

Agronomic Performances of Manure Composts in Simplified Soiless Tomato Cultivation

Aké Hermann Thierry Biékré^{1*}, Seu Jonathan Gogbeu², Guy Joël Olivier Atsin³, Serge Hervé Kimou⁴, Koffi Aimé Yao⁵, Bi Tra Tie⁵, Denezon Odette Dogbo¹

¹Training and Research Unit of Sciences of Nature, Laboratory of Biology and Improvement of Plant Production, Nangui Abrogoua University, Abidjan, Ivory Coast

²Training and Research Unit of Agroforestry, Laboratory of Plant Physiology and Pathology, Jean Lorougnon Guédé University, Daloa, Ivory Coast

³National Center for Agronomic Research (CNRA), Bimbresso Research Station, Banana-Pineapple-Plantain Program, Abidjan, Ivory Coast

⁴Science and Technology Department, Alassane Ouattara University, Bouaké, Ivory Coast

⁵Laboratory of Plant and Soil Analysis of the High School of Agronomy, Institut National Polytechnique Félix Houphouët-Boigny (INP-HB), Yamoussoukro, Ivory Coast

Email: *biekrehermann@yahoo.fr

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Abstract

Composts are recognised as an important source of nutrients for crops. The study aims to valorise agricultural by-products by composts made from broiler (A), laying hen (B) and bovine (C) manures in soiless tomato cultivation. Treatments consisted of these three composts and controls consisting of coconut fibres fed with a nutrient solution. The system is a randomised Fisher block with three replications. Each elementary plot consisted of nine tomato plants. Chemical parameters of the substrates and agronomic parameters of the plants were recorded from 14 to 49 days after transplanting (DAT). The pH stabilised at around 6.2 after varying from 7.1 to 8.0 in the composts. The high electrical conductivity (5.9 - 6.01 dS/m) was less than 1 dS/m at 49 DAT. Agromorphological parameters were close to the controls. Fruit necrosis was higher in the compost-based substrates (13.75% - 32.22%) than in the controls (<2%). Healthy fruit yields from the composts (38.7 - 48.7 t/ha) were high, although lower than those from the controls (49.9 - 57.4 t/ha). Fruit harvested from these substrates had a longer average shelf life (38.23 days) than the controls (28.5 days). This study showed that composts have fertilising properties for soiless tomato cultivation, in particular that of laying hen manure (48.33 t/ha). These composts could provide an alternative to the use of chemical fertilisers in soiless tomato cultivation.

Keywords

Chemical Fertilizer, Manure Compost, Simplified Soilless Cultivation, Tomato

1. Introduction

Soilless cultivation is a technique for growing plants outside their natural terrestrial soil environment [1]. Plant roots develop on reconstituted solid or liquid media containing dissolved fertilisers. Since the 1980s, this method of cultivation has grown considerably in developed countries, particularly in Europe [2] [3]. However, this cultivation technique as practiced in Europe is very expensive. Therefore, projects to develop another type of soilless agriculture that is simpler and less costly have emerged in South American countries, particularly in Brazil and Peru [4] the extension of simplified soilless cultivation or micro-gardening has also spread in West Africa, namely in Senegal, Burkina Faso and Ivory Coast [5]. However, soilless farming technology has always been based on irrigating crops with purely chemical nutrient solutions. To find more organic approaches to soilless cultivation, this study focused on the use of substrates based on farm by-product composts in soilless tomato cultivation. The aim was to demonstrate the suitability of farmyard manure composts for use as substrates in soilless tomato cultivation without the addition of mineral supplements.

2. Materials and Methods

2.1. Study Site

The experiment was conducted on a plot located at Songon-Kassemlé in the Autonomous District of Abidjan. This experimental site is located 15 km south-west of Abidjan, 400 m from the Abidjan-Dabou road and 500 m from the Ebrié Lagoon. The geographical coordinates are 5° 19'05" North latitude and 4° 12'37" West longitude, at an altitude of 36 m. Average temperature and rainfall calculated from data recorded by [6] were 25.9°C and 139.06 mm respectively during the growing period.

2.2. Materials

2.2.1. Plant Material

The plant material consisted of tomato seeds of the hybrid variety Lindo F1 from the International seed company Technisem and distributed by the company Semivoire in Ivory Coast. It is an early variety (75 to 80 days), tolerant to bacterial wilt and resistant to fusariosis.

2.2.2. Cultivation Substrates

Growing substrates were made from composts of agricultural manures and coconut fibers. The composts used in this work were obtained after 74 days of composting

by [7]. They were manufactured from broiler (A), laying hen (B) and cattle (C) manures. Their chemical composition is recorded in **Table 1**. The compost-based growing substrates are a mixture of each type of compost stored for 12 months and coarse coconut fiber (92/8; m/m). These coarse fibers and the fine coconut fibers used as controls were supplied by the companies Sodipex and Green Technology based respectively in the village of Songon-té and in the coastal town of Jacquville in Ivory Coast.

Table 1. Characteristic and chemical composition of manure composts.

Type of compost	C/N	Minerals content (g/kg of dry matter)					
		C	N	P	K	Ca	Mg
A2:1	7.91	261.2	33.0	20.8	28.6	46.1	11.2
B2:1	9.93	344.6	34.7	24.0	29.8	43.6	11.4
C2:1	9.82	154.2	15.7	3.2	11.4	8.2	3.3

A2:1: broiler manure compost; **B2:1:** laying hen manure compost; **C2:1:** bovine dung compost; **2:1:** ratio of the quantities of manure and fine coconut fibers, where the first number refers to the quantity of manure and the second number to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg (Source: [7]).

2.3. Methods

2.3.1. Experimental Design

Experimental design was a randomised Fisher block with three replications (**Figure 1**) carried out under a shelter covered with a transparent tarpaulin. The factor studied was the substrate, divided into three modalities A2:1 (substrate based on broiler manure compost), B2:1 (substrate based on layer hen manure compost) and C2:1 (substrate based on bovine dung compost). Two control treatments, T1 consisting only of fine coir fibers (commercial fiber) and T2, consisting of coarse coir fibers (artisanal fiber) were used. The elementary plot consisted of three culture cans containing one type of substrate. Three (03) tomato plants spaced 0.25 m apart were transplanted into each container, *i.e.* nine (09) plants per elementary plot (**Figure 2**) and 27 plants per treatment. Each canister had a surface area of 0.1125 m² (0.45 m long by 0.25 m wide) and was connected to an empty 5-litre bottle of mineral water, which was used to recover the drainage solution after irrigation. The experimental design consisted of a total of five treatments with three replications over an area of 80 m².

2.3.2. Experiments

1) Preparation of substrates and determination of minerals

The culture substrates were made from a mixture of coarse coconut fibers and each type of farmyard manure compost. The coarse fibers were first disinfected with sodium hypochlorite at 8 °C/hl diluted to 0.35%. The test substrate, consisting of 92% compost, was obtained by mixing 9.2 kg of compost with 0.8 kg of coarse coconut fibers. The assimilable minerals content of the compost-based substrates

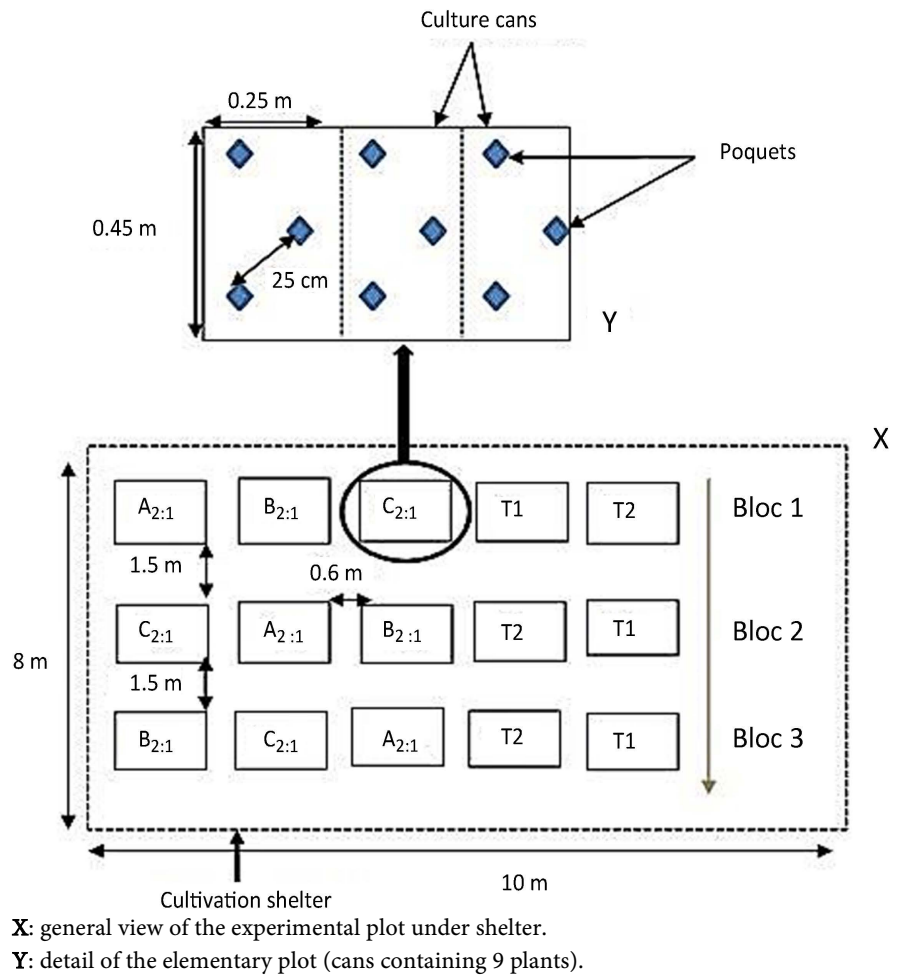


Figure 1. Diagram of the experimental device.



Figure 2. Elementary plot constituted of three cans.

was determined at the Laboratory of Plant and Soil Analysis (LAVESO) in Yamoussoukro, Ivory Coast. The substrates were mineralised by calcination. The macroelements K, Ca and Mg were determined by atomic absorption spectrophotometry. Phosphorus was determined by colorimetry [8] and nitrogen by the Kjeldahl method [9].

2) Transplanting and care of plants

The seedlings were transplanted 27 days after sowing (27 DAS) at a rate of three (03) seedlings per can. Before transplanting, all the different substrates were treated with a bactericide-fungicide (copper oxychloride 50%) at a dose of 75 g/15L of water. All compost-based treatments were sprayed with tap water, while the controls received the nutrient solution prepared according to the formulation of [10]. From transplanting to the start of flowering, the plants were watered twice a day using a watering can. The amount of water applied per watering was 3.75 L, or 7.5 L/each plot/day. Each plant received an average of 0.83 L of water per day. From flowering to the start of fruit ripening, double the amount of water was applied, *i.e.* 15 L/elemental plot/day. From ripening to the end of harvest, this amount was reduced to 7.5 L/day.

Control plants were fertigated under the above conditions using the nutrient solution. The macro-nutrient chemical composition of the nutrient solution calculated from the FRESH (Fertilizers REckoning for Simplified Hydroponics) software used by [5] given in **Table 2**. The amounts of macronutrients supplied by the nutrient solution per plant, per treatment and per day calculated from the FRESH software are given in **Table 2**. However, after seven days of fertigation, the control plants were watered with water only for two days before reusing the nutrient solution. The soilless system adopted in this study operated as a closed system. The drainage solutions collected in the recovery bottles were reused to water the plants, topping them up with water.

Table 2. Quantity of macronutrients supplied per plant and per elementary plot by the nutrient solution.

Nutrient solution	N	P	K	Ca	Mg
Concentration (g/L)	0.22	0.13	0.22	0.15	0.03
Quantity (g)/plant/day	0.18	0.11	0.18	0.12	0.025
Quantity (g)/elementary plot/day (before flowering and at ripening)	1.62	0.97	1.62	1.08	0.225
Quantity (g)/elementary plot/day (by flowering to ripening)	3.24	1.98	3.24	2.16	0.45

3) Parameters evaluated

Several parameters were evaluated. These included: pH and electrical conductivity of draining solutions, vegetative, health and production parameters and fruit shelf life. Data was collected once a week up to 35 days after transplanting (DAT). After this period, data was collected every two weeks.

➤ pH and electrical conductivity (EC)

pH and electrical conductivity were determined using the pHscan 10 pH meter and the ECscan 20 conductivity meter from BANTE. The method consisted in taking 50 mL of the draining solution from the substrate before watering, using a dosing device and a disposable plastic cup. The electrodes were immersed one after the other and the respective readings taken. After each reading, the electrodes were rinsed with distilled water.

➤ Vegetative parameters

All the plants in the elementary plot were measured. The vegetative parameters measured were the length of the main stem (LT), the diameter of the main stem (DT) and the total number of leaves (NF). The mean was calculated from the data from the three replications.

➤ **Health parameter**

This parameter consisted of identifying the presence of apical necrosis on the fruit (NFNe). The total number of fruit affected by necrosis was counted each week on all the plants in the treatment. After accumulation at the end of the harvest, the rate of apical necrosis (TxNe) of fruit per treatment was calculated using the following formula:

$$\text{TxNe} = \frac{\text{NFNe}}{\text{NTF}} \times 100 \quad (1)$$

TxNe: necrotic fruit rate.

NFNe: total number of necrotic fruits.

NTF: total number of fruits.

➤ **Fruit shelf-life**

After harvesting, two healthy fruits were selected from each treatment and stored in an airy place on honeycombed cardboard. Daily monitoring was carried out until the date on which the fruit began to deteriorate (softening and/or rotting). Fruit shelf life (FSL) was assessed on the basis of the harvest date and the date on which deterioration began.

➤ **Production parameters**

The production parameters used were the total number of flowers (NFL) per plant, the net yield (YdNET) and the potential yield (YdPOT) per treatment. The total number of flowers was determined by counting once a week from the 28th day after transplanting (DAT) and two weeks after 35 DAT. The fruits were harvested as soon as they turned light red. At the end of the harvest, the different quantities obtained per elementary plot were added together and the average of the three replications was determined. The total weight of fruit (healthy and damaged) was calculated. This total weight of fruit (TWF), divided by the surface area of the plot, gives the potential yield (YdPOT). The yield determined from the total weight of healthy fruit (TWHF) constitutes the net yield (YdNET). These yields per hectare were calculated according to the formulae below.

$$\text{YdPOT} = \frac{\text{TWF}}{\text{S}} \times 10 \quad (2)$$

$$\text{YdNET} = \frac{\text{TWHF}}{\text{S}} \times 10 \quad (3)$$

YdPOT: potential yield (t/ha).

YdNET: net yield (t/ha).

TWF: total weight of harvested fruit (healthy and damaged) (kg).

TWHF: total weight of healthy fruit harvested (kg).

S: surface of the elementary plot (1 m²).

10: yield conversion factor from kg/m² to t/ha.

2.4. Statistical Analysis

The data collected were analysed using SATISTICA 7.1 software. A one-factor analysis of variance (ANOVA) was performed for all the parameters to show whether there was a significant difference between the averages of the variables. Duncan's method was used to separate the averages at the 5% level.

3. Results and Discussion

3.1. Results

3.1.1. Chemical Composition of Substrates

The quantity of assimilable minerals varied to different degrees depending on the nature of the minerals and the type of substrate. Nitrogen content varied from 1.3 to 2 g/kg in the substrates. For phosphorus, the minimum and maximum values obtained were 500 (substrate C) and 911 mg/kg (substrate A). Potassium content did not differ greatly between substrates. It fluctuated around 2 cmol/kg. As for calcium, the lowest value was 8.60 cmol/kg in substrate C and the highest, 12.41 cmol/kg in substrate A. The lowest magnesium value (6.0 cmol/kg) was obtained in the substrate based on cattle dung (C), while in the substrates based on poultry manure, the content varied from 7.96 to 8.29 cmol/kg (Table 3). Statistical analysis of the values of these variables showed a significant difference between substrates ($p < 0.05$).

Table 3. Assimilable mineral content in growing substrates.

Substrates	N.ass (g/kg)	P.ass (mg/kg)	K ⁺ (cmol/kg)	Ca ²⁺ (cmol/kg)	Mg ²⁺ (cmol/kg)
A2:1	1.8 ± 0.1b	911.0 ± 14c	2.22 ± 0.11b	12.41 ± 0.26c	8.29 ± 0.27b
B2:1	2.0 ± 0.2b	843.3 ± 10.5b	2.29 ± 0.07b	11.68 ± 0.12b	7.96 ± 0.08b
C2:1	1.3 ± 0.3a	500.0 ± 5 a	2.00 ± 0.05a	8.60 ± 0.06a	6.00 ± 0.2a
F	8.24	1319.11	11.32	414.67	116.49
P	0.019	<0.001	0.009	<0.001	<0.001

Averages followed by the same letter in the same column are not statistically different according to Duncan's test at the 5% level. Average ± standard deviation; **A2:1**: substrate based on broiler manure compost; **B2:1**: substrate based on layer hen manure compost; **C2:1**: substrate based on bovine dung compost; **2:1**: ratio of the quantities of manure and fine coconut fibers, where the first number refers to the quantity of manure and the second number to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

3.1.2. Evolution of Substrates pH during Cultivation

Statistical analysis of the data recorded in Table 4 revealed significant differences between the calculated pH averages. The mean pH values obtained ranged from 6.4 to 8.1 in the substrates at 14 days after transplanting (DAT). The pH values of the T1 and T2 controls were the lowest (around 6.4). From 21 to 49 days after transplanting, the pH values fell sharply in the compost-based substrates and stabilised at around 6 (Table 4).

Table 4. pH variation in substrates during cultivation.

Substrates	Days after transplanting						F	P
	14	21	28	35	49			
A2:1	8.0 ± 0.1 e3	6.9 ± 0.3 c2	6.4 ± 0.1 ab1	6.3 ± 0.18 bc1	6.3 ± 0.06 bc1	57.83	<0.001	
B2:1	7.3 ± 0.3 b3	6.5 ± 0.1 abc2	6.4 ± 0.1 ab1,2	6.3 ± 0.10 abc1	6.3 ± 0.06 bc1,2	34.44	<0.001	
C2:1	7.1 ± 0.1 b3	6.6 ± 0.2 abc2	6.4 ± 0.1 ab1	6.2 ± 0.1 ab1	6.3 ± 0.06 bc1	39.41	<0.001	
T1	6.5 ± 0.1 a3	6.3 ± 0.1 a1,2	6.36 ± 0.1 ab2	6.4 ± 0.1 c2,3	6.2 ± 0.1 abc1	7.53	0.004	
T2	6.4 ± 0.3 a1	6.5 ± 0.3 ab1	6.5 ± 0.2 ab1	6.1 ± 0.10 a1	6.3 ± 0.1 bc1	1.98	0.17	
F	40.94	3.51	0.77	5.75	2.05			
P	<0.001	0.031	<0.001	0.005	<0.001			

Averages followed by the same letter in the same column or by the same number in bold on the same line are not statistically different according to Duncan's test at the 5% level. Average ± standard deviation; **A2:1**: substrate based on broiler manure compost; **B2:1**: substrate based on layer hen manure compost; **C2:1**: substrate based on cattle dung compost; **T1**: control based on fine coconut fiber; **T2**: control based on coarse coconut fiber; **2:1**: ratio of the quantities of manure and fine coconut fibers. where the first number refers to the quantity of manure and the second number to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

3.1.3. Variation in Electrical Conductivity in Substrates during Cultivation

Statistical analysis revealed significant differences between the calculated averages of electrical conductivity (EC) (**Table 5**). At 14 days after transplanting (DAT). Electrical conductivity varied from 1.6 to 6.01 dS/m in the compost-based substrates. In contrast, electrical conductivity in the T2 and T1 controls was 1.5 and 1.8 dS/m respectively. It decreased considerably in all the compost-based substrates. Reaching values ranging from 0.74 to 1.04 dS/m at 49 DAT.

Table 5. Variation in electrical conductivity (dS/m) in substrates during cultivation.

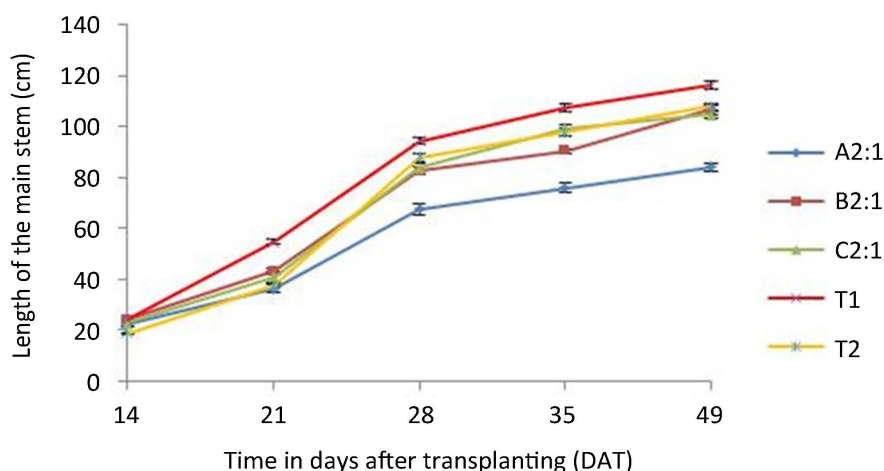
Substrates	Days after transplanting						F	P
	14	21	28	35	49			
A2:1	1.6 ± 0.04 a3	1.3 ± 0.13 ab2,3	1.16 ± 0.27 a2	0.83 ± 0.14 a1	0.74 ± 0.13 a1	14.38	0.003	
B2:1	5.9 ± 2.4 b2	4.78 ± 3.07 c2	2.8 ± 0.7 b1,2	1.07 ± 0.3 ab1	1.04 ± 0.1 b1	4.59	0.023	
C2:1	6.01 ± 4.6 b2	3.86 ± 0.9 bc1,2	3.85 ± 1.43 b1,2	0.81 ± 0.16 a1	0.9 ± 0.7 ab1	2.98	0.073	
T1	1.8 ± 0.08 a2	1.7 ± 0.12 ab2	1.51 ± 0.06 a1	1.37 ± 0.14 bc1	1.31 ± 0.2 c1	10.83	0.001	
T2	1.5 ± 0.2 a2	0.23 ± 0.47 a1	0.24 ± 0.06 a1	1.67 ± 0.08 c2	1.48 ± 0.15 c2	94.22	<0.001	
F	5.13	5.04	11.49	11.93	15.53			
P	0.015	0.017	<0.001	<0.001	<0.001			

Averages followed by the same letter in the same column or by the same number in bold on the same line are not statistically different according to Duncan's test at the 5% level. Average ± standard deviation; **A2:1**: substrate based on broiler manure compost; **B2:1**: substrate based on layer hen manure compost; **C2:1**: substrate based on cattle dung compost; **T1**: control based on fine coconut fiber; **T2**: control based on coarse coconut fiber; **2:1**: ratio of the quantities of manure and fine coconut fibers. Where the first number refers to the quantity of manure and the second number to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

3.1.4. Evaluation of Vegetative Parameters on Compost-Based Substrates

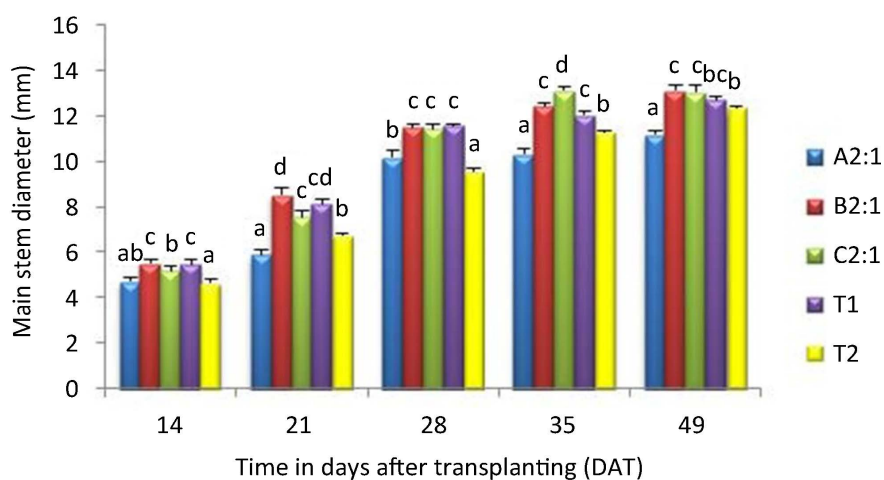
1) Effects of growing substrates on plant main stem length

Main stem length increased progressively during the cultivation period for all treatments (Figure 3). These lengths varied from 24.1 cm to 116.20 cm, from 14 to 49 days after transplanting. The longest main stem lengths of the plants were obtained in the T1 control. Nevertheless, the stem lengths of plants grown on substrates based on bovine dung compost (C2:1) and laying hen manure (B2:1) were close to the controls.



A2:1: broiler manure compost substrate; **B2:1:** laying hen manure compost substrate; **C2:1:** bovine dung compost substrate; **T1:** control based on fine coconut fiber; **T2:** control based on coarse coconut fiber; **2:1:** ratio of the quantities of manure and fine coconut fiber, where the first number refers to the quantity of manure and the second number to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

Figure 3. Effect of different substrates on the length of the main stem of tomato plants.



Histograms surmounted by the same letter for the same period are not statistically different at the 5% level (Duncan's test). **A2:1:** substrate based on broiler manure compost; **B2:1:** substrate based on layer hen manure compost; **C2:1:** substrate based on bovine dung compost; **T1:** control based on fine coconut fiber; **T2:** control based on coarse coconut fiber; **2:1:** ratio of the quantities of manure and fine coconut fibers in which the first number refers to the quantity of manure and the second number to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

Figure 4. Effect of different substrates on the diameter of the main stem of tomato plants.

2) Effect of the different substrates on the diameter of the main stem of the plant

The diameter of the main stem increased progressively for plants on all substrates from 14 to 28 days after transplanting (DAT), *i.e.* from 4.7 mm (A2:1) to 5.5 mm (B2:1). Plants grown on substrates based on laying hen manure compost (B2:1) and bovine dung (C2:1) recorded the largest stem diameters at 49 days after transplanting (DT > 13 mm). The broiler manure compost-based substrate had the smallest plant diameters (DT < 12 mm) (Figure 4).

3) Effects of growing substrates on leaf production

The total number of leaves emitted per plant increased for all substrates throughout cultivation. The T1 control recorded the highest number of leaves, ranging from 8.2 to 32.9 from 14 to 49 days after transplanting (Table 6). In plants raised on compost-based substrates, the number of leaves varied from 7.4 to 26.6.

Table 6. Variation in total number of leaves of tomato plants grown on different substrates.

Substrates	Days after transplanting					F	P
	14	21	28	35	49		
A2:1	7.7 ± 1.4 b1	10.7 ± 1.6 ab2	15.9 ± 2.3 a3	16.6 ± 1.8 a3	19.2 ± 1.1 a4	231.30	<0.001
B2:1	8.0 ± 1.7 b1	11.5 ± 1.9 b2	21.0 ± 3.7 b3	24.1 ± 2.7 b4	26.6 ± 4.9 b5	191.04	<0.001
C2:1	7.4 ± 1.9 b1	10.9 ± 2.0 ab2	20.4 ± 2.9 b3	24.7 ± 1.9 b4	29.3 ± 3.5 c5	468.17	<0.001
T1	8.2 ± 1.2 b1	13.7 ± 1.2 c2	21.0 ± 5.4 b3	29.4 ± 6.9 c4	32.9 ± 7.8 d5	113.30	<0.001
T2	6.6 ± 0.9 a1	10.6 ± 0.5 a2	19.2 ± 4.7 b3	25.2 ± 4.7 b4	28.2 ± 4.6 bc5	194.47	<0.001
F	5.35	21.51	8.72	38.71	33.20		
P	<0.001	<0.001	<0.001	<0.001	<0.001		

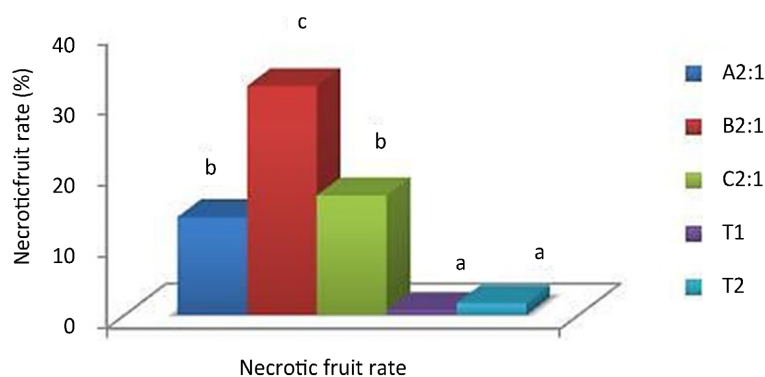
Averages followed by the same letter in the same column or by the same number in bold on the same line are not statistically different according to Duncan's test at the 5% level. Average ± standard deviation; **A2:1**: substrate based on broiler manure compost; **B2:1**: substrate based on layer hen manure compost; **C2:1**: substrate based on bovine dung compost; **T1**: control based on fine coconut fiber; **T2**: control based on coarse coconut fiber; **2:1**: ratio of the quantities of manure and fine coconut fibers in which the first number refers to the quantity of manure and the second number to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

3.1.5. Evaluation of the Effect of Substrates on Fruit Apical Necrosis

The histograms in Figure 5 show that the nature of the substrate had a significant influence on fruit apical necrosis. The rate of fruit necrosis varied from 0.67 to 32.22% depending on the substrate. The lowest rates of fruit necrosis (<2%) were obtained in the controls, in contrast to the plants grown on composts, which recorded high rates of necrosis. These rates were higher for fruit from plants grown on substrate B (32.22%) and lower for fruit from plants grown on substrates A and C (<17%).

3.1.6. Evaluation of the Effect of Substrates on Fruit Shelf Life

The analysis of variance for the average fruit shelf life showed a significant difference (Table 7). These shelf lives varied from 24.3 to 45.3 days after harvest (DAH) depending on the substrate. Fruit from plants grown on fine coconut fiber (T1 control)



Histograms marked with the same letter are not statistically different at the 5% level (Duncan's test). **A2:1**: substrate based on broiler manure compost; **B2:1**: substrate based on layer hen manure compost; **C2:1**: substrate based on bovine dung compost; **T1**: control based on fine coconut fiber; **T2**: control based on coarse coconut fiber; **2:1**: ratio of the quantities of manure and fine coconut fiber in which the first number refers to the quantity of manure and the second number to the quantity of fine coconut fiber; **1** = 25 kg; **2** = 50 kg.

Figure 5. Rate of necrotic fruit in plants grown on different substrates.

had the shortest shelf life, evaluated at 24.3 DAH. The longest shelf life was obtained for fruit from plants grown on substrate B (45.3 DAH). This was followed by fruit from substrate A (38.7 DAH).

Table 7. Fruit shelf life (FSL) of tomato plants grown on different substrates.

Substrates	FSL (DAH)
A2:1	38.7 ± 13.3 ab
B2:1	45.3 ± 11.5 b
C2:1	30.7 ± 5.8 ab
T1	24.3 ± 0.6 a
T2	32.7 ± 1.5 ab
F	7.13
P	<0.001

Averages followed by the same letter in the same column are not statistically different according to Duncan's test at the 5% level. Average ± standard deviation; **A2:1**: substrate based on broiler manure compost; **B2:1**: substrate based on layer hen manure compost; **C2:1**: substrate based on bovine dung compost; **T1**: control based on fine coconut fiber; **T2**: control based on coarse coconut fiber; **DAH**: days after harvest; **2:1**: ratio of the quantities of manure and fine coconut fibers in which the first number refers to the quantity of manure and the second number refers to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

3.1.7. Evaluation of Production Parameters

1) Effect of growing substrates on total number of flowers

Averages calculated using ANOVA 1 showed significant differences between treatments during cultivation. The total number of flowers per plant varied from 28 to 49 days after transplanting (DAT), except in the A2:1 substrate. At 35 days

after transplanting, the plants grown on the cattle dung compost substrate (C2:1) had the highest number of flowers (NFL = 27.3), followed by the T1 (24.0) and T2 (24.9) controls. At 49 days, the total number of flowers almost decreased in plants on all substrates (Table 8).

Table 8. Variation in total number of flowers on tomato plants grown on different substrates.

Substrates	Days after transplanting				
	28	35	49	F	P
A2:1	9.0 ± 5.0a1	7.9 ± 2.0a1	8.9 ± 1.2a1	1.07	0.346
B2:1	14.6 ± 4.8b2	13.8 ± 3.6b2	7.2 ± 0.9a1	40.23	<0.001
C2:1	13.7 ± 6.8b1	27.3 ± 5.9d2	16.0 ± 6.7b1	37.80	<0.001
T1	13.0 ± 9.1b1	24.0 ± 8.3c3	17.5 ± 5.4b2	15.19	<0.001
T2	15.5 ± 3.4b1	24.9 ± 4.3cd3	20.9 ± 4.3c2	40.98	<0.001
F	4.96	74.73	53.20		
P	<0.001	<0.001	<0.001		

Averages followed by the same letter in the same column are not statistically different according to Duncan's test at the 5% level. Average ± standard deviation; **A2:1**: substrate based on broiler manure compost; **B2:1**: substrate based on layer hen manure compost; **C2:1**: substrate based on bovine dung compost; **T1**: control based on fine coconut fiber; **T2**: control based on coarse coconut fiber; **2:1**: ratio of the quantities of manure and fine coconut fibers in which the first number refers to the quantity of manure and the second number refers to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

Table 9. Effect of different substrates on the yield of tomato plants.

Substrates	YdPOT (t/ha)	YdNET (t/ha)
A2:1	44.28 ± 4.25ab	39.76 ± 3.47ab
B2:1	58.75 ± 4.56c	48.33 ± 4.24bc
C2:1	42.89 ± 2.11a	38.78 ± 1.92a
T1	60.67 ± 11.06c	57.48 ± 9.26d
T2	54.67 ± 1.19bc	49.95 ± 0.64cd
F	6.06	7.52
P	0.009	0.004

Averages followed by the same letter in the same column are not statistically different at the 5% level (Duncan's test). Average ± standard deviation; **A2:1**: substrate based on broiler manure compost; **B2:1**: substrate based on layer hen manure compost; **C2:1**: substrate based on bovine dung compost; **T1**: control based on fine coconut fiber; **T2**: control based on coarse coconut fiber; **YdPOT**: potential yield; **YdNET**: net yield; **2:1**: ratio of the quantities of manure and fine coconut fibers, where the first number refers to the quantity of manure and the second number refers to the quantity of fine coconut fibers; **1** = 25 kg; **2** = 50 kg.

2) Effects of growing substrates on yield

Potential and net yields varied from 42.89 t/ha to 60.67 t/ha and from 38.78 t/ha to 57.48 t/ha respectively (**Table 9**). The T1 and T2 controls recorded the highest net yields, at 57.48 t/ha and 49.95 t/ha respectively. Among the compost-based substrates, plants placed on substrate B obtained the highest potential yield (58.75 t/ha). This was close to that of the T1 control. However, its net yield (48.33 t/ha) was statistically equal to that of control T2. In contrast, plants grown on substrates C and A had lower net yields of 38.78 t/ha and 39.76 t/ha respectively.

3.2. Discussion

3.2.1. Effect of Substrates on Variation in pH and Electrical Conductivity

The basic or slightly basic pH of compost-based substrates at the start of cultivation is probably due to the chemical state of the substrates. The basic nature of these substrates is due to the fact that, as the composts mature, the nitrogen released is stored in the form of ammonium cations (NH_4^+). These, in the presence of hydroxide anions (OH^-), give the ammonium hydroxide solution, which is basic. The basic pH state of composts had already been reported by certain authors [11]-[13]. Furthermore, according to [14] basic or relatively basic pH levels are characteristic of mature composts. The gradual fall in pH could be explained by the acidification of the environment due to the excretion of the H^+ ion by the roots. On the other hand, its stabilisation would be ensured by the buffering capacity of the humus formed [15]. This near-neutral pH would be favourable to the absorption of most of the assimilable minerals found in these substrates. This would justify the good development of plants grown on these different substrates. The high electrical conductivities (EC) recorded at the start of cultivation in compost-based substrates are thought to result from their high ion concentrations [1]. Indeed, these composts are rich in macroelements [7].

According to some authors, these high values could be a constraint to good crop development [16] [17]. However, according to [18] tomato crops could tolerate EC values of between 5 and 7.6 dS/m, but with a 50% drop in yield. The drop in conductivity observed after one month of cultivation would be due to the use of minerals and/or their adsorption [15]. In contrast, the conductivity values recorded in the control substrates correspond to the standards for electrical conductivity values in hydroponics [2] [19].

3.2.2. Effect of Substrates on Vegetative Parameters

The increase in vegetative parameters (length and diameter of the main stem, number of leaves) of plants grown on compost-based substrates indicates good assimilation of the nutrients present in these composts [20]. Indeed, the composts used in this trial are a good source of nutrients. The amount of macronutrients such as nitrogen, phosphorus and potassium varied respectively from 15.7 to 34.7 g/kg, from 2 to 24 g/kg and from 11.4 to 29.8 g/kg of compost [7]. In addition, the content of assimilable minerals determined in substrates based on these composts shows their bioavailability. These macronutrients are essential for

plant development. Nitrogen is a mineral required for photosynthesis, as it is involved in the structure of chlorophylls. It is also required for the synthesis of proteins, most of which are enzymatic and therefore involved in catalysing reactions [21]. Phosphorus, which is involved in nucleic acid synthesis and energy transfer, is essential for cell division. Potassium, as well as being involved in enzymatic processes, is involved in the opening of stomata, the driving force behind hydromineral absorption [22].

The presence of these minerals promoted plant growth, as evidenced by an increase in the size and number of leaves. These results were corroborated by those of [23]. This author showed that compost made from date palm by-products increased the growth of tomato plants in soil-less cultivation. The rapid development of the plants after transplanting into the bovine dung substrate (C) attests to the bioavailability and rapid release of macroelements by this compost [7]. Similar results were reported by [24] and [25]. On the other hand, poultry manure compost could release minerals less rapidly [25]. However, the bioavailability of these nutrients would be progressive and continuous in laying hen compost (B) during the plant development cycle. This hypothesis found its justification in the values of the vegetative parameters close to those of the controls grown in the mineral solution where the bioavailability of the minerals is permanent.

Also, the high level of organic carbon in laying hen manure stimulates the proliferation of microorganisms responsible for mineralisation and hence nutrient availability. On the other hand, in broiler manure compost, the low nitrogen and phosphorus content compared with that of laying hen manure is thought to be responsible for the low level of growth recorded [26] [27]. The growth of vegetative parameters in T1 and T2 controls is thought to be the result of the regular supply of nutrients to the plants by the nutrient solution. However, these parameters were better in control T1. This control, made up of fine fibers, offers physical characteristics that facilitate the absorption of the mineral solution and the assimilation of minerals by the plants. In fact, this nutrient solution is a mixture of chemical fertilisers that constantly made essential mineral elements available to the plants in balanced proportions during fertigation [25]. As a result, this nutrient solution ensures harmonious and rapid vegetative growth of tomato plants. A number of authors [4] [5] have shown that simplified hydroponics can guarantee good development for the plants grown there.

3.2.3. Fruit Health and Shelf Life

The low rate of necrosis recorded is thought to be due to the bioavailability of minerals such as calcium and potassium. This mineral balance in composts prevents certain metabolic diseases such as necrosis [28] [29]. The combination of good health and ionic balance, which contributed to good fruit development, meant that the shelf life could be extended from 30 to 45 days. Although organic fertilisers have a delaying effect on fruit senescence [30] [31], sanitary condition also plays an important role, as the storage times for fruit grown in hydroponic controls were 24 and 32 days. These times were much longer than those obtained by [32],

which were around 15 days.

3.2.4. Effect of Substrates on Production Parameters

The progressive and general decline in the total number of flowers per plant observed on the 49th day after transplanting can be explained in part by fruiting, *i.e.* the transformation of these flowers into fruit during this period [33] [34]. Indeed, during fruiting, the minerals absorbed are preferentially directed towards the fruits in order to enlarge them. This phenomenon creates an imbalance in the supply of certain minerals or a low supply of nutrients in other parts of the plant. Moreover, the high nitrogen content in the compost-based growing medium would favour vegetative development to the detriment of flower production [35]. Phosphorus could also be complexed on these substrates. A deficit in this mineral would also reduce flower formation. However, the high number of flowers in the T2 control plants is thought to be due to a supply of nutrients following the degradation and mineralisation of coarse coconut fibers during cultivation [36]. The lowest net yield (38.7 t/ha) obtained in this study on the substrate based on broiler manure compost is well above the average yield of around 36.6 t/ha according to [37]. These high potential and net yields attest to the ability of the substrates developed to ensure tomato production under simplified soilless conditions. The laying hen compost (B) produced a net yield close to that of the control plants watered with the nutrient solution. This result corroborates the effectiveness of laying hen manure-based compost as reported by [38]. Similarly, the work of certain authors [7] [25] had also noted that laying hen manure composts was a potential source of major and secondary minerals. Because of their richness in nutrients, this recovered waste could be used as a crop substrate without the addition of chemical fertilisers [38] [39]. The T2 control using coarse fiber (artisanal fiber) as a substrate had a net yield close to 50 t/ha. This result shows that this locally produced fiber, considered as waste, can be used as a crop substrate.

4. Conclusion

This study highlighted the fertilising potential of compost-based substrates for soil-less tomato cultivation. All these substrates showed interesting performances, which will make it possible to experiment with the production of other vegetables in organic soilless culture. Among these substrates, the one based on compost from laying hen manure stood out for its ability to ensure good productivity. This work shows that farm by-product composts can be used in organic soilless cultivation. Their use could also help to purify the environment.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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