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Ecological sanitation products reuse for agriculture in Sahel: effects on soil properties

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Abstract

The sanitary products (i.e toilet compost, urine, and greywater) from resource oriented sanitation are a low-cost alternative to chemical fertilizers and irrigation water for poor communities in dry areas. However, if these products are not managed carefully, increased soil salinity and sodium accumulation could occur. The aim of this study was to assess the effects of these products at different combinations on the properties of cultivated soil and on okra plant productivity. The treatments were: (1) fresh dam water (FDW) as a negative control, (2) FDW plus chemical fertilizer (i.e.NPK) (FDW + NPK) as a positive control, (3) treated greywater (TGW), (4) FDW plus Urine/Toilet Compost (UTC) (FDW + UTC), (5) TGW + UTC, (6) TGW + NPK. Effects on okra productivity were assessed by measuring the fresh fruit yield whereas effects on soil were evaluated through measurements of electrical conductivity (EC), sodium adsorption ratio (SAR) and total organic carbon (TOC) at various depths. Results showed that the yields obtained with TGW ($0.71\,\mathrm{t\,ha^{-1}}$) and TGW + UTC ($0.67\,\mathrm{t\,ha^{-1}}$) were significantly higher than the yields obtained with the positive control FDW + NPK ($0.22\,\mathrm{t\,ha^{-1}}$) meaning that the fertilizer value of the sanitary products was higher than that of chemical fertilizer. Concerning effects on soil, SAR values increased significantly in plots treated by TGW (8.86 ± 1.52) and TGW + UTC (10.55 ± 1.85) compared to plots fertilized with FDW (5.61 ± 1.45) and FDW + NPK (2.71 ± 0.67). The TOC of plots treated with TGW + UTC ($6.09 \pm 0.99\,\mathrm{g\,kg^{-1}}$) was significantly higher than those of FDW + NPK ($4.46 \pm 0.22\,\mathrm{g\,kg^{-1}}$). Combined sanitary products from resource oriented sanitation can be reused as a nutrient source and water for food production, provided that soil salinity is monitored and the soil has high drainage capacity.

1 Introduction

Food insecurity is partially explained by declining soil fertility, higher chemical fertilizer prices on the global market, and water scarcity especially in the Sahelian region. Al-

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though chemical fertilizers are widely used worldwide to increase fertility of agricultural soils, their use is still very low in Sub-Saharan Africa (SSA) with an application rate of 8 kg ha^{-1} year^{-1} (Morris et al., 2007). These researchers reported that low fertilizer use is one of the major factors explaining lagging growth in agricultural productivity in Africa, specifically SSA, relative to other regions.

In addition, the shortage of freshwater resources affects agricultural production in SSA countries. To mitigate this food crisis, closed-loop sanitation systems provide a way to reduce health risks while also recovering useful nutrients for sustainable agriculture (Esrey et al., 2001). Thus, nutrients obtained from urine and faeces recycled as fertilizers can help relieve poverty by improving household food security and saving money used to buy chemical fertilizers, which can be put to other productive uses according to the WHO (2006). Human urine is a liquid fertilizer containing nitrogen (mostly as urea), phosphates and potassium in dissolved form that is available for plant use (Kirchmann and Pettersson, 1995). Because of this, the application of human urine has been gaining popularity as a fertilizer for agricultural practices (Heinonen-Tanski and van Wijk-Sijbesma, 2005; Germer et al., 2011; Boh et al., 2013). Nutrients and organic matter found in human faeces are already widely recognized to improve soil fertility and crop productivity when recycled as fertilizers (Mnkeni and Austin, 2009; Useni et al., 2013). Several studies have shown that reused wastewater is a good management option for increasing water supplies for agriculture (Brzezińska et al., 2011). Akponikpè et al. (2011) reported that irrigation with treated wastewater results in 40 % more eggplant yield compared to irrigation with dam water. Furthermore, van Leeuwen et al. (2015) confirmed that organic farming can enhance soil biomass.

Despite the growing interest, negative environmental and health risks are sometimes associated with excreta and greywater reuse in agriculture. Several studies have focused on the health risks of human urine and composted faeces with regards to pathogens, pharmaceutical residues, and trace elements in agricultural (Höglund et al., 2002; Winker et al., 2010; Fidjeland et al., 2013). Additionally, Mara et al. (2007) showed that pathogens in greywater may cause diseases through direct contact as well as through the consumption of contaminated plants. However, health risks associated with the reuse of these sanitary products will not be investigated in this present study.

Soil salinization is one of the major causes of declining agricultural productivity in many arid and semi-arid regions of the world (Qadir et al., 2001). Qadir et al. (2008) estimated that about 34 million ha in Iran, including 4.1 million ha of the irrigated land, is salt-affected and annual economic losses due to salinisation in this country are more than USD 1 billion. In Australia, salinity, sodicity and acidity are three major soil constraints that limit crop and pasture yields and costless removal of these constraints would increase annual profits by AUD 187 million, AUD 1034.6 million, and AUD 1584.5 million respectively (Hajkowicz and Young, 2005). This phenomenon is particularly important in arid and semi-arid regions characterized by low rainfall, high evaporation, and low salt leaching from the topsoil (Muyen et al., 2011). Thus, the salinity issue is significant in the SSA region and to the reuse of sanitary products, particularly urine (Boh et al., 2013) and greywater (Travis et al., 2010), which are potential salt sources. Generally, fertilizer application increases the content of soluble salts in the soil, and WHO (2006) has cautioned against the use of urine fertilizer in saline soils. Concentrations of sodium (Na^+) and chloride (Cl^-) salts in urine are often too high, placing an additional risk if used in salt affected soils. Thus, over-applying of human urine may cause agricultural soil sodicity (Sene et al., 2013; Boh and Sauerborn, 2014) and increase soil electrical conductivity (Mnkeni et al., 2008; Hijikata et al., 2013), which inhibit plant growth. Moreover, greywater is often a source of elevated levels of compounds such as surfactants and salt, which can alter soil properties (Travis et al., 2010). Hijikata et al. (2013) showed that Na^+ and major cations in pilot gardens mainly derived from greywater following combined application with human urine.

Several studies have demonstrated the effects of salt accumulation in soil and impacts on vegetables growth and yields. Dasgan et al. (2002) observed that plant growth is affected by the osmotic and ion specific effects and by ionic imbalance when soil accumulates Na^+. Moreover, Na^+ inhibits plant growth by disrupting the water uptake in the roots, dispersing soil particles, restricting root growth, and reducing nutrient availability by competition with major ions (i.e. Na^+ and Cl^-) in the substrate (Franzen, 2007). Boh et al. (2013) concluded that a reduction of dry-matter in the urine compared to ammonium nitrate-fertilized plants under saline conditions could be associated with toxicities in plants caused by high concentrations of Na^+.

To alleviate this problem, Ganjegunte et al. (2008) demonstrated that successful wastewater reuse requires selection of salt tolerant crops, appropriate irrigation systems, soil suitability, and salinity management strategies. Additionally, to reduce salt accumulation in soil, compost supplemented with human urine is recommended by Shrestha et al. (2013). Oo et al. (2013) reported that compost and vermicompost are effective in alleviating soil salinity and improving maize productivity in Thailand. The researchers explained that the soil salinity was reduced because the compost and vermicompost increased exchangeable potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) while decreasing exchangeable Na^+ This suggests that Ca^{2+} was exchanged for Na^+, and exchangeable Na^+ thus leached out of the soil.

To date, there is very limited information on soil salinity and sodicity from greywater in conjunction with human urine/compost reuse on agriculture under Sahelian conditions. Hence, the objective of this study is to evaluate the effects of sanitary products on vegetable productivity and soil chemical quality. Specific objectives are: (1) assessment of urine, toilet composts and greywater combined effect on okra productivity and (2) their effect on soil salinity during the harvest period.

2 Material and methods

2.1 Research site

The experiment was implemented at the International Institute for Water and Environmental Engineering (2iE) at Kamboinsin (12°27′40.6′′ N and 01°32′56.0′′ W), Ouagadougou, Burkina Faso. The climate is semi-arid and characterized by a 25–30 °C mean monthly temperature, an annual average rainfall of 773 mm, and a reference

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evapotranspiration is 1900 mm year^{-1} (Ouédraogo et al., 2007). The study was performed during the dry season (March to June 2014).

Soils are of a tropical ferruginous type and the surface layer (0–15 cm) is sandy loam (58 % sand, 23 % silt and 19 % clay) while the sub-layer (15–30 cm) is sandy loam clay (48 % sand, 29 % silt and 23 % clay).

2.2 Experimental setup

The experiment was arranged in a completely randomized complete block design with six treatments replicated three times. The treatments were based on the nitrogen (N) requirement of okra plant which is 100 kg ha^{-1} (Grubben et al., 2004). Sene et al. (2013) suggested that the application of human urine volume based on the plant N requirement is a good method for urine reuse. The treatments were as follows : (1) fresh dam water (FDW) as a negative control, (2) FDW plus chemical fertilizer (i.e. NPK) (FDW + NPK) as a positive control, (3) treated greywater (TGW), (4) FDW plus Urine/Toilet Compost (UTC) (FDW + UTC), (5) TGW + UTC, (6) TGW + NPK. Thus, there were 18 plots of 1.50 m^2 each with an interval of 0.5 m.

Chemical fertilizer, NPK 14:23:14, was applied at the rate of 23 grams per plot (g plot^{-1}); equivalent to 0.15 tons per hectare (t ha^{-1}) through ring method before seeding. Proportions of 75 % nitrogen from the urine and 25 % nitrogen from the human faece-based toilet compost were applied according to Sangare et al. (2014).

Urine was applied two weeks after sowing at the rate of 1.5 liter per plot (L plot^{-1}) which was equivalent to 9615 liter per hectare (L ha^{-1}). A second application was supplied three weeks after the first application and a third three weeks after the second application. Toilet compost was supplied once before sowing with 70 g plot^{-1}, which is equivalent to 4.45 t ha^{-1}. Seven days after the seedlings emerged, they were reduced to two plants per hole which is equivalent to twelve plants per plot. During the experiment, the daily irrigation quantity was modified during the cultivation period. The total volume of 2.5 L plot^{-1} during the 15 days after sowing (DAS) was increased to

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10 L plot^{-1} until harvest. The total irrigation water volume and the total applied amount of Total Nitrogen (TN), sodium (Na^+) and chloride (Cl^-) derived from the irrigation water and human excreta during the experiment are shown in Table 1. The plants were watered twice per day following the watering-can practices of local gardeners. Plots were manually weeded three (3) times during the growing period and periodically treated with insecticides (K-Lambda and Pacha) to fight insects, nematodes, fungi, and pests.

2.3 Vegetable growth and yield

The experiments were carried out using okra (*Abelmoschus esculentus* (L.) Moench). Okra is a well-known tropical vegetable in the sub-Saharan area whose fruits can be harvested and dried for off-season consumption (Nana et al., 2009). The vegetative growth and yields were recorded by plant height, fresh fruit production, and aboveground biomass. The leaves, stems, and fruits were weighed for the wet aboveground biomass and were oven dried for 24 h at 105 °C to obtain the total dry biomass.

2.4 Irrigation water collection and sample analyses

Treated greywater was collected from High Rate Algal Ponds (HRAPs) at 2iE (treatment capacity: 21 m^3 day^{-1}). The HRAPs were discussed previously at the lab scale by Derabe (2014). Raw greywater came from the student residence hall of 2iE and was treated with primary purification. The raw greywater was maintained in rotation (88 turns min^{-1}) by an electromechanical mixer during seven and a half (7.5) days inside the algal pond. To remove the excess sludge a secondary clarifier received the effluent of HRAPs. The effluent from this clarifier was then stored in a pond before being pumped to a small tower. Finally, treated greywater was collected to supply an intermediate tank from which the plants were irrigated.

Fresh dam water (FDW) was collected from the small dam located in Kamboinsin, 18 km from Ouagadougou, which is used for gardening by the population during the dry season. For this study, FDW was collected from the tank installed in the field experimental site.

FDW and TGW samples were collected every three weeks and analyzed for the following parameters: pH and electrical conductivity (EC) by the Electrometric method, calcium (Ca^{2+}) and magnesium (Mg^{2+}) by the EDTA titrimetric method, sodium (Na^+) and potassium (K^+) by the Flame photometric method. The sodium adsorption ratio (SAR) describes the amount of excess Na^+ relative to Ca^{2+} and Mg^{2+} cations. SAR is a measure which indicates the sodicity of water and predicts possible adverse effects of Na^+ in soils. It has been estimated using the following Eq. (1):

$$\mathrm{SAR} = \frac{[\mathrm{Na}^+]}{\sqrt{\frac{[\mathrm{Mg}^{2+}]\times[\mathrm{Ca}^{2+}]}{2}}} \quad (1)$$

Na^+, Ca^{2+} and Mg^{2+} are expressed in milli-equivalents per liter (meq L^{-1}).

Total nitrogen (TN) was measured with the direct Hach method. Total phosphorus (TP) was determined using the ascorbic acid method with persulfate digestion. Anionic surfactants were measured by methylene blue method.

Microbiological analysis of wastewater irrigation samples targeted relevant hygiene indicator bacteria, such as *Escherichia coli* (*E. coli*) and faecal coliforms. Spread plate method was used after an appropriate dilution of the samples in accordance with the procedure in Standard Methods for the Examination of Water and Wastewater (APHA, 1998). The samples were diluted with sterile Ringer. After dilution, 0.1 mL of the diluted sample was spread out over the media (Chromo cult Agar), contained in Petri dishes which were placed in the drying oven for incubation at 44.5 °C for 24 h. *E coli* were identified by their blue or purple color and faecal coliforms were identified by their red-pink color. The concentration was expressed by forming colony unit (CFU) reported relative 100 mL of sample. The bacteria load was expressed by Eq. (2) according to Rodier (2009):

$$N = \frac{n}{V \times d} \times V_s, \quad (2)$$

where N = Bacteria load (CFU/100 mL); n = Number of colonies in Petri dishes; V_s = Reference volume (100 mL); V = Volume of test (1 mL); d = dilution factor.

2.5 Human excreta collection and sample analyses

Human urine and toilet compost were collected in a urine diverting toilet implemented with a pilot family in the peri-urban area of Ouagadougou, Burkina Faso. The compost was collected from the composting toilet designed to avoid accumulation of moisture in the composting reactor. The composting toilet was a continuous feed system with constant reaction conditions in terms of temperature and moisture contents of the matrix. Unlike traditional composting systems, biodegradation rates of organic matter are very important because faeces were daily added into the composting reactor of the bio-toilet and thus accelerated decomposition (Lopez et al., 2004). The reactor can be removed and carried to the appropriate area, such as farmland, and just be turned with opening top hatch. In this study, toilet compost was taken from pilot families reactors after 3 months and stocked at the research site where daily temperatures ranged from 35–48 °C during the study period. Composting was used to balance the relation of carbon and nitrogen and if there was excess nitrogen the amount of compost was reduced (Heinonen-Tanski et al., 2005). Before reuse, the toilet compost was spread in the sun for a week to completely inactivate bacteria and pathogens that were not destroyed during composting.

Human urine was also collected from the same composting toilet, stored in a plastic drum, and exposed to sunlight in bottles (1.5 L) before reuse as fertilizer.

Undiluted urine sample was used for pH and EC measurements by WTW 350i multi-parameters before reuse. For compost, pH and EC were determined from a ratio 1 : 10 (compost: deionized water) using WTW 350i multi-parameters. Cation and anion determination was performed with an urine sample diluted at ratio 1 : 250 (urine: deionized water) and with a compost sample diluted at ratio 1 : 10 (compost: deionized water). The cation and anion concentrations were determined following the same procedure used for the irrigation water sample.

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Regarding microbiological analysis, feacal coliforms in urine were determined following the same procedure used for the irrigation water sample. Compost samples of 25 g were homogenized in 225 mL of buffer (phosphate) and a 10 fold dilution series was performed in maximum recovery diluents (Ringer solution). Feacal coliforms were cultured following the method 9215 A in APHA (1998). Relevant dilutions were spread on plates in duplicate on the media chromo cult coliform agar ES (Difco, France) and were incubated at 44.5 °C for 24 h. The bacteria load was expressed according to Eq. (3):

$$N = \left(\log_{10}\left(\frac{n}{\frac{P}{V} \times V_t \times d}\right) \times \mathrm{DW}\right), \tag{3}$$

where N = Bacterial load in compost; n = Number of colonies in Petri dishes; P = Weight of compost or soil samples (25 g); V = Volume of Buffer phosphate; V_t = Volume of test (1 mL); d = factor of dilution; DW = Dry Weight.

2.6 Soil physico-chemical measurements

The samples were taken at depths of 0–15 and 15–30 cm, air dried, and ground and sifted through a 2 mm mesh sieve in the laboratory. Soil pH and EC were determined in a 1 : 2.5 and 1 : 5 soil/water ratio respectively. Particle size analysis was performed by sieving and the sedimentometry method. Total organic carbon (TOC) in the soil samples was determined according to the modified Walkley and Black (1934) method.

For cation elements, soil was saturated with pure water (1 : 10) and the soil suspension was centrifuged at 3000 rpm for 10 min and the supernatant filtered with 0.45 mm glass microfiber filters (Whatman). Ionic concentrations (Na^+, Mg^{2+} and Ca^{2+}) were determined by the same methods described above. The results were expressed in meq kg^{-1} and were used in Eq. (1) to determine the SAR value. These parameters were tested to determine the effects they may have on plant growth.

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2.7 Statistical analyses

The data collected for different parameters were analyzed for variance. The means of the parameters for all treatments were calculated. The significance of the difference between all treatment means was evaluated by the Tukey multiple comparisons of means test at 95 % confidence intervals ($p < 0.05$). Statistical analysis of these results was carried out using R for windows version 2.15.1.

3 Results and discussion

3.1 Physical-chemical and microbiological characteristics of the irrigation water

The average physical-chemical and microbiological parameters measured during this study for both sources of irrigation water are shown in Table 3. Overall values of the analyzed parameters were higher for TGW than for FDW. The physical characteristics (pH and EC) of both water sources were in agreement with the recommendations of the FAO (Pescod, 1992). In terms of nutrient contents, high nitrogen, phosphorus, and potassium values were observed in TGW compared to FDW. These two major nutrients in TGW irrigation can promote plant growth (Travis et al., 2010). Additionally, the sedimentable HRAPs treatment can reduce the anionic surfactant (Derabe, 2014). Anionic surfactant in FDW was not detected.

The microbiological quality of TGW showed higher levels of coliforms than that of FDW. The faecal coliforms count in TGW and FDW averaged 4.05×10^3 and 2.05×10^3 CFU 100 mL^{-1} respectively, and did not meet current standards which are $< 10^3$ CFU 100 mL^{-1} for unrestricted irrigation, according to WHO (2006). *E. coli* was not detected in any of the irrigation water samples. Toscano et al. (2013) who reported that the UV rays significantly improved the quality of wastewater in terms of inactivation of pathogens such as total coliforms, *E. coli, salmonella* and enterococci.

3.2 Physical-chemical and microbiological characteristics of human excreta

The physical and chemical properties of human urine and toilet compost are summarized in Table 2. The urine sample had the highest electrical conductivity (EC), 2.5 times more than that of toilet compost. Mnkeni et al. (2008) showed that excessive urine application inhibited plant growth due to increasing soil EC. Human urine characterized by a higher SAR value (119), could be sources of soil salinity and/or sodicity. Total N in the urine sample was within the range of previous studies such as Kirchmann and Pettersson (1995).

The bacteria load results showed that, urine and compost can be used for cooking vegetables like Okra, cereal crops, industrial crops, fodder crops, pasture and trees.

3.3 Plant height

The results showing the effect of bio fertilizers and both irrigation waters on okra growth are given in Fig. 1. Overall, the greatest height enhancement was obtained in plot irrigated with TGW compared to plots irrigated with FDW during all the cultivation days.

The plant height measurement for all treatments was not statistically different among them until after 56 cultivation days. This study showed that plants irrigated with TGW (31.63 ± 2.41 cm) were not significantly higher compared to plants treated with TGW + UTC (30.33 ± 8.78 cm) during the cultivation days. However, the plant heights in plots treated with TGW + UTC (30.33 ± 8.78 cm) were significantly higher than those treated with FDW + NPK (19.02 ± 2.25 cm) at 69 cultivation days. These results corroborate other studies which demonstrated that the use of wastewater and/or treated greywater can encourage good plant growth, mainly because of the significant amount of nutrients (Singh et al., 2012). The total N amount applied from TGW was 90 % more than those from FDW during the cultivation growth.

Compared to plots irrigated with TGW, the lowest plant heights were reported for plots irrigated with FDW. Plant growth in these plots was not significantly affected when supplied with human urine and toilet compost.

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3.4 Vegetable yields

The different components of okra yield obtained with treatments are summarized in Table 4. Similar to plant height, the number and yield of okra fresh fruit was significantly ($p < 0.05$) increased in plots irrigated by TGW compared to plots irrigated by FDW. Indeed, irrigation with TGW alone improved significantly ($p < 0.05$) the number of okra fruit (9.50 ± 2.71) compared to irrigation with FDW alone (4.90 ± 2.25). Additionally, a significantly higher number of fruits were obtained with plants treated with TGW + UTC (11.33 ± 2.57) compared to FDW + NPK (4.25 ± 2.86). However, no significant differences were observed between fruit number obtained from plant irrigated with TGW (9.50 ± 2.71) and TGW + UTC (11.33 ± 2.57). This result showed that TN derived from TGW and TGW + UTC is sufficient for okra plant growth.

Regarding okra fruit yields, the effect of TGW ($0.71 \pm 0.33\,\mathrm{t\,ha^{-1}}$) was significantly higher ($p < 0.05$) compared to FDW ($0.23 \pm 0.16\,\mathrm{t\,ha^{-1}}$), which is in accordance with previous studies (Akponikpè et al., 2011). This improved yield could be ascribed to water and nutrient supplies, but it most likely occurs because nutrients are provided and released continuously by TGW.

In addition, the fruit yields using TGW + UTC ($0.67 \pm 0.32\,\mathrm{t\,ha^{-1}}$) were significantly higher ($p < 0.05$) than those obtained using FDW + NPK ($0.22 \pm 0.17\,\mathrm{t\,ha^{-1}}$). A possible reason for this result might be that the urine and toilet compost (UTC) were richer in nutrients which are required for plant production. The nutrients and the variety of inorganic and organic compounds in human urine promote crop growth (Kirchmann and Pettersson, 1995). At the same time, the addition of organic amendments (i.e. compost) improves soil structure, aggregate stability, and moisture retention capacity (Bhattacharyya et al., 2008). Higher fruit production in the plots with UTC could be explained by enhanced organic carbon content and microbial activity in the soil (Nakhro and Dkhar, 2010). Pradhan et al. (2009) showed also that compost or ash reduced emissions from nitrogen fertilizer and maintained soil potential. This agrees with the observations of Shrestha et al. (2013), who showed an improved yield, for sweet pepper when UTC was used. In general, the main advantages of toilet compost are that it releases nutrients gradually, raises soil organic matter contents, and minimizes N evaporation.

However, the lower fruit yields of plants treated with FDW + NPK may be associated with larger gaseous nitrogen losses from NPK and poor nutrients contained in FDW. Indeed, Mermoud et al. (2005) reported the high evaporation which leads to high volatilization of nitrogen in Kamboinsin area. Besides, chemical fertilizer can remain undissolved lying in the upper layer of dry soil during the dry season, if there is insufficient irrigation. Furthermore, commonly used chemical fertilizers include fertilizers containing a single nutrient which is usually nitrogen (N), phosphorus (P), and potassium (K) and no other nutrients such as Ca, Mg, Zn, Fe, B important for vegetable growth.

In regards to only fertilizer sources, okra yields of the plots treated with UTC were not significantly higher ($p < 0.05$) than those fertilized with NPK with the same irrigation water sources. In fact, okra fruit production obtained with TGW + UTC ($0.67 \pm 0.32\,\mathrm{t\,ha^{-1}}$) was not significantly higher compared to those with TGW + NPK ($0.61 \pm 0.42\,\mathrm{t\,ha^{-1}}$). For FDW, okra fruit yield was not significantly different ($p < 0.05$) between FDW + UTC ($0.47 \pm 0.18\,\mathrm{t\,ha^{-1}}$) and FDW + NPK ($0.22 \pm 0.17\,\mathrm{t\,ha^{-1}}$). These results confirmed that the nutrients supplied, especially TN from TGW are more important than FDW for plant production, as shown in Table 1. Unfortunately, excess N derived from TGW and especially urine leads to over-fertilization of plants. This excess N application affects nitrogen concentration in plant shoots and roots (Mnkeni et al., 2008; Sene et al., 2013).

As opposed to fruit productions, the dry aboveground biomass yields were not significantly different ($p < 0.05$) between all the treatments applied during this study.

3.5 Physical characteristics of soils

The soil pH values at different depths (0–15 and 15–30 cm) before and at the end of the cultivation periods are indicated in Fig. 2. Overall the soil pH in all treatments increased at the end of cultivation compared to that before cultivation at both depths

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(0–15 and 15–30 cm). However, there was no significant difference ($p < 0.05$) between pH values of the soil (5.42 ± 0.23) before and after the cultivation period apart from pH of soil treated with TGW (7.07 ± 0.80), TGW + UTC (7.74 ± 0.11) and FDW + UTC (7.04 ± 0.88) at the depth of 0–15 cm. This study thus shows that the application of TGW and UTC could lead to an increase in soil alkalinity over time. Similar observations were found by Mnkeni and Austin (2009) who showed that pH of human manure is alkaline and will have a liming effect on acidic soil (i.e. increasing soil pH). Indeed, soil pH increase may be due to the mineralization of carbon and the subsequent production of OH^- ions from compost application (Mkhabela and Warman, 2005).

At the depth of 15–30 cm, no significant difference ($p < 0.05$) was observed between soil pH values before and after the cultivation period (Fig. 2).

3.6 Salinity and sodium hazards of cultivated soil

The soil salinity, measured through EC values in all treatments after irrigation compared to this initial soil at both depths (0–15 and 15–30 cm), is presented at Fig. 3a. The general results showed that soil EC values at the depth of 0–15 cm were higher compared to those at the depth of 15–30 cm. This result coincides with the study of Ben-Hur (2005) who has shown that the salts are located mainly at the depth of 0–20 cm in sandy soil.

The highest significant EC value ($p < 0.05$) was obtained with TGW + UTC (447.2 ± 278.4 µS cm^{-1}) compared to FDW (211.5 ± 21.0 µS cm^{-1}), FDW + NPK (222.3 ± 53.5 µS cm^{-1}), and initial soil (96.1 ± 3.5 µS cm^{-1}) at the depth of 0–15 cm. These results agree with Hijikata et al. (2013) who indicated that the combined application of urine and greywater significantly elevates soil EC values. Additionally, greywater irrigation also increases soil EC values (Al-Hamaiedeh and Bino, 2010; Faisal Anwar, 2011). In fact, Faisal Anwar (2011) reported that the salinity level for different plots irrigated with greywater is between 707–789 µS cm^{-1}. Similar to the 0–15 cm depth, at the depth of 15–30 cm, soil EC values were significantly higher in plots treated with TGW + UTC (350.1 ± 92.5 µS cm^{-1}) compared to those plots fertilized with FDW + NPK

(174.9 ± 9.2 µS cm^{-1}) and compared to the soil before cultivation (92.4 ± 7.0 µS cm^{-1}) (Fig. 3a). However, no significant difference was observed between plots treated with TGW (147.8 ± 18.8 µS cm^{-1}) and FDW (138.2 ± 11.2 µS cm^{-1}).

The sodium in the soil was indicated as sodium adsorption ratios (SAR) at the depths of 0–15 and 15–30 cm before and after cultivation days, as presented in Fig. 3b. Overall SAR values of soil in all treatments increased after cultivation compared to the soil before cultivation at both depths (0–15 and 15–30 cm). One possible reason might be a fast concentration the mineral constituents brought by the irrigation water (Sebastian et al., 2009) and by human urine occurs as a result of a high evapotranspiration rate in the study area (Mermoud et al., 2005).

At the depth of 0–15 cm, the SAR value of soils treated with TGW + UTC (10.55 ± 1.85) was significantly higher than those treated with FDW + NPK (2.71 ± 0.67) and soil before cultivation (0.95 ± 0.21). Thus, this study shows that all plots irrigated with TGW resulted in higher SAR values compared with those irrigated with FDW excepted the plot fertilized by FDW + UTC. A possible reason could be the high Na applied through TGW and the urine volume application in our experimental conditions. Apart from nitrogen, urine contains dissolved salts of Na^+ and Cl^- which explain the increase in substrate salinity at a higher application dosage (Boh et al., 2013). The sodium effects derived from greywater have been shown by several studies (Al-Hamaiedeh and Bino, 2010; Travis et al., 2010). Travis et al. (2010) reported the highest SAR in sandy soil irrigated with raw greywater. On the other hand, Hulugalle et al. (2006) reported that irrigation with treated sewage effluent increases the exchangeable Na, and the exchangeable Ca and K in the clay-textured surface. This could be due to high quantity of sodium salts typically found in laundry detergents included in greywater (Christova-Boal et al., 1996). Additionally, plots amended with UTC resulted in higher SAR values which are likely due to the largely Na^+ content in the urine. Sene et al. (2013) showed that continuous urine application increases the SAR value of the fertilized soil. Problems with salt accumulation in soil can be worse in dry climates, where increased water needs in combination with high evapotranspiration rates are common. An accumulation of salts can result in a decrease in the soil's capability to absorb and hold water (Mungai, 2008).

The lowest SAR values in plots treated with FDW (5.61 ± 1.45) and FDW + NPK (2.71 ± 0.67) are likely explained by the low Na^+ concentrations in FDW.

At the depth of 15–30 cm, SAR values were significantly higher in plots treated with TGW and fertilized with UTC compared those treated with FDW and FDW + NPK (Fig. 3b).

Moreover, SAR values of soil at 0–15 cm depths were significantly higher ($p < 0.05$) compared to those at 15–30 cm depths. Generally, surface horizons are often more susceptible to increased Na^+ concentrations (Johnston et al., 2013). Qureshi and Qadir (1992) reported that Na^+ replaced from cation exchange sites stays suspended or moves little to the lower depths. To mitigate this problem, Ahmad et al. (2013) reported that crop rotation improves leaching of sodium (Na^+) and other ions. Additionally, Johnston et al. (2013) showed that soil salinity decreases following the addition of gypsum plus sulfur to saline-sodic (i.e. SAR > 40) irrigation water. Nevertheless, these researchers advised that the application of the required dose of sulfuric acid with pre-sowing irrigations is better for the reclamation of saline-sodic soils to avoid plant phytotoxicity.

3.7 Total organic carbon in cultivated soil

Figure 4 shows the effect of different treatments on total organic carbon (TOC) in soil before and after the cultivation periods at the depth of 0–15 cm. There were no significant differences ($p < 0.05$) in the TOC values between treatments receiving TGW and UTC. However, TOC of plots treated with TGW + UTC ($6.09 \pm 0.99\ g\ kg^{-1}$) was significantly higher compared to those of FDW + NPK ($4.46 \pm 0.22\ g\ kg^{-1}$) and soil before cultivation ($4.00 \pm 0.20\ g\ kg^{-1}$) at the depth of 0–15 cm. On the other hand, no significant difference was observed in soils treated with TGW + UTC ($6.09 \pm 0.99\ g\ kg^{-1}$) and TGW ($5.79 \pm 0.66\ g\ kg^{-1}$). Generally, the application of organic amendments increases carbon pools which are significantly correlated with soil organic carbon (Srinivasarao et al., 2014). As such, the application of compost can increase TOC in soils as shown by Rivero et al. (2004). That study reported the positive influence of compost on soil organic matter quality under tropical conditions. Furthermore, Jaiarree et al. (2014) showed that soil carbon storage increased significantly after compost application to tropical sandy soil. Similarly, Oo et al. (2013) showed that compost and vermicompost amendments improved cation exchange capacity, soil organic carbon, total nitrogen, and extractable phosphorus in saline soil.

4 Conclusion

The overall results of this study indicate that combined sanitary by-products from resource oriented sanitation can be reused as a nutrient source and irrigation water for food production. This study showed that yields obtained with treated greywater ($0.71\,t\,ha^{-1}$) and the combination of greywater with urine and compost ($0.67\,t\,ha^{-1}$) are significantly higher than the control treatment of dam water and chemical fertilizer ($0.22\,t\,ha^{-1}$). This result means that fertilizer value of the sanitary products is higher than that of conventional fertilizer. However, urine and compost applied in association with greywater irrigation did not significantly increase the plant yield compared to only greywater irrigation. Concerning the sanitary products effects on soil, SAR values increased significantly in plots irrigated with greywater (8.86 ± 1.52) and a combination of greywater and urine and compost (10.55 ± 1.85) compared to the control (dam water) and conventional treatment (dam water and chemical fertilizer). Overall, these results provide evidence that the application of TGW and UTC could lead to an increase in soil alkalinity over time. To mitigate salinity effects, greywater and fresh water irrigation could be alternated. In addition, the soil should have a good drainage capacity and should be regularly monitored to avoid any salt accumulation.

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Table 1. Total amount of N, Na^+ and Cl^- derived from irrigation water and human excreta during the cultivation experiment.

Different Treatments	Total N g plot^{-1} 68 days^{-1}	Total Na^+ g plot^{-1} 68 days^{-1}	Total Cl^- g pot^{-1} 68 days^{-1}
FDW	0.96	3.68	1.81
TGW	9.14	40.42	11.27
FDW + NPK	7.27	3.68	1.81
TGW + NPK	15.46	40.42	11.27
FDW + UTC	18.93	77.93	58.24
TGW + UTC	27.12	114.67	67.70

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Table 2. Physical and chemical properties of human excreta.

Parameters	Urine	Toilet Compost
pH*	8.10	9.04
EC ($\mu S\,cm^{-1}$)	21 000	4190
Total Nitrogen (TN)	$2.90\,g\,L^{-1}$	$54.7\,g\,kg^{-1}$
Total Phosphorus (TP)	$0.04\,g\,L^{-1}$	$194\,g\,kg^{-1}$
Potassium (K^+)	$3.20\,g\,L^{-1}$	$848\,g\,kg^{-1}$
Sodium (Na^+)	$5.20\,g\,L^{-1}$	$565\,g\,kg^{-1}$
Calcium (Ca^{2+})	$0.06\,g\,L^{-1}$	$160\,g\,kg^{-1}$
Magnésium (Mg^{2+})	$0.05\,g\,L^{-1}$	$96\,g\,kg^{-1}$
Chlorure (Cl^-)	$2.60\,g\,L^{-1}$	$497\,g\,kg^{-1}$
SAR*	119	11
Total organic Carbon (TOC)	–	$800.2\,g\,kg^{-1}$
C / N	–	14.62
Faecal coliforms	$5.12\ \log_{10}$ CFU $100\,mL^{-1}$	$4.40\ \log_{10}$ CFU $g\,DW^{-1}$

* No unit, CFU: Colony Forming Unit; DW: dry weight

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Table 3. Physico-chemical characteristics of treated greywater and fresh dam water.

Parameters	Units	Treated greywater (TGW) ($n = 4$)	Fresh dam water (FDW) ($n = 3$)	References
pH	–	7.84 ± 1.48	7.34 ± 0.28	6.5–8[a]
EC	$\mu S\,cm^{-1}$	589.2 ± 412.6	193.6 ± 5.50	1–3000[a]
TN	$mg\,L^{-1}$	15.90 ± 1.34	1.67 ± 1.17	
TP	$mg\,L^{-1}$	11.90 ± 1.50	2.8 ± 0.9	
K^+	$mg\,L^{-1}$	23.10 ± 5.20	11.5 ± 1.8	
Cl^-	$mg\,L^{-1}$	19.6	3.15	
Na^+	$mg\,L^{-1}$	70.3 ± 8.5	6.4 ± 1.3	
Ca^{2+}	$mg\,L^{-1}$	19.8 ± 3.2	20.4 ± 6.8	
Mg^{2+}	$mg\,L^{-1}$	4.4 ± 2.8	4.0 ± 0.7	
SAR	–	3.17 ± 1.89	0.30 ± 0.12	15[a]
Surfactant	$mg\,L^{-1}$	1.41	n.d.	
Faecal coliforms	$CFU\,100\,mL^{-1}$	$4.05 \pm 2.1 \times 10^3$	$2.05 \times 10^3 \pm 0.9 \times 10^3$	$\leq 10^3$ [b]
E. coli	$CFU\,100\,mL^{-1}$	n.d.	n.d.	$\leq 10^3$ [b]

n.d. not detected; n: number of samples; [a] Pescod (1992); [b] WHO (2006).

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Table 4. Yield components of okra obtained from different fertilizer treatments (same small alphabetic letters do not differ significantly at the 5 % level of probability at different treatments).

Different Treatments	Number of fresh fruits	Fresh Fruit Production ($t\,ha^{-1}$)	Dry leaf + stem ($t\,ha^{-1}$)	Dry above ground biomass ($t\,ha^{-1}$)
FDW	4.90 ± 2.25c	0.23 ± 0.16b	0.20 ± 0.10	0.25 ± 0.08
TGW	9.50 ± 2.71ab	0.71 ± 0.33a	0.30 ± 0.20	0.46 ± 0.20
FDW + NPK	4.25 ± 2.86c	0.22 ± 0.17b	0.21 ± 0.10	0.26 ± 0.08
TGW + NPK	8.08 ± 2.81b	0.61 ± 0.42a	0.24 ± 0.09	0.36 ± 0.09
FDW + UTC	6.66 ± 2.53bc	0.47 ± 0.18ab	0.31 ± 0.14	0.41 ± 0.14
TGW + UTC	11.33 ± 2.57a	0.67 ± 0.32a	0.33 ± 0.01	0.48 ± 0.06

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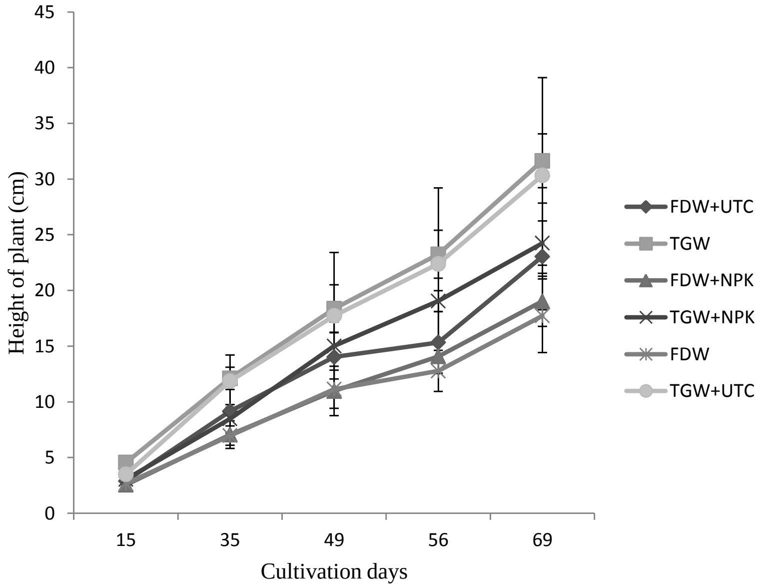

Figure 1. Effect of different treatments on the height of okra plant during cultivation days.

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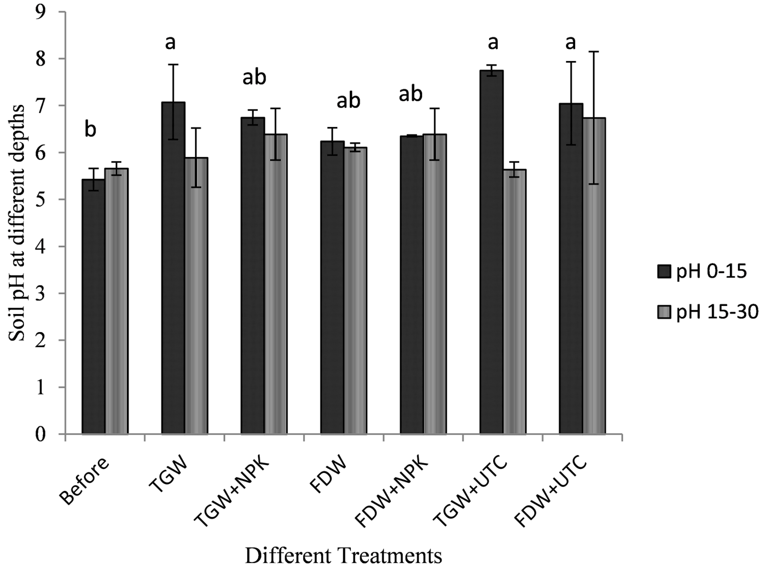

Figure 2. Soil pH values at different depths (0–15 and 15–30 cm) before and after cultivation periods (same small alphabetic letters do not differ significantly at the 5 % level of probability at the depths of 0–15 and 15–30 cm respectively).

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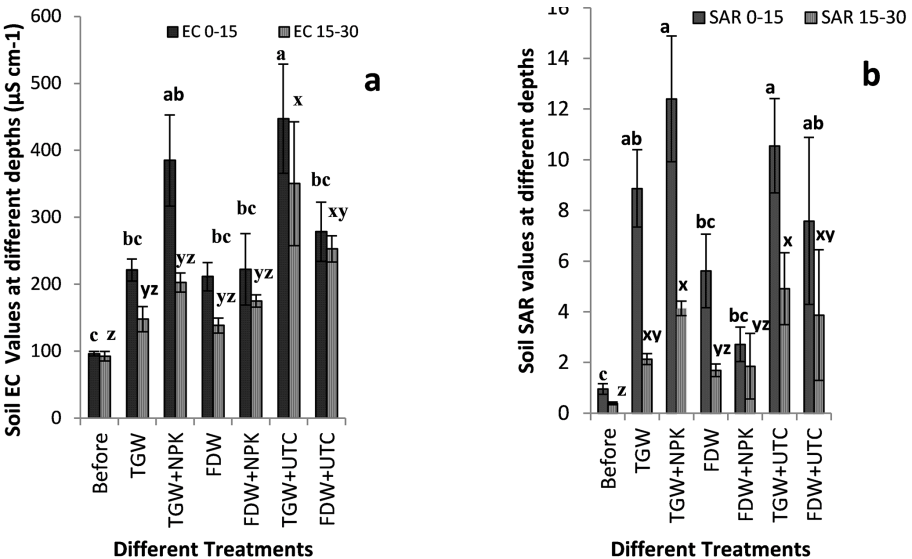

Figure 3. Soil EC **(a)** and SAR **(b)** values at different depths (0–15 and 15–30 cm) before and after the cultivation periods (same small alphabetic letters do not differ significantly at the 5 % level of probability at the depth of 0–15 and 15–30 cm respectively).

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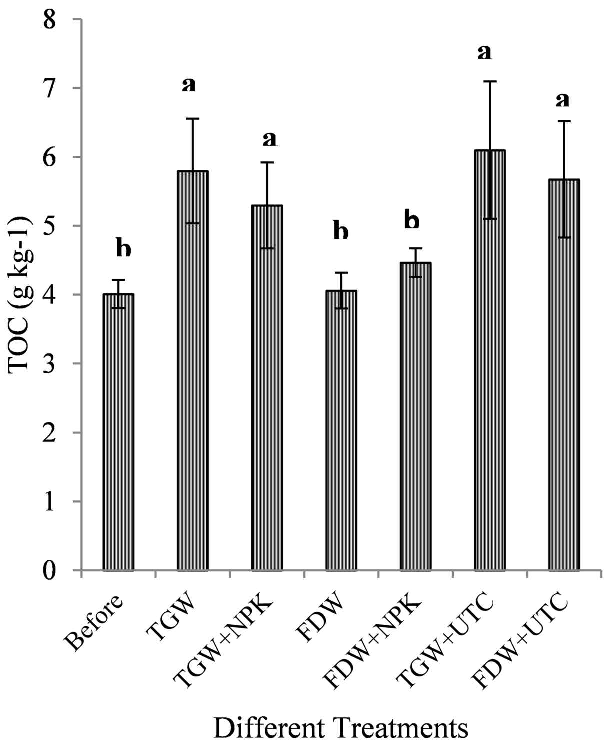

Figure 4. Different total organic carbon (TOC) values of soil at the depth of 0–15 cm before and after cultivation periods (same small alphabetic letters do not differ significantly at the 5 % level of probability at different treatments).

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