VeSV- Value at the end of the Sanitation Value Chain

Final Report

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Executive Summary

Bangladesh is no stranger to composting projects using both green waste and faecal sludge (FS). There have been many initiatives over the years with varying degrees of success. Similarly there have been hundreds, if not thousands of projects to improve access to latrines, latrine use and latrine management. Again there has been a great deal of success, especially in increasing the number of latrines being built. However, a key gap regarding the safe collection and processing of the waste from the pit still remains. In cases where projects have attempted addressing this, the solution has rarely been viable on a large scale. That is where this project—VeSV—is different. The aim of this project is to provide scientific evident to support the commercial viability of collecting and composting faecal sludge from single pit latrines for use in agriculture and horticulture.

The gap between a good idea and commercial success is bridged on this project by producing primary scientific data based on qualitative and quantitative research methods and by engaging a number of stakeholders across sectors. A rigorous research was conducted to characterize raw faecal sludge material from single pit latrines in rural Bangladesh, as the starting point to develop value across the sanitation chain from processing FS material, through adding value by recovering nutrient and finally by assessing the potential commercialization of the final product in the fertilizer market. Crucially academics, NGOs, business groups and existing fertiliser, composting and latrine management companies were involved as part of our Reference Group, which helped to develop practical engineering solutions in harmony with the right and relevant context in rural Bangladesh.

Our research outcomes include the development of safe methodologies for pit emptying; the assessment of people's intentions to change current operation and maintenance practices of pit latrines at household level and their willingness to participate in commercially viable and sustainable methods for FS management; the assessment of optimised engineering process for FS stabilisation and the production of a safe, high quality fertilizer that is desirable to farmers; and the identification of potential hurdles that may obstruct the widespread adoption of business models for FS fertiliser.

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Introduction

The aim of this project was to identify feasible options to transform current approaches for faecal sludge (FS) management in rural Bangladesh, particularly in places where single pit latrines have been implemented. Our approach considers the need for reducing public health risks linked to handling biologically hazardous waste (i.e., faecal sludge) and the potential to recover valuable resources (i.e., nitrogen, phosphorus, potassium, carbon, etc.). The vision for the project from the outset was for the effective long-term management of faecal sludge in the estimated 30 million toilets, which will soon serve Bangladesh's largely rural population. The key to success is in smartly inserting reliable and efficient technical processes for pathogen inactivation, delivering consistent physicochemical characteristics in the final product (i.e., nutrient rich compost), together with policy interventions and a robust financial framework, which will help develop not only a sustainable market for the products resulting from the proposed treatment techniques, but also an affordable approach for the very important operational and maintenance activities (i.e., pit emptying, FS transport, treatment, etc.)

Our multi-disciplinary research team used a range of approaches and methodologies including the use of formative market research techniques and primary data analysis to describe the market of households, who want to have their pits safely managed, and that of potential users of processed wastes; together with laboratory and field based trials covering the safety of pit emptying, the drying and co-composting of faecal sludge and product testing. The project aimed to cover the whole process chain, from the source to the market, as shown in Figure 1 below.

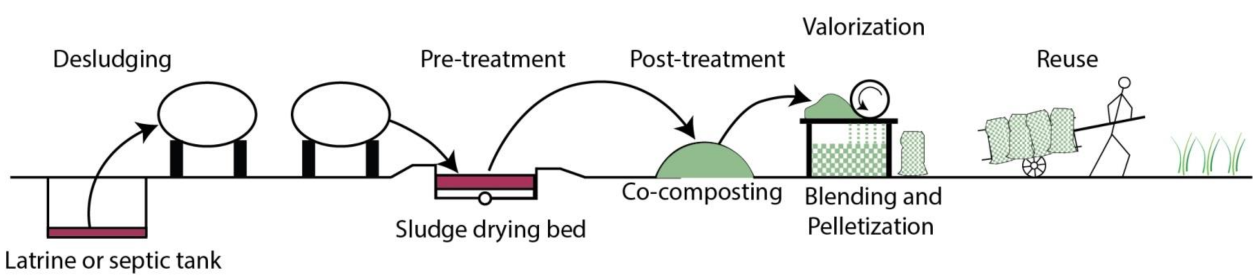


Figure 1 Faecal sludge flow from latrine to agricultural end use

Section 1 - Desludging single pit latrines and faecal sludge handling: technical and economic opportunities and constraints in pit emptying and sludge transport

1.1 Pumps and personal protective equipment (PPE)

The purpose of this analysis was to identify the types of pumps that could be viable in rural areas to assist sweepers to empty pits. Current practices of pit emptying involve sweepers using buckets, shovels, ropes and in some cases, their bare hands, a process that is fraught with well-known health and environmental risks. Sweepers often do not use gloves or protective clothing, and come into contact with faecal sludge. When the pit is emptied, the contents are usually drained into shallow, one-foot troughs dug in the vicinity of the households. The sludge can also be drained into water bodies.

Completely mechanical processes of emptying using vacuum trucks (i.e., so called Vacutugs) may work in urban areas. However they are unlikely to gain prominence in use in rural Bangladesh, since villages have narrow access roads. In these conditions, the use of a pump may at least help reduce contact of sweepers to faecal sludge by partly mechanising the emptying process, and reduce the time for pit emptying and interruption to the service, even though the problem of disposal of sludge is not solved.

Based on a literature review, and consultation with experts, four pumps were selected for testing in rural conditions— i.e., gulper, electric, diesel and diaphragm pumps were tested (see Figure 2). Our study sites for collecting socioeconomic data were purposively selected based on the number of BRAC-financed pits per square kilometer[1]. The four sub-districts or upazilas selected for the collection of socioeconomic data were Bhaluka (Mymensingh), Fultola (Khulna), Chhagolnaiya (Feni), and Senbagh (Noakhali). We selected Bhaluka and Fultola to test pumps for pit emptying, as these upazilas are larger in area and population.

We hired seven local people already familiar with current operational practices for pit emptying (i.e, four sweepers in Bhaluka and three sweepers in Fultola), who allowed us to learn about existing practices. We also hired three sweepers from WSUP (Water & Sanitation for the Urban Poor) in Dhaka to demonstrate the use of the selected pumps to local sweepers in rural areas and to test the selected pumps by using them to empty the pits of rural households, who had volunteered to take part in this study. In addition to testing and comparing the equipment for pit emptying, we supplied sweepers with personal protective equipment (PPE) to test the feasibility of reducing contact with (and health risks from) faecal sludge during manual operations. Photographs in Figure 2 show the four pump types used on this study.

[1] We focused on BRAC financed pits, so that we could get a list of households to enable us to randomly select the sample of respondent households, in order to reduce selection bias

(a) Gulper pump

(b) Electric pump

(c) Diesel pump

(e) Diaphragm pump

Figure 2 Different types of pumps tested for pit emptying practices.

Table 1 shows some of the key characteristics of the pumps used in this study. The results from the testing of the different pumps suggest that the use of pumps in rural conditions is not entirely straightforward. The gulper has low capital and operational costs and is effective for cleaning pits containing sludge with a wide range of moisture content (i.e., from liquid to dry FS); however its bulky size and weight is likely to damage the superstructure and slab of the latrine. It also requires special transportation, and its operation is complicated in comparison with other tested options.

The diaphragm pump is light in weight and easy to use. It has low energy and maintenance costs, requires few workers and it is unlikely to cause damage to the latrine. The diaphragm pump was able to empty a pit latrine 30% faster than manual emptying. However, it has high capital costs, with a pump costing BDT 30,000.

The diesel pump significantly reduces the emptying time in comparison with the other tested options. However, it has high capital and operational costs, and is heavy to transport and use.

The electric pump has low capital costs, is light weight and easy to use. However, with the erratic supply of electricity in rural areas, its use in pit emptying practice is likely to be limited.

Table 1 Comparison of different pumps to gauge the feasibility of its use in rural areas

Parameter	Gulper	Diaphragm	Diesel	Electric
Capital / Purchasing costs	Low	High	Med	Low
Energy costs (per pit)	Low	Low	High	Med
Maintenance costs (annual)	Low	Low	High	Med
Ease of use in rural areas	Difficult	Easy	Difficult	Easy
Ease of handling	Difficult	Easy	Difficult	Difficult
Labour requirement (per pit)	Medium	Low	Medium	Medium
Need for transportation (per pump)	Yes	No	Yes	No
Ideal pit depth (foot)	3-5	3-10	10-15	3-10
Pit emptying charges (BDT per pit)	500-1500	500-1500	1500-2000	1500-2000
Health and Environmental risks	High	Low	Med	Med
Probability of damaging latrine	High	Low	Med	Low
Preparation time (minutes)	15-20	10-15	20-30	15-20
Pit emptying time (minutes)	20-30	15-20	5-10	5-10

Given these constraints, the diaphragm pump emerged as the most feasible option for reducing contact with sludge while emptying rural pits. Debriefing conversations with sweepers in Bhaluka and Fultola revealed that they were unlikely to purchase the pump of their own accord due to its high capital costs. Therefore, the government/municipality would need to provide a subsidy/incentives to facilitate the purchase of these pumps. However, this is a one-time subsidy, and not a recurring one. The cost of the pump will likely be recovered over the lifetime of the pump.

The personal protective equipment provided to the sweepers during manual cleaning reduced exposure to faecal sludge, as was evidenced by cleaner hands and feet after the pits had been emptied. Sweepers confirmed that the protective equipment has indeed reduced contact with faecal sludge. However the protective equipment was reported to be uncomfortable to wear due to the heat and humidity. The sweepers did not seem keen to wear the protective clothing beyond this field experiment. Given these constraints, the use of protective equipment when cleaning pits is unlikely to be popular among sweepers.

1.2 Are current pit emptying and sludge disposal practices of single pit latrine owners amenable for creating viable business opportunities for sludge collection and transportation?

The purpose of this analysis was to understand what households do when pits are full, and how the sludge is disposed. This analysis would contribute to identifying potential scenarios for creating business opportunities for FS collection and transportation. To this end, from the purposively selected upazilas, 1,440 households with pit latrines were randomly selected for a household survey. Of the 1,440 households surveyed, only responses from 1,390 households were used to understand the current practices pertaining to latrine use and management, and sludge disposal. The households were classified into three types for this purpose:

- Type 1 - households that are currently using the same pit latrine that was constructed for their household through the BRAC WASH I project. These households had either emptied their pit, or were yet to empty their pit. For these households, the pit emptying strategy that had been used or was planned to be undertaken was explored. There were 1,307 of such households in the dataset.
- Type 2 – households that are currently using a pit latrine that is different from the one that was constructed for them through the BRAC WASH I project. These are households that had built a new pit, rather than emptying the old one. For this group, the reasons for building a new pit, the current state of the old pit, and their planned actions when the new pit also filled up were explored. There were 83 such households in the dataset.
- Type 3 - households who are not currently using pit latrines. These households neither emptied the BRAC-built pit, nor did they build a new one. For these households, the current state of the pit, and the households' current access to sanitation were explored. There were only 2 households that fit this description and therefore, we omitted reporting on these two households.

The vast majority of households (1,307 or 94% of the total sample) were still using the pit financed by BRAC. The average age of a toilet was four years, with approximately five users per toilet. Households also shared their toilets with non-household members. Thus it is evident that the installation of pit latrines has opened access to toilets beyond the original recipients of the latrines in the BRAC programme. Of these households, 394 (30%) had emptied their pits at least once and 913 had yet to empty their pits[2].

The most popular method of emptying was for the household to hire a sweeper, and pay some money to get the job done, with 90% of households that had emptied their pits adopting this strategy. The average amount paid by a household to a sweeper was BDT 300, ranging from a low of BDT 100 to a high of BDT 1,200.

The most popular method of disposing of the waste from the pit was to dig a shallow trough, around a foot deep, near the latrine, and drain the contents into the trough, with 80% of households who had emptied their pits reporting this practice. The trough is usually left open for a few days until the liquid contents seep into the topsoil and then, it is finally covered. The second most popular method of disposal is dumping the contents of the pit into a water body, with 9% of households who had emptied their pit reporting this practice.

As a share of households that had emptied their pits at least one, 88% of households reported that they would never use the decomposed contents of the pit for any purpose, 8% of households reported that they would consider using the decomposed contents on their farm, and around 4% said that they would consider using the decomposed contents as fuel. As a share of households that had dug a shallow

[2] Households that emptied their pits had more latrine users than in households that were yet to empty their pits.

trough, 85% reported their opposition for using decomposed sludge whilst 10% and 5% of households were willing to use decompose sludge either as a fertiliser or as a fuel, respectively. Thus it is evident from this survey that most households reported not using the decomposed waste for any purpose.

Of the households that had yet to empty their pits, 5% indicated that they would build a new latrine when the pit of the current one filled up. 91% of households reported that they would hire a sweeper to empty the pit, while 4% reported that they would empty the pit themselves. These responses are similar to those of households that had emptied their pits.

83 households (6%) were using a different latrine to the one provided by BRAC. The average age of this new pit was 2.2 years, with around five users per latrine. The number of users for this subgroup is no greater than those in the case where the household was still using the original pit. The most common reason for building a new pit latrine was because the old pit has broken or leaked, with 54% of households reporting this reason[3]. Households mostly financed the building of the new pit themselves. The actual and intended pit emptying and sludge disposal practices of households who have emptied their new pit or were yet to empty their pit respectively, were identical to the ones reported above. This is unsurprising, given that households built new pits mostly when the old pit started leaking

This analysis suggests that there is a large market for pit emptying and sludge transportation services. Households empty pits when they are full, and the sludge is disposed of in ways that create environmental and health risks. Thus there are avenues to create businesses for collection and transportation of fecal sludge.

1.3 Are latrines owners willing-to-pay for sludge transportation services?

The purpose of this analysis was to understand whether the producers of latrine waste are amenable to contributing to the cost of transporting sludge. Unless the pit emptying process is completely mechanised using a vacuum truck or bowser, FS emptying and transportation remain separate parts of the process. Transporting sludge is expensive; however households may be willing to bear a portion of the transportation cost. This is because current practices of sludge disposal involve households emptying the contents of their pit in the vicinity of their homes, which pollutes both land and water bodies. Understanding this willingness to contribute is important, because it would help reduce the burden of subsidy borne by the government.

The willingness-to-pay for sludge transportation was elicited using a double-bound, contingent-valuation bid method. Households were provided with an explanation for the advantages of transporting sludge away from households and were asked to think about paying for such a service. The base bids for sludge transportation were constructed to be BDT 400, BDT 600, BDT 700 and BDT 800, based on literature reviews and consultation with experts. Bids were randomly allocated among households within a village. If the household accepted its allocated base bid, it was asked if it was willing to pay the next raised bid. If a household declined its allocated base bid, it was asked if it was willing to pay the next lower bid. We

[3] Only 5 households, (6% of those that had built new latrines, and less that 1% of all households) had built a new pit latrine after the BRAC provided one had filled up.

asked households their willingness-to-pay for sludge transportation when manual methods of pit emptying are used. These questions were administered to 1,440 pit latrine owners across 4 upazilas, and the data from 1,390 households was used in this section.

Table 2 shows the share of households willing to pay each of the bids. Our results suggest that households are willing-to-pay a modest fees to transport wastes away from their house's premises. 51% of the households were willing to pay less than BDT 400 towards transportation, with 27% willing to pay between BDT 400-600.

Table 2 Share of households willing to pay each bid for sludge transportation services

Fee (BDT)	< 400	400-600	600-700	700-800	> 800
%	51	27	13	5	4

The respondent's perceptions about alternative pit emptying practices were also elicited by asking respondents to count physical objects. Respondents were given ten marbles, and were asked to express the degree of their response to a statement by putting marbles in a cup. Respondents were asked their perceptions of the cleanliness, safety and convenience of manual and mechanical pit-emptying.

Table 3 Perceptions regarding pit emptying

Question	Score out of 10		
	Mean	Min	Max
How clean is manual emptying perceived?	7.6	3	10
How safe is manual emptying perceived?	6.4	0	10
How convenient is manual emptying perceived?	6.3	0	10
How clean is mechanical emptying perceived?	9.4	0	10
How safe is mechanical emptying perceived?	9.4	0	10
How convenient is mechanical emptying perceived?	6.5	0	10
	Positive response, %		
Does manual emptying take longer than mechanical?	96		
Do you think manual emptying is more expensive than mechanical?	12		
Is manual emptying more suitable than mechanical?	23		
Is mechanical emptying is more suitable than mechanical?	77		

As seen in Table 3, manual emptying was perceived to be moderately clean and safe, while mechanical emptying was perceived as safe and clean. 96% of households felt that manual emptying and transporting took longer time than mechanical emptying and transporting. Only 12% thought manual emptying was more expensive than mechanical. 77% of households thought that mechanical emptying and transporting would be more suitable than manual methods. However, both mechanical and manual methods were ranked moderately convenient. This last point suggests households' perceptions of onsite sanitation in general, irrespective of emptying and transporting methods. Thus, a steep charge for transportation is unlikely to be acceptable; a modest charge may work and it would help reduce the burden of a subsidy. The fact that households are willing to contribute towards the cost of transporting the faecal sludge has implications for the types of business models that can be considered for application to rural Bangladesh, as well as the for the types of subsidies that would be borne by the government. This is discussed in more detail in section 8 of this report.

Section 2 – Pre-treatment options for faecal sludge including sand bed drying and bio-drying

Moisture content in FS samples collected from single pit latrines varies depending on the age of the sludge and weather conditions (i.e., dry and rainy seasons). During dry seasons, the typical moisture content is about 80%, while during rainy seasons there is a great chance for FS to be diluted inside the pit due to a higher water table, and moisture content may increase up to 90%. Bearing that in mind, there is a need for developing pre-treatment units, which should be able to adjust moisture content to levels compatible with composting processes (i.e., moisture content in composting piles varies between 40 and 60%). A comprehensive FS quality survey was conducted to determine typical physical, chemical and microbiological characteristics in samples collected from single pit latrines (i.e., 32 FS samples in total). In addition, two drying options were tested including sand bed drying and bio-drying, in order to identify optimum conditions for FS dewatering as a pre-treatment prior to co-composting.

2.1 Faecal sludge characteristics

In order to identify the main characteristics of raw FS, representative samples were collected from single pit latrines in the following sub-districts, districts: Mirzapur, Gazipur (samples collected from 4 pit latrines in Feb 2014 and from another 4 pits in Jul 2014); Phultola, Khulna (6 pits, Feb 2014); Senbagh, Noakhali (6 pits, Aug 2014); Bhaluka, Mymensingh (6 pits, Jun 2014); and Chagolnaiya, Feni (6 pits, Jun 2014).

During field work, it was found that the actual construction of single pit latrines were slightly different, particularly with regard to the depth of the pit, which varied from 3 to 10 ft (0.91 – 3.05m); pit diameter was standard at 2.75 ft (0.83m). The majority of the pits sampled in this study were for the use of family members (3 – 9 people), but in some cases it was found that pit latrines were open to other nearby users as well (i.e., Khulna, Noakhali). High water table has a strong influence on the operation of the pits, particularly in Khulna where the pits were found full due to that factor. Pit filling rates ranged from 30-50 litres per person per year.

Table 4 Physical and chemical characteristics of FS samples from single pit latrines

District	Moisture (wt%)	pH	Conductivity (mmho/cm)	TVS (wt%)	TOC (wt%)	TN (wt%)	C/N	PO_4-P (wt%)
Gazipur	83.68	7.35	3.34	68.56	36.38	3.70	9.52	2.10
Noakhali	88.10	7.08	5.02	68.65	37.23	3.91	10.09	2.13
Khulna	91.34	7.94	4.76	74.37	39.32	3.66	10.91	2.25
Mymengsingh	90.54	7.73	3.51	68.09	54.34	3.15	12.83	1.67
Feni	90.54	7.81	4.58	77.88	41.19	3.98	11.12	2.49
Mean	88.84	7.58	4.24	71.51	41.69	3.68	10.89	2.13

TVS = Total volatile solids; TOC = Total organic carbon; TN = Total nitrogen; C/N = carbon to nitrogen ratio

The resulting mean physical, chemical and microbiological characteristics of FS per district are reported in tables 4 and 5. For the stabilisation of FS via composting processes, it is required that pre-treatments units developed in this study should be able to reduce moisture content from 90% to 50%. On average, the carbon to nitrogen ratio found in FS samples (10:1) presents the potential for co-composting FS with other organic wastes locally available, in order to improve the nutrient content and value as fertiliser.

(a) FS sampler

(b) Pit survey

(c) FS sample collection

(d) FS storage for transportation to pilot facility

Figure 3 Pit latrine survey and FS sample collection

Microbiological characteristics reported in Table 5 confirmed the actual challenge for the stabilisation of FS material, particularly when strategies for reuse/recycling of resources include handling, transportation and recovery of nutrients into agriculture. In particular, the prevalence of helminth eggs in FS material was targeted as the main concern regarding the quality of any final product with the potential to compete in the fertiliser market. One particular FS sample from the Noakhali district had the highest number of helminth eggs (511 eggs/g), which made a strong influence on reported mean values; also, it is important to highlight that 12 out of 32 FS samples did not contain helminth eggs. These values fall within the range quoted in previous research (Strauss et al., 1997).

Table 5 Microbiological characteristics of FS samples from single pit latrines

District	Total coliforms, cfu/g	*E. coli*, cfu/g	Helminth eggs	
			egg/g	Group
Gazipur	5.2E+06	3.5E+06	20	*Ascaris lumbricoides*
Noakhali	7.9E+04	2.3E+04	119	*Ascaris lumbricoides, Trichuris trichiura, Enterobius vermicularis, Hymenolepis nana*
Khulna	1.4E+05	9.8E+04	32	*Ascaris lumbricoides, Hymenolepis nana,*
Mymengsingh	1.9E+05	9.0E+04	13	*Enterobius vermicularis, Taenia spp*
Feni	1.8E+06	7.6E+05	23	*Enterobius vermicularis, Ascaris lumbricoides,*
Mean	1.5E+06	9.0E+05	41	

2.2 Sand bed drying

Pre-treatment units for FS dewatering were develop at pilot scale in an existing composting facility at MATI Organics (Purbapara, Gazipur, Bangladesh), which is located approximately 50 km away from Dhaka city centre (see Figure 4). At the project site, two identical sand drying beds with mix media (i.e., dry rice straw, sand and gravel) were constructed with a surface area of 12 m^2 and designed to operate with a maximum solid loading rate of 450 kg m^{-2} yr^{-1}, each (see Figure 5). The primary purpose of these drying beds is to dewater and dry FS collected from single pit latrines before co-composting.

2.2.1 Sand bed drying during the dry season

FS dewatering and drying was initially carried out under direct sunlight during the dry season February-March, 2014 (i.e., ~5 hours of sun per day). Results reported in Figure 6 shown that the designed drying beds are able to reduce initial moisture content from 85% to 50% within a 15-day drying cycle. An extended drying cycle of 30 days in total provided further moisture reduction, resulting in a drier FS with only 36% moisture (see Figure 6 (a)). Along with moisture removal, drying and dewatering pre-treatment processes contribute to pathogen inactivation in dry FS with 40% heminth egg inactivation, and 90% *E. Coli* and 70% total coliform removals in 15 days (94% removal for *E. Coli* and Total Coliforms in 30 days). It was noted that the percolate from each drying bed does not contain helminth eggs, which confirms the excellent performance and efficiency of the filtration system. Unlike septage, FS from a matured single pit (i.e., 2 years pit) contains lesser amount of water and hence, its percolate from a sand drying bed is not as demanding in terms of post-treatment requirements.

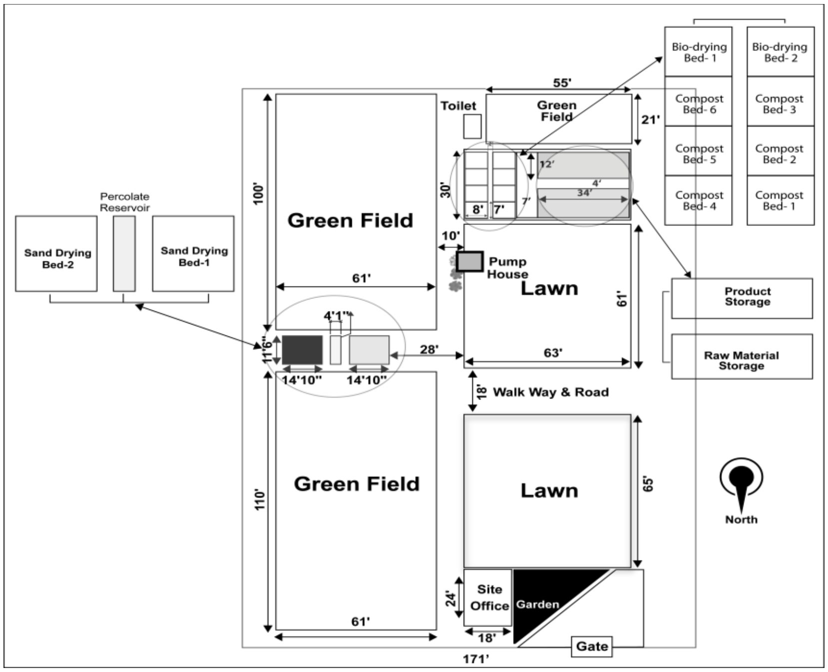


Figure 4 Plot plan of pilot-scale dewatering and composting units at Purbapara, Gazipur.

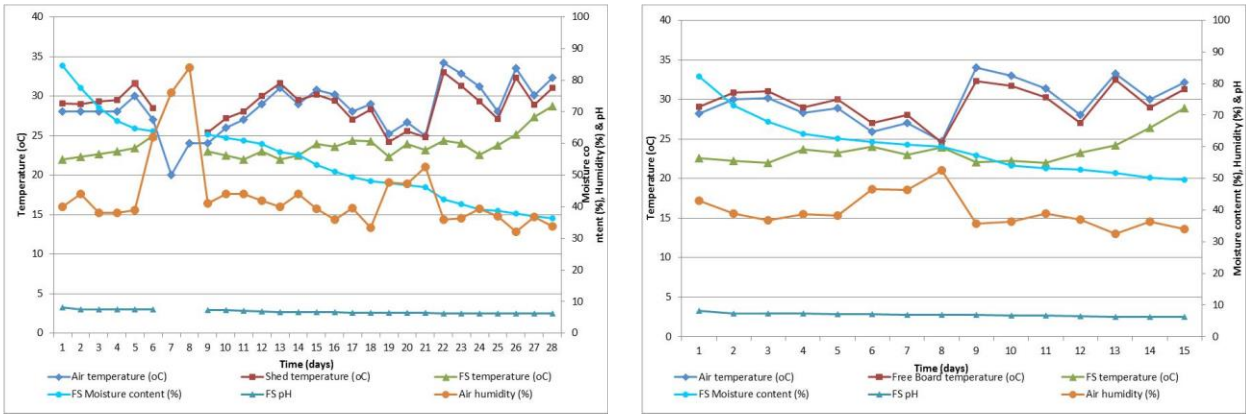
(a) Drying beds – masonry work

(b) Drying beds – plastering work

(c) Drying bed 1 with plastic cover

(d) Drying bed 2 with rigid cover

Figure 5 Sand drying beds at Purbapara, Gazipur

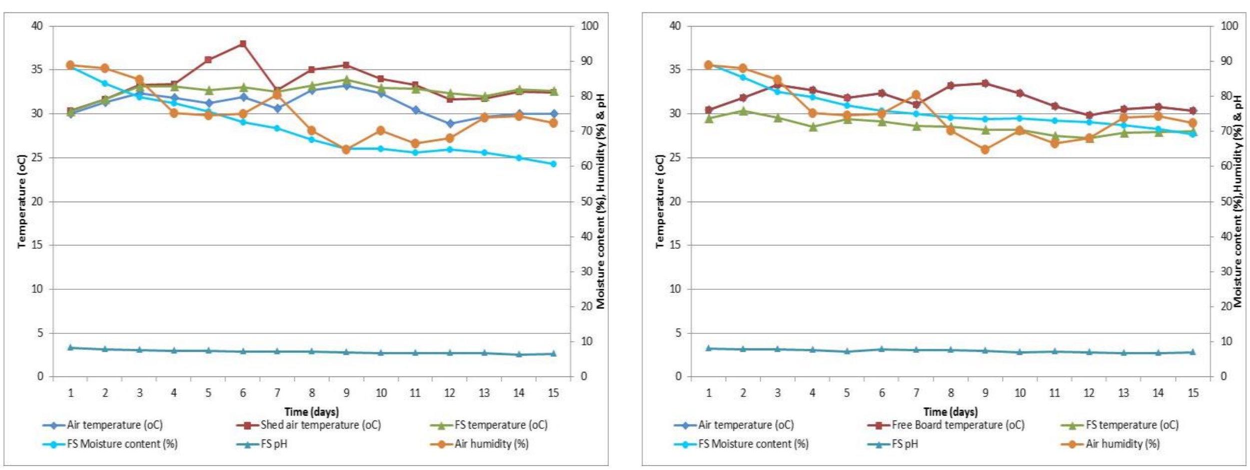


(a) Drying bed 1 – Dry season (b) Drying bed 2 – Dry Season

Figure 6 Changes in FS characteristics during dewatering using drying beds during the dry season

2.2.2 Sand bed drying during the rainy season

FS dewatering and drying was also conducted during the rainy season in July 2014. Results reported in Figure 7 show that within a 15-day drying cycle, it was possible to reduce FS moisture from 88% to 60% and 69% in drying beds 1 and 2, respectively. Lower air temperature, higher air humidity and shorter sunshine hours during the day made a strong influence on the poorer performance of drying beds, when compared with results obtained during the dry season. In terms of pathogen inactivation, drying beds were able to remove 99% of total coliforms and *E. coli* in 15 days, and achieve 30-50% helminth egg inactivation, thanks to higher FS temperature during the drying cycle. It was also noted that the percolate from each drying bed did not contain helminth eggs.



(c) Drying bed 1 – Rainy season (d) Drying bed 2 – Rainy season

Figure 7 Changes in FS characteristics during dewatering using drying beds during the rainy season

Sand beds represent an effective pre-treatment alternative for FS dewatering and drying and make an important contribution to pathogen inactivation. Special attention is needed to consider its restrictions during rainy seasons and hence, full-scale units need to manage appropriate solid loading rates to cope with longer drying cycles. Nevertheless, it does not seem to make a great impact on full-scale operations, as a good FS management programme would need to encourage pit emptying practices during dry seasons, which will ultimate reduce detrimental impacts caused by a high water table during rainy seasons.

2.3 Bio-drying

Biodrying is a process that uses the heat energy generated by microorganisms utilising biodegradable material to reduce the moisture content of that material under anoxic conditions. It was envisaged that biodrying would enhance the drying process particularly during rainy seasons with added benefits such as faster FS stabilisation during composting. Pilot-scale bio-drying beds were constructed at the experimental facility in Purbapara, Gazipur (see Figure 8). Prior to the biodrying process the faecal sludge was partially dewatered using sand beds to a moisture content of around 70%

(a) Loading bio-drying units with pre-treated FS

(b) Adding sawdust to adjust C:N ratio

(c) Sample collection for analysis

(d) Final product after bio-drying

Figure 8 Bio-drying beds at Purbapara, Gazipur

Raw FS samples were collected from various sources for pre-treatment (i.e., dewatering for 3 days) in sand drying beds. Bio-drying beds were loaded with dewatered FS (71% moisture) and mixed with sawdust with a ratio 65:35 FS to sawdust. Key parameters were used to monitor daily changes in the FS-sawdust mix during 18 days (April-May, 2014), including moisture content and temperature at 9 different points. Air temperature was also recorded, as well as physical, chemical and biological characteristics of FS before and after bio-drying (see Figure 9).

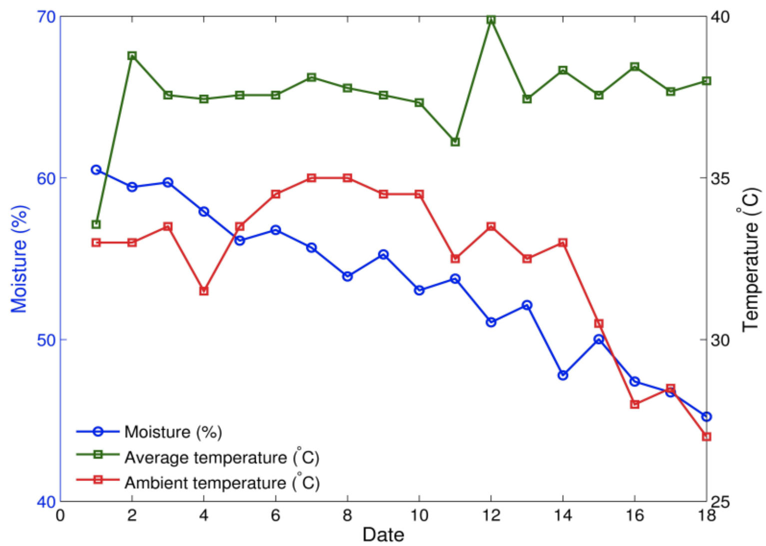


Figure 9 Average moisture and temperature in FS during bio-drying from 9 sampling points

As expected, temperature increased considerably during bio-drying with single readings varying between 30 and 47°C. Moisture removal did not improve when compared with results obtained from sand drying beds; and the removal achieved was only 25% with a longer drying cycle. Total coliforms and *E. coli* removals were both 99% and with regard to helminth eggs inactivation, it was only 16%. Also, higher temperatures favoured additional nitrogen losses due to ammonia volatilization (i.e., remaining total nitrogen was 1.84%, while total nitrogen from sand beds was 2.63% after 15 days and 2.45% after 30 days during the dry season. Total nitrogen figures for sand beds during rainy season experiments were 2.57% on average.

The two drying processes that were compared were dewatering using sand beds alone and a shorter dewatering cycle together with a biodrying process. The results showed that the second option of dewatering followed by biodrying did not significantly improve the drying process and brought additional complications regarding nitrogen losses through ammonia volatilization during biodrying. For this reason it is recommended that sand beds should be used to reduce the moisture content of the faecal sludge prior to co-composting.

A comparison was made between two sand bed designs and the results showed that drying bed 1 (clear plastic cover) outperformed drying bed 2 (rigid cover) in that it reduced the length of the drying cycle particularly during the rainy season. In addition the pathogen reduction was significantly better in drying bed 1 than drying bed 2.

Section 3 - Post Treatment: Co-composting of dried faecal sludge

3.1 Characterisation of bulking agents and dried faecal sludge

The primary decision on bulking agents was based on local availability. Different types of windrows were prepared, varying the relative proportions of bulking agents and faecal sludge

Rice crop residue and cow dung constitute a major portion of traditional biomass in rural areas of Bangladesh and sawdust is available both in urban and rural areas. A large amount of organic solid waste is generated every day in approximately 522 cities in Bangladesh. Therefore, these raw materials were selected as suitable co-composting materials for faecal sludge. Tables 6 and 7 show the physical, chemical and microbial characteristics of the various bulking agents used in the co-composting experiments.

It can be seen that the conductivity of the organic market waste was in excess of 3mmho cm^{-1}; therefore it was important to ensure that when using organic market waste, the fraction used was not so high that it would detrimentally impact the conductivity of the windrow material. When using cow dung and organic market waste, it was also necessary to add rice husk in order to maintain a C:N ratio between 28:1 and 31:1.

Table 6 Physical; and chemical characteristics of the bulking agents use during the co-composting experiments

Bulking agent	Moisture content (wt %)	pH	Conductivity (mmho/cm)	Total Nitrogen (wt %)	Total Volatile Solids (wt %)	Total Organic Carbon (wt %)	PO_4-P (wt %)
Cow dung	83.30 ± 1.90	7.67 ± 0.15	0.78 ± 0.06	1.65 ± 0.14	64.99 ± 6.92	34.34 ± 4.92	0.60 ± 0.08
	86.98 ± 1.11	7.73 ± 0.22	0.77 ± 0.11	1.71 ± 0.10	58.49 ± 4.80	30.91 ± 2.53	0.55 ± 0.07
Rice straw	13.14 ± 1.07	7.79 ± 0.28	2.54 ± 0.89	0.30 ± 0.09	71.87 ± 1.56	37.90 ± 0.62	0.12 ± 0.04
Organic market waste	56.08 ± 1.52	7.84 ± 0.08	3.09 ± 0.56	1.43 ± 0.93	62.72 ± 5.34	33.27 ± 2.91	0.68 ± 0.04
	43.83 ± 1.82	7.56 ± 0.10	3.16 ± 0.74	1.26 ± 0.11	42.23 ± 1.49	22.38 ± 0.78	0.48 ± 0.06
Sawdust	13.71 ± 0.74	6.57 ± 0.22	0.39 ± 0.10	0.11 ± 0.01	95.85 ± 3.98	50.81 ± 2.21	0.12 ± 0.04
Rice husk	6.72 ± 0.75	6.53 ± 0.19	0.42 ± 0.04	0.38 ± 0.08	70.42 ± 3.28	37.29 ± 1.68	0.11 ± 0.03

The analysis of the organic market waste – row 1 – used in windrow 3 and row 2 – used in windrow 5
(Values shown are means from three replicates ± 1 SD)

Table 7 Microbial characteristics of the bulking agents use during the co-composting experiments (Values shown are means from three replicates)

Bulking agent	Total coliforms (cfu/g)	*E. coli* (cfu/g)	Helminth eggs (eggs/g)
Cow dung	100	100	ND
	80	35	ND
Rice straw	ND	ND	ND
Organic market waste	800	ND	ND
	300	ND	ND
Sawdust	ND	ND	ND
Rice husk	ND	ND	ND

ND = no detectable.

3.2 Windrow setup and composting process operation

The co-composting tests were also conducted in the pilot plant at Purbapara, Gazipur. The area for composting processes included a covered shed designed to accommodate 6 windrows and 2 bio-drying bays, with concrete floor, as previously shown in Figure 4.

3.2.1 Co-composting of sand-bed dried faecal sludge

Three windrows were constructed from sand bed dried faecal sludge and different bulking materials on 11th March 2014. Figure 10 shows a photograph of these three and Table 6 shows their composition. Windrows 1-3 were operated with an active composting stage of up to 12 weeks followed by a maturation stage. During the active stage the windrows were turned and water was added to control moisture content. The maturation period was approximately one month and during this period the windrows were kept undisturbed and no additional water was added.

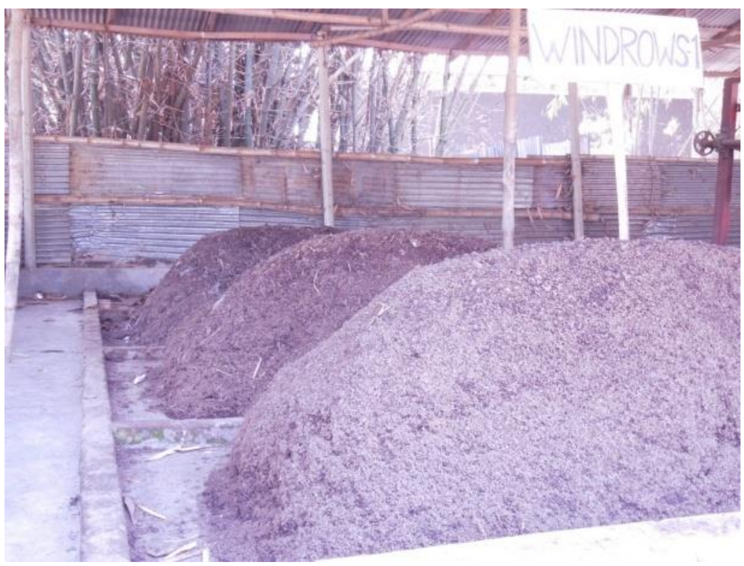


Figure 10 Three windrows produced using the sand bed dried faecal sludge

At the outset of the composting trials with windrows 1-3, it was observed that the average temperature of the windrows dropped at night compared to average daytime temperatures. This might be due to the reduced ambient temperature at night, which might initiate greater heat loss from the windrows to the surrounding environment. To offset this undue heat loss and temperature drop at night, a breathable thin layer of jute fabric was used to cover the windrows at night, and during the day the windrows were uncovered.

The use of this jute fabric cover worked very well and had the following benefits:

1. It reduced heat loss which helped the windrows to maintain their temperature during the night
2. Any evaporated water vapour from the windrows condenses onto the fabric surface and diffuses back into the windrow which reduces the water requirement for maintaining the optimum moisture content of the windrow.

Table 8 Composition and characteristics of windrows using sand bed dried faecal sludge

	Windrow 1	Windrow 2	Windrow 3
Composition (% dry weight)	25% dried FS 25% cow dung 50% rice husk	25% dried FS 25% cow dung 30% rice straw 20% rice husk	25% dried FS 30% MSW 45% rice husk
Initial dry weight (kg)	380	380	560
Initial bulk density (kg/m^3)	460	460	475
Size L x W x H (m)	1.8 x 1.2 x 0.9	1.8 x 1.2 x 0.9	2.4 x 1.2 x 0.9
Initial volume (m^3)	1.35	1.35	1.80
Initial effective surface area (m^2)	4.14	4.14	5.19
Surface area:volume ratio	3	3	3

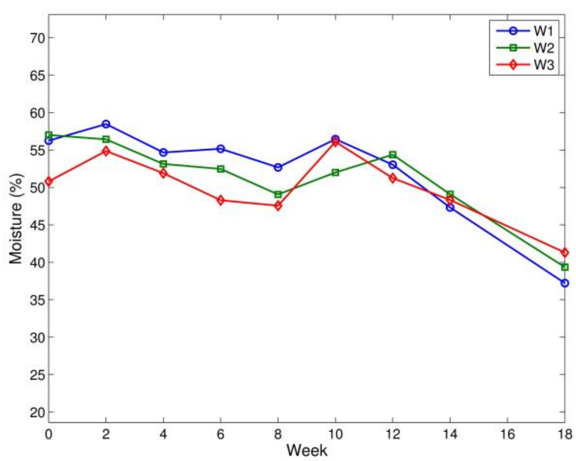


Figure 11 Moisture content of windrows 1-3

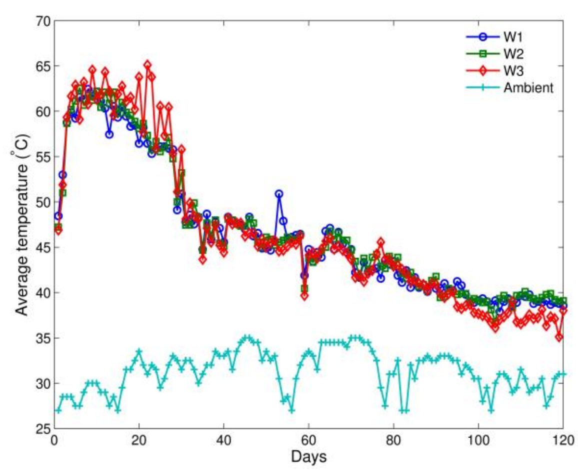


Figure 12 Average temperatures of windrows 1-3 together with the ambient temperature

Figure 12 shows the time temperature profiles for windrows 1-3 along with the ambient temperature. It can be seen that after a single day, the average temperatures of all the three windrows crossed 50^{o}C, maintaining an average temperature above 55^{o}C for 26 consecutive days. During this time period, for approximately half of the time (13 days) the windrows have an average temperature ≥ 60^{o}C. Data for the inner and outer zones of the windrows showed that the inner zone temperatures were approximately 5^{o}C higher. The time temperature profiles of all three windrows falls within the safety zone as presented by Feachem et al. (1983). This is borne out in the microbiological analysis of the material which showed that for all three windrows the material was free of *E. coli* and helminth eggs after 4-6 weeks. When the average windrow temperature was above 50°C, turning frequency was twice a week for these three windrows; when temperatures dropped below 50°C the turning frequency was reduced to once a week.

Moisture content was maintained during the active phase through the addition of fresh water in order to maintain moisture content between 50 and 60%. Figure 11 shows that the moisture content remained above 45% in all three windrows. During the maturation phase the moisture content dropped steadily down to almost 35% after 18 weeks. Due to project time restraints it was not possible to allow additional time for the moisture content to drop further to the Bangladesh standard of less than 20%

Figure 13 shows the C:N ratio for the three windrows and it can be seen that there is a steady drop in the C:N ratio over the composting period and that all three windrows have a final C:N ratio that falls within the recommended range for compost (Bangladesh and UK, PAS100, standard for C/N = 20).

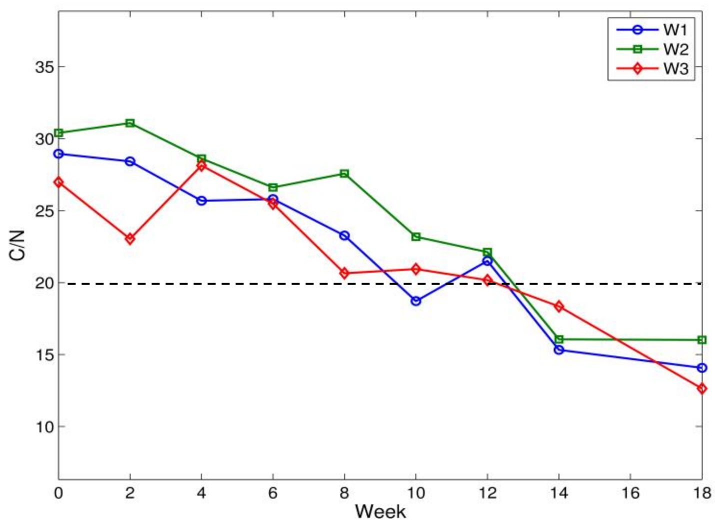


Figure 13 C:N ratio for windrows 1-3
(Dashed line indicates the Bangladesh and UK, PAS100, standard for C:N ratio)

3.2.2 Co-composting of bio-dried faecal sludge

Three windrows were constructed from bio-dried faecal sludge and different bulking materials on 6th May 2014 (Figure 14). Table 9 below shows the composition of these three windrows. Windrows 4-6 were operated in the same way as described for windrows 1-3, in terms of turning and the addition of water during the active phase. However, unlike windrows 1-3, during the maturation phase these windrows continued to be turned and water added to control the moisture content.

Figure 15 shows the time temperature profiles for windrows 4-6 and what is immediately apparent is that they show a different profile to that observed for windrows 1-3. Overall the temperature during the active period was lower at approximately 55°C. However this temperature was maintained for a longer period of almost 2 months. This time temperature profile is also well within the safety zone suggested by Feachem et al. (1983). As was observed with windrows 1-3, the inner zone temperatures were approximately 5^{o}C higher than the outer zone.

Table 9 Composition and characteristics of windrows using bio-dried faecal sludge

	Windrow 4	Windrow 5	Windrow 6
Composition (% dw)	50% dried FS 50% sawdust	25% dried FS 25% MSW 50% sawdust	25% dried FS 40% cow dung 35% sawdust
Initial dry weight (kg)	480	480	450
Initial bulk density (kg/m^3)	454	465	490
Size L x W x H (m)	2.1 x 1.2 x 0.9		
Initial volume (m^3)	1.6		
Initial effective surface area (m^2)	4.7		
Surface area:volume ratio	2.96		

Figure 14 Photograph showing windrows 4-6 on the left hand side

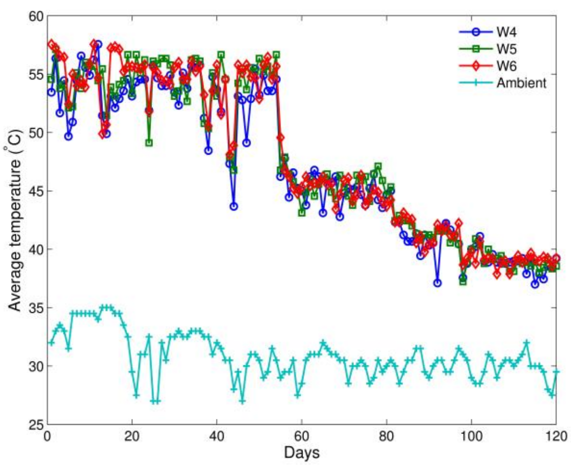


Figure 15 Average temperatures for windrows 4-6 together with the ambient temperature

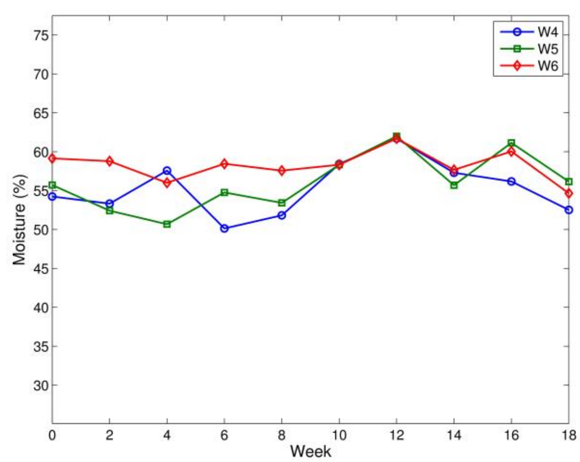


Figure 16 Moisture content for windrows 4-6

Figure 16 shows the moisture content of windrows 4-6 and it can be seen that for all three windrows the moisture content remained in excess of 50% throughout the whole 18-week period. Figure 17 shows the C:N ratio for the three windrows and it can be seen that there is a steady drop in the C:N ratio over the composting period and that all three windrows have a final C:N ratio that falls within the recommended range for compost (Bangladesh and UK, PAS100, standard for C:N ratio).

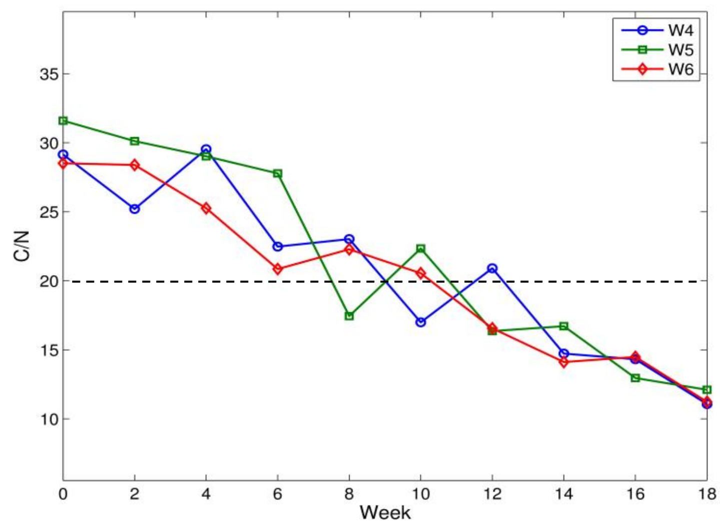


Figure 17 C:N ratio for windrows 4-6.

3.3 Changes in nutrient values during alternative co-compost processes

Figures 18 and 20 display the concentration of total nitrogen in windrows 1-3 and 4-6 respectively. Both graphs show the same behaviour with the concentrations remaining stable at around 1.2 to 1.4 % during active phase and an increase up to around 1.6 during the maturation phase. This increase in total nitrogen can be attributed to a concentration effect as a consequence of strong degradation of organic carbon compounds as has been observed in previous research (Tiquia and Tam, 2000).

Figures 19 and 21 display the concentration of nitrate nitrogen and these show that the additional turning and moisture control during the maturation phase for windrows 4-6 had an impact. A continued increase in the concentration of nitrate nitrogen (i.e., concentration effect + nitrification) was observed for windrows 4-6 compared to a drop in concentration observed for windrows 1-3 after 14 days.

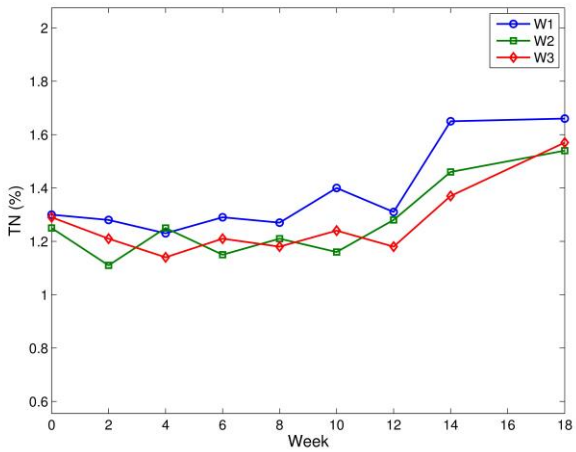


Figure 18 Total nitrogen concentrations for windows 1-3

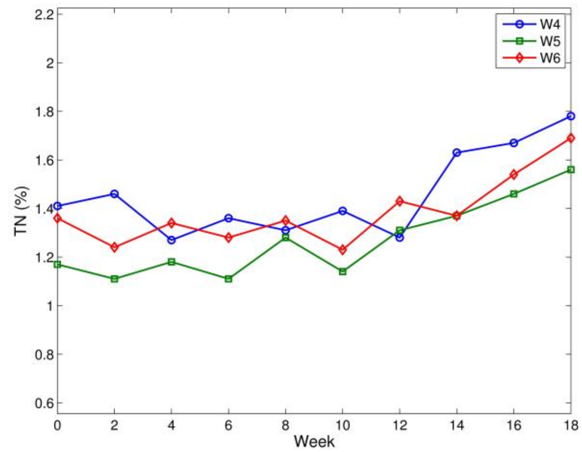


Figure 20 Total nitrogen concentrations for windrows 4-6

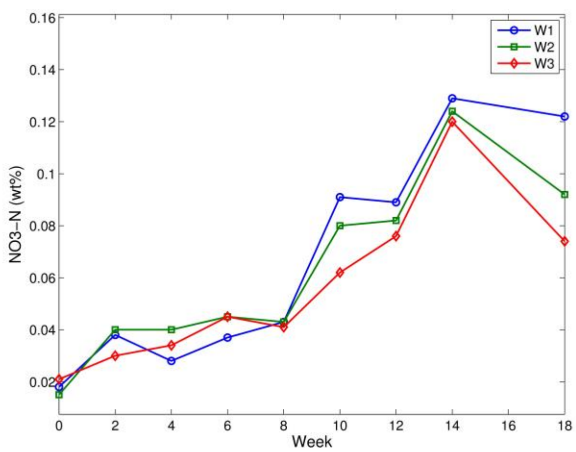


Figure 19 Nitrate nitrogen concentrations for windrows 1-3

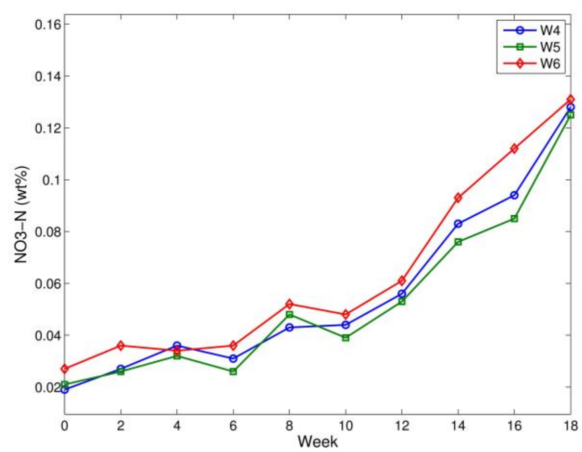


Figure 21 Nitrate nitrogen concentrations for windrows 4-6

3.4 End product evaluation: characteristics and safety in relation to WHO and Bangladesh standards

Table 10 shows the physical, chemical and microbiological composition of the final product from each of the 6 windrows together with concentrations for various parameters taken from the national standards for organic fertiliser in Bangladesh. These standards have to be met by any organic fertiliser in order to be produced commercially in Bangladesh.

It can be seen that for the majority of the parameters measured, where there is a corresponding standard in Bangladesh, the material produced meet the required standard. However for sulphur (windrows 1-6), zinc (windrows 1, 2, 4, 5 and 6), chromium (windrows 1, 3 and 5), nickel (windrows 1, 2, 3, 5 and 6) and lead (windrow 6), the end products fell outside the standards given. The data would suggest that sulphur is almost certainly coming from the faecal sludge. However, it is not clear what the source of the heavy metals is, as elemental analysis was not carried out on the raw sludges or the bulking agents.

The fact that some of the parameters are outside the standards in Bangladesh is of some concern as it would suggest that these products will not meet the standards and for that reason would not be permitted for use on land. The sludges used in this study were typical from pit latrines and the bulking agents chosen were those commonly available locally. Therefore, the fact that after drying and co-composting the concentration of sulphur and certain heavy metals are above Bangladesh standards has serious implication for the management of faecal sludge in Bangladesh. It is important to note that the standards for sulphur and most heavy metals in Bangladesh are significantly lower than those in other countries such as Sri Lanka and in member countries of the European Union. As an alternative and rather than exclusively limiting the net content of sulfur and heavy metals in the final FS compost, it is recommended that based on soil and crop characteristics, the load of FS compost on crop land should be limited instead (i.e., max. kg of FS compost with a max. content of an X pollutant per hectare per year).

The Bangladesh standard has no provision for the microbiological constituents of organic fertiliser. The WHO Guidelines (2006) recommend a limit for helminthes of 1 egg/g and for *E. coli* of 1000 cfu/g for faecal sludge to be used in agriculture. Since all the compost products were free of total coliforms, *E. coli* and helminth eggs the microbial quality of the products will not impact on the feasibility of use in agriculture.

Table 10 Final characteristics of the material in windrows 1-6

Parameter	Windrow 1	Windrow 2	Windrow 3	Windrow 4	Windrow 5	Windrow 6	Bangladesh standards
Faecal Sludge	Sand beds			Bio-dried			
EC (mmho/cm)	1.76 ± 0.17	1.98 ± 0.08	2.82 ± 0.23	1.29 ± 0.08	1.54 ± 0.12	2.08 ± 0.14	-
pH	7.10 ± 0.19	7.40 ± 0.14	7.36 ± 0.25	7.35 ± 0.22	7.70 ± 0.26	7.56 ± 0.04	6.0-8.5
Moisture (%ww)	37.22 ± 2.29	39.36 ± 1.55	41.30 ± 3.12	52.52 ± 2.34	56.15 ± 1.57	54.65 ± 1.78	10-20
TVS (%dw)	42.33 ± 3.03	45.21 ± 0.78	36.32 ± 0.59	36.52 ± 3.13	34.97 ± 2.78	33.81 ± 1.19	-
TOC (%dw)	25.08 ± 1.70	23.91 ± 1.17	24.71 ± 2.13	19.85 ± 1.79	18.99 ± 1.50	18.22 ± 1.20	10-25
C/N	15.12 ± 0.20	15.52 ± 0.45	15.83 ± 2.12	11.15 ± 0.77	12.17 ± 0.16	10.80 ± 0.41	<20:1
Total N (%dw)	1.66 ± 0.13	1.54 ± 0.04	1.57 ± 0.13	1.78 ± 0.11	1.56 ± 0.12	1.69 ± 0.16	0.5-4.0
PO_4-P (%dw)	1.12 ± 0.06	1.21 ± 0.11	1.26 ± 0.09	1.38 ± 0.08	0.97 ± 0.07	1.21 ± 0.06	0.5-3.0
NO_3-N (%wt)	0.12 ± 0.00	0.09 ± 0.01	0.07 ± 0.01	0.11 ± 0.03	0.13 ± 0.01	0.13 ± 0.01	-
NH_4-N (%dw)	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	-
Total Coliforms (cfu/g)	nil	nil	nil	nil	nil	nil	-
***E. coli* (cfu/g)**	nil	nil	nil	nil	nil	nil	-
Helminth (eggs/g)	nil	nil	nil	nil	nil	nil	-
Si (% dw)	21.96	19.04	16.42	18.71	15.98	18.25	-
Ca (% dw)	6.49	6.85	5.57	5.23	6.78	8.69	-
Fe (% dw)	2.77	3.30	2.95	3.58	3.48	3.14	-
K (% dw)	2.57	3.01	2.61	2.73	2.49	2.85	0.5-3
Mg (% dw)	1.59	1.50	1.15	1.24	1.18	2.05	-
S (% dw)	1.14	1.12	1.00	1.21	0.92	1.27	0.1-0.5*
Mn (% dw)	-	0.24	ND	ND	ND	0.30	-
Zn (% dw)	0.11	0.11	0.08	0.15	0.18	0.16	< 0.1**
Cr (% dw)	0.03	ND	0.03	ND	0.03	ND	< 0.005%***
Cu (% dw)	0.02	0.02	0.02	0.02	0.02	0.02	< 0.05%
Ni (% dw)	0.01	0.01	0.02	ND	0.02	ND	< 0.003%****
As (ppm)	0.37	0.54	1.18	0.38	1.02	0.43	20 ppm
Pb (ppm)	11.40	22.12	18.24	17.66	19.32	50.88	30 ppm
Cd (ppm)	1.10	0.71	0.76	2.26	0.76	1.44	5 ppm

ND – not detectable according to the lower limit of detection for XRF analysis (Si, Ca, FE, K, Mg, S, Mn, Zn, Cr, Cu, Ni) and AAS (As, Pb, Cd)
*There is no standard in the UK or Sri Lanka for sulphur
**The standard for zinc in the UK is 400ppm (0.04% dw)
***The standard for chromium is 100ppm in the UK (0.01% dw) and 1000ppm (0.1% dw) in Sri Lanka
****The standard for Nickel is 50ppm (ND5% dw) in the UK and 100ppm (0.01% dw) in Sri Lanka

3.6 Recommendations on co-composting options for faecal sludges

This study has shown that co-composting is a viable option for the management of faecal sludge in Bangladesh. Trials were carried out using two faecal sludges and a range of locally available bulking agents and the results suggest that the composting process proceeded well regardless of the sludge or the mix of bulking agents used. The study showed that the mixing of the sludge and bulking agents is extremely important to ensure the material within the windrows is homogenous. Experience from this study suggests that hand mixing alone cannot achieve this and that machine mixing is required.

Experience from this study showed that the use of a permeable cover on the windrows at night can minimize moisture loss and maintain temperature during the cooler night time period. In addition to this it is recommended that in order to minimize recontamination of the material during the maturation phase the composting area should be separated from the surrounding area using a fine mesh to avoid problems with vermin. This study has also shown that turning and water addition during the active and maturation phases increased the concentration of nitrate in the final product.

The final product quality was also shown to be generally within the standards required in Bangladesh (People’s Republic of Bangladesh, Ministry of Agriculture, 2006) with the exception of sulphur, zinc, chromium, nickel and lead. It is unclear where the heavy metals originated and further research to determine the presence of heavy metals in both faecal sludges and bulking agents would be needed to identify the source of these and determine if the issues can be overcome.

Use of the percolate from the sand drying beds for moisture control during composting is not recommended due to issues with the high concentration of salts in the percolate, which have an adverse effect on the conductivity of the windrow material. Since this cannot be used in the co-composting process, we recommend the addition of lime to raise the pH above 11 so that it can then be safely disposed on land.

Section 4 Valorisation: adding value to compost depending on the product

4.1 Enhancing nutrient value depending on the nature of the co-compost

The nutrient value of the 6 types of co-compost final products can be found in Table 10. When compared with synthetic fertiliser nutrient values such as N-P-K and urea, the nutrient values of the compost are rather low. As a result, the compost would be considered as a soil conditioner rather than a fertilizer. By increasing the nutrient value of the compost, a competitive fertiliser could be produced. To achieve this, blending with high nutrient waste resources would be an option. However, it is not always easy to find high nutrient waste sources locally; hence synthetic fertilizer was used as the nutrient source. The nutrient addition was done based on the total N value. The N value was increased 100% by adding the synthetic fertilizer (i.e., 50% N from co-compost and 50% N from synthetic fertilizer).

This blending was done using a simple process or manual mixing, which is low cost and can be conducted in poor countries where mechanisation is a limitation. In previous studies carried out in West Africa (Ghana) there were three forms of fertilizer (a) Dry powder (b) Paste and (c) Liquid. It was found that using it in its powder form proved to be very effective in terms of the ease by which it could be mixed with compost. The photographs in Figure 22 show the mixing of the three forms of synthetic fertiliser. Based on these result, powder synthetic fertilizer was added to the compost during this study and mixed thoroughly. The enriched product was tested on local leafy crops as described in section 5.

Figure 22 Blending with three forms of synthetic fertilizer (Source: IWMI Ghana office)

4.2 Pelletisation of the faecal sludge compost

The advantages of pelletizing compost include reduction in volume/bulkiness which in turn helps to reduce transport costs and make handling of the end product easier. There are also benefits in terms of optimising nutrient release which due to the disintegration of the pellets over time may allow a steady nutrient release. In order to achieve these objectives the characteristics of the pellets should be such that they are durable and therefore do not get crushed during transportation and they should also have suitable disintegration and nutrient release properties.

4.2.1 Alternative techniques for pelletisation

There are two main types of pelletisers namely, (a) extruders and (b) die-roller type pelletizers, and they are assessed and described in Table 11.

Table 11 Types of pelletiser

Characteristics	Die-roller pelletizer	Extruder pelletizer
Description	• The compost is fed between the disks (1 or 2) and/or roller, and the rotation forces compost into disk holes. • It requires low moisture (typically 20-30%).	• It has a barrel into which the raw material is forced by a screw into a die. • It requires higher moisture levels (typically 40%).
Advantages	• It does simultaneous grinding so pre grinding is not needed • Pellet strength can be controlled by varying the gap between die and the roller	• The temperature can be controlled by adjusting the pressure
Limits	• It can be damaged by foreign bodies (e.g. metal, stones, etc.)	• It is easily blocked by foreign bodies or when the product has a low fluidity
Key operating parameters[1]	• Feeding rate	• Speed of the screw • Moisture content of the product

[1] Depends on the feed properties (Hara, 2001).

There are also some granulators which produce spherical granules, and one example is the Hosoya Fermenting system. The Hosoya system, of Japanese origin, is designed to treat large quantities of manure which is converted into an organic fertilizer using bacteria activity. The system consists of a series of rotating metallic knives or forks with which the manure is completely turned, aerated and gradually pushed to the exit of the installation. The final product of the Hosoya system is a granulated material (<12 mm in size), formed as a result of the turning in the channel of the initially muddy-textured raw material. Figure 23 shows a schematic of the system and a photograph of the end product.

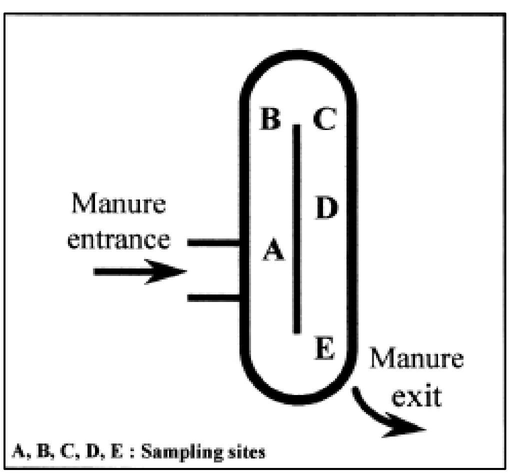


Figure 23 The Hosoya fermenting system (source: Nikiema *et al.*, 2014)

In general, the compost is ground into powder form before conducting the pelletizing process. Grinding is an energy consuming process as (a) compost has to be dried before grinding, and (b) grinding itself is an energy consuming activity. In this case, to avoid additional grinding and drying steps, a disk type pelletizer was selected (i.e., disk and roller).

4.2.2 Pelletisation results

It has been evidenced that fecal sludge that has been co-composted with sawdust is difficult to pelletize (Nikiema *et al*., 2014). Hence this trial was conducted on dried faecal sludge and sawdust co-compost and it was assumed that if this material can successfully be pelletized, all the other co-compost products also would be able to be pelletized by using the same methodology. Figure 24 shows photographs of the pelletising machine and the pellets produced.

Figure 24 pelletisation machine and pellets produced

Optimum moisture content, particle size and impact of binding agent

Moisture content - The initial moisture content of the compost samples was measured and altered to the moisture content of the optimum range. Optimum moisture content was identified on production rate, quality of pellets (by visual inspection). If the moisture content was high the pellets had a tendency to stick together, and if moisture content was low pellets would not be produced properly as expected due to the low plasticity of the compost. The suitable moisture content range was identified by employing a trial and error method and it was found that the desirable moisture content ranged between 18% and 41%.

Compost particle size – The hole diameter and thickness of the pelletizer die was noted as 5 mm. The biggest particle size used for pelletizing was 4 mm (i.e., <4mm compost). When higher particle sizes were used, it was assumed that the compost particles are compressible and particles get ground during the pelletizing process. While proving the assumptions were valid, good quality pellets were produced using 0-4mm particle range. Ideal pellet size was found to be 5 mm in diameter and 15 mm to 17 mm in length, irrespective of binder and NPK content.

Binding agents – Arrowroot starch, a cheap, locally available binding agent was identified and was used. In this case 1% of the binding material by weight was used. The appearance of the pellets (by visual inspection) was no different with and without the use of the binding agents.

Bulk density of the pellet - The bulk density of the pellet was found to be 1.5 g cm^{-3} to 1.7 g cm^{-3}, which was approximately four times higher than the original co-compost material.

Parameters to be adjusted for quality pellet production (i.e., diameter, length, surface smoothness, compactness) – the die-roller type pelletizer should be warmed up to a temperature of between 80-100^{o}C before actual pelletisation begins when pelletizing a sawdust and oil mixture. The presence of water vapour from the pelletisation chamber during the process indicates the appropriate temperature for pelletisation. A gap of between 0.1-0.3 mm between the die and the roller was ascertained to be the optimum for quality pellet production.

4.3 Key findings and recommendations

A number of observations and recommendations were made as follows:

- It was found that compost with < 4 mm particle size can be pelletised without any problems
- By using a disk roller type pelletiser additional grinding and drying steps can be avoided
- The gap between the roller and disk is the critical factor in adjusting the machine for different materials. The optimum gap between the die and roller should be maintained within the range of 0.1 to 0.3 mm during pelletisation.
- The pelletisation chamber should be preheated to a temperature between 80 and 100°C before pelletisation starts
- Pelletisation reduced the volume of the compost product by 75% and based on this it can be recommended as an appropriate alternative for commercialisation.
- The optimum synthetic fertiliser to compost ratio is still to be studied
- The strength characteristics of the pellets with various binding agents are still to be studied (i.e., nutrient release properties, disintegrated properties, etc.).

Section 5 - Health and food safety

5.1 Crop trial set-up and operation

The main objective of the crop trials was to identify the performance of faecal sludge co-compost (FSC) (including nutrient-enhanced and pelletized versions) compared to other alternatives such as municipal solid waste (MSW) compost and synthetic fertilizer. The different treatments included:

- Control 1: No fertilisation
- Control 2: local common practice (Urea + TSP + MOP)
- NPK alone
- Commercial compost – MSW based compost
- Faecal sludge compost – from windrow 3
- Faecal sludge compost + NPK
- Pelletised faecal sludge compost + NPK
- Pelletised faecal sludge compost

5.1.1 Crop selection

During the initial development of this project a decision was made to carry out the crop trials using tomatoes. Tomatoes have a cropping period of approximately 90 days and hence, it would be possible within the anticipated timescales of the project to observe only plant growth but not the harvest data. Since the most important information to come out of the pot trials is the impact of the different products on crop yield rather than plant growth a decision was made to switch to a crop with a shorter crop cycle.

The proposed methodology is applicable to any crop although the nutrient value calculation must be conducted by considering the identified crop. After careful consideration a decision was made to use spinach as the study crop in this project. In order to determine the correct seed or variety of spinach crop to be used in the pot trials, a small number (at least 5) of commercial farmers were interviewed. Through these interviews, it was also possible to obtain accurate information regarding the actual nutrient application rates and methods that are currently used and implement this practice as Control 2 in the study.

The study design was set up such that it was a randomized trial with a total of eight different treatments and each treatment had four replicate pots and was also done in parallel, amounting to eight pots per treatment. This gives a total of 64 pots.

5.1.2 Soil selection and preparation

The soil was selected based on the most common soil present in the agricultural areas of the particular region in which the selected crop is grown. The top layer of the soil, (i.e., the first 0–10 cm) was excavated from the identified site and any unwanted objects such as vegetation, stones, debris were discarded during excavation. After transporting to the laboratory, any soil clogs remaining were separated or broken down using a wooden mallet. The soil was then dried at room temperature, after which it was passed through a 6mm sieve.

5.1.3 Pot preparation

The pot trials were carried out in 2-litre capacity pots with a tray placed at the bottom of the pots to capture any excess water escaping from the pots. All the pots were wetted up to field capacity levels using de-ionised/clean water. The water requirement is calculated based on the soil field capacity value obtained through a separate experiment. The pots were placed in the shallow tray and regularly watered to maintain their water content approximately to field capacity levels throughout the duration of the experiment. A digital moisture meter was used to give a qualitative indication of the moisture content and the pots were watered based on these results. Generally the pots were watered daily. Any water that percolated through the pot and into the tray was collected and used to water the same pot in order to minimize the nutrient loss via leaching.

51.4 Determination of Soil and commercial compost nutrient status

This was carried out before the crop trial. A composite soil sample from each treatment was air-dried at 36°C, mixed thoroughly and crushed gently to allow it to pass through a 4mm sieve. A sub-sample was then ground again and passed through a 2mm sieve. The resulting sample (< 2mm) was then analysed then analysed for pH, total nitrogen, nitrate-nitrogen, total phosphorus and total potassium. The commercial compost was also analysed for pH, total nitrogen, nitrate-nitrogen, total phosphorus and total potassium.

5.1.5 Calculation of the nutrient requirement for the chosen test crop

According to the literature the nutrient requirements for spinach is 50 kg N ha^{-1} (Jones et al, 2005). However, for a short cycle crop grown in winter (e.g., spinach), it is recommned that the 50% of nitrogen requirements should be in the from of nitrate (DFRA - Department of Forest Resources and Agrifoods, 2003). This criterion was used for calculating fertilizer requirement for all treatments except Control 2 in which the amount of nitrogen added is higher and reflects current practice in Bangladesh. It was further assumed that 50% of the applied synthetic urea was in the form of available nitrogen. Therefore, FS compost and NPK was mixed in such a way that each contributes equally to the available nitrogen.

Table 10 shows the amounts of the different fertilisers or components that were added to the pots and also the number and timing of the applications for each treatment. Nitrate (available nitrogen as NO_3-N), phosphorus (P), potassium (K) and total nitrogen (TN) concentrations of the soils were found to be 0.0005%, 0.0034%, 0.0128% and 0.12% on a dry basis respectively. Therefore the applied amount of nitrate, P, K and TN for each of the treatment (except control-1) per pot are also given in Table 10. When applying the fertilizer, the broadcasting method was used. After application, the fertilizer was mixed with the top soil contained within the pots and the pots were then allowed to stand for approximately one week before the start of the cultivation process – i.e., before the transplantation of the plants.

Table 12 Fertiliser application rates (data is on a dry weight basis)

Treatment	Fertilizer	Application pattern	Application amount (g/pot)	Total Nitrogen (g/pot)	Available Nitrogen (g/pot)	Phosphorus (g/pot)	Potassium (g/pot)
1	Control 1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2	Control 2	All different treatments were added 1 week before cultivation	Urea – 0.87 TSP – 1.38 MOP – 0.95	0.1621	0.0811	0.0175	0.0322
3	NPK (15:15:15)		Urea – 0.35 TSP – 0.35 MOP – 0.27	0.7167	0.0811	0.3756	0.6976
4	Commercial compost		59.6	0.7042	0.0811	0.4668	1.0102
5	Faecal sludge compost		38.7	0.4332	0.0811	0.2422	0.5212
6	Faecal sludge compost + NPK		FSC – 19.35 Urea – 0.18 TSP - 0.18 MOP - 0.13	0.4332	0.0811	0.2422	0.5212
7	Pelletised Faecal sludge compost		38.7	0.7042	0.0811	0.4668	1.0102
8	Pelletised Faecal sludge compost + NPK		FSC – 19.35 Urea – 0.18 TSP - 0.18 MOP - 0.13	0.8073	0.4036	0.0191	0.1145

5.1.6 Preparation of plants for pot trials

The seedlings were grown from seeds in the same greenhouse in which the pot trials were conducted using the same soil. After 25 days, the seedlings were transplanted into the experimental pots with a single plant per each 2-litre pot.

5.1.7 Analysis of plants and soil

During the experimental period the number of leaves on each of the spinach plants was counted every week until harvesting time. The spinach plants were harvested after 30 days and after harvesting a number of parameters were measured:

- Fresh weight of the edible part of the plant
- Dry weight of the edible part of the plant (dried at $70^{o}C$ to constant weight)
- Moisture content
- Chemical parameters including TKN and Nitrate-N
- Microbiological parameters including total coliforms, *E. coli* and helminth eggs

Analysis of the soil in the pots was also carried out before the start of the pot trials and this included TKN, Nitrate-N, moisture content, water-holding capacity, and relevant microbiological parameters.

5.2 Evaluation of the impact of co-composted faecal sludge on plant growth

Figure 25 shows the number of leaves measured on each of the plants and it can be seen that there appears to be no significant difference in the number of leaves on the plant grown using the different fertilisers. However when we look at the dry weight of the edible part of the plants after harvesting (Figure 26) there appears to be a significant difference between different treatments.

The lowest weight (<2g) was seen for the plants grown without any additional nutrients (Control 1) which is what it would be expected. The results for the NPK alone, the faecal sludge alone and the pelletised faecal sludge alone were comparable with dry weights around 3.5g. Improved performance was seen with Control 2 which was set up to mimic local agricultural practice and this gave an average dry weight of approximately 4.5g. Table 12 shows the P and K concentrations per pot and it is clear that the higher dry weight was obtained despite the fact that the P and K values were the lowest of all the treatments used with the exception of Control 1.

The best performance during the pot trials was observed for the plants grown using the faecal sludge compost plus additional NPK. Once again this improved performance cannot be accounted for by the P and K concentrations in the pots for this treatment. The average dry weight of the plants was more than 5g. However what is interesting is that the pelletised version of this treatment (FSC + NPK) performed much worse with an average dry weight of around 2.5g. It is hypothesized that this may be due to the fact that the pelletisation process may have led to the NPK being bound within the pellet and no longer readily available for use by the plants. However, over longer time periods than during this trial, it may be expected that the pellets break down to release NPK for uptake by the plants.

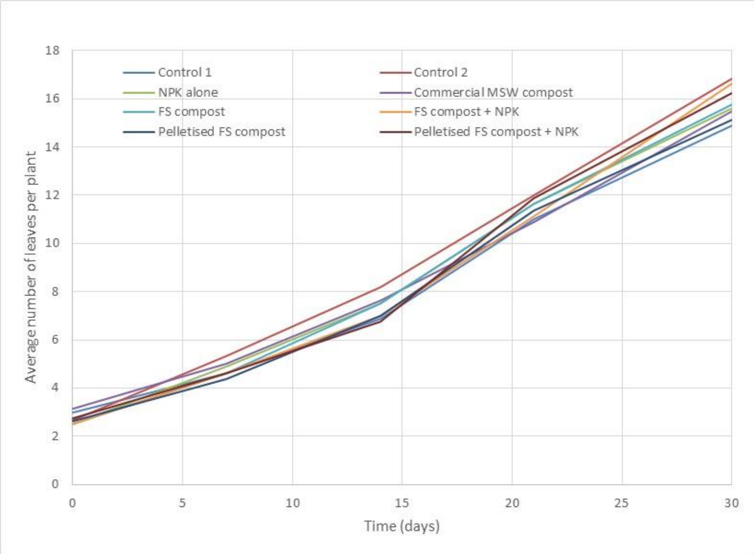


Figure 25 Impact of treatments on the average number of leaves per plant (average of 8 replicates)

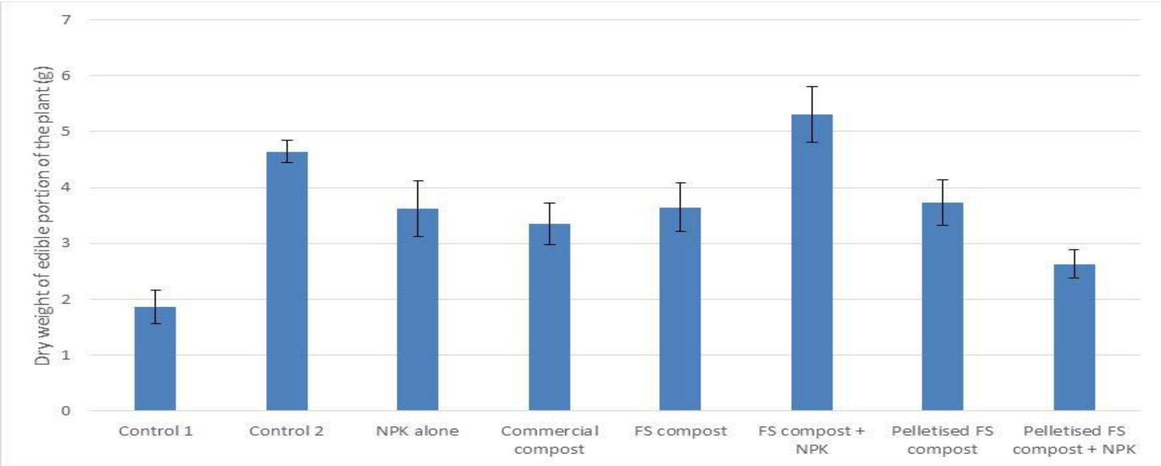


Figure 26 Impact of treatments on the final dry weight of the edible part of the plant (average of 8 replicates, error bars ± 1 SD)

5.3 Evaluation of moisture, nitrate-N, total nitrogen and pathogen concentrations in final product

Table 13 shows the concentration of bacterial and helminth eggs in the edible part of the spinach plants measured after harvesting. It can be seen that all of the plants tested negative for helminth eggs. It can also be seen that the majority of the plants tested negative for both total coliforms and *E. coli*. However in the case of the plants grown on the chemical fertilisers alone (Control 2) there was evidence of contamination with both total coliforms and *E. coli*. The plants grown on the pelletised faecal sludge compost contained significant concentrations of total coliforms.

Results of the microbial analysis of the faecal sludge compost presented earlier showed that the material was free of any bacterial or helminth contaminants and therefore it is unlikely that this is the source of the contamination observed in the spinach plants. However analysis of the soil used in the pot trials revealed that it contained 9.8×10^3 cfu g^{-1} of total coliforms and 5×10^2 cfu g^{-1} of *E. coli*.

Although the soil may be the source of the contamination and as it was used in all the pots, but did not appear to affect all the plants, it may be hypothesised that the contamination of the edible part of the plants occurred during watering or harvesting when some of the edible parts of some of the plants may have come into direct contact with the soil.

Table 13 Concentration of pathogens in edible part of the plant

Treatment	Total coliforms (cfu/g)	*E. coli* (cfu/g)	Helminths (eggs/g)
Control 1	ND	ND	ND
Control 2	52	45	ND
NPK alone	ND	ND	ND
Commercial compost	ND	ND	ND
FS compost	ND	ND	ND
FS compost + NPK	ND	ND	ND
Pelletised FS compost	960	ND	ND
Pelletised FS compost + NPK	ND	ND	ND

Figures 20, 21 and 22 show the average moisture content, nitrate-N and total nitrogen concentration in the edible part of the plants. In terms of moisture content the data shows that there was no significant difference between any of the plants regardless of the treatment used.

The concentrations of total nitrogen and nitrate-N varied between treatments. As expected the concentrations in the edible part of the plant for those grown without addition of fertiliser (Control 1) was very low. There was a significant difference between the total nitrogen and nitrate nitrogen concentrations in the plants grown on NPK alone and in Control 2 (which is also NPK alone). This is due to the fact that a significantly higher application rate was used in Control 2 and this is reflected in the higher total nitrogen and nitrate-N in the plants.

All the organic fertilisers (MSW and faecal sludge) showed high levels of total nitrogen and nitrate-N in the edible parts of the plants. Levels of nitrate were close to the limit of 2000 mg kg^{-1} fresh weight set out in EU legislation. There are no such limits on nitrate concentrations in Bangladesh.

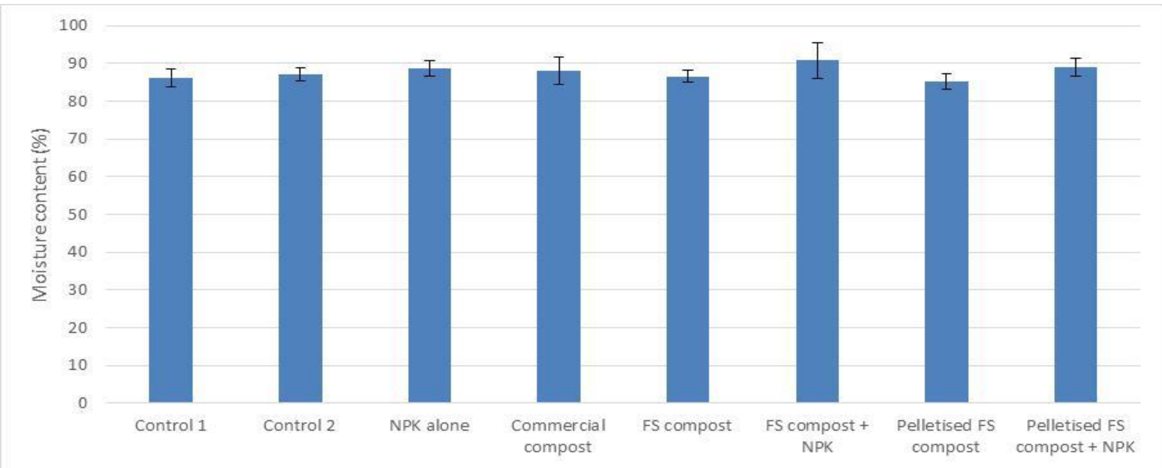


Figure 27 Final moisture content in the edible part of the plant (average of 8 replicates, error bars ± 1 SD)

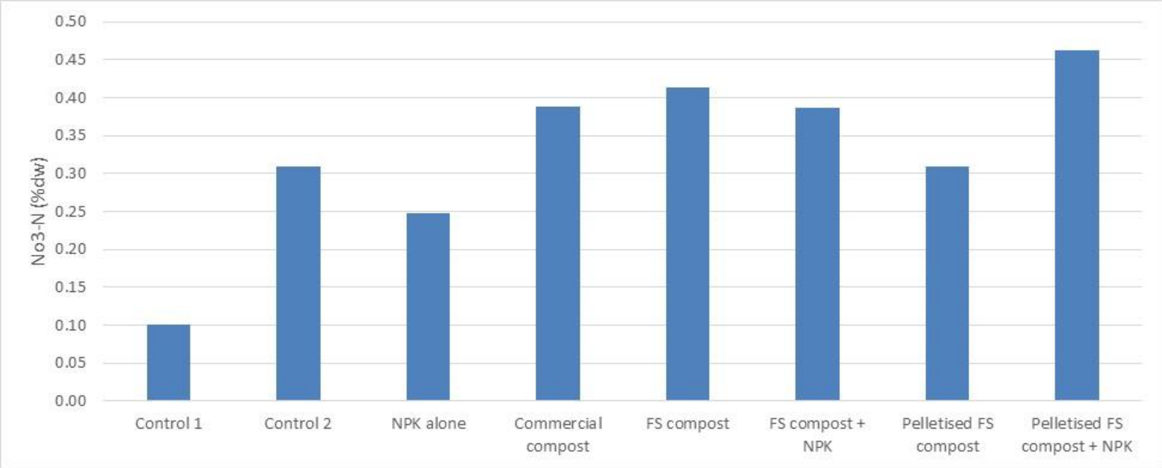


Figure 28 Final concentration of Nitrate-N in the edible part of the plant

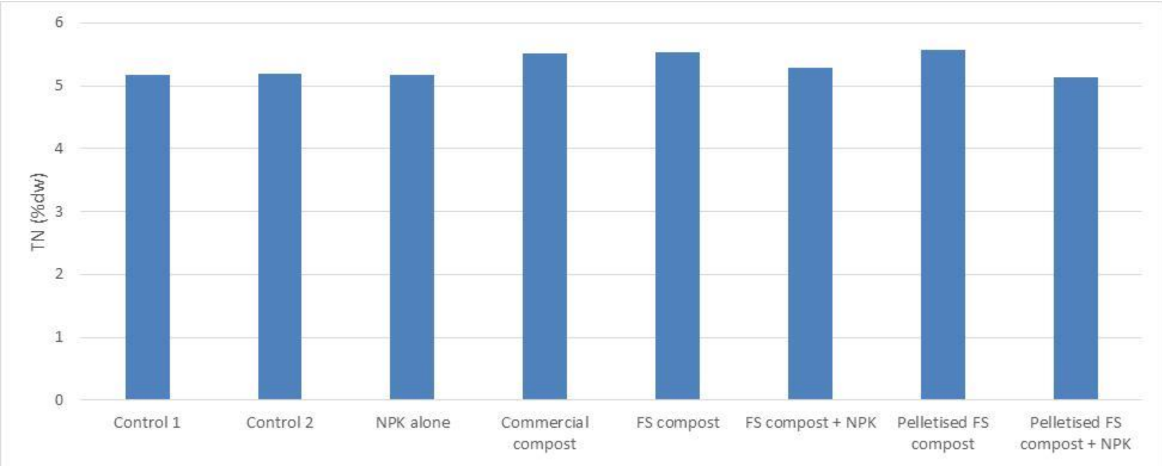


Figure 29 Final total nitrogen concentrations in the edible part of the plant

5.4 Comparison between the results from the pot trials and national and international food standards

Currently there are no food safety standards in Bangladesh although according to the World Health Organisation (WHO) in 2014, a National Food Safety Advisory Council is under formation in Bangladesh, which will develop the policy and strategy for food safety and quality control. Therefore at present it is not possible to compare the chemical and microbial components of the spinach grown in the pot trials to any national standards in Bangladesh.

Internationally there is a limit set out in the EU which states that the upper limit for nitrate in spinach is 2000 mg kg^{-1} based on wet weight and as already stated the highest concentration of nitrate in the spinach grown in these trials was around this EU limit. The WHO first set an upper limit for nitrate in food in 1962 and that limit still stands today. According to the WHO the acceptable daily intake of nitrate for humans is 3.7 mg NO_3^- kg^{-1} of body weight. For an average 60kg adult this equates to 222 mg of NO_3^- per day. Taking the results from the pot trials the highest concentration found in the edible part of the spinach plant was 2289 mg kg^{-1} (wet weight). Therefore taking the acceptable daily intake suggested by the WHO, an average adult would be able to safely consume 100g of fresh spinach per day from the pot trials.

5.5 Conclusions and recommendations from crop trials.

A number of observations/conclusions can be drawn from the results obtained from the pot trials as follows:

- The performance of the faecal sludge compost and pelletised faecal sludge compost was comparable to that of using NPK alone and commercial compost in terms of the dry weight of crop produced.
- A significantly better performance was observed for enriched faecal sludge compost compared to any other treatment in terms of the dry weight of crop produced.
- When enriched faecal sludge compost was pelletised the performance was adversely affected and this is thought to be the result of the fact that after pelletisation the NPK was not readily available to the plants
- Care needs to be taken during watering and harvesting as poor practice may result in the transfer of microbial pathogens from the soil to the surface of the plants
- In terms of moisture content the data shows that there was no significant difference between any of the plants regardless of the treatment used
- All the organic fertilisers (MSW and faecal sludge) showed high levels of total nitrogen and nitrate-N in the edible parts of the plants.
- Levels of nitrate in the plants from some treatments involving commercial compost and faecal sludge compost were close to the limit of 2000 mg kg^{-1} of fresh weight set out in EU legislation.
- The concentrations of nitrate in the spinach do not pose a significant health risk when compared to the recommended daily intake suggested by the WHO.

Section 6 – Potential for faecal sludge reuse in the form of compost

6.1 What is the potential of faecal sludge to meet the NPK demand of agriculture in Bangladesh?

The purpose of this analysis was to understand whether faecal sludge can meet a significant share of the NPK demand in Bangladesh. If the share that can be met is relatively small it may not justify the costs involved in collecting and transporting the faecal sludge, co-composting, and valorization. On the other hand, if the share is sizable, then there are likely to be multiple gains, not just in the form of less polluted land and water, but also as a nutrient source.

At the national level, the potential of faecal sludge to meet the NPK demand of key crops in Bangladesh (e.g., rice, wheat, barley, jute and tea) was examined by carrying out a desk study using data from 2 sources. The data collected from household surveys on sludge disposal, agricultural practices and existing fertiliser use was supplemented with data from various secondary sources on the typical nitrogen, phosphorus and potassium content in of human waste (i.e., feces and urine).

The data collected from Bangladesh suggest that annually about 456,460 tons of NPK is produced and about 1,529,620 tons are imported which adds up to a total of approximately 2 million tons per year (FAO, 2011). The total NPK fertiliser requirement of the principal crops mentioned earlier is estimated at around 3 million tons. For the purposes of this analysis it was assumed that 100% of the nutrient contained in human faeces and urine can be collected and it is assumed that the rates of production per capita are similar to those quoted for India as 7.4, 1.1 and 4.11 g cap^{-1} day^{-1} for N, P and K, respectively (Jonsson *et al*., 2004). It is acknowledged that using these values will slightly overestimate the contribution of nutrients made by faecal sludge.

Bangladesh is currently unable to meet its actual NPK demand from both local production and imports. Accounting for the difference in faecal sludge characteristics due to different diets in Bangladesh, and different sowing dates of the key crops and cropping patterns, it could be reasonably concluded that faecal sludge generated in Bangladesh can potentially meet up to 17%, 15% and 10% of the N, P and K requirements of the principal crops, respectively. (Please refer to Tetong, 2014, for a description of the how these numbers were calculated).

6.2 Is compost a substitute or complement for NPK in the smallholder market?

The purpose of this analysis was to understand the season in which fertiliser and compost are used, as well as the crops that compost is primarily used for. This has implications for placing and marketing a potential fecal sludge product.

A set of questions on compost and NPK use were administered to 1,440 randomly selected households across 4 upazilas in Bangladesh. Respondents were asked to provide this information for the current pre-monsoon season (Kharif I, between March-July, 2014), the previous post monsoon season (Rabi, between November 2013 and March 2014), and the last monsoon season (Kharif II, between July-November, 2014). For each of these agricultural seasons, information was elicited regarding the crops that were grown by the household, and whether the farmer has applied fertilizers and compost for cultivating that crop. For each agricultural season, farmers were asked to report the quantities of urea, potash, TSP, DAP, compost and poultry litter purchased.

In this sample, 46% of households were smallholders on their own or rented land and the data from these 644 households was used in order to understand patterns in fertiliser and compost use (Table 14). The peak agricultural season for NPK was the Kharif I season, before the start of the rainy season, with 65-75% of farmers using NPK in this season. An average of 71 kg, 44kg and 24 kg of N, P, and K was used per smallholder household in this season. The use of NPK during the monsoon (July-October) and post monsoon (October to March) is lower, with fewer farmers (30-36%) using lower quantities. Farmers used NPK predominantly to grow rice, followed by sugarcane.

Table 14 NPK and organic fertilizer use over the last three cropping seasons

KHARIF I SEASON (MARCH 14-JULY 14)

Fertiliser used	% of farmers	Mean amount per household (kg)	Range
N	76	71	4-300
P	75	44	0-300
K	66	24	0-300
Organic compost	16	34	0-300
Poultry Litter	16	33	0-300
Cow dung	62	254	0-800

RABI SEASON (OCTOBER 13- MARCH 14)

Fertiliser used	% of farmers	Mean amount per household (kg)	Range
N	36	51	5-200
P	34	34	2-250
K	31	15	0-110
Organic compost	10	100	0-500
Poultry Litter	9	42	0-600
Cow dung	29	193	0-800

KHARIF II SEASON (JULY 13 - OCTOBER 13)

Fertiliser used	% of farmers	Mean amount per household (kg)	Range
N	36	52	5-350
P	36	32	2-225
K	32	17	0-100
Organic compost	7	48	0-350
Poultry Litter	7	11	0-100
Cow dung	30	232	0-800

The purchase of compost from the organised market is low, with only 16% of smallholders using such a compost product in the pre-monsoon season. However the use of cow-dung is prevalent, with 62% of farmers in this sample reporting a mean amount of 254 kg in the pre-monsoon season. In the monsoon and post monsoon season, the purchase of compost fell, with fewer smallholders using smaller quantities on average. The same pattern is observed in the use of cow-dung. Farmers reported using compost/cow dung to predominantly grow rice and sugarcane.

The results suggest that compost (e.g., purchased compost, cow-dung or any other type) is a complement to NPK. Given the weak supply chains for compost in Bangladesh, a new faecal sludge product could be marketed using the existing supply chains for NPK, rather than relying on the supply chains for compost, which can consist of producers selling directly to farmers rather than through dealers.

6.3 What characteristics would smallholders consider important when buying a potential product made from faecal sludge?

The purpose of this analysis was to understand the barriers to the adoption of a potential product made from faecal sludge, and to identify characteristics that would be important for the adoption of a faecal sludge compost product by farmers.

Perceptions regarding the use of a potential faecal sludge compost product were elicited by asking respondents to count physical objects. Respondents were given ten marbles and asked to express the degree of their agreement to a statement by putting marbles in a cup. Beliefs on the importance of product characteristics in purchasing a potential faecal sludge product were elicited. Farmers were also asked a set of questions on what they thought compost could be made from in order to gauge awareness regarding compost. These perceptions were also elicited by counting physical objects.

In terms of product characteristics (Table 15), the price of the potential product, its government certification, and its access in the market emerged as vital characteristics for purchasing faecal sludge compost. Farmers had a strict preference for the price to be comparable to other fertilisers in the market, and for the product to be certified by the government for quality. Farmers also had a preference for the product to be conveniently available. Incidentally, these same characteristics emerged as important when farmers were asked about the important factors they took into consideration while purchasing NPK. Factors such as pelletisation, appearance of the compost and its safety were less important.

Table 15 Importance of different characteristics in a potential fecal sludge compost product

Factor	Mean*	Std. Dev
its price is the same as other fertilizers in the market	9.21	1.51
it is mixed with NPK to make it better	8.42	2.21
it is certified by the government	8.99	1.61
it is marketed by BRAC	8.54	1.51
it is made by BRAC	8.38	1.68
it is made into pellets, rather than a powder	7.43	2.32
it looks like any other compost available in Bangladesh	7.27	2.39
it is easy to store	7.46	2.12
it is available at a convenient location	8.42	1.89
it can be purchased on credit	7.95	2.27
it is locally made, rather than imported	7.52	2.13
it is safe to handle and use	7.16	2.30
it is also used by my friends and neighbours	7.78	2.58

*0=not at all important; 10= extremely important

With respect to awareness regarding the use of compost (Table 16), 73-77% of respondents stated that compost could be made from animal excreta, plant waste and kitchen wastes. However only 39% were aware that compost could also be made with human excreta, and just 26% were aware that it could be made from municipal solid waste. On the positive side a majority of farmers (80-86%) were aware that compost improved soil fertility and moisture.

These results suggest that an awareness and information campaign will be needed to communicate to farmers the viability of making compost from faecal sludge, and its potential use in agriculture. Bangladesh has had experience in launching such national awareness and information campaigns with arsenic, and the lessons learnt from that experience may be transferred to this endeavor.

Table 16 Awareness regarding the use of compost

Factor	Mean %
Compost can be made from animal excreta	77
Compost can be made from plant waste	73
Compost can be made from kitchen waste	75
Compost can be made from latrine waste	39
Compost can be made from rubbish	26
Compost improves soil fertility	86
Compost improves soil moisture	80
Compost reduces erosion	55

6.4 What should the price of compost be for smallholders?

The household data suggests that the price of any potential compost should be similar to other composts already available in the market. In order to understand the range of prices of currently used compost, a number of compost manufacturers, dealers and sub-dealers of compost were interviewed.

The price of regular compost, when sold directly by manufacturers to the farmers varies from BDT 13-20 kg^{-1}. When sold through dealers and sub-dealers, the compost is being sold at a price of BDT 18 kg^{-1} on an average. Waste Concern sells its compost to ACI at BDT 7-8 kg^{-1}, and ACI sells it to customers at a price BDT 11-12 kg^{-1} (i.e., including the transportation, storage and promotional cost). When this compost is blended with chemical fertilizer, it was sold at a price BDT 15 kg^{-1}. Vermicompost is sold at a price of BDT 20 kg^{-1}, and the selling price of nutrient enriched compost manufactured by Faruk Fertilizer Ltd is BDT 55 kg^{-1} in the market. Thus, the price of a potential compost product would ultimately be determined by the type of compost, the transportation and marketing strategy, and by consumer segment, and could range from BDT 18-55 kg^{-1}, depending on the market segment.

6.5 What other markets may be targeted with a potential compost product?

The smallholder market, on its own, may not be a profitable business venture. Other markets for compost could potential be horticulture businesses, nurseries and municipal parks. Horticulture and nursery businesses typically cultivate high-value products such as vegetables and flowers, and buy compost in bulk. Similarly public parks and green belts maintained by municipalities, public and private agencies could be large market segment for compost.

To understand the feasibility of targeting these additional markets, a purposively selected sample of agroforestry, aquaculture, nurseries, horticulture, and plantation businesses across the country were interviewed in order to understand the quantity of compost used in these sectors, the price per ton of compost, and dispositions towards using a potential compost made from faecal sludge.

All businesses demonstrated awareness about compost use and its benefits, but were unfamiliar with the production and use of compost from urban waste. The annual use of compost was highest in the plantation sector (Table 17), but so is the variance. The peak season for compost use in plantations and nurseries is mainly during the winter (October to February) and in some cases continues until April-June. Since plantations and nurseries purchase compost in bulk, creating a product that meets the requirements of these segments might be a cost effective strategy.

Table 17 Use of compost in the different sectors and the indicative price.

Sector	Average use (tons/yr)	Average Price (BDT/ton)
Agroforestry	1.5	18,250
Aquaculture	14	3,490
Nurseries	15	27,000
Horticulture	3.5	24,000
Plantation	105	4,000

Section 7 - Institutional factors: how these inhibit the composting business

To understand the institutional factors that inhibit the composting business, a number of compost companies, relevant experts and fertiliser and compost dealers and distributors were interviewed. The primary issues observed were regulations on compost production; availability of finance for the operations; sales and marketing; consumer awareness; and political turmoil causing loss to the business due to reduced sale during peak season.

7.1 Compost Product Certification and Regulations

The biggest barrier for compost companies is the complicated and time-consuming compost certification procedure. In Bangladesh the lack of a suitable policy environment and the complicated regulatory process restricts the smooth operation and supply of compost to the market. The current certification procedure entails following steps although it should be noted at this point that this procedure only applies to branded packaged compost products and not unpackaged ones.

- An enterprise needs to apply and report to the Fertiliser Sub-Committee at each stage of the application. As the committee meets infrequently and has lengthy agendas, many applications are deferred and delays are common.
- After the completion of laboratory tests (Bangladesh – 3 tests, Asia generally – 1 test) field trials begin. Unlike other Asian countries, Bangladesh has no provision for granting temporary licenses for production during this period.
- Based on completion of satisfactory field trials, a second application is submitted to the Department of Agriculture Extension (DAE), which issues the certificate for the compost product valid for 5 years. However, there is no defined procedure for renewal of certificate therefore it is not clear what happens when the 5 year certificate expires.

According to Katalyst (2009) the granting of a license in Bangladesh may take 600 days compared to 40, 45 and 60 days in the Philippines, India and Thailand, respectively; although according to compost companies in Bangladesh it may be more than 3 years in some cases. Individual certification is required for each product and this has been reported by some companies to take 6-8 years to get all their products certified.

Between 2008 and 2014 the number of companies in Bangladesh that have certified compost products has increased from 5 up to 32 (Bangladesh Fertilizer Association and Bangladesh Organic Products Manufacturer Association) with another 200 companies awaiting certification. Having a certificate does not ensure the company can sell the branded product, as further informal approval from the upazilas is required before any product can be marketed within the upazila.

From interviews carried out amongst compost companies there are a number of other regulatory challenges that act as a barrier for new compost companies to enter the market including:

- The need for regular laboratory testing of product quality with results sent to the Ministry of Agriculture. If the compost does not meet the required quality it may result in the issue of an arrest warrant. The cost of testing is BDT 40-50 lakhs.
- Registration with the Bangladesh Fertilizer Association has strict membership requirements which may be a problem for new companies.
- Bangladesh has stricter heavy metals standards compared to other South Asian countries.
- Currently in Bangladesh there is a government subsidy on chemical fertilisers, while there is none for balanced fertilizer which is enriched compost with chemical fertiliser. Despite the fact that they actively promote compost and encourage integrated plant nutrient system (IPNS), the subsidy remains the biggest barrier to increase procurement of compost by farmers.
- Composting companies are not eligible for the same concessional import duties and tax holidays as those given to waste management, solar energy and biogas companies for example.

7.2 Impact of technological know-how, access to finance, product sales, market awareness and land ownership

Compost companies in Bangladesh operate at a very small scale and generally individual plant production is < 300 tons yr^{-1}; although Otoo and Drechsel (2015) reported production of 3,000-15,000 tons yr^{-1} in some medium to large companies. As a result the small companies suffer from a number of challenges and in an interview carried out as part of this study a number key barriers relating to technology, finance and sales of product were identified:

- Lack of technological know-how – this can be a barrier for optimizing the composting process, for example the use of a de-composting agent or activator may reduce the composting processing time and allow the company to deliver product to market faster (Rashid, 2011)

- Access to finance – Typically small composting companies are self-financed or have taken hand loans from relatives and friends, with very few accessing loans from banks. Commercial lending rates in Bangladesh are high (16 to 18% per annum) and therefore repayments place a considerable burden on composting industries and significantly reduce profits. At the other end of the chain their customers – i.e., farmers--are also subject to the same lack of access to finance. This means many require credit from companies to buy products such as compost which puts even more strain on small compost companies as it affects their working capital. This vicious circle and barrier will remain as long as there is no significant improvement in access to finance in rural areas of Bangladesh.

- Product sales – In interviews compost companies highlighted the lack of knowledge amongst farmers of the benefits of compost as one of the key challenges in the sale of their products. In addition to this the relatively slow impact on crop productivity compared to chemical fertilisers may also be an important factor for adoption. However it should also be noted that compost companies do not allocate sufficient marketing budget to increase awareness and strengthen their supply chain for increased accessibility to their product. As mentioned previously, chemical fertiliser subsidies also impact compost sales.

- Market awareness - Compost marketing is an essential part of any successful composting business and in many cases composting businesses have failed to maintain their activities due to a lack of demand for their product or a poor marketing strategy (Ali, 2004; Zurbrugg, 2003).

Despite having a long history of organic fertiliser use before the introduction of chemical fertilisers, the current use of compost in modern farming is limited (Diaz *et al.*, 1993) Therefore market awareness and marketing are key to the success of any composting business.

- Land ownership - There has been a long tradition in Bangladesh for land to be managed by landlords who were traditionally the higher social classes. Those that farm under tenancy are influenced by a number of issues including:
    - Sharecroppers receive only 50% of the profit from the sale of their produce yet they have to pay the full cost of irrigation and fertilisation and will therefore opt for the cheaper chemical fertiliser option.
    - When cultivating land via a lease there is no incentive to maintain the sustainability of the land and there is a tendency to use chemical fertilisers for faster yields and a quick profit. They do not consider soil/environmental health and will continue to use chemical fertiliser instead of organic compost.

7.3 Political Turmoil

Political instability is one of the key impediments to economic development in Bangladesh and a key feature of the system is the period of unrest known locally as '*hartal*'. During interviews, compost companies reported heavy economic losses during hartal periods. Recently the major hartal periods have coincided with the key compost sales season, with companies reporting sales of less than 40% of annual compost produced.

7.4 Fertiliser dealer model in Bangladesh and its relevance for compost companies

One of the objectives of the interviews carried out as part of this research was to understand the overall business operations of dealers and distributers in general but also to find out what affects the compost business value chain.

Most dealers are registered with either the Bangladesh Agricultural Development Corporation (BADC) or Bangladesh Chemical Industries Corporation (BCIC). Registration with BADC or BCIC allows them to tap into the supply of urea and chemical fertilisers that is controlled by the government and fixed regardless of demand. Government regulations limit the number of dealers per union to 1 BADC and 1 BCIC. The number of BADC sub-dealers is not restricted; however the number of BCIC sub-dealers is limited to 1 per ward (9 in total). Selection of dealers and decisions on the quality of fertiliser made available is done by the BADC/BCIC and the Agricultural Officer at upazila level, respectively. Dealers are selected based on their financial status, experience in running the business and assessment of their shop location and establishment; their performance is monitored monthly by the committee. Dealers and sub-dealers pay BDT 2 lakh and BDT 30,000 as a security deposit respectively.

Medium or larger compost companies rely on the existing the fertilizer dealer networks to sell their product, since farmers prefer purchasing all required agriculture inputs from a single entity. These dealers tend to make credit available to the farmers. As a result of the system, compost companies are reliant on a limited number of dealers and distributors.

Section 8 - Key finding, recommendations and next steps

Advances in the provision of improved sanitation facilities (e.g., pit latrines) have made a great contribution to improving living condition to millions of people around the world, but particularly in rural Bangladesh. Unfortunately, poor current practices for pit latrine management pose serious health and environmental risks. One of the main challenges related to the correct use and maintenance of pit latrines is the lack of reliable methods for pit emptying. In that regard, it was found that manual pit emptying can be replaced by safer and more reliable methods. Consequently, the use of diaphragm pumps for pit emptying emerged as the most feasible option for reducing contact with sludge while emptying rural pits. However, it was found that local sweepers were unlikely to purchase a pump of their own accord due to its high capital costs. Therefore, the government/municipality/entrepreneurs would need to provide subsidies/incentives/ investments to facilitate the purchase of these pumps. The cost of the pump will likely be recovered over the lifetime of the pump, if a sustainable tariff scheme/ business plan is implemented.

Along with the right mechanical equipment, personal protective equipment was also identified as an important component for a competent pit emptying service, which can also help to improve working conditions for sweepers by reducing their exposure to raw faecal sludge. However, a change of culture in pit emptying practices is required among sweepers, as they confirmed that protective equipment was found uncomfortable and reported not being keen to wear any protective clothing.

Improving the service provided by pit latrines requires developing a market for pit emptying and FS transportation to treatment facilities. This research work found that such market can be developed, but also found that households are only willing to contribute a modest charge for such service; therefore, a subsidy scheme from the government/municipality may contribute towards that goal. Additionally, the creation of a value-added product (e.g., FS compost), could improve the chances of business development. In fact, the content of NPK and carbon to nitrogen ratio found in FS samples (10:1) collected as part of this study, support the potential for co-composting FS with other organic wastes locally available, in order to improve the nutrient content and value of a product with a potential market.

For the stabilisation of FS via composting processes, it is required the use of pre-treatments units able to reduce moisture content from 90% to 50%. In that regard, sand beds represent an effective pre-treatment alternative for FS dewatering and drying and at the same time, they make an important contribution to pathogen inactivation. FS management programmes need to encourage pit emptying practices during dry seasons, which will ultimate reduce detrimental impacts on pit operation caused by a high water table during rainy seasons; that practice would also help to better manage the limitations that sand drying beds have when weather conditions are not favourable (rainy season).

FS co-composting with local organic wastes was identified as an important route for improving FS compost quality, along with a well operated composting process for pathogen inactivation. FS compost can be pelletized without any problems, which may help to its commercialization and acceptance among farmers and other alternative consumers.

The performance of the faecal sludge compost and pelletised faecal sludge compost was comparable to that of using NPK alone and commercial compost in terms of the dry weight of crop produced. A significantly better performance was observed for enriched faecal sludge compost compared to any other treatment in terms of the dry weight of crop produced. When enriched faecal sludge compost was pelletised the performance was adversely affected and this is thought to be the result of the fact that after pelletisation the NPK was not readily available to the plants; however, regular use of pelletised FS compost may help to overcome this hurdle. In terms of the quality of the final FS fertiliser product, it was found to be generally within the standards required in Bangladesh with the exception of sulphur, zinc, chromium, lead and nickel.

Bangladesh is currently unable to meet its actual NPK demand from both local production and imports. Accounting for the difference in faecal sludge characteristics due to different diets in Bangladesh, and different sowing dates of the key crops and cropping patterns, it could be reasonably concluded that faecal sludge generated in Bangladesh can potentially meet up to 17%, 15% and 10% of the N, P and K requirements of the principal crops, respectively although it is accepted that given the assumptions this may be a slight overestimation. In fact, it was found that compost products (e.g., purchased compost, cow-dung or any other type) are already used as a complement to NPK.

Given the weak supply chains for compost in Bangladesh, a new faecal sludge product could be marketed using the existing supply chains for NPK, rather than relying on the existing supply chains for compost. However, an awareness and information campaign will be needed to communicate to farmers the viability of making compost from faecal sludge, and its potential use in agriculture. Bangladesh has had experience in launching such national awareness and information campaigns with arsenic, and the lessons learnt from that experience may be transferred to this endeavor.

The price of a potential FS compost product would ultimately be determined by the existence of a reliable supply chain of raw materials; type of compost; the transportation and marketing strategy; the access to existing fertiliser/compost distributions networks; and by consumer segment. The expected price for FS compost could range from BDT 18-55 kg^{-1}, depending on the market segment; in particular, the most attractive markets for compost could potentially be horticulture businesses, nurseries and municipal parks.

Business model – Co-composting of Fecal sludge from Single Pit Latrines in Rural Bangladesh

In this section we recommend a potential business model for collection and 'treatment for reuse' of fecal sludge from single pit latrines. We propose as treatment solution the drying and co-composting of municipal solid waste (MSW) and fecal sludge. The complexity of Bangladesh rural setting with respect to the common high water table which makes on-site burial of fecal sludge in many locations risky and undesirable, combined with high population density and challenges of common trucks to access pit latrines, as well as the limited transportation capacity to transport fecal sludge to official treatment sites demands a solution that is specific to the region. The organizational scale of this model or the choice between centralized (upazilla level) or decentralized (union) treatment solutions is largely determined by the volumes which vary with scale, and so the transport costs, and required treatment capacities where the land requirements (size of drying beds) can be a major challenge.

The primary value proposition is to transform a mix of organic waste (organic portion of MSW and fecal sludge) into a high value fertilizer. Using a mix of organic resources has advantages for the composting process and final product quality. The business concept in brief is thus to collect the waste from households and commercial establishment on a fee for service basis and transport it to a treatment plant. Fecal sludge is dried on drying beds and co-composted with the organic portion of

MSW. The compost produced is sold to farmers, nursery, plantations, and municipalities or real estate for landscaping purpose. The primary revenue streams are from providing a waste collection service on fee basis and from sales of compost.

The cash flows needed to move and transform the fecal matter from its point of origin to its point of demand will thus have to build on opportunities in the interface of sanitation and agriculture, while taking account of the challenges of municipalities to provide sustainable waste management solutions, the currently still limited compost use, high public expenditure on fertilizer subsidies but also declining agricultural productivity from soil degradation.

To get a business model working in this context across the whole sanitation chain requires significant logistical modeling and budgeting to optimize resource flows, volumes and costs. Moreover, any business model recommended in this context cannot rely on one entity but requires a multi-partnership structure where partners are likely to serve different part of the sanitation value chain from pit emptying, transportation, treatment and market development of the reuse product. The different components are likely to involve (multiple actors of the) private and public sector, preferably regulated within a public-private-partnership (PPP).

The basic principle of reuse oriented fecal sludge management is to maximize the opportunities offered on one hand by (a) the willingness of households to invest in the removal of "fecal sludge as waste" and (b) the demand of farmers or plantations for "fecal sludge as resource", while to minimize the costs of sludge removal, transport, and transformation into a safe product. Depending on the distance between supply and demand or e.g. the cost of the treatment, subsidies will be needed as a third revenue stream to keep the system viable, but are likely economically justifiable by reduced health and environmental costs.

Thus this multi-partnership business model recommends a "push-pull" business model where key revenue streams can be initiated at both ends of the sanitation chain, i.e. the "push away" by households to incentivize the collection of fecal sludge and "pull" by a developing market to establish a reliable supply chain for sale of compost. Assuming a market niche, the pull factor can be a direct revenue for the treatment plant and will have to cover marketing. Our data from similar cases confirm that a breakeven is possible and could even reach profits depending on market demand and the value proposition (like tailored made compost pelletization).

The willingness to pay of the households, on the other hand, will likely be limited as so far it only covers desludging and on-site burial. Now it would have to finance also transportation off-site. Obviously, distance will become here a major challenge with a high risk of illegal dumping. Thus the business model needs to provide a range of decentralized transfer stations manned by a watchman where delivery is incentivized, ideally by the household fee (payment only against safe delivery receipt).

The gap in the finance model is the transport between transfer station and treatment site. This is, however, not only a financial challenge where the call for subsidies comes in, but also a logistical one. The volumes arriving at the transfer stations should not exceed the volume the treatment plant (and here in particular the drying beds) can absorb. This requires some process modeling based on desludging rates, available land, and time needed for drying and has to take care that the treatment plant capacity is well aligned with the number of households served to avoid illegal dumping. It is likely that the operation will only work at union scale for pairs of standard 200m^2 drying beds.

The "push-pull" business model offers thus a triple value proposition. The first value proposition is to provide improved waste management services on a fee for service basis that has associated benefits in safety for the concerned household. The second value proposition pertains to the compost product – producing high quality compost from the processing of MSW and fecal sludge for supporting agricultural production. The third value derives from reduced public health and the environment risks by incentivizing a transparent fecal sludge management process which so far is a grey and informal area.

Fecal sludge supply: Based on census data, the number of households per upazilas can vary for 20,000 to 150,000. If we assume that an average upazila has 45,000 households with 90% of households with single pit latrines, thus the number of pits per upazilas is about 40,000. Our research suggests that only 30% of households had emptied their pits at least once in 4 years. Based on this observation, if we assume that once every 4 years pits are emptied, which means annually about 10,000 households would empty their pits or ~28 households emptying their pits every day. Our household study suggests that the average pit holds 1 cubic meter. Thus the total volume of fecal waste 'harvested' per day is about 28 cubic meter at the upazila level. The scale of transfer stations, their sizes and those of treatment plant/drying beds, as well as the location of transfer station can be modeled based on the available sludge and transport costs.

Transfer stations & Treatment: The setting up of transfer stations do not yield revenue and incurs regular operation and management cost. We recommend government provide tipping fees which is calculated based on volume and transport distance (every transfer station is served) for delivering fecal sludge to treatment plant. Since the operations and management of transfer stations work closely with the treatment plant, we recommend that the entity managing the treatment plant is also in charge of managing transfer station.

Management of MSW is the responsibility of the government and it is suggested that the Governmental landfill sites will host the fecal sludge drying beds and co-composting stations. In urban and peri-urban regions of Bangladesh there are practices of government contracting collection, management and treatment of MSW to private sector. A similar structure of contracting management to private sector to manage transfer stations and treatment of fecal sludge combined with collection, transportation and treatment of MSW is suggested. In regions with existing institutional arrangement for MSW collection and treatment, we recommend banking on the set up and incorporate management of transfer station and treatment of fecal sludge. The business environment for private sector participation in waste management in Bangladesh is gradually developing in urban areas, however the same is not the case for rural areas where MSW collection is non-existent. To encourage private sector participation in rural areas, government need to establish institutional mechanisms for MSW collection, allocate land and provide capital subsidy to establish transfer stations and treatment plants which are relatively low cost investments in proven and robust technologies which do not require electricity. An alternative scenario for rural context in view of non-existential MSW collection mechanism, the treatment of fecal sludge can be combined with other organic waste generated in the region, for example – crop residue, livestock waste etc.

Market development: The strategy for sale of compost product should be that it is marketed to the most cost-effective customer segment to improve operations efficiency. Smallholders are unlikely to be the most cost-effective market because they purchase compost in smaller quantities with a limited ability to pay and the use of compost is variable between seasons and years. Our research also suggests that horticulture, nurseries and plantations purchase compost in bulk and are willing to pay ~ BDT 20,000 per ton. The transaction costs of targeting these market segments is low and could be borne by the segment itself if this simplifies supply.

The “pull” strategy of the business model is to develop a sustainable market and supply chain for compost which plays the most significant role in improving the cost recovery of the recommended “push-pull” sanitation business model. The various commercial enterprises supported by BRAC including agriculture can play key role in the “pull” strategy by developing the market and supply chain of fecal sludge based compost product. The BRAC model comprises of collaborative network of BRAC managed enterprises which are a support mechanisms to allow its development programs to be sustainable. BRAC manages multiple enterprises under the agriculture sector. These enterprises closely engage with individuals and commercial farmers who can become the key market for the compost produced. BRAC Tea estates alone can be the bulk purchaser of compost. BRAC tea estates enterprise has more than 4,000 acres of tea cultivation and has plans to increase its production up to 8,000 acres in the near future. Our research suggests that in Bangladesh, on an average 300 kg per acre of compost is applied per year and based on it, BRAC’s tea estates would consume about 2,400 tons of compost annually.

Role of BRAC, Government and Private Sector: As mentioned earlier, the business model mandates a multi-partnership “push-pull” strategy. To successfully implement the recommended business model, it is critical for BRAC to be the bootstrapping agency and drive the implementation of such a win-win model which lifts fecal sludge management out of its informality and mainstreams what is so far a health hazard transforming into a safe and valuable product. In this multi-partnership, BRAC, government and private sector has key role to play across the entire business value chain.

Depending on different scenarios of owner and operator across the business value chain, the role played by each entity can vary. A possible scenario for owner and operator structure in the recommended business model is as follows (see also Table 18).

- Pits are emptied by manual sweepers (usually micro enterprises) who transport the sludge to transfer stations which are operated by (see next bullet).
- A larger private entity is contracted by the Government to operate the transfer stations and the further transport of the fecal sludge to the drying and composting site, which could be the nearest landfill site. The Government would support this transport via tipping fees (function of volume + transport distance).
- The company in charge would ideally be the same also operating the MSW transportation and combined treatment to allow revenues from the compost sale to co-support the transport from the transfer stations as far as possible. The same private entity will enter with BRAC into contract to secure a reliable sales volume via bulk purchase from BRAC’s enterprises in the agriculture sector.
- The government owns the land for the transfer station and landfill/treatment site. It is responsible for establishing institutional mechanisms to make such a model operational and by providing a suitable business environment through necessary policy reforms.
- As a bootstrapping agent, for an initial pilot, BRAC could operate the compost station and its sales to analyse how far its enterprises could absorb the product. This will require demand analysis to tailor compost quality and packaging to customer needs. As operator of the compost station, BRAC would in this pilot also operate the transfer stations and transport which allows

to perform operational Cost-Benefit Analysis from the transfer station to compost sales, to fine-tune options for cost savings and revenue maximization, and estimate the amount of the tipping fee.

Future Research: It should be duly noted that within the scope of this research and in developing the business model, some of the aspects were not covered due to time and money constraints. The research does not provide a detailed financial assessment relevant to Bangladesh context. The pilot plant constructed under this research to test the technology was implemented at a very small scale and it cannot be extrapolated to mirror real time settings and the recommended business model. There is need to identify suitable scales for the model from supply to treatment and demand. This can be done via modeling based on similar work in other countries.

Table 18 Role of BRAC, Government and Private Sector in the business model

	BRAC	Government	Private Sector
Across the business model value chain	• *Bootstrapping agent:* Play the trailblazing role by using its existing infrastructure to set up a pilot fecal sludge treatment plant as a demonstration model to show it to donors and government for replicating in other parts of the country. • *Policy advocacy:* Advocate for a suitable environment to improve fecal sludge management via resource, recovery and reuse and ease of implementation of the business model	• *Policy environment:* Provide a business environment and level playing field to improve fecal sludge management through market based approach in rural Bangladesh and promote reuse. • *Subsidy:* Provide smart subsidies as required by the business model and any critical support necessary to make the business viable with the long term goal to ensure that its operations are based on market principles with improved operational cost recovery and lesser reliance on subsidy.	• *Fundraising & Partnership arrangements: Large private sector* raise appropriate financing and partnership arrangement to operate "push-pull" business model.
Pit Emptying and Transportation of Sludge	• *Best practices and guidelines:* BRAC should develop best practices and guidelines for safe pit emptying and advocate for mandatory scheduled desludging of pits. • *Awareness and Training:* Undertake training of manual sweepers to adopt safer practices of pit emptying and create awareness amongst manual sweepers and household on the benefits of disposal of sludge to nearest transfer station. In partnership with manual sweepers, identify strategic locations for transfer station.	• *Transfer station:* Involve BRAC and manual sweepers to identify strategic transfer station location. Allocate land and establish transfer station points in villages/municipality. In addition, the government should contract private entity to manage transfer station and collection of MSW. • *Tipping Fees:* Provide tipping fees to the operator managing transfer stations to deliver the sludge to treatment plant. The fees should be a function of volume and transport distance.	• *Pit Emptying:* Manual sweepers to empty pit and transport the sludge to nearest transfer station • *Management of transfer stations:* Operating the transfer station and transport sludge to treatment plant • *MSW Collection:* Private entrepreneur should ensure collection and transportation of MSW from household and businesses.
Co-Compost Treatment plant	• *Policy Advocacy:* Advocate for treatment for reuse and not just treatment alone and promote investment that focus on both fecal sludge and MSW treatment to make co-compost. • *Technical support:* Using the research results, BRAC should provide necessary technical knowledge and necessary capacity development measures for establishing such a treatment plant.	• *Treatment Plant:* Allocate land, provide capital subsidy and contract the same private entity in charge of managing transfer stations to operate the treatment plant.	• *Operations of treatment plant:* Smooth operations of the treatment plant to ensure production of compost that meet Bangladesh standards
Reuse & Market	• *Market Development:* Using its existing infrastructure and sister concerned organisations in the agriculture sector, BRAC should assist to develop markets and supply chain for sale of compost product. • *Policy Advocacy:* Advocate for promotion of reuse of fecal sludge in Bangladesh regulations. Improve regulations for easing compost certification and create a level playing field in comparison to subsidy provided for fertilizers.	• *Price support for Compost:* IPNS strongly promotes usage of both compost and chemical fertilizer, however government provides subsidy for chemical fertilizer. A level playing field needs to be created where compost and chemical fertilizer are provided equivalent price support.	• *Marketing, Branding and Product Sales:* While BRAC leads the market development of compost, private entrepreneur needs to undertake marketing, branding and sale of compost through other channels

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