Nutrient Recovery from Human Excreta for urban and peri-urban Agriculture[1]

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1. Introduction

The accelerated growth in global urban population implies an increasing demand for sanitation services which many developing countries especially in sub-Saharan Africa (SSA) are unable to meet As municipal authorities face major challenges in managing both solid and liquid waste, recycling has the potential to provide a win-win situation by reducing waste flows, ensuring environmental health, enhancing soil properties and creating livelihoods. Urban wastes especially human excreta consist of nutrients and organic matter that can be recycled for use for agriculture in and around cities where the challenge of urban food security has facilitated the development of urban and peri-urban agriculture (UPA). Small farms are established on idle lands, along road frontages, and in valleys which are prone to degradation and nutrient depletion due to continuous cropping.This consequently leads to low crop yield. Sole use of inorganic fertilizers in UPA is not sustainable in such continuously cultivated land. It is important to aim at improving the organic matter (OM) in addition to nutrient levels for improved and sustained crop production. For this, recycling of excreta provides a good opportunity.

Research projects have been conducted by IWMI and partners since 2001 to provide information on the utilization of excreta and wastewater in agriculture. Excreta are rich source of essential plant nutrients such as nitrogen, phosphorus and potassium. Each day, humans excrete in the order of 30 g of carbon (90 g of organic matter), 10-12 g of nitrogen, 2 g of phosphorus and 3 g of potassium. Most of the organic matter is contained in the faeces, while most of the nitrogen (70-80 %) and potassium are contained in urine. The organic matter and nutrients contained in excreta can be recycled and reused as fertiliser-cum-soil conditioner – an effect not shared by chemical fertilisers and of dare need in tropical soils. Decomposed excreta improve soil structure; increases water holding capacity, reduce pests and diseases and neutralize soil toxins and heavy metals (Esrey et al., 2001). In this paper, lessons have been drawn from farmers' practice of excreta recycling and results from research studies conducted in West Africa (see list of references).

The excreta described here are those collected from on-site sanitation systems (OSS) comprising of non-sewered household latrines, public toilets, VIPs and septic tanks etc which are described as faecal sludge (FS). In urban areas of low and middle income countries, OSS predominates over water-borne, sewered ones. In sub-Saharan Africa, more than 75 % of houses with toilet facilities in large cities and up to 100 % in towns are served by on-site sanitation facilities. FS management remains a serious problem that causes contamination of soil and water bodies and endangers human health and the environment. The recovery approach can reduce the negative impact on the environment and have positive public health impact if safely treated before reuse in agriculture. The type of storage/collection and treatment determine how much of these resources can be recovered and harnessed, and at the same time, how safe the final product is for the end

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user. Tested options for FS recycling under different climatic environment and related recommendations are discussed.

2. Study Background and Data Collection

The data highlighted in this paper were collected under different conditions. Brief description of the different study background is given below

Land application of FS in Ghana

Although large quantities of FS are dumped into depressions or watercourses but in many areas in Ghana, some farmers like to empty septic trucks into their farms. Investigations were carried out among selected farming communities in two urban agglomerations (Tamale and Bolgatanga) in the North and one district, Manya Krobo in the southern part of Ghana. In all 150 farmers were interviewed through focus group discussion and questionnaire survey between year 2003 and 2006. The adoption of FS as an alternative to inorganic fertilizer in crop production was investigated. The study also identified factors that influence its use, the constraints as well as the agronomic and economic benefits. Data collected were analysed through the use of descriptive statistics, budgetary analysis and the probit model. Details have been described in Cofie et al 2005, 2009

Storage of FS

In Teshi community within Accra, Ghana a FS treatment plant consisting of two settling-thickening tanks for solids-liquid separation and a series of three ponds to treat FS supernatant was constructed close to a landfill. The aim of the municipality was to mix dried settled sludge with composted solid waste (SW) for use in agriculture. However, the composting section has not been functioning well due to breakdown of sophisticated machinery and lack of proper maintenance. A study was carried out to focus mainly on the FS recycling. Usually, desludging of FS from the ponds takes place concurrently with mixing with sawdust, which is acquired from local timber markets. Significant amount of sawdust is mixed with one full pond of sediments which is about 70 tons each time the pond is desludged. Then the sludge is dumped close to the tanks and allowed to dry until reuse. In the trial, heaps consisting of settled sludge and sawdust mixture were made and the pathogen concentration was monitored over time to find out how long to store the mix to ensure hygienic safety for use in agriculture. Among the pathogens causing gastro-intestinal infections, helminth eggs were chosen as indicators to determine hygienic quality of the sludge. More details in Cofie et al (2008)

Co-composting of FS with organic solid waste

In Kumasi, Ghana, a low-cost decentralized co-composting plant was set up to test technical options for producing compost form FS and organic solid waste (SW). Given the high water content of FS from OSS, unplanted drying bed was designed and used as solid-liquid separation unit to dewater the FS. Fresh public toilet sludge and septage mixed in a ratio of 1:2 were dewatered on the drying bed. The dewatered FS was then mixed with organic solid waste in a volume ratio of 1:2 for co-composting. Samples of SW, FS and the mixture were collected before, during and after composting and characterised for nutrient and pathogen concentrations. The agronomic effect of composted FS and FS/SW compost were investigated on cabbage and Maize (Cofie et al, Adamtey et al)

Enrichment of excreta based compost with minimal fertilizer

To enhance the use of excreta based compost in crop production, a study was conducted in Ghana (from 2005-2008) to blend co-compost produced from human excreta and municipal solid waste with minimal amount of inorganic nitrogenous fertilizers. The purpose was for crops to benefit from the complimentary effect of such mixture viz: fast release of nitrogen especially for short duration crops in the urban areas, long term effect of organic matter from the compost fraction, and reduction in the required volume of compost for use in peri-urban areas. The mix, termed *Comlizer* was then characterised and tested on the soil and crop performance. (Adamtey et al 2009)

3. Methodology

Laboratory analysis

Data reported have been generated using standard laboratory and field procedures for the various sample types. For analysis of FS samples, Standard Methods for the Examination of Water and Wastewater (1992) was used. The concentration method outlined by Schwartzbrod (1998) based on modified US-EPA method, was used to quantify helminth egg concentration while the viability was determined using the Safranine dying method developed by de Victorica and Galvan (2003). For the analysis of composted FS, soil and plant samples, the methods outlined by TMECC, (2002) and Okalebo et al. (2002) were used accordingly.

Investigation in farmers' field

Farmers applied about 56 m^3 per hectare of partially stabilized FS in three different locations in northern Ghana. The FS was spread on the soil surface in December. The volume applied supplied an estimated amount of N, P, K and carbon in the order of 455, 61, 121, and 1,183 kg/ha respectively to the soil. The discharged excreta was incorporated into the soil at the onset of dry season in April following year.
Maize (Zea mays, L var. Obatampa,) and Sorghum (S. bicolor local, unimproved red variety) were intercropped which is the usual practice and planted on ridges,. Maize was first planted at the spacing of 30-cm x 30-cm and after its emergence (1-2 days), sorghum was planted at a spacing of 40-cm- x 40-cm. Two weedings were carried out during the period, the first one was 3 weeks after planting. During the first weeding, the thinning out was carried out where there were more than 2 plants per stand. The second weeding was carried out 6 weeks after planting.. An area of 50-m x 50-m was demarcated for monitoring of plant growth. Fifteen plants each of maize and sorghum were specifically marked for monitoring during the growth period. At maturity the marked plants were carefully harvested and grain weight was recorded before and after oven drying at 105o C for 24 hours
To investigate the effect of FS on soil over the growing period, soil samples were collected at different times during the year. Samples were taken with the aid of soil auger diagonally, across each selected field and at two different soil depths (0-20 and 20-40cm) in December. Second sampling was done in the following April (i.e. after soil incorporation of excreta), while final sampling was after harvesting (i.e. October). Samples were collected in triplicate, 72 samples were taken from every location, with the total number of samples being 216 at each sampling time. The samples were air-dried and crushed to pass through a 2mm and analysed.

Design of Experimental Plots and data collection

The rates of FS and FS based compost applied were calculated based on the Nitrogen content and crop requirement as recommended by FAO, and the Grain and Legume development board of the Crop Research Institute Ghana. According to the reports maize requires a minimum of 91 kg N /ha and a maximum of 210 kg N/ha while cabbage requires a minimum of 73.5kgN /ha and a maximum of 121 kg N/ha (Sinnadurai,1979) for successful growth and development in Ghana. Three application rates between the two limits were tried out in the field.

Cabbage

Nursery and field experiment

Cabbage was nursed in a soil sterilized with hot water at a temperature of 100ºC. Uniform seedlings were transplanted unto the permanent field (Plate 8). The design was split plot design. Each experimental plot was replicated three times. The total plot size was 21.5m by 21.5 m and each experimental unit was 2.4m x 4.5 m consisting of four rows of 40 plants. Planting distance was 60cm by 45cm. The following field operation was carried out:

- Watering was done twice a day.
- Weeds were controlled when ever necessary.
- Insecticides were sprayed whenever necessary to control insects and pest.
- Growth and yield data were collected for analysis
- Plant nutrients and heavy metals uptake as well as pathogen concentration under the different treatments were assessed and analysed

Maize

The experiment was based on a split plot design. The treatments served as the main plots and the different rates of application based on N content (i.e. 91 kg N ha-1, 150 kg N ha-1 and 210 kg N ha-1) served as the sub-plots. Each experimental plot consisted of 26 poly bags of size 43.2 x 35.6 cm flat, and spaced at a distance of 30 cm by 80 cm and replicated three times. This experiment was done under controlled irrigation as the water use efficiency was to be investigated. This study prior a bigger field study

Maize cv. Abelehii was grown in poly bag was filled with 15 kg sandy loamy soil, Ferric Lixisol, which has been sieved through 5 mm mesh size. Three seeds per poly bag were sown and thinned to one seedling, five days after emergence. Through out the growing period the moisture content of the soil was adjusted to 60% field capacity using Time Domain Reflectometer (TDR 300) ®. To prevent runoff and soil water evaporation, water was gently added to the soil in each poly bag and the surface was immediately covered with black polythene sheet. Weeds were removed with hands and spraying against stem borers was done whenever necessary. Water-use efficiency (WUEcwu) was determined according to Howell (2001) by dividing the economic yield (i.e. maize grain at a moisture content of 13%) by the cumulative water use.

Eight plants per treatment were used for agronomic data collection.

The chlorophyll content of the fifth leaf (from the base of the selected plants) was measured using Chlorophyll Meter (model, Minolta SPAD-502®). Leaf area was measured using Leaf Area Meter (model CI-202, CID INC®). Leaf area index (LAI) was calculated as the total leaf area per plant divided by the ground area in the poly bags. Percent leaf senescence was determined on the ninth week by counting the number of senescent leaves and expressing it as a percentage over the total number of leaves per plant. Two plants were selected randomly from each treatment plot, and oven dried at 70ºC for 72 hours and the dry weight taken. Eight plants per treatment plot were randomly harvested at physiological maturity and the grains dried to 13% moisture content and the weight taken. The mean grain yield was expressed as kg plant-1. The harvest index was calculated by expressing the grain yield over the final total dry matter yield. The root volume was estimated by the water displacement method after the roots were carefully removed from the soil and washed with water. This paper used mean data of growth parameters, yield and nutrient uptake across treatments. The effect of the rate of application of the treatments on growth, yield and nutrient uptake has been discussed in Adamtey et al. (under review)

4. Results and Discussion

FS Treatments for Recycling

Options for FS recycling vary depending on climatic environment and socio cultural context. Recommendations for applying different options are presented in box 1.

Box 1. Options for recycling FS for urban and peri urban agriculture

Recycling Option	Where feasible and Recommended Practice
Land application and drying	**Long Drying:** feasible under hot climate e.g above 35^{o}C for up to 4 months in the year. Also appropriate where there is demand for FS use. o FS type - septage stored for long e.g over a year are better than fresh one as they are partially stabilised and hence contain less pathogen than public toile sludge which is usally store for few weeks or months before desludging. o Spread the FS on the fields over a relatively large area to give a thin layer o Drying of FS till it forms a cracked layer Above 37^O C, this can be achieved from 4 months onwards o Use of protective covering such as gloves and boots adviced
Extended Storage	**FS type:** settled sludge from stabilization ponds or settling tanks o Heaped under shade or in the open o Need to be stored for more than 3 months
Co-composting	Basic Requirement: primary treatment followed by aerobic composting
Primary treatment	**FS characteristics**: o Partly stabilised septage (or mixture septage/public toilet sludge with ≤ 30 % share of public toilet sludge) **Drying bed**: o Unplanted drying bed: 15 days drying cycle o 25-30 cm sludge layer on beds o 100-200 kg TS/m^{2}y **Sand characteristics** o Sand particles do not crumble o Sand easily available locally o Sand thoroughly washed prior to application unto the gravel base **Protection of filter layers** o Reduce pressure flow via: o Splitting chamber, inlet channel, and splash plates **Biosolids** o 0.1m3 /m3 fresh FS o Hygienisation necessary prior to use in agriculture as biosolids

	Percolate o 50-80 % of raw FS volume o Quality fairly comparable to tropical wastewater o Salinity too high for irrigation
Composting	**Feedstock:** dewatered FS or source separated feaces and sorted organic solid waste (SW) **Mixing ratio:** 2:1 of FS to SW by volume. Minimum size $3m^3$ **Composting Temperature**: uniform windrow temperature between 50^oC and 65^oC **Composting period**: 3 months **Turning Frequency**: Every 10 days **Moisture**: 50-60% (active phase); 40-50% (maturation phase) **C/N ratio**: 20-30 (initial material) **Co-compost quality** should meet established standards. For Helminth eggs, concentration should not be more than1/g TS

Characteristics of FS and FS Based Compost

The chemical and biological characteristics of FS are presented in Table 1

Table 1. Characteristics of FS

Parameters	Unit	FS
pH		6.21 ± 0.99
Acidity	cmol/kg	2.30 ± 1.61
Carbon ©	%	11.39 ± 7.70
Nitrogen (N)	%	2.06 ± 0.24
Potassium (K)	%	0.39 ± 0.41
Calcium (Ca)	%	0.76 ± 0.54
Magnesium (Mg)	%	3.29 ± 3.07
Phosphorus (P)	%	2.44 ± 0.09
Copper (Cu)	mg/kg	97.50 ± 6.05
Manganese (Mn)	mg/kg	195.33 ± 1.69
Zinc (Zn)	mg/kg	515.0 ± 15.04
Iron (Fe)	mg/kg	938.4 ± 25.39
Lead (Pb)	mg/kg	156.67 ± 34.0
Cadmium (Cd)	mg/kg	trace
Mercury (Hg)	mg/kg	trace

E. Coli	CFU*/g	$4.07 \times 10^8 \pm 2.04$
Total Bacteria	CFU/g	$6.10 \times 10^8 \pm 1.05$
Total Fungi	CFU/g	$4.67 \times 10^6 \pm 1.54$
Clostridium	CFU/g	$4.93 \times 10^8 \pm 1.48$
HE count	No./gTS	25–83
HE viability	No /gTS	3-5

Field Trials:

Land application of FS

Table 2. Selected soil chemical properties of the on-farm sites after Faecal sludge application, Tamale, Ghana

		----%------			--------------------------------- mg/kg--------------------------------------								
Farms	pH	OC	TN	CEC	Av.P	K	Ca	Mg	Na	Al	Cu	Zn	Mn
					---------------- Sheshigu-----------------								
A	4.8	0.76	0.05	4.35	11.58	62.22	120.4	59.82	40.99	1.52	3.85	3.19	71.86
B	4.8	0.62	0.04	3.22	12.28	53.28	84.99	57.28	16.36	1.77	3.55	3.21	19.96
C	4.8	0.80	0.04	3.05	8.09	26.47	83.56	43.74	15.01	1.22	3.09	2.58	23.42
Control	4.9	0.72	0.03	3.07	7.61	26.29	107.80	43.40	21.87	1.54	2.75	2.77	29.13
					--------------Tuu-Tengli-----------------								
A	4.5	0.57	0.05	3.62	14.00	39.43	76.44	56.86	20.21	1.59	2.98	3.00	18.69
B	4.4	0.95	1.05	4.32	20.69	33.17	163.80	70.77	19.48	1.88	3.72	3.29	25.94
C	4.4	0.97	1.86	4.12	19.52	29.65	127.74	58.43	24.16	1.72	3.33	3.04	33.82
Control	4.6	0.57	0.05	3.99	19.24	23.57	88.53	42.85	30.69	1.52	2.97	2.97	25.16
					---------------- Zujung -------------------								
A	5.2	0.62	0.05	3.72	13.88	57.98	96.45	76.16	24.44	1.29	3.38	3.44	17.95
B	4.6	1.48	0.38	3.70	16.66	44.49	69.40	55.76	20.69	1.40	3.28	3.09	17.31
C	4.8	0.35	0.03	2.70	6.15	24.05	49.30	28.25	26.15	1.32	2.69	2.69	26.87
Control													

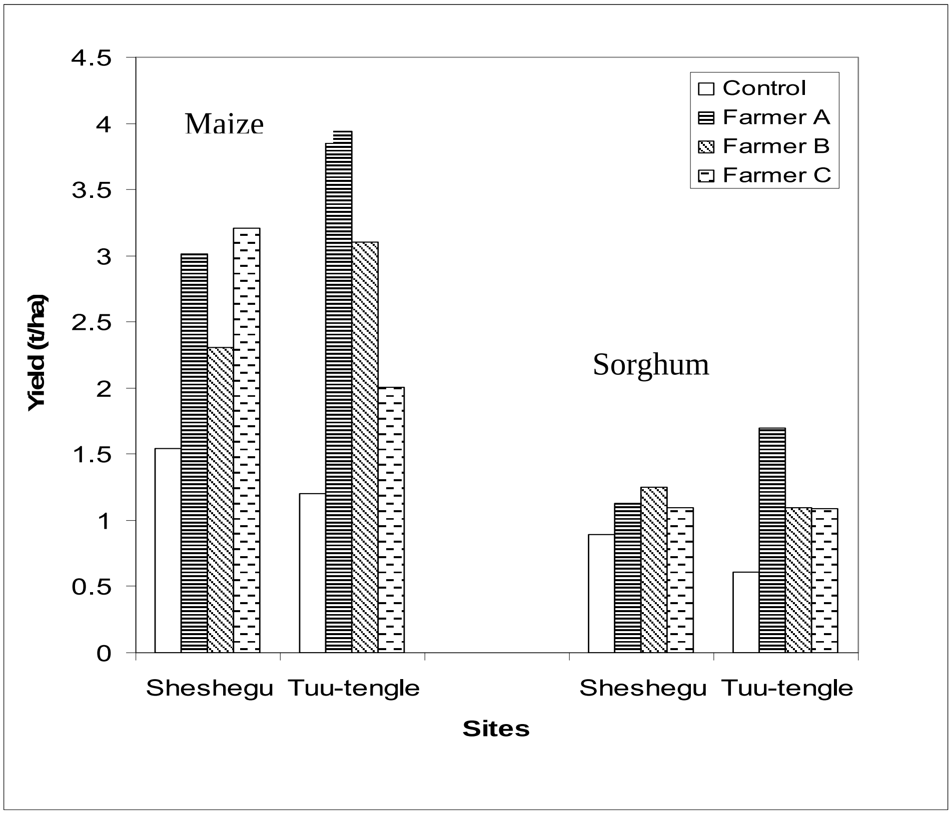

Fig. 1. Yield of Maize and Sorghum in farms with and without FS application at two sites in Tamale. (A, B, and C = farms with FS applied; Control = no FS). Two - threefold higher yields of crops grown on FS-treated soils as compared to untreated soils.

Co-composting of FS and SW

Table 3. Effect of FS and FS based compost on the growth characteristics of Maize

Treatment	Application rate[2]	Plant height[3]	No leaves		Chlorophyll content[3]
		cm			
Soil (S) alone	NA	135.68	12		35.18
S + DFS	7.3 t ha^{-1}	223.45	16		48.68
S + FS Cocompost[1]	14 t ha^{-1}	204.10	14		46.94
S + NPK + $(NH_4)_2SO_4$	450 kg NPK + 399 kg $(NH_4)_2SO_4$	165.73	14		47.13

[1]FS Co-compost: i.e solid waste + FS
[2]Application rate was based on the recommendation of Adamtey et al. (2009)
[3]Plant height and leaf area measured at 10th week
[4]Leaf chlorophyll content was measured at 8 week

Table 4. Effect of FS and FS co-compost on the Yield of Maize (Zea mays L.)

Treatment	Application rate*	Yield (kg/ha)
Soil (S) alone	NA	3336.72
S + FS Cocompost	14 t ha^{-1}	5071.35
S + FS	7.3 t ha^{-1}	6180.48
S + NPK + $(NH_4)_2SO_4$	450 kg NPK + 399 $(NH_4)_2SO_4$	5630.56
* Application rate was based on the recommendation of Adamtey et al. (2009)		

Table 5. Effect of FS and FS based compost on the Nutrient uptake of Maize crop (Zea mays L.) at final harvest (mg/plant in parenthesis)

Treatment	Application rate	Nutrient Uptake (kg ha^{-1})		
		N	P	K
Soil (S)	NA	20.00 (460)	2.00(48)	44.08 (1058)
S + FS	14 t ha^{-1}	44.92(1078)	3.83 (92)	75.33 (1808)
S + Cocompost	7.3 t ha^{-1}	40.37(969)	4.21 (101)	69.67(1672)
S + NPK + (NH4)2SO4	450 kg NPK + 399 $(NH_4)_2SO_4$	42.75(1.026)	4.75(114)	100.67 (2416)

Table 6 Effect of FS on the growth and Yield of Cabbage

Treatment	Application rate	No. of leaves	Leaf length (cm)	Leaf canopy(cm)	Yield t /ha
Soil (S)		9	29	55.4	19.47
S + FS	4.4 t ha^{-1} (121kg N ha^{-1})	12	29.2	60.1	39.67
S + NPK + (NH4)2SO4	450 kg NPK (73.5 Kg N/ha)	11	31.1	65.8	37.58

Table 7. Concentration of heavy metals in Cabbage grown with FS

Treatment	Mn	Cu	Zn	Fe	Pb	Cd	Hg
	mg/ plant	mg/ plant	mg/ plant	mg/ plant	mg/ plant	mg/ plant	mg/ plant
Soil (S)	8.29	1.13	13.7	66.59	Trace	Trace	Trace
S + FS	9.39	3.12	19.26	53.12	Trace	Trace	Trace
S + NPK + (NH4)2SO4	5.09	1.09	8.14	35.04	Trace	Trace	Trace

Table 8 Nutrient uptake by Cabbage grown with FS and FS based-composed (mg/plant)

Treatment	N	P	K
Soil (S)	780.76	137.08	119.20
S + FS	1470.95	446.03	275.21
S + NPK + $(NH_4)_2SO_4$	1442.56	340.48	224.00

Application recommendations

Cabbage

FS only: 4.4 t ha^{-1} ≈ 121 kg N ha-1

FS cocompost: 10 t ha^{-1} ≈ 121 kg N ha-1

Maize

FS Only: 7.3 t ha^{-1} ≈ 210 kg N ha-1

FS co-compost: 14 t ha^{-1} ≈ 210 kg N ha-1

Mode of application: Incorporation into the surface soil

General Observations

- Good demand for FS use in agriculture due to generally positive perception
- FS based compost produced bigger girth of maize cobs compared to inorganic fertiliser or soil without amendment.
- Yield from FS plots was 10% higher than that for chemical fertilizer.
- More than 50% of maize crops from FS plots tassel, form silk and matured one week earlier than crops on fertilizer treated plots.
- Fresh grains from treatment S + DFS were sweeter than those from inorganic fertilisers.

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