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Fecal Sludge Derived Products as Fertilizer for Lettuce Cultivation in Urban Agriculture

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Abstract: Fecal sludge (FS) contains a significant amount of plant nutrients. FS (treated/untreated) has been used as soil ameliorant in several countries. Use of FS-based compost on lettuce may meet reservations due to possible microbiological contamination. The objectives of this research are: (1) To determine the fertilizer value of different formulations of sawdust and fecal sludge compost (SDFS) pellets, and (2) to compare the effect of these SDFS formulations with poultry manure, commercial compost, mineral fertilizer, and non-fertilization on lettuce cultivation. The SDFS products were made by enriching, and pelletized with ammonium sulphate, mineral-NPK, or ammonium sulphate + muriate of potash + triple superphosphate. Lettuce was cultivated in a greenhouse and an open field. The result showed that the saleable fresh weight lettuce yield obtained from all SDFS pellets with/without enrichments were higher than those obtained from commercial compost, poultry manure, mineral fertilizer, or no fertilizer. Cultivation in the open field gave higher yields than those in the greenhouse. No helminth eggs were detected in composts or lettuces. Some fecal coliforms were detected in lettuces fertilized with almost all fertilizers tested, including NPK and non-fertilized control. A properly treated fecal sludge-based fertilizer can be a sustainable solution for lettuce production, which helps urban and peri-urban agriculture.

Keywords: composting; enriched organic fertilizers; hygiene; soil fertilization; sustainable production; yield quality

1. Introduction

In several African countries, large amounts of fecal sludge (FS) are disposed of in the environment without appropriate treatment, creating high risks for public health due to enteric pathogens [1] and polluting waters. On the other hand, FS contains valuable plant nutrients (i.e., 8.2 g N/L, 1.1 g P/L and 2.2 g K/L) [2,3]. Due to its high fertilizer value, FS is widely used in agriculture with/without treatments in several countries, including Ghana [4,5]. Since the use of untreated FS can pose a high health risk [5,6], it is important to treat/sanitize it before fertilizer use. FS recycling for agriculture can be practiced by de-watering and composting [7,8].

The International Water Management Institute (IWMI) developed a new process of enrichment and pelleting of dried FS (DFS) compost with the aim to make FS an efficient fertilizer, which is easy to handle. Although co-compost has been produced using municipal solid waste and DFS, its low N-content (only 1%) was the main constraint to its adoption by farmers [5]. Mixing mineral fertilizer with compost (organo-mineral fertilizer) increases the nutrient concentrations. Furthermore, pelletizing using mechanical pressure [9] enhances the value and homogeneity of the nutrient concentrate.

The transportation costs of compost pellets are lower compared to those of the bulky organic compost fertilizer [10].

Application of higher amounts of fertilizer is expected to increase soil fertility and agricultural yields. Higher yields are important to feed the increasing population in sub-Saharan Africa. A shift of many dwellers from rural areas to urban centers will increase the need for sanitation facilities and fecal sludge management. Moreover, agriculture in and around urban areas is becoming a means of livelihood for many people [11]. Particularly, urban vegetable production has become the main source of income for thousands of producers in many urban cities in developing countries [12]. The production of lettuce and other vegetables can also take place in the greenhouse, though that practice is not currently prominent in Ghana. Evaluation of the greenhouse production of lettuce could provide good insight into how this can be practiced in urban areas of Ghana [13].

Recycling of organic matter is essential for maintaining and/or improving soil fertility and soil quality to increase agricultural yield. The combined application of organic and inorganic fertilizer has shown to improve the productivity of maize and cabbage compared to either the use of organic or mineral fertilizer only [14–16]. However, the fertilization value of pelletized N enriched DFS compost on lettuce is not well known. Lettuce can be cultivated for many rotations per year, so the application of organo-mineral fertilizer would be good for long-term sustainability. The agronomic trials of this work were done both in the greenhouse and field to be able to compare the quantity and quality of the yields in both cases, and to find out how the environmental factors influence the efficiency of the treatments applied.

The main objective of this work was to test if dried fecal sludge products could serve as valuable fertilizers so that it would be possible to improve sanitation and recycle FS as sustainable nutrients. Therefore, we have tested the fertilization value of eight fertilization treatments. These treatments included four different dried/dewatered fecal sludges (FSs): (1) Plain sawdust + dried fecal sludge compost (SDFS), (2) SDFS enriched with ammonium sulphate (AM + SDFS), (3) SDFS enriched with NPK (NPK + SDFS), and (4) SDSF enriched with ammonium sulphate + muriate of potash and triple superphosphate (AMT + SDFS), and conventional fertilizers (5) poultry manure (PM), (6) commercial compost (AC), (7) mineral NPK fertilizer, and (8) non-fertilization. The enriched SDFS fertilizers were pelletized. Cultivations were done in two sequenced cultivations, and only the first cultivation was fertilized. We evaluated the size of both lettuce yields, the quality of first lettuce cultivations, and the residual soil chemical properties after the second cultivations, where the fertilizations were done only before the first cultivations. The lettuce was selected as a test crop because it is relatively important in urban cultivation in Ghana.

2. Materials and Methods

2.1. Source of Fertilizer Materials: FS and Compost Preparation and Chemical Properties of Fertilizers

Fecal sludges were collected from septic tanks of public toilets and discharged into drying beds in Ghana (5°33′ N). The fecal sludge was dewatered and dried under sunlight for 2–3 weeks. Following that the dewatered FS (DFS) was gamma radiated (20 kGy) for 48 h. The gamma radiation was used to hygienize the DFS. Then DFS was mixed with sawdust (SD) (1:3), and this mixture was composted in windrows. Composting time was approximately one week at 45–55 °C, and composting continued until the compost temperature became stabilized, which took 100 days.

For the enrichment process, the mature composts were grounded, and one category was enriched with mineral-NPK, and another category was enriched with $(NH_4)_2SO_4$, muriate of potash, and super triphosphate to achieve 3% N content. These fertilizers were mixed with gamma-radiated starch or pre-gelatinized starch (3%), and finally pelletized to reduce dusting risks, reduce the volume, and to make fertilizer more homogenic so that its application will be more accurate. Details of the process are described by Nikiema et al. [8]. Mineral fertilizer (NPK), poultry manure (PM), and ACARP commercial compost (AC) were purchased from the local market. The concentrations of N, P, K, and C were analyzed from AC, PM, SDFS, AM+SDFS pellet, NPK + SDFS pellet, and AMT + SDFS pellet before application using the methods described in Section 2.2.1 (Table 1).

Table 1. Treatment code and chemical properties of different types of fertilizer. NA = not applicable, and fertilization amounts (in parenthesis).

Fertilization Treatments	Code	N	P	K	C
		Concentrations as g/kg and fertilization amounts as kg/ha.			
Control, no fertilization	CNTRL	0	0	0	0
Mineral fertilizer, NPK 15-15-15, Yara, Ghana analyzed by Yara	NPK	150 (126)	60 (50.4)	120 (100.8)	NA
Commercial compost from municipal organic waste, ACARP, Ghana	AC	21 (126)	23 (138)	13 (78)	270.2 (1621)
Poultry manure	PM	11 (126)	14 (160,4)	7 (80.2)	70.2 (804.1)
Co-compost produced using dried fecal sludge and sawdust	SDFS	16 (126)	11 (86.6)	5 (39.4)	110 (866)
SDFS enriched with ammonium sulphate pellet	AM + SDFS	30 (126)	11 (46.2)	5 (21)	110 (462)
SDFS enriched with NPK 15-15-15 pellet	NPK + SDFS	30 (126)	17 (71.4)	16 (67.2)	110 (462)
SDFS enriched with ammonium sulphate + muriate of potash (KCl) + triple super phosphate pellet	AMT + SDFS	30 (126)	12 (50.4)	24 (100.8)	110 (462)

2.2. Cultivation Trials

Greenhouse and field trials were conducted at the Valley View University, Accra, Ghana (5°47′ N, 0°7′ W) between February–April. The annual precipitation in Accra was 810 mm, and the mean annual temperature was 26.4 °C. The soil used in the experiment was a well-drained savannah soil classified as Ochrosols or Ferric Acrisols/Ferric Lixisols with a sandy-loam texture [17]. After the first experimental cultivation period, the same soils in the same pots and field sites were used in the second cultivation without fertilization to test the residual effect of all the fertilization treatments. Thus, the soils were fertilized only before the first cultivation by mixing fertilizers with soil.

2.2.1. Physico-Chemical Analyses of Soils

Soils used for the open field were sampled from the top layer 15 cm for analyses before and after cultivations. The whole soils from greenhouse pots were taken for analyses. The soils were air-dried, sieved using sieves of 8 mm, 2 mm, 0.5 mm, and 0.2 mm. The organic carbon (OC) was determined from soil samples that passed through the 0.5 mm sieve. The other parameters were determined from soils passed 8 mm but not 0.2 mm. This sieving was the common praxis in the soil laboratory of Ghana University.

The soil cation exchange capacity (CEC), available nitrogen (N), available phosphorus (P), and available potassium (K), ammonium (NH_4-N), nitrate (NO_3-N), total P, total-K, exchangeable calcium (Ca), exchangeable magnesium (Mg), and micronutrients available zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), and boron (B) were analyzed following standard procedures [18] using mainly spectrophotometry. The pH and electrical conductivity (EC) were measured using USDA-USCC methods [19]. Total organic carbon (TOC) was determined as described by Walkley and Black [20]. The total N was determined with the Kjeldahl method [21].

2.2.2. Experimental Setup and Cultivation

Seeds of lettuce (*Lactuca sativa*, cultivar Eden, Technisem, France) were nursed under greenhouse and open field conditions. The experiment was based on the application of N at a rate of 126 kg N/ha for the first cultivation period, which corresponds to the N-application used successfully for lettuce [22] and about what is commonly used in Ghana. The applied carbon and other elements are presented in Table 1.

The experiments were done as four parallels.

Greenhouse Experiment

The greenhouse was made of a transparent polyvinyl chloride roof allowing about 12 h of solar radiation daily, and all four sides were covered by a mosquito net to prevent animal damages but to allow air circulation. Polyethylene pots with the surface area of 0.07 m^2 a higher amount for the experiment. Each pot was filled with about 15 kg of the air-dried and sieved (2 mm sieve) topsoil (0–15 cm). The experiment consisted of eight fertilization treatments as four replicates making a total of 32 pots, completely randomized blocked in the greenhouse.

After two weeks of seedlings, all 32 pots received their appropriate fertilization and the seedlings (one seedling per pot) were transplanted three days after the fertilizer application. Tap water was used for watering of greenhouse pots to maintain the moisture content of soils at 40–60%.

Two insecticides were applied twice for each cultivation cycle. They were (1) Attack Botanical Insecticide, Emamectin benzoate (1.9%), Non-Hazardous Ingredients (98.1%) Iprochem company ltd, China, and (2) Akape (Anty Ataa) broad-spectrum insecticide (a. i.) imidacloprid 200 g/L Iprochme Company LTD, China.

After the harvesting of the first lettuce yields, the new seedlings were planted to the same pots as used in the first cultivation. The new lettuce plants were cultivated similarly as the first cultivation excluding that there were no new fertilizations.

Field Experiment

Correspondingly in the open field, 32 plots were prepared, each with an area of 0.5 m^2 (1 m × 0.5 m) with a 50 cm distance between plots. In the field, there were six plants per bed at a spacing of 30 cm × 30 cm within and between rows. There were the same eight fertilization treatments with four replicates each design as a randomized complete block design. The same insecticide applications were used as in greenhouse experiments.

The similar cultivations without new fertilization regimes were followed to establish the residual effect of the fertilization in open field conditions were under the greenhouse. The second cultivations received the same number of plants and agronomic practices as in the case of the first cultivations.

2.3. Harvesting the Lettuces and Their Chemical Analyses

Both the first and the second lettuce yields from both greenhouse and open field were harvested after both growth times of 48 days. The fresh weights were measured immediately after harvesting. Similarly, oven drying at 60 °C to determine dry weight was started in harvesting day, and took four days.

Dried lettuce samples were grounded, and 0.5 g was taken for chemical analyses. The total N of lettuces was determined with the Kjeldahl method [21]. The other parameters of lettuces were determined using the same methods as with soils [18].

2.4. Hygiene Analyses of Lettuces and Composts

The fresh lettuce samples were washed thoroughly with tap water to remove dirt as is normally done before consumption. These lettuces were homogenized and diluted to sterilized water, and these dilutions were inoculated on Chromocult coliform agar (Merck KGA 64271 Darmstadt, Germany) to detect potential coliforms. The plates were incubated at 37 °C for 24–48 h [21]. All colonies with purple to blue-black color were counted and presented as CFU/g fecal coliforms, unfortunately, no further confirmation identification was done.

The flotation and sedimentation method following a modified US-EPA method [23] was used to determine the helminth eggs in all composts and lettuces. Ten grams (dry weight) of the sample was homogenized with 1 L water and a small portion of detergent (washing powder) using a blender. The sample was left for overnight. The supernatant was separated from the sediments by centrifuge at 1450 rpm for 3 min. In the flotation stage, a zinc sulphate solution (0.573 g/mL) was added to the sediment and centrifuged again at 1450 rpm for 3 min. The supernatant was transferred into a 1 L container, filled with distilled water, and left overnight.

In the next day, 100 mL of bottom layer was centrifuged at 1600 rpm for 3 min and re-suspended with acid/alcohol (5.1 mL H_2SO_4 + 330 mL C_2H_5OH + 664.9 mL water) 60% v/v and ethyl acetate 40% v/v. The mixture was then centrifuged at 2200 rpm for 3 min. At this stage, three layers were clearly visible. The upper two layers were carefully removed, and about 1 mL of the sediment liquid in the tube was observed under a light microscope. The shapes and sizes of the eggs were recorded as described in the WHO's Integrated Guide to Sanitary Parasitology [24].

2.5. Taste Assessment

Triangle and ordinal taste testing of the lettuce were conducted using the established procedure [25]. A taste panel included 24 individuals whose ability to recognize basic tastes (sweet, sour, salty, and bitter) had been confirmed. The panel consisted of nine women and 15 men between the ages of 25 to 40 years. The tasting sessions were organized under daylight in the Valley View University, Accra, Ghana. Panel members could freely drink water and use any differences as texture or color of lettuce during the tasting process.

In three triangle tests, the participants were served three lettuce samples in plates marked with blind code numbers. In the first test, two lettuce samples from SDFS fertilizations and one sample from NPK fertilization were served. In the second test, two lettuce samples were served from SDFS fertilizations and one sample from NPK + SDFS pellet fertilization. In the third triangle test, two lettuce samples were served from NPK + SDFS pellet fertilizations and one sample from NPK fertilization. In this session, the tasters had to determine (or guess), which sample was different.

In the ordinal test, the participants were served three lettuce samples fertilized with NPK, SDFS fertilizers, and NPK + SDFS pellet fertilizer, and labelled with blind codes. The participants were asked to evaluate which sample they preferred to the first, second, and third position.

2.6. Statistical Analyses

All analyses were done in SPSS (IBM, 20th edition). First, two-way ANOVA was used to analyze the effect of the different fertilization treatments on the fresh and dry matter yield of the lettuce under the greenhouse and the field. Secondly, a paired t-test was used to analyze the effect of the two experimental conditions (greenhouse and field) on the fresh and dry matter yield. The paired t-test was used also to test the residual effect of the different nutrient sources on the yield of the second season. A two-way ANOVA test or paired t-test was also performed to test the treatments residual effect of the fertilizers on the soil physicochemical properties.

3. Results

3.1. Fertilization Treatment Effect on the First and Second Fresh Biomass of Lettuces Cultivated in the Field or Greenhouse

All fresh lettuce yields obtained from open field were higher than the corresponding yields obtained from the greenhouse. The highest lettuce fresh yields were obtained if the fertilization was done with different sawdust + dried fecal sludge (SDFS) compost products, and these fertilizations gave the high yields in the second cultivation. The highest lettuce yields were obtained when fertilized with ammonium sulphate enriched SDFS (AM + SDFS) or enriched with ammonium sulphate + muriate of potash + triple superphosphate SDFS pellet. All the SDFS fertilizations gave significantly higher yields ($p < 0.05$) than mineral fertilizer NPK, PM = poultry manure, and AC = ACARP commercial compost. The yield is counted as tons per hectare (counted as 500,000 plants/ha), since in commercial horticulture the cultivation areas can be hectares. The lettuce yield obtained without any fertilization was still lower (Table 2).

In the greenhouse experiment, all SDFS products gave similar first biomass yields. Moreover, all the SDFS based fertilizers and PM fertilization gave a significantly higher ($p = 0.001$) biomass than the commercial compost (AC), NPK, and non-fertilized control.

In the field, fresh biomass of the second cultivation was similar to the yield of the first cultivation. The fresh biomass yields from AMT + SDFS and the SDFS fertilizations were slightly higher (not significant, $p = 0.09$) than those from control (no fertilization) and the PM, evidently due to high standard error (Table 2).

On the contrary, in the greenhouse result, all lettuce yields of the second yield were much lower than the yields of the first cultivation, and the yields were also much lower than those produced from the open field. Thus, the mean lettuce yields from SDFS fertilization was 7.65 g/plant (DW) in the field, while it was only 2.70 g/plant (DW) in the greenhouse.

3.2. Effect of Different Planting Conditions on the Fresh and Dry Weight of Lettuce

The total biomass yields of fresh lettuce were significantly higher ($p < 0.0001$) in the field than those obtained in the greenhouse. Leaf area was greater in greenhouse lettuce compared to those in the field (data not shown). The lettuce produced in the greenhouse had light green leaves, while the leaves grown in the field were dark green.

The result of the field cultivation shows that the AMT + SDFS fertilization gave a significantly higher ($p < 0.001$) dry biomass yield compared to the other sources of fertilizers (Table 3). Additionally, AM + SDFS, NPK + SDFS, and the NPK fertilizers gave similar yields, and these yields were significantly higher than the yields obtained from control, poultry manure, and commercial compost fertilizations. The dry matter (%) yield of lettuce was significantly higher in lettuces cultivated in the greenhouse compared to the field for all treatments (Table 3).

Table 2. Fresh weight of lettuce from two consecutive cultivations under field and greenhouse conditions. Values present means and standard errors of the mean for fresh weights as ton/ha (N = 4). The different letters show statistic differences in the rows. The codes are as presented in Table 1.

	No SDFS-Fertilizers				**SDFS-Fertilizers**			
Fertilization	CTRL	NPK	AC	PM	SDFS	AM + SDFS	NPK + SDFS	AMT + SDFS
Field								
The first and fertilized cultivation	3.85 ± 0.95 d	4.85 ± 0.59 b	5.55 ± 0.71 b	4.99 ± 1.40 b	7.65 ± 0.76 a	7.35 ± 1.51 a	5.99 ± 0.74 b	7.35 ± 1.80 a
The second residual fertilization	4.15 ± 0.57	5.31 ± 0.53	4.72 ± 0.84	5.48 ± 0.84	5.2 ± 1.4	4.79 ± 0.81	5.92 ± 0.76	4.58 ± 0.55
P value between the 1st and the 2nd	0.69	0.54	0.48	0.64	0.76	0.38	0.98	0.25
Greenhouse								
The first and fertilized cultivation	2.48 ± 0.32 a b	3.32 ± 0.37 a b	3.06 ± 0.25 a b	4.60 ± 0.36 a	4.10 ± 0.45 a	4.38 ± 0.06 a	5.03 ± 0.45 a	3.74 ± 0.45 a
The second residual fertilization	1.80 ± 0.33	1.53 ± 0.80	1.60 ± 0.40	4.20 ± 0.30	2.70 ± 0.40	1.61 ± 0.34	1.72 ± 0.45	2.40 ± 0.33
P value between the 1st and the 2nd yields	0.16	0.02	0.02	0.44	0.03	0.00	0.02	0.47

Table 3. The dry matter (%) of the first yield of lettuce cultivated in the field and greenhouse using different fertilization treatments. Values are means and standard errors of the mean (N = 4). Different letters show statistically significant differences in rows. See Table 1 for the codes.

Site	**Sawdust + Fecal Sludge Fertilizers**							
	CTRL	**NPK**	**AC**	**PM**	**SDFS**	**AM + SDFS**	**NPK + SDFS**	**AMT + SDFS**
Field	5.20 ± 0.50 c	6.31 ± 0.33 b	5.4 ± 0.52 c	5.40 ± 0.8 c	4.70 ± 0.05 c	6.40 ± 0.31 b	5.90 ± 0.45 b	7.10 ± 0.23 a
Greenhouse	9.20 ± 0.30 a	8.70 ± 0.40 a	7.20 ± 0.60 c	8.90 ± 0.30 a	7.30 ± 0.40 c	7.70 ± 0.2 b	6.50 ± 0.35 d	8.00 ± 0.01 b
p-value	0.000	0.000	0.002	0.015	0.001	0.000	0.06	0.003

3.3. Nutrient Concentration in Lettuces Produced by Different Fertilizations

The mineral nutrient concentrations in the lettuces cultivated in the open field and the greenhouse are presented in Table 4. The result showed that total N, P, K, Ca, Mg, Fe, Zn, and Mn in all the treatments were rather similar to those of the control. The contents of N, K, Ca, and Mn were higher in lettuce dry weights produced in the greenhouse than if they were produced in the field (Table 4).

Table 4. Nutrient composition (g/kg DW) in the lettuce produced using different fertilizer materials. The codes are presented in Table 1. Values represent means and standard deviations. N = 4. The statistical differences were performed but due to high standard deviations, the statistical differences are lacking.

Fertilizers	CTRL	NPK	AC	PM	SDFS	AM+SDFS	NPK + SDFS	AMT + SDFS
In open field								
Total N	22.4 ± 2.7	24.4 ± 1.3	24.1 ± 3.5	24.9 ± 1.4	25.3 ± 2.1	23.5 ± 1.3	21.5 ± 3.9	23.9 ± 2.8
Total P	8.1 ± 1.3	7.6 ± 2.2	8.2 ± 0.9	9.2 ± 1.4	8.0 ± 1.4	8.3 ± 1.5	10.7 ± 1.2	8.1 ± 0.6
Total K	35.1 ± 9.3	36.4 ± 7.2	34.2 ± 4.6	46.5 ± 7.3	32.4 ± 4.4	37.1 ± 2.7	33.0 ± 9.1	32.2 ± 9.1
Ca	4.9 ± 2.6	6.4 ± 2.1	7.3 ± 2.8	7.1 ± 2.5	9.2 ± 2.3	6.9 ± 4.1	4.5 ± 3.1	5.7 ± 3.5
Mg	5.2 ± 0.6	5.9 ± 0.6	5.4 ± 0.7	6.2 ± 1.1	6.2 ± 0.8	5.7 ± 1.6	5.0 ± 0.7	5.0 ± 2.7
Fe	2.8 ± 1.1	6.0 ± 1.5	3.3 ± 1.3	3.1 ± 0.1	2.6 ± 1.0	5.2 ± 2.2	7.6 ± 1.2	5.0 ± 2.1
Zn	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Mn	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.2 ± 0.0
In greenhouse								
Total N	34.4 ± 2.7	33.7 ± 2.9	33.4 ± 2.3	37.0 ± 3.7	35.1 ± 2.6	37.6 ± 3.9	35.8 ± 2.6	34.1 ± 1.3
Total P	6.6 ± 0.6	5.6 ± 2.0	7.2 ± 1.2	6.5 ± 1.1	6.5 ± 0.6	6.7 ± 1.9	6.8 ± 1.1	5.9 ± 0.8
Total K	37.9 ± 2.8	30.6 ± 1.4	37.5 ± 5.6	35.4 ± 4.2	48.7 ± 2.0	39.4 ± 4.3	40.1 ± 3.9	38.7 ± 2.4
Ca	7.9 ± 3.1	9.2 ± 1.4	8.9 ± 1.6	8.2 ± 1.1	8.6 ± 2.6	10.7 ± 1.9	11.8 ± 1.4	10.0 ± 1.2
Mg	7.1 ± 0.5	7.1 ± 0.6	6.7 ± 0.5	6.7 ± 0.7	7.6 ± 0.6	8.1 ± 0.7	7.8 ± 0.4	7.6 ± 0.3
Fe	4.2 ± 0.8	5.0 ± 1.2	3.5 ± 1.6	3.7 ± 1.2	4.3 ± 1.1	3.4 ± 0.2	3.9 ± 1.7	3.8 ± 0.6
Zn	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1
Mn	0.6 ± 0.1	0.5 ± 0.4	0.7 ± 0.3	0.6 ± 0.1	0.5 ± 0.3	0.7 ± 0.1	0.7 ± 0.2	0.7 ± 0.2

3.4. Effect of Fertilization on Soil Physico-Chemical Properties

Physico-chemical properties of the soil before and after cultivated are presented in Table 5. The total N, organic carbon, and total K in soil did not change during the cultivation, but nitrate concentrations of some greenhouse soils had increased. Ammonium nitrogen concentration was higher in open field soils fertilized with SDFS fertilizers, municipal compost, and poultry manure than when fertilized with mineral NPK or control (Table 5).

Total P was reduced after cultivation, and the EC values in greenhouse soils were significantly higher than the EC values of field soils after both harvestings (Table 5).

Table 5. Physio-chemical properties of the soils before cultivation and after the second cultivations. (N = 4). ND = not done. Different letters in the same row between after harvesting soils show a significant difference ($p < 0.05$) from each other (seen only in NH_4). See the codes in Table 1.

After Harvesting in Soils of the Open Field									
	Before Cultivation	**CTRL**	**NPK**	**AC**	**PM**	**SDFS**	**AM + SDFS**	**NPK + SDFS**	**AMT + SDFS**
Total N (g/kg)	1.4 ± 0.2	2.3 ± 0.2	2.1 ± 0.7	2.3 ± 0.8	2.4 ± 0.2	1.7 ± 0.5	2.3 ± 0.7	2.7 ± 0.5	2.8 ± 0.5
NH_4 (mg/kg)	ND	283 ± 158 a b	283 ± 158 a b	518 ± 103	468 ± 115 a c	406 ± 16 abc	532 ± 77 c	570 ± 163 c	487 ± 35 bc
NO_3 (mg/kg)	ND	63 ± 6	74 ± 16	65 ± 9	66 ± 17	76 ± 10	68 ± 7	69 ± 2	75 ± 11
Total P (mg/kg)	700	213.8 ± 14.1	209.0 ± 10.1	179 ± 40	198.8 ± 44.8	204.0 ± 79.8	169.5 ± 48.8	170.0 ± 41.1	184.5 ± 35.8
TK (g/kg)	1.0	1.2 ± 0.0	1.2 ± 0.2	1.1 ± 0.1	1.0 ± 0.2	1.0 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	1.0 ± 0.2
pH 1:1	6.9 ± 0.1	6.1 ± 0.2	6.1 ± 0.2	6.0 ± 0.0	6.2 ± 0.1	6.0 ± 0.5	5.7 ± 0.4	6.0 ± 0.5	5.7 ± 0.4
EC 1:1 µS/cm	160	177.5 ± 28.7	177.5 ± 28.7	273 ± 138	152.5 ± 25.0	225.0 ± 99.8	192.5 ± 36.9	140.0 ± 49.7	172.5 ± 61.8
O/C%	1.8 ± 0	1.7 ± 0.3	1.4 ± 0.3	1.9 ± 0.5	1.5 ± 0.4	1.7 ± 0.4	1.7 ± 0.2	1.8 ± 0.3	1.4 ± 0.3
O/M%	1.3	2.9 ± 0.5	2.5 ± 0.5	2.2 ± 1	2.7 ± 0.7	2.8 ± 0.6	2.6 ± 0.4	2.8 ± 0.6	2.7 ± 0.1
CEC (cmol/kg)	ND	8.6 ± 0.2	8.7 ± 0.7	9 ± 1	8.8 ± 0.4	8.9 ± 0.7	9.1 ± 0.8	8.7 ± 1.3	8.7 ± 0.8
After harvesting in soils of the greenhouse									
Total N (g/kg)	1.4 ± 0.2	2.7 ± 0.2	2.6 ± 0.8	3.6 ± 0.3	3.1 ± 0.6	3.4 ± 0.3	3.1 ± 0.4	3.4 ± 0.2	3.2 ± 0.3
NH_4 (mg/kg)	ND	389 ± 21 b	118 ± 21	121 ± 19	75 ± 6 a	89 ± 12 a b	74 ± 2 a	84 ± 11 a b	91 ± 3
NO_3 (mg/kg)	ND	152 ± 24	152 ± 24	84 ± 25	94 ± 12	61 ± 14	146 ± 13	77 ± 8	86 ± 25
Total P (mg/kg)	700	126.5 ± 48.5	217 ± 49	209 ± 25	205.0 ± 39.4	212.0 ± 26.7	195.5 ± 37.2	194.8 ± 48.9	196.3 ± 47.4
TK (g/kg)	1.0	1.0 ± 0.0	1 ± 0	0.8 ± 0.2	0.9 ± 0.1	1.0 ± 0.1	0.9 ± 0.2	1.0 ± 0.1	1.0 ± 0.0
pH 1:1	6.9 ± 0.1	5.9 ± 0.5	6 ± 0.1	7 ± 0	6.7 ± 0.2	6.6 ± 0.2	5.7 ± 0.1	6.3 ± 0.3	6.1 ± 0.
EC 1:1 (µS/cm)	160	648 ± 176	648 ± 176	463 ± 206	490 ± 174	493 ± 238	528 ± 227	405 ± 147	618 ± 77
O/C%	1.8 ± 0	2.2 ± 0.5	2.2 ± 0.5	1.5 ± 0.9	1.1 ± 0.1	2.2 ± 1.0	1.9 ± 0.2	2.0 ± 0.8	1.0 ± 0.6
O/M%	1.3	3.9 ± 0.9	3.9 ± 0.9	2.1 ± 1.4	1.9 ± 0.1	1.2 ± 0.2	2.9 ± 0.5	3.4 ± 1.3	2.3 ± 0.9
CEC (cmol/kg)	ND	8.4 ± 0.5	8 ± 0	9 ± 1	8.7 ± 0.7	9.2 ± 1.1	9.3 ± 0.6	9.3 ± 0.7	9.0 ± 0.8

3.5. Hygiene of Lettuces and Helminth Eggs in Lettuces and Fertilizers

All lettuce leaves, excluding lettuce cultivated in a greenhouse and fertilized with AM + SDFS, contained fecal coliforms more than the detection limit (Table 6). No helminth eggs were found (0 egg/10 g) in any DFS-based fertilizers and any lettuces obtained by any fertilization treatments.

Table 6. Log_{10} numbers and their standard deviations for fecal coliforms in fresh lettuce fertilized with different treatments. Numbers are as colony forming units (CFU/g) (N = 4). BDL = below detection limit (10 CFU/g). See Table 1 for the codes.

Fertilizer	Field	Greenhouse
Control	4.5 ± 0.2	3.0 ± 0
NPK	4.6 ± 0.1	4.1 ± 0.2
PM	4.6 ± 0.2	3.8 ± 0
AC	4.5 ± 0.1	4.8 ± 0.1
SDFS	4.5 ± 0.1	4.0 ± 0.4
AM + SDFS	4.6 ± 0.0	BDL
NPK + SDFS	4.8 ± 0.0	3.9 ± 0.4
AMT + SDFS	4.6 ± 0.1	4.1 ± 0

3.6. Effect of Fertilization on the Taste of Lettuce

The result of the taste assessment of lettuce produced in the greenhouse showed that there were no differences ($p < 0.005$) in the tastes of lettuces using different fertilizer materials. Out of the 23 participants, 15–20 reported no taste difference of lettuce fertilized with SDFS compost, SDFS pellet, and NPK in triangle test. However, the tasters preferred NPK + SDFS fertilized lettuce to lettuce grown with composted SDFS or NPK ($p < 0.05$). In the ordinal taste test, there were no significant preferences between the different lettuce samples irrespective of the type of fertilization.

4. Discussion

4.1. Fertilization Treatment Effect on the Lettuces Cultivated in the Field or in Greenhouse

If using the same amounts of nitrogen as kg/ha either as SDFS products enriched with inorganic fertilizers or as totally organic fertilizers, the total amount of fertilizers will be reduced if using SDFS products enriched with inorganic fertilizers. Thus, the work costs needed for transportation and fertilization will be lower. In addition, the need of commercial inorganic fertilizers will be less than if using only commercial NPK, so these fertilizers should be cheaper than if using only NPK fertilization. SDFS products produced higher fresh lettuce yields than the other fertilizer treatments tested. The higher fresh yields obtained with SDFS containing fertilizers could be caused by the fact that the combination of mineral N with organic matter in SDFS derivatives was more efficient in meeting the high N requirement of lettuce as a leafy vegetable than that only organic N or only mineral N [26]. Since fresh lettuce as such can be sold, the higher fresh yields obtained when used enriched SDFS products would give the higher income for farmers.

In the field cultivation, lettuce production in second cultivation was similar to the first, which showed that there were still residual fertilizers which can be uptaken by the 2nd crops. Results from the application of the PM and AC were not significantly different from each other and the control treatment (Table 2).

In greenhouse cultivation, the lettuce biomass yields in second cultivation were low and similar, except AC and AM + SDFS treatment.

The higher biomass in the field might be because of greater light intensity and space for root growth compared to growing in pots in the greenhouse. Unfortunately, light intensity data were not available. The larger leaf area in greenhouse lettuce compared to those in the field may have been caused by higher shadowing.

The color of lettuce leaves in the greenhouse was light green, while the leaves grown in the field were dark green. This could be due to the higher chlorophyll content in the field crops (not assessed). This is also supported by the fact that the N content is higher in lettuce cultivated in the field compared to the greenhouse as reported that leaves produced under shed contained less protein compared to the leaves produced under the direct sun [27]. The higher dry matter content might have been caused by limited sunlight in the greenhouse, which resulted in the formation of thin and elongated leaves that were found to move in the direction of the rising sunlight [28]. The lettuce with high dry matter-%, pale color, and elongated leaves are not attractive to buyers.

Similarly, the second yields in the greenhouse were clearly lower than the yields in the field. These lower yields may have been caused by the fact that the mean salinity (measured as EC) of greenhouse soils was as high as 537 µS/cm (mean in all greenhouse soils), while with the EC in the open field the mean of all soils was 189 µS/cm (counted from the data of Table 5). This difference is significant in a paired t-test ($p = 3.4 \times 10^{-5}$). Evidently, the availability of water due to low irrigation highly reduced the second yields of lettuce in the greenhouse. Anyhow, the high dry weight of lettuce describes good growth, but it is not economically important since dried lettuce is not sold.

The good yields obtained from an open field of the present work confirm the results presented by earlier researchers who used human fecal fertilizers for radish and capsicum [29] or okra [30] in water-stressed tropical areas where yields were similar if fertilization was done with human waste or animal manure. The mixture of composted human feces and urine gave better yields than pure urine [31]. The organic matter, as well as the plant nutrients of co-composted fecal sludge products, may have better fertilizer value for soil (Table 1) as discussed in the literature [29–31].

The dry matter of lettuce was significantly higher in lettuces cultivated in the greenhouse compared to the field. In Ghana, the field cultivation of lettuce would be more profitable, since the fresh yields were higher in the field than in the greenhouse (Table 2). Additionally, the cultivation in the greenhouse pots may be more expensive, since greenhouse cultivation needs more investment costs than the cultivation in the open field.

The N, K, Ca, and Mn content (in DW) were higher in lettuce produced in the greenhouse than if they were produced in the field. It should be noted that lettuce grown in the greenhouse had lower fresh weights (Table 2), but higher dry matter-% (Table 3) than the lettuce grown in the field. The N-content in Table 4 includes leaf protein, nitrate, and non-protein nitrogen compounds. Similarly, the Mn-concentration was clearly higher in lettuces produced in the greenhouse than in those produces in the field. Thus, possible the Mn-accumulation showed higher in lettuce produced in the greenhouse compared to those produced in the field.

4.2. Effect of Fertilization on Soil Physico-Chemical Properties

Nutrient requirements of plants depend on the type of crop, soil, and weather conditions, etc. The effect of these different fertilization regimes on soil chemical properties are evaluated with N, P, K, pH, EC, OC, OM, and CEC contents. The nitrate concentrations of some greenhouse soils had increasing, which may indicate an increased risk of nitrate leaching to groundwater and surface waters [32]. Ammonium nitrogen concentration was higher in open field soils fertilized with organic-based fertilizers, i.e., SDFS fertilizers, municipal compost, and poultry manure than when fertilized with mineral NPK and control. This might be due to improved mineralization efficiency in soil fertilized with waste-based fertilizer.

The use of organic fertilizers increased the soil organic matter, but when two yields of lettuce were cultivated, most of the organic matter had been degraded, as can be seen in Table 5. On the other hand, the total P was reduced after cultivation, and this might be because plant uptake was higher than the P supplemented. In general, there is a negative balance of NPK in Sub-Saharan soil and it depleted the soil [29]. Sustainable agricultural management practices, such as the use of organic amendments, are recommended since the addition of organic amendments improved soil physical properties and chemical properties, e.g., organic carbon, and this effect can be long-lasting [33–35].

It would be interesting to study if a higher use of SDFS fertilizers and thus also a higher P fertilization could give higher yields and lead to an increase in soil P-concentration. The EC values in greenhouse soils were almost three times higher than the EC values of field soils after both harvestings (Table 5). This change may indicate that there has been a shortage of water at least during the second cultivation of lettuces, which can also explain the low lettuce yields in the greenhouse.

Organic carbon data showed that the application of organic fertilizer does not significantly increase the soil carbon within two follow up cultivation trials. This might be because of (1) the application of organic carbon is rather small, (2) high degradation in tropical climate, (3) washed away organic matter by rain and wind. Our result showed that the O/C was slightly higher residual soil in the greenhouse compared to what was found in field soil (Table 5). This also supports the earlier argument that the greenhouse soil was not eroded with rain and wind as well as lower temperature in the greenhouse compared to the field environment.

4.3. Hygienic Quality of Lettuces and Their Taste

Fecal coliforms were detected in lettuce fertilized with almost all treatment. Evidently, the sources of fecal coliforms were not fertilizers used, since coliforms were found also in lettuce fertilized with mineral NPK or cultivated without any fertilization. This result indicates that there can be a risk of coliform contamination in vegetables grown near the soil surface, and this risk did not depend on how it was fertilized or if it was cultivated in the greenhouse or the field.

The fecal coliform $\log_{10}$ numbers are higher than those considered acceptable levels in Canada [36] or the USA [37], where standards stipulate fecal coliforms <1000 CFU g^{-1} (=3 as Log_{10} numbers). We, anyhow, did not further analyze if the colonies found belonged to *Escherichia coli* or some other species. Similar levels of total coliform and *E. coli* have been reported in USA in packed lettuce and spinach leaves which were not disinfected [38]. In USA, it is recommended that the disinfection procedure of lettuce should be done by using chlorine or other disinfection procedures, and this is often done on the commercial scale [39]. In addition, our results suggest that the lettuce should be washed properly before consuming preferrably using, i.e., chlorine or lye as disinfectants.

The taste assessment of lettuce produced in the greenhouse showed that there were no differences ($p < 0.005$) in the tastes of lettuces using different fertilizer materials. The finding of this experiment was similar to what was found of the tasting experiment of cabbages produced using human urine fertilization, mineral fertilizer, or no fertilization [25].

5. Conclusions

This study provides evidence that the use of treated faecal sludge-based fertilizer can be a good solution for food security in West Africa. This practice can also improve soil quality and reduce environmental pollution. Furthermore, waste-based fertilizer could allow poor farmers a possibility to save money, since mineral fertilizers have high prices. Faecal sludge-based fertilizer could be commercialized as it has been successfully done in Uganda [40] and in Haiti and Kenya [41]. In these areas, farmers are willing to pay a reasonable price for these fertilizers, and they can then sell their yields.

The study showed that a high and even higher amount of lettuce can be produced using SDFS based fertilizer compared to other tested fertilizers. Similarly, lettuce produced in the open field had a higher yield with better quality compared to what was produced in the greenhouse. The taste and chemical quality of lettuces obtained with SDFS fertilizers were good. No helminth eggs were detected in SDFS products or lettuces. A few *E coli* colonies (not confirmed) were found in all lettuces independently of fertilization. Therefore, it is recommended to wash properly with clean, disinfected water before consuming it.

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