce fruit. At 70, 90 and 110 DAT, plants in pots amended with compost gave a significantly higher number of fruits compared to the positive control. On day 110, C2 compost (15%) presented the highest number of fruits followed by C1 compost (15%) with respective values of 90.00±1.52 fruits and 72.00±0.57 fruits. The positive control produced 26.00±1.15 fruits **(Figure 3B)**.

The number of ripe fruits and their average mass were determined 90 and 110 DAT. The results are shown in **Figure 4**.



Results are presented as means ± standard deviations of 5 replicates. C1 = 100% chicken droppings, C2 = 75% chicken droppings + 25% fish bone powder, C3 = 50% chicken droppings + 50% fish bone powder, C4 = 25% chicken droppings + 75% fish bone powder, 5%, 10%, 15%: T^+=Soil amended with NPK, T^-=Unamended soil, 5%, 10%, 15% = compost soil proportions (m/m).

Figure 4: Variation in the number of tomato ripe fruits (A) and average mass of ripe fruits (B) as a function of the proportion of compost soil mixtures and as a function of time.

The number of ripe fruits of the tomato plants was determined according to the proportions of the mixtures of the compost soil variants and according to the time 90 and 110 days after transplantation (DAT). From this figure, it follows that the negative control plants (non-almond soil) did not produce fruit. At 90 and 110 DAT, plants in pots amended with compost gave a significantly higher number of ripe fruits compared to the positive control. On day 110, compost C2 (15%) presented the highest number of ripe fruits followed by compost C1 (15%) with respective values of 85.00 ± 3.60 ripe fruits and 69.00 ± 1.15 ripe fruits. The positive control produced 24.00±0.89 ripe fruits. **(Figure 4A)**

The average mass of mature fruits of tomato plants were determined as a function of the proportions of the mixtures of the compost soil variants and as a function of time 90 and 110 days after transplantation (DAT). From this figure, it appears that the negative control plants (non-almond soil) did not produce fruit. At 90 and 110 DAT, plants in pots amended with compost gave a significantly higher average fruit mass than in the positive control. On day 110, compost C2 (15%) presented the highest average masses of ripe fruit followed by compost C1 (15%) with respective values of 96.25±1.15g and 93.45±1.52g. The average fruit mass from the positive control plants was 63.33±2.56g **(Figure 4B).**

3.2. Discussion

The objective of our work was to evaluate the effect of compost made from chicken droppings and fish bones on the physicochemical and biological properties of the soil, and the production tomato. The compost produced was mature and of good quality given the physicochemical characteristics obtained in the different components.

The pH of the compost-amended soils was higher than those of the controls. This is explained by the fact that in modified organic soils, there is a flow of protons from the soil to the sites of organic matter, which consequently increases the pH of the soil. In addition, organic materials are rich in humic substances and can consume protons **(Haynes and Mokolobate, 2001**; **Wong and Swift, 2003**).

Electrical conductivity (EC) is the concentration of salts in soil. Therefore, an increase in cations in soils leads to an increase in electrical conductivity (**Ceglie and Abdelrahman, 2014)**. The increase in the concentration of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) in the various amended soils explains the increase in electrical conductivity **(Kuba et *al*., 2008)**.

The compost soil proportions C2 and C1 (15%) gave the best yields with a C/N ratio of 24.12 and 24.30 respectively. According to **Springob and Kirchmann (2003)**, a C/N ratio of fewer than 12 leads to leaching, if it is between 12 and 25, there is neither leaching nor immobilization of nitrogen. This explains the high yield obtained.

The increase in the concentration of phosphorus in the soil results in an improvement in the fertility of these soils because its increase is correlated with a decrease in aluminium toxicity **(Haynes, 2002**; **Naramabiye et *al*., 2008**), which means improved conditions for plant growth. In addition, the superiority of the number of fruit obtained from soils amended by compost is also due to the incorporation of chicken droppings known to be rich in phosphorus during composting. Our results are in line with those of **Kitabala et *al*. (2016)** who showed that the addition of compost made from chicken droppings in tomato cultivation increases yield. Indeed, phosphorus is an important element in the fruit production stage **(FAO, 2019)**.

The increase in concentrations of exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) observed in amended soils would be due to cation inputs by organic amendments **(Mokolobate and Hyanes, 2002**; **Fuchs et *al*., 2004**; **Smith, 2009**). The high calcium concentration in these amended soils is of great interest because the buffering capacity of the soil depends on its quantity and availability, which reduces the potential for soil nutrient leaching **(Mokolobate and Hyanes, 2002**). This is in line with the work of **Bougnom et *al*., (2020)** who showed that compost made from cow dung and wood ash increases the exchangeable cation concentrations of Bokito and Nkolbison soils.

The increase in the bacterial and fungal biomass of the soils amended with the compost is the consequence of the improvement of the physicochemical parameters of the soils, following a contribution of organic matter; the microorganisms finding the substrate necessary for their metabolism on the spot, the organic amendment will potentiate the nitrogen and the carbon of the biomass as well as the microbial activity over several years **(Ros et *al*, 2006)**.

The increase in cellulase and protease activities in soils amended with compost follows the increase in fungal and bacterial biomass. Soil enzymes are mainly of microbial origin; they are measurable and respond quickly to any change in soil management **(Dick et *al*., 1996)**. In the same direction, **Caldwell (2005)** stipulated that Enzymes are potential indicators of soil quality and are closely linked to the activity and abundance of microorganisms. The increase in growth parameters and plant yield would be attributed to the improvement of physicochemical, biological and microbial parameters of the soil, which creates favourable growth conditions for the plant, by providing the necessary nutrients to plant growth. Our results are conform with those of **Lynch et *al.*, (2004)** and **Talimiroua (2010)** which showed that the contribution of organic matter improves the physicochemical and biological properties of the soil favourable to the growth of the plant. Indeed our study has shown that local resources such as organic waste, applied to poor and acidic tropical soils can provide the necessary nutrients for food and plant growth, therefore increasing the yield of cultivated plants. This leads us to conclude that compost made from chicken droppings and fish bones could be a good alternative to synthetic chemical fertilizers.

4. Conclusion

The compost variants produced from chicken manure and fish bones were rich in nitrogen, phosphorus and potassium with a C/N ratio ranging from 21.88 to 30.27. The compost improved the physicochemical (pH, nitrogen, phosphorus, Mg^{2+}; Ca^{2+}; K^+ and Na^+), biological (bacterial and fungal biomass) and biochemical (cellulase, protease, dehydrogenase, β-glucosidase, acid phosphatase and alkaline phosphatase activities) properties. soil compared to soil amended with NPK fertilizer. The use of compost has improved tomato production. It was greater with the 15% C2 variant (85 fruits), i.e. more than 70 times compared to the tomato obtained with the NPK fertilizer (12 fruits). Compost made from chicken manure and fish bones is an alternative to conventional agrochemicals to improve the physicochemical, biological and biochemical properties of the soil and tomato production.

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