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ORIGINAL RESEARCH

Effects of co-composting of faecal sludge and agricultural wastes on tomato transplant and growth

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Abstract
Purpose Faecal sludge (FS) has been co-composted with many organic solid wastes globally. Agricultural wastes, such as oil palm empty fruit bunches (EFB) and cocoa pod husks (CPH), have received very little research attention as far as combining with FS is concerned. This study aimed at co-composting these wastes at different ratios to produce safe compost for use as soilless medium for raising tomato transplants.
Methods Dewatered FS (DFS) was mixed with shredded EFB and CPH at five different ratios: 1DFS:1EFB, 1DFS:1CPH, and DFS:EFB:CPH in ratios of 1:1:1, 2:1:1, and 2:2:1 and composted for 3 months. Select physico-chemical parameters and pathogens were monitored every fortnightly and 3 weeks, respectively.
Results Maximum temperatures obtained ranged 46.8–54.5 °C. Though these temperatures were lower than sanitizing temperatures prescribed by USEPA, no *E. coli* was found in any of the piles at the end of composting. The ratio 2DFS:2EFB:1CPH was found to be the safest formulation and hence was used to grow tomato under greenhouse conditions. Tomato seeds were sown in three different growing media: 100% FS-based compost, 100% rice husk biochar, and 50% FS-based compost–50% rice husk biochar mix.
Conclusion Results showed that FS-based compost was a suitable growing medium for tomato. Further studies into the optimal rate and frequency of application of compost teas on tomato are recommended.

Keywords Faecal sludge · Co-composting · Cocoa pod husks · Transplant · Compost tea · Tomato

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Introduction

Insufficient waste management has led to growing interests in approaches to safe emptying, transport, and disposal of faecal sludge (FS) (Strauss and Montangero 2002). Numerous technical developments have attempted to address the problems of emptying, transporting, and disposal of FS from urban centres (Boot and Scott 2008). Currently, the focus of research is shifting from FS disposal to reuse, with fertilizer and soil conditioner being among the most common reuse options. FS, like animal manure, is a good soil conditioner and a renewable source of plant nutrients, such as nitrogen (N), phosphorus (P) and potassium (K) (Cofie et al. 2004), and organic matter. These are lacking in arable soils found in the tropics. There is, therefore, need to transform this valuable waste into useful soil amendments for crop production. This will represent an important option for both sustainable waste management and sustainable agriculture (Chang and Davila 2007; Dick and McCoy 1993). Although FS contains these beneficial resources that can be applied to arable soils, the raw sludge contains high pathogen concentrations and direct use without prior treatment puts both farmers and consumers at risks. Composting is one way to sanitize dewatered FS (DFS). On its own, there is too little organic content to achieve thermophilic conditions (i.e., temperatures above 55 °C) during composting, which is necessary for complete pathogen destruction. Co-composting with carbon-rich materials, such as oil palm empty fruit bunches (EFB) and cocoa pod husks (CPH), can impart two key benefits: (a) enabling of thermophilic temperatures and (b) prevention of nitrogen volatilization (Jeong and Kim 2001). Previous composting studies in Ghana experimented with co-composting DFS with municipal solid wastes and sawdust (Kone et al. 2007; Cofie et al. 2009). The use of other agricultural wastes, such as EFB and CPH, has received very little research attention in terms of co-composting with DFS. It is estimated that approximately 400,000 tonnes of cocoa beans are produced annually (Ofosu-Budu et al. 2001, personal communication), and based on this annual production, an estimated 550,750 tonnes of dry cocoa husks are produced (Adamtey 2005). Annual production of EFB in Ghana can be estimated based on annual production of approximately 3,135,000 tonnes of fresh oil palm fruit bunches (calculation based on average yield of 11 tonnes per hectare) (Toledano et al. 2004). Agro-industrial wastes are posing serious challenges for the agro-industries (Abu Qdais and Al-Widyan 2016). Similarly, an estimated amount of about 3.5 million tonnes of human excreta is produced in Ghana based on an average production of 400 g cap^{-1} day^{-1} (Mann 1976). This leaves a lot of human and agricultural wastes in the environment, which are traditionally directly incinerated or deposited in landfills resulting in the production of significant amounts of greenhouse gases (Zhang et al. 2013) or sometimes reapplied to land as a conditioner and could pose health and environmental risks. Many studies have reported that organic wastes composts, such as from sewage sludge (Perez-Murcia et al. 2006), municipal solid waste (Ostos et al. 2008), animal manure (Atiyeh et al. 2001; Eklind et al. 2001), green waste (Grigatti et al. 2007; Ribeiro et al. 2007), and agro-industrial waste (Papafotiou et al. 2004; Bustamante et al. 2008) can be used with very good results as growth medium instead of peat (Kala et al. 2012). These composts and other solid manures are great, but they have one major disadvantage of taking a longer time to breakdown in the soil to release nutrients. Therefore, for successful growing of vegetables and other horticultural crops, such as tomato, which require rapid nitrogen sources, the use of compost tea could play a significant role. Compost tea has evolved from historical horticultural practices, such as steeping manure or plants in water, with the liquid applied to crops for nutritional and plant health reasons. In recent decades, the majority of published studies examining compost tea have focussed on foliar plant disease suppression using liquid materials produced by steeping compost in water for several days to weeks (Scheuerell 2004). It is increasingly being used as an alternative plant disease control measure in commercial horticulture (Diver 2001; Scheuerell and Mahaffee 2002). Compared to the numerous reports on the use of compost tea for managing foliar diseases, little work has been done to assess the nutritional benefits of compost tea on plant growth (Pant 2009). Studies into the nutritional effect of compost tea on horticultural plants are, therefore, necessary. As a liquid fertilizer, its high nutrient value and rapid availability make it a great tonic for the plants. This study, therefore, aims at (i) co-composting DFS, EFB, and CPH at different formulations to determine the appropriate formulation that will produce safe compost for use in soilless medium for tomato transplant production and (ii) to assess the nutritional effect of compost tea brewed from the FS-based compost on the vegetative growth of tomato.

Materials and methods

The study was carried out at the University of Ghana, Forest and Horticultural Crops Research Centre (FOHCREC) (6°05′N; 0°05′W). Climate of the area is humid tropical and monthly average temperature reaches a maximum of 28–29 °C in February and March, and a minimum of 25–26 °C in July/August. Rainfall pattern is bimodal with peaks (150–200 mm) in May/June and September/October (Adamtey 2005). Raw FS coming from household and public toilets at a ratio of 2:1 (*v*/*v*) was dewatered on sand drying beds to obtain DFS. The DFS was characterized and mixed at different formulations with shredded (size 2–3 cm) EFB and CPH, obtained from nearby oil palm processing industries and cocoa farms, respectively. The formulations were as follows: 1 DFS:1 EFB; 1 DFS:1 CPH; and DFS:EFB:CPH in ratio of 1:1:1, 2:1:1, and 2:2:1, respectively. The mixtures were moistened with water to about 60% moisture content following the method described by Estevez-Schwarz et al. (2012) and laid in windrows. Each of the five treatment formulations was replicated three times in a completely randomized design. Average size of a pile was 2 m long, 1.5 m wide, and 0.6 m high. Piles were turned manually every 3 days for the first 2 weeks and then once a week for the rest of the 10 weeks. Throughout the experiment, the moisture contents of the piles were maintained as recommended by Day and Shaw (2000). Daily temperature readings were taken by inserting a thermometer probe into three perforated bamboo pipes of approximately equal sizes mounted in each pile. Samples of the co-composting material were taken every 2 weeks for physicochemical analyses (pH, EC, TOC, NH_4-N, NO_3-N, Total N, P, and K). *E. coli,* total coliform, and helminth egg populations particularly *Ascaris* eggs were determined in samples every 3 weeks.

Feedstock and co-compost analyses

The feedstock and co-compost samples were air dried and milled (<0.5 mm) to homogenize the samples. Total N was determined by the modified Kjeldahl method described by Black (1965). Ammonium (NH_4-N), Nitrate (NO_3-N), Total P, Avail-P, and K were determined by methods, as described in Okalebo et al. (2002). The pH and electrical conductivity (EC) were measured using methods described in USDA and USCC (2001). Total organic carbon (TOC) was determined by the methods described in Walkley and Black (1934). For all samples, total coliform and helminth egg counts were determined using the spread plate method (APHA-AWWA-WEF 2001) and the flotation and sedimentation method following a modified USEPA method (Schwartzbrod and Gaspard 1998), respectively. Compost samples were prepared for total coliform and *E. coli* population estimates as follows: each sample was thoroughly mixed and a subsample of 10 g (dry weight) was weighed into 90 ml of sterile phosphate-buffered saline and shaken vigorously for about 2 min. Further tenfold serial dilutions were made, and Chromocult coliform agar (MERCK1 KgaA 64271 Darmstadt, Germany) was inoculated from each dilution. The inoculated media were incubated at 35–37 °C for 24–48 h (APHA-AWWA-WEF 2001). All colonies with purple-to-blue–black colour were counted as *E. coli.* Temperature, pH, C:N ratio, and CO_2 evolution rates of co-compost were used to determine co-compost stability and maturity. Carbon dioxide (CO_2) evolution rates were determined by methods, as described in Okalebo et al. (2002). Criteria for selecting the best co-compost formulation were based on subjective performance star ratings in terms of pathogen reduction, total nutrient content, and amount of N-mineralised and N-loss. The ratings were as follows: ***** = Excellent, **** = Very Good, *** = Good, ** = Fair and * = Poor. The formulation with the highest number of stars was the best.

Greenhouse experiment

The best co-compost produced above was used as the soilless medium together with rice husk biochar to grow tomato transplants. The matured compost was first milled and sieved through a 2 mm sieve to obtain a uniform texture before mixing with the rice husk biochar to prepare three growing medium types: a 100% FS-based compost (FSC), a 100% rice husk biochar (RHB), and a 50% FS-based compost: 50% rice husks biochar mix (FSC-RHB). Tomato seeds (*Lycopersicon esculentum var. M2*) were sown in the three different growing medium at three seeds/plug and irrigated with tap water until the seeds germinated. Germinated seeds were counted starting from the fourth to tenth days after seeding (DAS). The percentage emergence and mean days to emergence (MDE) were calculated as described by Gerson and Honma (1978). The young transplants were continuously irrigated with tap water until most of them were showing second true leaves after which they were thinned to one plant per plug. Compost tea (CT) was brewed from the same co-compost for fertigation by steeping 2.5 kg of the compost in 15 L of distilled water (1:3 *v*/*v*) for 6 days following the bucket-fermentation method described by Diver (2001). For application, the CT stock solution was further diluted to 1:5 (CT-1) and 1:10 (CT-2) (stock solution:distilled water). The two compost tea dilutions were prepared in 20L batches and analysed for NPK content before applying to the transplants. To compare with the CT solutions, inorganic fertilizer solutions containing 400 mg N/L:176 mg P/L:332 mg K/L (In-fert-1) and 200 mg N/L:176 mg P/L:332 mg K/L (In-fert-2) were also prepared. After thinning the transplants, irrigation with tap water was terminated. The transplants were then sub-irrigated with the fertilizer solutions (CT-1, CT-2, In-fert-1, or In-fert-2) until the growth medium was saturated. Ordinary tap water served as control solution. Sub-irrigation with the fertilizer solutions was carried out for 21 days after which the experiment was terminated. The experiment was carried out in a complete randomized design with three replications.

Transplant sampling and analyses

Total N in the growth medium and compost tea solutions were determined by the semi–micro-Kjeldahl method (Black 1965). Total phosphorus (P) and potassium (K) were determined using the spectrophotometer (Philip PU8620 UV/VIS/NIR model) and Jenway flame photometer (PFP7), respectively. Plant available N (NH_4 and NO_3) were determined according methods described by Bremmer (1965). Electrical conductivity (EC) and pH of the medium and nutrient solutions were determined following standard procedures, as described in USDA and USCC (2001). Bulk density and water holding capacity of the medium were determined according to methods described in Okalebo et al. (2002) and Vengadaramana and Jashothan (2012), respectively. Transplants were sampled (five plants/treatment rep) every 7 days and the following growth parameters measured: leaf chlorophyll content, number of leaves, plant height, root length, stem diameter, shoot dry matter (DM), root DM, and shoot/root ratio. The leaf chlorophyll content was measured using Apogee chlorophyll content meter (Model CCM- 200), plant height and root length (in cm) were measured with a rule, and stem diameter was measured 1 cm above growth medium surface with a pair of Vernier callipers. The plant samples were then severed and separated into root and shoot parts. They were oven dried at 68 °C for 48 h to obtain dry weight/dry matter.

Statistical analysis

Analysis of variance (ANOVA) was performed on all data using Genstat 9th edition (Release 9.2) statistical package. Data for the microbial analysis were log transformed, while N-mineralised and N- and P-losses were transformed into percentages before ANOVA. Treatment means which were found to be significantly different from each other at ($p < 0.05$) were separated by the Least Significant Differences (LSD) tests. Two tailed correlation analysis between selected characteristics of the compost were determined using SPSS for windows software (version 16). Significant correlations at the 1% level ($p < 0.01$) have been considered.

Results

Co-composting DFS with EFB and CPH

General characterisation of the co-compost feedstock saw total N to be the highest (3.1%) in DFS followed by CPH and then EFB. Ammonium (NH_4-N) in the DFS was about fivefold higher than that in the EFB and CPH (Table 1). The C:N ratios were 43.5, 25.1, and 11.1 for EFB, CPH, and DFS, respectively. Potassium (K) level in CPH was about three and two times higher than that in the DFS and EFB, respectively.

Table 1 Physico-chemical characteristics of feedstock used in co-composting ($x \pm$ SD) *(n = 3)*

Parameters	DFS	EFB	CPH
pH (1:5)	7.7 ± 0.0	8.9 ± 0.1	8.6 ± 0.1
TOC (%)	34.3 ± 2.0	64.6 ± 4.4	41.1 ± 0.8
C:N	11.1 ± 0.2	43. 5 ± 1.4	25.1 ± 1.0
Total N (%)	3.1 ± 0.2	1.5 ± 0.1	1.6 ± 0.0
Total P (%)	1.5 ± 0.5	0.1 ± 0.0	0.3 ± 0.0
Total K (%)	0.8 ± 0.0	1.3 ± 0.0	2.2 ± 0.1
NH_4-N (mg kg^{-1})	2062.8 ± 205.2	378.0 ± 5	399.5 ± 3.0
NO_3-N (mg kg^{-1})	662.4 ± 86.4	363.6 ± 126.0	320.4 ± 54.0
Avail-P (%)	NA	NA	NA

EFB empty fruit bunches, *CPH* cocoa pod husks, *DFS* dewatered faecal sludge, *NA* not available

Total coliform populations in the DFS ranged between 2.0×10^3 and 3.0×10^5 CFU g^{-1} with an average of $6.2 \times 10^5 \pm 7.1 \times 10^5$ CFU g^{-1}, while *E. coli* levels ranged between 0 and 6.0×10^3 CFU g^{-1}. The average helminth egg population was 1/10 g. The characteristics of the various formulations at the start of co-composting process are shown in Table 2. At the end of co-composting, total N was highest in piles 1 DFS:1 CPH and 2 DFS:2 EFB:1CPH followed by pile 2 DFS:1 EFB:1CPH (Table 2). The differences were, however, not significant. Pile treatment 1 DFS:1 EFB:1 CPH had the lowest total N, but it was not significantly different from pile 1 DFS:1 EFB. Total P did not vary significantly between pile treatments 1 DFS:1 CPH, 1 DFS:1 EFB:1 CPH, and 2 DFS:1 EFB:1 CPH. However, the highest concentration of P was measured in pile 2 DFS:2 EFB:1 CPH and the lowest in pile 1 DFS:1 EFB:1 CPH. Total K was the highest in pile 2 DFS:2 EFB:1CPH and the lowest in pile 1 DFS:1 EFB. Electrical conductivity (EC) was significantly higher in pile 1 DFS:1 CPH compared to the other treatment piles. There were, however, no significant differences between piles 1 DFS:1 EFB, 1 DFS:1 EFB:1 CPH, 2 DFS:1 EFB:1CPH, and 2 DFS:2 EFB:1CPH. In all cases, once the piles were formed, the temperature rose rapidly (Fig. 1). Temperature in all the piles peaked on Day 3, with 1 DFS:1 EFB; 2 DFS:1 EFB:1CPH, and 2 DFS:2 EFB:1 CPH reaching thermophilic conditions (Fig. 1). The maximum temperature attained by each pile ranged between 46.8 and 54.5 °C and the minimum temperature ranged between 31.7 and 32.9 °C.

In general, the CO_2 evolution rates indicating microbial respiration decreased with time over the 12-week period for all the piles (Fig. 2). Within the first week, the CO_2 evolution rates were the highest (8.4 mg g^{-1} compost per day) in pile 2 DFS:2 EFB:1CPH and the lowest (2.7 mg g^{-1} compost per day) in pile 1 DFS:1 CPH. By the fifth week, the evolution rates of pile 1 DFS:1 CPH became the highest (1.7 mg/g compost per day) amongst the treatments with pile 2 DFS:2 EFB:1CPH being the lowest (0.8 mg g^{-1} compost day^{-1}). At the end of the 12 week, all the piles recorded stable CO_2 evolutions which were less than 1 mg CO_2 g^{-1} compost day^{-1}.

The C:N ratios decreased drastically over the first 2–4 weeks of co-composting for all the piles, and remained low through the week 8 when concentrations began to increase (Fig. 2). Table 2 shows the levels of NH_4-N and NO_3-N and org-N after the 12-week composting period. The nitrogen was found predominantly in its organic form, with levels ranging between 89 and 95%, while the inorganic forms (NH_4-N and NO_3-N) ranged between 5 and 11%.

Table 2 Physico-chemical characteristics of co-compost piles at start and end of co-composting ($p < 0.05$) ($n = 3$)

Piles	EC (μS cm^{-1})	C/N ratio	Total N (%)	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	Total P (%)	Avail-P (%)	Total K (%)	*N*-mineralised			*N*- and *P*-losses	
									% Org-N	% NH_4-N	% NO_3-N	% N	% P
At start													
1DFS:1EFB	2150	38.2	2.2	1828.8	284.4	2.6	0.3	1.3	90.5	8.2	1.3	–	–
1DFS:1CPH	2875	32.2	3.1	2368.8	392.4	3.1	0.3	1.9	90.9	7.8	1.3	–	–
1DFS:1EFB:1CPH	2275	45.2	1.8	1569.6	241.2	2.4	0.3	1.6	89.8	8.9	1.4	–	–
2DFS:1EFB:1CPH	1750	61.0	1.5	954.0	252.0	2.4	0.1	1.5	92.1	6.2	1.7	–	–
2DFS:2 EFB:1CPH	2525	51.4	2.0	1785.6	190.8	2.4	0.2	1.5	90.2	8.8	0.9	–	–
LSD	551.4	10.37	0.38	604.2	66.79	0.54	0.05	0.21	1.46	1.57	0.35		
At end													
1DFS:1EFB	1975	20.3	1.2	367.2	849.6	0.8	0.2	0.7	89.4	3.2	7.4	73	84
1DFS:1CPH	2725	12.2	1.8	334.8	1000.8	0.7	0.3	0.9	92.4	1.9	5.4	63	86
1DFS:1EFB:1CPH	2175	19.7	1.1	381.6	561.6	0.6	0.1	0.9	91.0	3.6	5.4	71	88
2DFS:1EFB:1CPH	1925	17.9	1.4	334.8	594.0	0.7	0. 2	0.8	93.5	2.3	4.2	44	82
2DFS:2 EFB:1CPH	2025	19.7	1.8	327.6	568.8	0.9	0.2	1.0	94.9	1.9	3.2	56	82
LSD	417.3	4.20	0.17	30.09	185.36	0.12	0.04	0.14	1.82	0.40	1.55	9.2	3.0

EFB empty fruit bunches, *CPH* cocoa pod husks, *DFS* dewatered faecal sludge, and *LSD* least significant difference

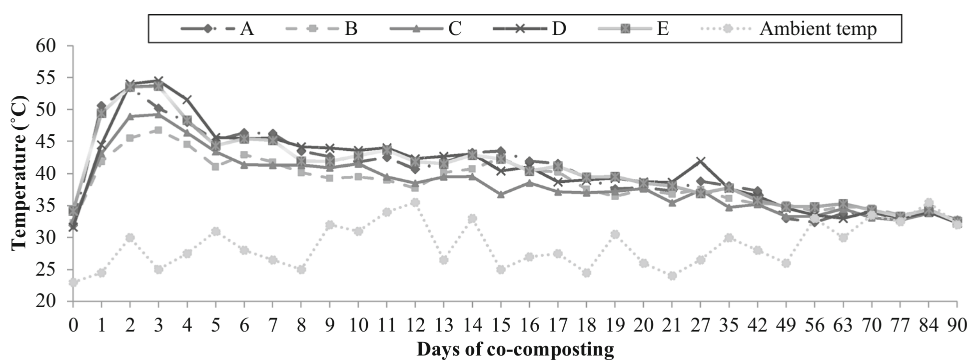

Fig. 1 Changes in temperature in the different piles during the co-composting process ($A = 1$ DFS:1 EFB, $B = 1$ DFS:1 CPH, $C = 1$ DFS:1 EFB:1 CPH, $D = 2$ DFS:1 EFB:1CPH and $E = 2$ DFS:2 EFB:1CPH)

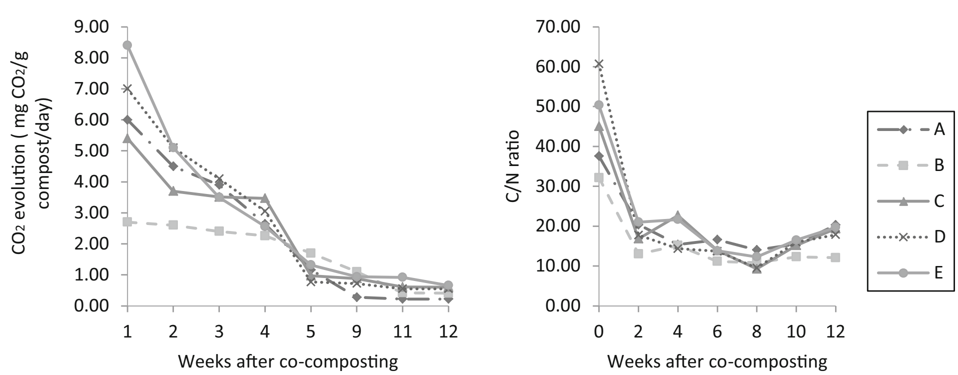

Fig. 2 Changes in CO_2 evolution and C/N in the different piles during the co-composting process ($A = 1$ DFS:1 EFB, $B = 1$ DFS:1 CPH, $C = 1$ DFS:1 EFB:1 CPH, $D = 2$ DFS:1 EFB:1CPH and $E = 2$ DFS:2 EFB:1CPH)

Significant ($p < 0.05$) losses of N and P were observed for all the treatment piles. The percentage nitrogen losses ranged from 44 to 73%, while phosphorus losses ranged from 82 to 88% (Table 2). There were, however, no significant differences in N-losses between piles 1 DFS:1 EFB and 1 DFS:1 EFB:1 CPH and then between piles 1 DFS:1

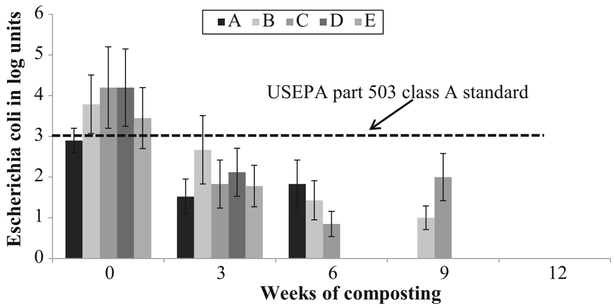

Fig. 3 Changes in *Escherichia coli* population in compost piles during composting process (*A* = 1 DFS:1 EFB, *B* = 1 DFS:1 CPH, *C* = 1 DFS:1 EFB:1 CPH, *D* = 2 DFS:1 EFB:1CPH and *E* = 2 DFS:2 EFB:1CPH)

CPH and 1 DFS:1 EFB:1 CPH. The change in levels of *E. coli* is represented in Fig. 3. *E. coli* levels were the highest in co-compost piles DFS:1 EFB:1 CPH and 2 DFS:1 EFB:1CPH (4.2 log units) and this was significantly ($p < 0.05$) higher than that of 1 DFS:1 EFB, 1 DFS:1 CPH, and 2 DFS:2 EFB:1 CPH. Apart from co-compost pile 1 DFS:1 EFB, all the other compost piles recorded *E. coli* concentrations above the USEPA part 503 class A exceptional quality (EG) compost standard (USEPA 1993) at the beginning of the co-composting process. For this standard to be achieved, *E. coli* and faecal coliform concentrations must be <1000 MPNg^{-1} or <3 log units CFUg^{-1}. This standard was adopted, because Ghana is yet to have a standard of its own and USA for many years has championed the concept of pathogen reduction as a number one compost quality standard (USEPA 1993). No *E. coli* was, however, recorded in the co-compost piles at the end of the composting period. The total coliform levels, ranging between 3.1 × 10^4 and 8.9 × 10^4 CFUg^{-1} at the beginning of the composting process, reduced to levels between 3.1 × 10^2 and 8.0 × 10^3 CFUg^{-1} after the period. Helminth eggs were not found in any of the co-compost piles at the end of the co-composting process.

The formulation 2 DFS:2 EFB:1 CPH was found to be the best mixing ratio for co-composting these three organic wastes. This formulation had the highest star ratings (15*), and it contained the highest nutrient (N, P, and K) content and least pathogen content among others, as shown in Table 3, and was used for the greenhouse experiment.

Greenhouse experiment

Electrical conductivity (EC) increased with increasing compost concentration in the growing medium (Table 4). The pH was significantly higher in FSC-RHB (7.8) than in FSC (7.5) and RHB (7.3). Total N, Total P, and Total K were higher in FSC than in FSC-RHB, though the differences were not significant at $p < 0.05$. Nitrate (NO_3) levels showed the following decreasing order: FSC > FSC-RHB > RHB. Available P was significantly higher in FSC-RHB than in the other growing media.

The dilution factors did not influence the pH of the compost tea solutions (CT-1 and CT-2) and the inorganic fertilizer solutions (In-fert-1 and In-fert-2) (Table 5). Higher concentrations of Total P and K were recorded in the compost tea solutions than in the inorganic fertilizer solutions.

The different growing media formulation affected tomato seed germination, emergence, and early vegetative growth. Germinated tomato seeds emerged in RHB 24 h earlier than in both FSC and FSC-RHB (Table 6). Percentage emergence was also higher in RHB medium than in the other two growing media.

Young transplants were taller in FSC than in RHB medium (Table 7); however, plant height was not significantly different between FSC and FSC-RHB media. Transplants in the RHB growth medium were significantly thinner than transplants growing in both FSC and FSC-RHB media. Transplants in the FSC medium recorded the highest shoot/root ratio, whereas those growing in the RHB medium recorded the least shoot/root ratio.

However, after 21 days of treatment, plant height, stem diameter, total (shoot and root) DM, leaf chlorophyll content, and number of leaves were significantly higher in both FSC and FSC-RHB media than in the RHB medium (Table 8). Shoot/root ratio was higher in FSC than in the FSC-RHB. Leaf chlorophyll content and root DM were significantly higher in FSC-RHB than in FSC.

The different nutrient solutions significantly affected growth of the transplants in the greenhouse. Growth response of transplants to the inorganic fertilizer solutions (In-fert-1 and In-fert-2) was significantly higher than that of the compost teas (CT-1 and CT-2) and the control (water) (Table 9). However, there were no significant differences in growth between In-fert-1 and In-fert-2 except in root DM, where it was significantly higher in In-fert-2 than in In-fert-1. Similarly, shoot DM, number of leaves, stem diameter, and plant height were higher in CT-1 than in CT-2. However, there were no significant differences in chlorophyll content, root DM, and shoot/-root ratio between the two compost tea solutions. Interestingly, the control solution recorded higher plant height, higher root DM, and higher root volume than in the CT-2 solution.

Increasing concentrations of FS-based compost in the growing medium (from 0 to 100%) and decreasing dilutions of the compost tea solutions (CT-2 to CT-1) resulted in significant increases in tomato shoot DM and shoot/root ratio (Table 10). Stem diameter, root length, leaf

Table 3 Selecting the best compost ratio based on selected parameters

Compost treatment	Faecal coliform reduction	N- and P-losses	N-mineralization	Total NPK	Total
1DFS:1EFB	*	*	*****	**	9 (*)
1DFS:1CPH	**	***	****	****	13 (*)
1DFS:1EFB:1CPH	***	**	***	*	9 (*)
2DFS:1EFB:1CPH	****	*****	**	***	14 (*)
2DFS:2EFB:1CPH	*****	****	*	*****	15 (*)

Table 4 Physico-chemical characteristics of growth medium types ($n = 3$ for each media)

Parameters	FSC	FSC-RHB	RHB	LSD ($p < 0.05$)
pH (1:5)	7.5	7.8	7.3	0.03
EC (1:10) (dS/cm)	2.1	1.6	0.0	0.08
Bulk density (g/cm^3)	0.7	0.6	0.3	0.02
Water holding capacity (per gram)	1.2	1.7	3.1	0.13
Total N (%)	1.8	1.7	1.1	0.28
NH_4 (mg/Kg)	205.0	223.0	158.0	96.10
NO_3 (mg/Kg)	1156.0	423.0	187.0	142.10
Total P (%)	0.5	0.4	0.1	0.16
Avail. P (%)	0.1	0.2	0.0	0.01
Total K (%)	1.1	0.9	0.5	0.05
C/N	19.8	13.3	11.0	3.82

FSC = 100% FS-based compost, FSC-RHB = 50% FS-based compost: 50% rice husk biochar mix and RHB = 100% rice husks biochar

Table 5 Physico-chemical characteristics of compost teas and inorganic fertilizer solutions ($n = 3$)

Parameters	CT-1	CT-2	In-fert-1	In-fert-2	LSD ($p < 0.05$)
pH	8.1	8.1	5.6	5.6	0.16
EC (dS/cm)	0.6	0.1	0.9	0.2	0.10
Total N (mg/L)	74.8	72.8	400.0	200.0	N/A
NH_4 (mg/L)	41.3	30.0	200.0	100.0	N/A
NO_3 (mg/L)	41.4	41.7	200.0	100.0	N/A
Total P (mg/L)	1085.0	560.0	176.0	176.0	N/A
Avail-P (mg/L)	51.5	51.4	176.0	176.0	N/A
Total K (mg/L)	7420.0	3340.0	332.0	332.0	N/A

CT-1 = 1:5 (compost tea stock:water), CT-2 = 1:10 (compost tea stock:water), In-fert-1 = 400 mg N/L:176 mg P/L:332 mg K/L, In-fert-2 = 200 mg N/L:176 mg P/L:332 mg K/L), and N/A = not available

Table 6 Effect of growing medium on tomato seed germination and emergence

Substrate type	Percentage emergence (%)	Mean days to emergence (MDE)
FSC	68.7	6.6
FSC-RHB	78.7	6.6
RHB	84.0	5.6
LSD ($p < 0.05$) ($n = 15$)	10.90	0.59

FSC = 100% FS-based compost, FSC-RHB = 50% FS-based compost: 50% rice husk biochar mix and RHB = 100% rice husks biochar

Table 7 Early vegetative growth of tomato transplant before treatment (sub-irrigation)

Substrate type	Plant height (cm)	Stem diameter (mm)	Root length (cm)	No. of true leaves	Shoot DM (mg)	Root DM (mg)	Shoot/root ratio
FSC	7.4	0.2	2.3	1.9	12.0	3.0	4.0
FSC-RHB	6.8	0.2	2.8	1.9	11.0	3.0	3.7
RHB	5.7	0.1	3.4	0.9	7.9	3.0	2.7
LSD ($p < 0.05$) ($n = 15$)	1.19	0.03	0.57	0.37	0.70	0.63	0.62

FSC = 100% FS-based compost, FSC-RHB = 50% FS-based compost: 50% rice husk biochar mix and RHB = 100% rice husks biochar

Table 8 Effect of substrate type on vegetative growth of tomato transplants after 21 days of treatment ($n = 3$)

Vegetative growth parameters	Growing medium			
	FSC	FSC-RHB	RHB	LSD ($p < 0.05$)
Plant height (cm)	27.1	26.7	14.2	0.98
Stem diameter (mm)	0.4	0.4	0.3	0.01
Shoot DM (mg/plant)	441.3	447	118.0	28.48
Root DM (mg/plant)	74.3	101.9	34.7	8.17
Chlorophyll content (CCI)	9.6	11.5	6.3	0.68
No. of leaves	6.5	6.3	4.5	0.23
Shoot/root	6.2	4.5	3.3	0.63

FSC = 100% FS-based compost, FSC-RHB = 50% FS-based compost: 50% rice husk biochar mix and RHB = 100% rice husks biochar

Table 9 Effect of compost teas and inorganic fertilizer solutions on vegetative growth of tomato transplant after 21 days of treatment (sub-irrigation) ($n = 3$)

Vegetative growth parameters	Nutrient solutions					
	CT-1	CT-2	In-fert-1	In-fert-2	*W*	LSD ($p < 0.05$)
Plant height (cm)	19.9	17.2	29.2	28.5	18.6	1.27
Stem diameter (mm)	0.3	0.3	0.4	0.4	0.3	0.02
Shoot DM (mg/plant)	279.4	213.3	490.0	506.1	221.1	36.77
Root DM (mg/plant)	51.7	44.4	86.1	102.8	66.4	10.55
Chlorophyll content (CCI)	6.3	6.0	14.2	13.2	6.1	0.87
No. of leaves	5.3	4.7	6.8	7.0	4.9	0.30
Shoot/root	4.8	4.2	5.7	5.2	3.3	0.80

CT-1 = 1:5 (compost tea stock:water), CT-2 = 1:10 (compost tea stock:water), In-fert-1 = 400 mg N/L:176 mg P/L:332 mg K/L, In-fert-2 = 200 mg N/L:176 mg P/L:332 mg K/L) and W = control

chlorophyll content, and root DM reduced with increasing compost concentration but were hardly significant. Similarly, there were no significant differences between FSC and FSC-RHB substrates in terms of root DM and plant height.

Interactions between medium type and inorganic fertilizer solutions show that total (shoot and root) DM were significantly reduced at the highest compost concentration (FSC) and the highest nitrogen (N) concentration in the inorganic fertilizer solutions (In-fert-1). Leaf chlorophyll content was significantly higher in FSC-RHB medium than in the others, but no significant difference was observed between In-fert-1 and In-fert-2.

Discussions

The temperature of the co-compost treatment piles was generally above 45 °C for the first few days but did not exceed 55 °C. According to Singh et al. (2011), the primary process criteria used for ensuring the microbiological safety of composts have been narrowly defined as time—temperature conditions. For complete sanitation of composts, the USEPA standard demands temperature of >55 °C for 2 weeks with five turns (USEPA 1993). Though the temperatures in this study did not meet any of the international requirements, they were higher than the maximum 45 °C temperature observed by Kala et al.

Table 10 Combined effect of growing medium and nutrient solutions on vegetative growth of tomato transplants after 21 days of treatment

	Nutrient solutions				
	CT-1	CT-2	In-fert-1	In-fert-2	*W*
Plant height (cm)					
FSC	25.6	22.4	31.6	30.7	25.5
FSC-RHB	24.7	20.4	32.9	33.3	22.2
RHB	9.4	8.9	23.2	21.4	8.0
LSD ($p < 0.05$) ($n = 3$)	2.20				
Stem diameter (mm)					
FSC	0.4	0.4	0.4	0.4	0.4
FSC-RHB	0.4	0.4	0.4	0.5	0.4
RHB	0.2	0.2	0.4	0.4	0.2
LSD ($p < 0.05$) ($n = 3$)	0.01				
Chlorophyll content (CCI)					
FSC	7.2	7.1	14.4	12.4	7.0
FSC-RHB	8.2	7.3	16.9	16.9	8.5
RHB	3.5	3.6	11.2	10.3	2.7
LSD ($p < 0.05$) ($n = 3$)	1.51				
Shoot dry matter (mg/plant)					
FSC	455.0	368.3	503.3	515.0	365.0
FSC-RHB	358.3	253.3	728.3	711.7	281.7
RHB	25.0	18.3	238.3	291.7	16.7
LSD ($p < 0.05$) ($n = 3$)	63.69				
Root dry matter (mg/plant)					
FSC	71.7	65.0	66.7	71.7	96.7
FSC-RHB	75.0	61.7	121.7	153.3	97.7
RHB	8.3	6.7	70.0	83.3	5.0
LSD ($p < 0.05$) ($n = 3$)	18.260				

FSC = 100% FS-based compost, FSC-RHB = 50% FS-based compost: 50% rice husk biochar mix, RHB = 100% rice husks biochar, CT-1 = 1:5 (compost tea stock:water), CT-2 = 1:10 (compost tea stock:water), In-fert-1 = 400 mg N/L:176 mg P/L:332 mg K/L, In-fert-2 = 200 mg N/L:176 mg P/L:332 mg K/L) and W = control (water)

(2012). The lower temperatures observed in this study could be due to the composting methods employed (open windrows) or to the dissipation of heat due to the small volume of the piles. This confirms earlier reports by Kala et al. (2012) that heap sizes affect the temperature generation during composting. The possible implication of the pile temperatures on pathogen reduction saw the level of *E. coli* in all piles declining below the USEPA class A compost standard by the third week of composting. The complete deactivation of *E. coli* in all piles at the end of composting (week 12) indicates that complete deactivation might have occurred during the cooler curing phases of composting and not during the active thermophilic phases. This confirms earlier reports by Droffner and Brinton (1995) that *Salmonell*a and *E. coli* were found to survive for 59 days at about 60 °C, although pathogens were destroyed during the cooler curing process in industrial compost. Results from this study suggest that high temperatures might not be the only factor responsible for *E. coli* deactivation. This phenomenon is in agreement with Dumontet et al. (1999) that other factors, such as pH, presence of metabolic, and antagonistic compounds produced by indigenous micro flora, accumulation of toxic NH_3, and microbiological competition for nutrients, are also involved in the deactivation. However, it is not clear from this study which of the measured factor or set of factors might have led to the inactivation of *E. coli* as none of the factors tested showed any significant correlation with the *E. coli* counts. Deactivation might, however, be due to competition among the microbes in the system. According to Kone et al. (2007), exposure to temperature over 45 °C for at least 5 days is known to inactivate *Ascaris* eggs which are very predominant in faecal sludge in developing countries. Similarly, the same reason could account for the complete elimination of Ascaris eggs from all compost piles at the end of the composting process. The decrease in carbon dioxide (CO_2) evolution rates over the 12 weeks period showed the microbial activities subsiding as the co-compost piles neared stability. This was as a result of a decrease in the amount of biodegradable substrate and N available (Hsu and Lo 1999). However, the differences in CO_2 production rates observed for the different piles show that the rates may have been affected by the differences in the easily biodegradable materials and the feedstock ratios. This confirms an earlier report by Ayuso et al. (1996) which stated that microbial activities to a large extent depend on the nature of the organic matter added to soil or the compost mixtures. A C:N ratio less than 20 could be considered as a satisfactory maturation level of compost (Heerden et al. 2002). This assertion was confirmed by this study, where the final C:N ratios of the piles ranged between 12 and 20. Ammonium (NH_4-N) concentration decreased as compost piles approached maturity. In all cases, the Ammonium (NH_4-N) levels showed negative correlations (correlation coefficients ranging between 55% and 71% (R^2) with time. This is in agreement with Laos et al. (2002) that NH_4-N concentration decreases towards stable values at the end of the thermophilic stage of composting. However, a reverse situation in the case of nitrate (NO_3- N) concentration with positive correlation coefficients ranging between 65 and 90% (R^2) was observed. These observations also agree with observations by other authors (Sun 2006; Huang et al. 2004; Banegas et al. 2007). The production of NO_3-N is very important, because it is the most available N for plant uptake. Hence, N-mineralization is a crucial process, because it converts organic N into ammonium (NH_4^+) and nitrates (NO_3^-). In this study, N-mineralisation was very low (<11%), making organic N the major form of nitrogen in the piles. This makes the compost a slow release nitrogen source (as also expected in other compost), contrary to the mineral fertilizer, where all the nitrogen is in the plant available form. However, the co-compost may have a longer residual effect on the soil as the microbes continue to breakdown organic N to the available form. In general, the piles with higher percentages of the DFS had significantly higher total N than in the other treatment piles at the end of co-composting. This indicates that the increase in DFS component during composting with EFB and CPH could result in higher N content of the final co-composts. This confirms earlier reports by Kala et al. (2009). In the present study, total N varying from 1.05 to 1.76% falls within an earlier report by Kulhman et al. (1989). Nitrogen losses during composting depend on the materials (feedstock) used and on the pH values of the mixtures (Sanchez-Monedero et al. 2001). It may also vary depending on several environmental factors, such as aeration, moisture content, and temperature (Bishop and Godfrey 1983), and also the frequency of turning. High total nitrogen losses during composting—as seen in this study—are a common trend, and such as the results of this research are largely attributable to decreases in NH_4-N (Rao Bhamidimarri and Pandey 1996). de Bertoldi et al. (1985) reported that the initial C/N ratio of the material also affects loss of N during composting. This could probably explain why pile 2DFS:1EFB:1CPH recorded the least losses in N at the end of composting. P-losses in this study were surprisingly higher (82–88%) than the N-losses. The feedstock ratio did not seem to have any effect on P loss. The losses were probably due to the higher solubility and subsequent leaching of phosphoric compounds in the compost materials as the process met with the minor raining season in the region. Thus, it may not be advisable to do co-composting of such or similar feedstock in the open without sheltering from rains as this might lead to a significant loss in nutrients. Total K on the other hand, which ranged between 0.7 and 1.0%, was higher than the recommended level (0.3%) suggested by Council of the European Communities (1986) in compost. The total K level recorded indicated that the major sources of K in the co-compost may have been CPH followed by EFB. 2 DFS:2 EFB:1CPH co-compost was selected as the best combination ratio, because it had relatively higher NPK content, had most pathogen reduction, though it had the least N-mineralised percentage. Even though this assertion may be subjective, the primary aim of composting DFS is to make it safe for handling and land application followed by the other agronomic benefits, such as organic matter and nutrient content.

Tomato seeds germinated and emerged faster in the RHB medium than in the FS-based compost amended media (FSC and FSC-RHB), indicating that the RHB medium may be preferred for seed germination. In addition, RHB had the lowest bulk density and the highest water holding capacity (WHC) amongst the three media types considered in this study. These may have provided the most favourable air and water infiltration for seed emergence. This agrees with an earlier report by Ball (1985) who reported that, a loose, porous medium is preferred for seed germination. Faecal sludge-based compost (FSC) recorded the lowest seed germination and emergence in this study and this may have been due to presence of certain inhibitory properties in the compost such as the high electrical conductivity (EC). This also confirms an earlier report by Wong and Chu (1985) that chemical constituents and properties of compost extracts, such NH_3, salts, ethylene oxide, heavy metals, and pH, affected seed germination and root elongation. Early vegetative growth of the tomato transplants after emergence was observed to be higher in the FS-based compost amended media (FSC and FSC-RHB) than in the RHB medium. This can be attributed to the relatively higher plant nutrients in the compost than the rice husks. According to Roe et al. (1997), plants that have adequate nutrition and water generally tend to have a higher shoot/root ratio than plants that are deficient in either. In this study, the lowest shoot/root ratio of transplants was recorded for RHB, while relatively higher ratios were recorded for the FS-based compost amended media, indicating that conditions in terms of water and nutrient availability for growth of transplants were more favourable in the compost amended media. However, between FSC and FSC-RHB, an interesting interaction may have occurred between the physical characteristics of the medium and its nutrient supplying capabilities. Transplants in the FSC were taller and slender compared to those in the FSC-RHB which had thicker stems. However, the other selected growth parameters measured were not significantly different. Stem diameter and root systems, according to Arenas (1999), are variables deemed most important by Florida Transplant Growers when it comes to transplant quality. After 21 days of treatment (sub-irrigation), transplants in the compost amended medium still showed superior growth qualities over transplants in RHB. This could be attributed to the relatively higher nutrient contents in the compost compared to RHB as discussed above. Similar observations were reported by Diaz-Perez et al. (2006). However, between transplants in FSC-RHB and FSC, there were no significant differences between the measured growth parameters except in the case of leaf chlorophyll content and root DM which were significantly ($p < 0.05$) higher in the FSC-RHB. This could mean that the relatively low bulk density of the FSC-RHB compared to the FSC medium may have provided lower resistance to the spread of the transplant root system to take up much water and nutrients. In addition, the FSC-RHB substrate may have provided better plant anchorage and nutrient uptake hence the more chlorophyll content found in the leaves. The direct cause of improved plant growth following compost extract (compost tea) application is often not clear (Shrestha et al. 2012). According to Merrill et al. (1997), the mineral nutrients extracted from compost can improve soil fertility directly. Other claims include a role for the extracted microbiota in improved mineralisation of soil organic matter and solubilisation of soil minerals, chelation of ions (Janzen et al. 1995), suppression/biocontrol of certain plant root and foliar diseases (Bernal-Vicente et al. 2008), and microbial production of plant growth promoting hormones, such as auxins (Garcia et al. 2002), or cytokinin-like substances (Arthur et al. 2001). In this study, transplants fertilized with CT-1 performed significantly ($p < 0.05$) better in terms of vegetative growth than CT-2. This can be due to higher nutrient content (nutritional effect) of CT-1. Similar results were also observed by Shrestha et al. (2012), where it was noted that growth benefit of compost tea was not directly biological in nature. They further observed that the high dose of compost extract may have had a positive impact on plant growth. Furthermore, responses to CT-2 were in most cases not significantly different ($p < 0.05$) from that of the control (water) indicating that CT-2 may have been too diluted resulting in lower nutrient content. Both inorganic fertilizer solutions (In-fert-1 and In-fert-2) had a higher positive effect on tomato transplant growth and leaf chlorophyll content than was observed in the compost tea treatments (CT-1 and CT-2) and control (water), indicating that a relatively higher nitrogen (N) concentrations may be preferred by the tomato transplants for growth and chlorophyll formation. However, there were no significant differences ($p < 0.05$) in transplants growth responses to In-fert-1 and In-fert-2 except for root DM, which was significantly higher in In-fert-2. This could probably mean that increasing the N concentration beyond 200 mg N/L may not necessarily result in any significant transplant growth and hence may not be cost effective. Similar results were also obtained by Kang and van Iersel (2004), where increasing concentration of N beyond 210 mg N/L did not further increase growth of *Salvia splendens*. In general, the root systems of the transplants in the compost tea treatments (CT-1 and CT-2) were poorly developed compared to transplants in the inorganic fertilizer solutions and control (water). This might be attributable to some sort of toxicity as a result of microbial activities around the root region. Comparing interactions between growing medium and inorganic fertilizer solution showed superior transplant qualities over that of the compost tea solutions and growth media. Interactions between compost tea solutions (CT-1 and CT-2) and growing medium showed that the highest total DM (shoot DM + root DM) was observed in the FSC medium fertilized with CT-1. This could be attributed to the higher nutrient contents in both FSC medium and CT-1 solution. A different observation was, however, made for the interactions between the inorganic fertilizer solutions and the medium types. Total DM was significantly ($p < 0.05$) reduced beyond FSC-RHB and In-fert-2 solution. This reduction in total DM could be as a result of the relatively higher EC levels arising from both the FSC medium and In-fert-2 solution, resulting in some form of toxicity or inhibition. Electrical conductivity (EC) levels approaching 3.0 dS/cm are considered higher than desirable (Davidson et al. 2000). This confirms earlier reports by Lumis et al. (2000) that reduced growth at the high fertilizer rate is the result of substrate EC and nitrogen levels being too high.

Conclusion

In conclusion, the study showed that co-composting DFS with EFB and CPH can be used as an alternative option for managing these wastes and to produce a suitable soil amendment. However, the quality of the compost could be further improved by reducing nutrient losses. Available options which were not tested in this study include carrying out the composting under sheds to protect the compost from rains and reduce leaching of nutrients, adding more bulking agents, such as biochar to trap nitrogen which could be lost through volatilization. Increasing the heap sizes could also increase the heap temperatures and further improve the sanitization of the compost. The fact that 2DFS:2EFB:1CPH was the best combination according to the criteria used indicates that this optimal ration also supports the idea of using this as a waste management solution as more human waste is used which subsequently can improve sanitation. Tomato seeds in this study germinated faster in RHB medium than in the other two FS-based compost amended growth medium, i.e., FSC and FSC-RHB. However, early vegetative growth of the transplants was higher in quality in the FSC and FSC-RHB growth media than in the RHB medium. FS-based compost is, therefore, a suitable growing medium for tomato. Though the compost tea solutions (CT-1 and CT-2) affected the growth of tomato transplants positively, its effects could not be compared with the inorganic fertilizer solutions. Indeed, transplants fertilized with In-fert-2 showed the highest growth response. Doubling the nitrogen concentration in the inorganic fertilizer did not result in any significant growth of tomato transplants. The compost tea solution CT-1 is, however, recommended for organic production of tomatoes. However, further studies into the optimal rate and frequency of application of compost teas on tomato are recommended.

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