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Training Manual for Fecal Sludge-based Compost Production and Application

Josiane Nikiema, Robert Impraim, Olufunke Cofie, Eric Nartey, Nilanthi Jayathilake, Felix Thiel and Pay Drechsel

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Resource Recovery and Reuse (RRR) is a subprogram of the **CGIAR Research Program on Water, Land and Ecosystems (WLE)** dedicated to applied research on the safe recovery of water, nutrients and energy from domestic and agro-industrial waste streams. This subprogram aims to create impact through different lines of action research, including (i) developing and testing scalable RRR business models, (ii) assessing and mitigating risks from RRR for public health and the environment, (iii) supporting public and private entities with innovative approaches for the safe reuse of wastewater and organic waste, and (iv) improving rural-urban linkages and resource allocations while minimizing the negative urban footprint on the peri-urban environment. This subprogram works closely with the World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Programme (UNEP), United Nations University (UNU), and many national and international partners across the globe. The RRR series of documents present summaries and reviews of the subprogram's research and resulting application guidelines, targeting development experts and others in the research for development continuum.

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The authors

Dr. Josiane Nikiema is a senior researcher at the International Water Management Institute (IWMI) and is based in Accra, Ghana. She has a PhD in chemical engineering from the Université de Sherbrooke, Canada. Her fields of expertise include domestic wastewater treatment and reuse, recovery of nutrients and organic matter from fecal sludge and organic solid waste, and testing business models for safe resource recovery and reuse.

Dr. Olufunke O. Cofie is a principal researcher with a background in soil science. She heads IWMI's West Africa office in Accra, Ghana, and has worked over the past 15 years on the interface of sanitation and agriculture.

Mr. Robert Impraim has an MSc in crop science and was a research officer for recycling and reuse at IWMI's Ghana office. He is currently a PhD student at the University of Melbourne, Australia.

Mr. Eric G. Nartey has an MSc in environmental science. He is a research officer for recycling and reuse at IWMI's Ghana office.

Mrs. Nilanthi Jayathilake has an MSc in environmental engineering and management. She is a research officer for septage management and reuse at IWMI headquarters in Colombo, Sri Lanka.

Mr. Felix Thiel (formerly Felix Grau) has an MSc in agricultural sciences. He is a PhD student at Ruhr University Bochum, Germany, working on Fortifer use in agriculture at IWMI headquarters in Colombo, Sri Lanka.

Dr. Pay Drechsel is a principal researcher at IWMI, Colombo, Sri Lanka, coordinating projects in the interface of agriculture, waste management and sanitation.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

ACRONYMS AND ABBREVIATIONS

BOD	Biological oxygen demand
C	Carbon
Cd	Cadmium
cm	Centimeter
C:N	Carbon to nitrogen ratio
COD	Chemical oxygen demand
Cr	Chromium
Cu	Copper
DFS	Dewatered fecal sludge
ECN	European Compost Network
EPA	Environmental Protection Agency
EU	European Union
FS	Fecal sludge
FSM	Fecal sludge management
Hg	Mercury
K	Potassium
kg	Kilogram
L	Liter
mm	Millimeter
MoFA	Ministry of Food and Agriculture (Ghana)
MPN	Most probable number
MSW	Municipal solid waste
MT	Metric tons (tonnes)
N	Nitrogen
N/A	Not available or not applicable
Ni	Nickel
OC	Organic carbon
O&M	Operation and maintenance
P	Phosphorus
Pb	Lead
PPE	Personal protective equipment
PPRSD	Plant Protection and Regulatory Services Directorate (Ghana)
TK	Total potassium
TM	Trademark
TN	Total nitrogen
TP	Total phosphorus
TRC	Technical Review Committee
TS	Total solids
TSS	Total suspended solids
WHO	World Health Organization
Zn	Zinc

SUMMARY

Fecal sludge (FS) from on-site sanitation systems has to be well composted to reduce its pathogenic risk for reuse in agriculture, forestry or landscaping. Over the last decade, the International Water Management Institute (IWMI) has explored the use of FS in combination with other organic waste sources to optimize the FS treatment and composting or co-composting process for the production of a safe organic fertilizer, which can – depending on demand – be enriched with crop nutrients or pelletized for volume reduction, delayed decomposition or easier application.

Based on IWMI's experience, in particular in the Accra-based *'Fortifer'* production plant, this training manual has been compiled for plant managers and trainers to help ensure that staff involved in FS treatment and production, and application of an FS-based co-compost adopt best practices in all processes involved. The manual can be adapted to local needs as required. 'Best practice' in this context comprises aspects related to health and environmental safety as well as technical knowledge related to operation and maintenance. The manual comprises the steps needed as well as the 'do's and don'ts' for the following topics: safety measures and compliance, FS reception and the use of drying beds, selection of appropriate co-composting materials, the composting process, product enhancement (enrichment, pelletizing), labeling, recording and storage. The manual also includes information on compost registration and certification, as well as guidelines for co-compost application in the field.

1. INTRODUCTION

Recovering nutrients from organic waste makes particular sense in tropical regions where soils are commonly highly weathered and of inherent low fertility. In Ghana, for example, an additional 168,600 metric tons (MT) of plant nutrients per year are required to meet the growth targets for all major crops identified in the country's Agriculture Sector Investment Plan as soils are infertile and only productive with proper management (FAO 2005; IFDC 2012). Given high fertilizer prices, the recovery of nutrients from unavoidable food waste and human excreta should be paramount. Resource recovery would also reduce the amount of waste released unproductively into the environment. In the Greater Accra Region, for instance, poor fecal sludge management (FSM) results in estimated annual losses of 18,200, 2,200 and 4,900 MT of nitrogen (N), phosphorus (P) and potassium (K), respectively, which pollutes groundwater and surface water resources (Nartey et al. 2016).

While there is good reason for hesitation in recovering nutrients from sewage sludge (which derives from treatment plants that receive sewage from various sources, including potentially industrial and toxic ones), most excreta in low-income countries are not mixed with other wastewater in sewers, but are collected at the household level in tanks or latrines. These on-site sanitation systems are not only common in rural areas, but also serve over 2.7 billion urban dwellers globally, either at the individual household level or through shared facilities such as public toilets (Cairns-Smith et al. 2014). Such installations, including pit latrines, aqua privies and septic tanks, must be emptied on a regular basis, commonly by vacuum trucks.

Fecal sludge (FS) from on-site systems is a mixture of human excreta usually diluted with flush water and toilet paper, and sometimes other (household) waste types such as sponges, bones, plastics and sand. The characteristics of FS are highly variable from country to country and, within the same country, depending on the origin and type of the sanitation facility being used. If we consider the physical properties of FS only, two main types can be distinguished:

- Low strength (flushing water-diluted) FS usually comes from households' septic tanks. It is often stabilized (digested) due to its age (at least one to three years old) and therefore is dark brown or black. It contains from less than 1% up to 3% of total solids (TS).

- High strength (concentrated) FS is often obtained from public toilets, bucket latrines or any pour-flush or non-flush sanitation facility. This type of FS contains more than 3% of TS. It is yellowish or brown when it is less than a year old (Nikiema et al. 2014).

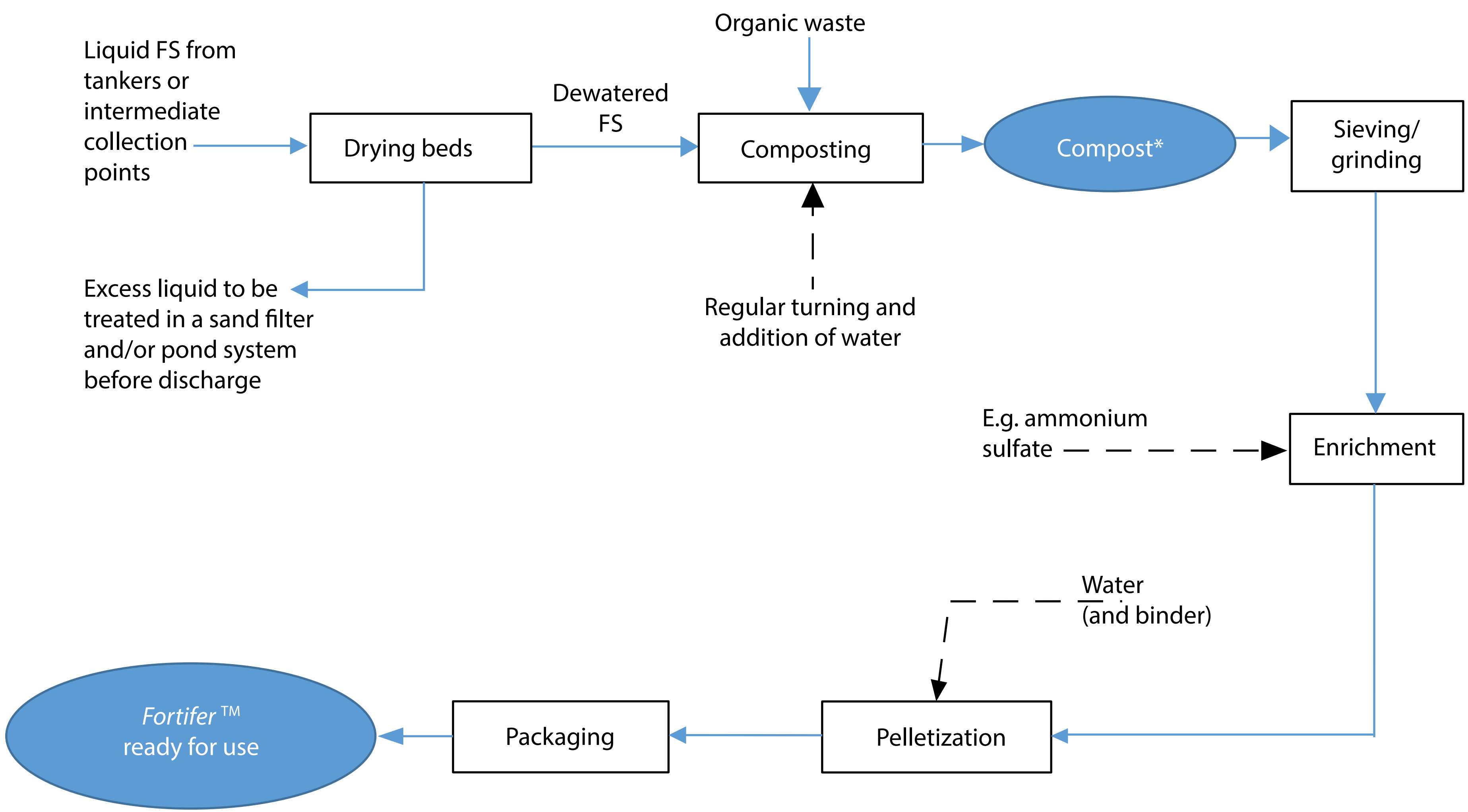
Over the last decade, the International Water Management Institute (IWMI) has explored the use of FS in combination with different organic waste sources to optimize the recycling of nutrients and organic matter for crop production through dewatering, co-composting, enrichment (e.g., with mineral fertilizer) and pelletization (Nikiema et al. 2014; Cofie et al. 2016). This resulted in the development of the *Fortifer* product, i.e., a 'fortified' (enriched) organic fertilizer (Figure 1). In this context, co-composting means that the FS has been composted together with another organic waste, like food waste from markets. *Fortifer* is trademark-registered in Ghana and has been approved for farm use by Ghana's Ministry of Food and Agriculture (MoFA). The production plant is located in the Greater Accra Region of Ghana (Figure 2).

This training manual should help to ensure that staff involved in the sourcing, production and application of a FS-based co-compost, like *Fortifer*, adopt best practices in all processes. The manual can be adapted to local needs as required.

'Best practice' in this context comprises aspects of health and environmental safety as well as technical knowledge related to operation and maintenance (O&M).

IWMI encourages the (commercial) production of co-compost and fortified co-compost under any name. The brand name *'Fortifer'* is only officially registered with a trademark (™) in Ghana. As IWMI is required to trace the impact of its work, any use of this training manual or any other publication by the Institute, as well as the adoption of the *'Fortifer'* trademark should acknowledge IWMI following the creative commons condition of attribution.

FIGURE 1. THE *FORTIFER* PRODUCTION PROCESS.



* Compost or co-compost can be used without any further treatment or be enriched and/or pelletized.

FIGURE 2. THE *FORTIFER* PRODUCTION PLANT, GREATER ACCRA REGION, GHANA, BEFORE BEING COMMISSIONED IN MAY 2017.

2. SAFETY FIRST (MEASURES AND COMPLIANCE)

Handling FS and other organic waste sources demands strict compliance with safety regulations, which should be the first item on the agenda of any FS-related training unit. The main risks identified in the *Fortifer* co-composting process are:

1. FS contains pathogens that may pose health risks to humans if safe handling and processing procedures, including hygiene standards, are disregarded.
2. Environmental risks from poor treatment of the drainage water derived from the FS drying beds, such as eutrophication of water bodies, or an increase in antimicrobial resistance.
3. Organic wastes from markets may contain pathogens, but also other contaminants like glass, which may have harm handlers if safety measures are neglected.
4. Operations related to drying beds, composting and machinery usage may expose workers to potential occupational risks, including dust and odor.

Under these circumstances, staff must:

- Wear suitable personal protective equipment (PPE).
- Wash their hands with soap during breaks and immediately after work or take a bath/shower.

Supervisors must provide:

- Well-fitting PPE, handwashing facilities, soap, towels, sanitizers, and separate shower places and toilets for workers of different gender.
- Incentive systems for safety compliance that can include rewards (e.g., best worker of the month) as well as a two-to-three step warning and fine system for disregarding regulations.
- A cool working space with shade and sufficient ventilation because wearing PPE can be uncomfortably hot.

PPE	Risks addressed	When/where	Recommended attire
 Wellington boots	Feet contact with pathogens/ liquid waste/dangerous materials.	All locations on site.	
 Goggles	Eye contact with particles, dust and or liquids generated by machinery or through laboratory operations.	All sites near machinery or compost piles; use goggles which fit over spectacles.	
 Hand gloves	Manual contact with pathogens, sharp objects.	All locations on site.	
 Overalls	Bodily contact with pathogens, dirt.	All locations on site.	
 Face mask	Inhaling particles, dust and odor.	All locations on site.	
 Helmet	Injury from falling objects.	Where heavy equipment is being used.	

3. DRYING OF FECAL SLUDGE

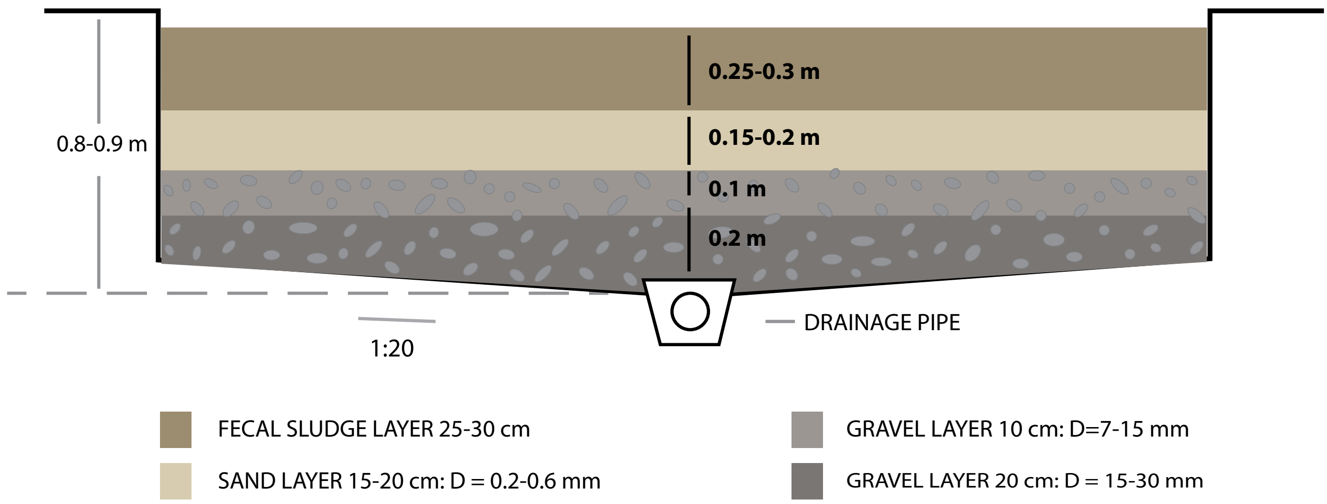
FS that is used for co-composting should have a moisture content of less than 70%. However, FS collected from household septic tanks is usually very watery (through flush water) with a moisture content of over 90%. Dewatering of the liquid FS is therefore required and this can be achieved through various mechanical or nonmechanical mechanisms (Nikiema et al. 2014). This manual focuses on the use of sand **drying beds** (Figure 3) for dewatering of liquid FS.

FIGURE 3. AERIAL VIEW OF FOUR DRYING BEDS BEFORE LOADING WITH FS AT THE *FORTIFER* PRODUCTION PLANT, GREATER ACCRA, GHANA.

3.1 Preliminary Work

Drying beds, such as those constructed at the *Fortifer* treatment plant in Ghana, involve the use of sand and gravel layers for dewatering and producing about 19 MT of dewatered fecal sludge (DFS) per 1,000 m^3 of fresh FS (Figure 4).

FIGURE 4. DRYING BED LAYERS.



Source: Cofie et al. 2006.

The surface of a currently unused drying bed should be in optimal sludge-receiving condition. For this, the sand layer of the drying bed should remain friable and porous to ensure rapid dewatering, as 50% to over 75% of the water in the FS is removed through percolation, the rest being lost to evaporation. Apart from protecting the sand against compaction, the bed surface must be even and neat, with no presence of foreign materials, i.e., it must comprise sand only.

Do	Do not
— Check that drains and grids are not blocked with waste. — Properly dispose of foreign materials collected from the drying bed by sending them to a designated waste disposal site.	— Leave cleared weeds, stones, plastic sheets/bags and other foreign materials close to the drying bed. — Use heavy equipment in preparing drying beds to avoid surface compaction.

Weed management: In principle, weeds should **not** grow on a drying bed. Weed growth may happen when the drying bed remains unused and unattended to. It is a sign that routine maintenance is insufficient. The operator should prevent this from happening. Weed seeds can enter the compost and remain viable if composting is not done efficiently (temperatures of 50 °C and above are lethal to most seeds). This could cause problems for the purchaser and damage your reputation as a source of quality compost products. To test composts for their weed seed germination, see Box 1.

The test of weed regrowth should not be mistaken for the more common seed germination test for compost phytotoxicity (Box 2).

Description of the process	
	• If applicable, the weeds/grass should be gently scooped. • Ensure minimal disturbance of the sand/gravel layer. • Do not use weedicides as the compost should be free of contaminants.
	• Collect the weeds and remove them. • Such organic waste could be co-composted.

BOX 1. WEED SEED GERMINATION TEST.

Residual seed viability should be tested for each batch of finished compost that you intend to offer for sale. Use the following procedures to test for weed seeds.

- Take a sample of at least 4 liters (L) of compost.
- Moisten the compost sample to 60% moisture.
- Fill a seeding tray, preferably two, with the sample to a depth of about 1-1.5 inches and record the total liters used, along with identification of the compost batch and date.
- Place the seed tray in a warm location with decent light, where the temperature is maintained at or above 21 °C.
- Maintain soil moisture – before sprouting begins (a moistened cloth or paper towels placed on the compost surface helps to maintain the moisture level).
- Once sprouting begins, place the trays in full sunlight or under lights if necessary.
- Maintain sprouting conditions for at least three weeks.
- Count total sprouts found and divide by the liters of compost used.
- Record the results along with any observations, such as types of weeds that germinate.

Internationally, weed content tolerance ranges from 0.8 to 5.0 seeds per liter of compost. Some European countries have a legal requirement to test commercial compost products for weed seed germination. Denmark's voluntary standard includes three content levels, which provide a useful benchmark for the kind of results to find:

Very low: Less than 0.5 seeds and plant parts per liter compost
Noticeable: Up to 2.0 seeds and plant parts per liter compost
High: More than 2.0 seeds and plant parts per liter compost

Source: Vermont Department of Environmental Conservation (https://cutt.ly/1wHNePH)

BOX 2. SEED GERMINATION TEST FOR COMPOST TOXICITY.

Compared with the test for weed regrowth from still living weed seeds in the compost (Box 1), the seed germination test requires the addition of fresh seeds into the finished compost to see if it is not phytotoxic. This could be caused through certain pesticide residues or heavy metals, excessive ammoniacal nitrogen, a high pH, salts or organic acids. Common test criteria are (i) seedling emergence, and (2) seed vigor.

The test can be done, for example, with cucumber, radish, cress, or Chinese cabbage seeds, planted in a 1:1 compost/vermiculite soil and moistured with distilled water. A control without compost is important.

% Emergence = 100 x number of emerging seeds divided by the number of planted seeds. A rough assessment could be >90% = Very Mature; 90-80% = Mature; <80% = Immature.

Measure again after 10-14 days for seedling vigor, for example, via the hypocotyl length (the stem of a germinating seedling, between root and seed leave) or the fresh weight of the shoot.

% Vigor = 100 x number of seedlings with well-developed structures in compost divided by the number of seedlings with well-developed structures in the control soil. A rough assessment could be >90% = Very Mature; 90-80% = Mature; <80% = Immature

Another test could be to compare seed germination rates (days) in compost extract solution vis-à-vis the germination rate in deionized water.

In case the seedlings perform below expectation, analyze the compost for its salinity, etc., to understand why the germination test results were low.

Source: Test Methods for the Examination of Composting and Compost, The U.S. Composting Council. http://www.extsoilcrop.colostate.edu/Soils/powerpoint/compost/seed_germination.pdf

Tools	
Hoe	To remove weeds
Rake	To pile the foreign materials on the bed
Spade/shovel	To put the foreign materials into a wheelbarrow
Wheelbarrow	To carry the materials to the disposal site

Description of the process

Use a rake to gently remove all foreign (nonsand) materials on the drying bed. These may include stones and old DFS from previous drying. This also loosens up the drying bed surface and enhances water infiltration. A clean drying bed ready to use is shown on the right.

Maintenance and troubleshooting

Problem photographs	Issue	Solution
	This depression results from pressurized FS feeding directly onto the drying bed surface which disturbed the layers of the bed.	**Restore the gravel/sand layers.** Rebuild gravel and sand layers, depending on the depth of the depression, under professional supervision.

Maintenance and troubleshooting

Problem photographs	Issue	Solution
	The sand layer is less than 10 cm strong so the underlying gravel layer becomes visible.	**Top-up with sand.** At least 10 cm of sand layer is required. Ensure the ground is levelled.
	Cracks appear on the structure of the drying bed resulting in leakage of FS.	**Restore with mortar** to avoid spillage of FS.
	Small tree stumps in the drying bed.	**Any plants should be removed when their root systems are still shallow.** Roots should be removed with care and under professional supervision as both the roots and their removal may disturb the bed gravel layers and filter characteristics of the bed.
	Grass growing on the drying bed surface.	**Quick action is required.** The grass should be removed immediately as described above for weeds.

3.2 Feeding of the Drying Bed

After adequately preparing the drying bed, it can be fed with FS. Given that FS from public toilets with little flushing water can be very concentrated, a mix of FS sources is recommended to homogenize the feedstock and optimize the drying process (Table 1).

TABLE 1. TYPICAL EXAMPLE OF DIMENSIONS RELATED TO FS DRYING BEDS.

Material input	
The ratio of household septage to public toilet septage (volume) of about 2:1	2:1
From public toilets (m^3 $year^{-1}$)	4,000
From households (m^3 $year^{-1}$)	8,000
Total volume of liquid FS (m^3 $year^{-1}$)	12,000
Drying bed size (m^2)	Ca. 240
Drying bed load (m^3 liquid FS) per drying cycle and bed	Ca. 70-90
Drying time (days), function of infiltration (sand quality) and evaporation (weather)	7 to 21
Amount (MT) of DFS obtained from 12,000 m^3 of liquid FS	228

Source: IWMI 2017.

Transport of FS to the plant is usually done by vacuum trucks (honey suckers). Due to the high pressure with which the FS exits the vacuum truck, the sludge should be discharged into a concrete receiving chamber and **not** directly onto the drying surface in order to prevent disturbance to the filter layers. The chamber also allows the use of a grid to filter materials which should not enter the drying beds, like plastic bags (Figure 5). Tubes and valves connect the mixing chamber with the drying beds on the right of Figure 5.

Tools	
Hose	To connect the truck to the feeding area of the receiving chamber

FIGURE 5. RECEIVING AND MIXING CHAMBERS OF THE 'FS FEEDING AREA' WITH A GRID FOR COARSE CONTAMINANTS.

Description of the process

Step 1: Position the truck, connect the hose to the truck and open the FS valve to desludge into the receiving chamber.

- The liquid FS will start flowing into the receiving chamber. Trucks bringing different FS types should alternate, resulting ideally in one-third of the trucks with denser public toilet FS and two-thirds with more watery FS from households.
- Start the pump to channel the grid-filtered FS into the mixing tank.
- The mixing tank should allow mixing of the available types of FS (e.g., from public toilets and households).
- Clean the receiving chamber and its grids daily or when the accumulation of waste becomes excessive.

Step 2: Feed the drying beds from the mixing tank.

- Open the valve of the mixing chamber and feed the FS into the drying beds (as each drying bed has its own valve, the FS can be channeled to a particular bed).
- Typically, each drying bed of about 240 m^2 will be fed with 70-90 m^3 of FS.
- After feeding, the level of FS on the drying bed should not exceed a height of 30 cm to avoid overflow and to facilitate the dewatering process.
- Each drying bed should be filled within 48 hours.

Description of the process

Step 3: Resting (drying) period.

- Stop the feeding of fresh FS onto the bed.
- Allow the dewatering process to take place. The filtration step lasts for 2-3 days in general when the FS is already stabilized. Then evaporation becomes the dominant dewatering method.
- Depending on weather conditions and type of sludge, this may require 7-21 days.
- Leachate from drying beds has to be collected and requires further treatment to meet standards for safe discharge.

Step 4: Rain will decelerate the dewatering process and increase the drying bed leachate volume, affecting the related treatment capacity. If the drying beds are not under a high roof, manual covering of the drying bed (see photograph) is recommended.

- Before leaving the production site at the end of the working day during the rainy season, all drying beds must be covered, if possible, to minimize the risk of rain affecting the drying process.
- Upon resuming work in the morning, the drying bed covers should be removed for sun exposure.
- During the day, in the event of rainfall, staff should temporarily cover all drying beds.

Do

- Feed the drying bed with a blend of FS, from both private (household) or (public toilet) on-site facilities. The recommended ratio is 2:1 for private household to public FS.
- Record the volume and characteristics (type of FS, age, origin, etc.) of FS being emptied onto each bed.
- Ensure the bed is not overfed or underfed.

Do not

- Feed the drying bed with sludge from hazardous sources, i.e., from hospitals, industries or similar operations. This could result in poor co-compost quality with high levels of contaminants, such as heavy metals.
- Discharge the FS from the truck directly onto the drying bed surface.

- Walk on the drying bed surface during the drying process.
- Allow FS to overstay on the drying bed.
- Add fresh FS onto partially dried or dried FS.
- Allow large volumes of FS to accumulate in the receiving tank for long periods.

Maintenance and troubleshooting	
Issue	**Solution**
Cleaning of the grids	Grids are installed in the receiving chamber to retain the foreign materials present in the FS. To allow continuous flow, the grids must be cleaned at least once per day or as much as needed.
Excess feeding	The height of FS on the drying bed should be about 30 cm after feeding is completed. Excess loading rates may result in prolonged and ineffective drying. During the feeding process, workers must regularly check that the level of the FS in the drying bed stays within the limit.

3.3 Removal of the Partially Dewatered Fecal Sludge from the Drying Bed

The FS should be removed from the drying bed when the sludge surface shows cracks using a spade or shovel or any other suitable equipment. The equipment used for the removal should not compact the drying surface. The barest minimum of sand should be removed along with the DFS in the process. It is important to ensure that the surface of the drying bed is not disturbed during the DFS removal process.

The DFS is not 'dry' in the sense of zero water as it still contains about 50-60% of water.

In Ghana, 1 m^3 of raw mixed FS generates about 0.02 MT of DFS. A drying bed of about 240 m^2 and a load of about 100 m^3 thus generates about 2 MT of DFS. The removal of these 2 MT of DFS from one drying bed will require about three hours by two laborers.

Tools	
Spade	To scoop out the DFS
Wheelbarrow	To carry the DFS to the co-composting area
Polypropylene bags or any other type of bag that is suitable and available	In case the DFS must be stored

Description of the process

Removal of DFS from the drying bed.

- When cracks develop on the surface of the sludge, this is an indication that the sludge is sufficiently dewatered and can be removed.
- The moisture content at that point in time is about 50-60%.
- Sludge removal involves the collection of all DFS and transporting it to the co-composting site, or collecting, bagging and loading the vehicle if the drying site is far from the co-composting plant.

Description of the process	
	Step 1: Extraction of DFS lumps. • Remove the DFS manually using a spade. • With a wheelbarrow, transport the DFS to the co-composting site, if the drying beds are close by.
	Step 2: Transporting DFS to the co-composting platform. • As much as possible, the DFS should be co-composted immediately after removal from the drying beds. • Moist DFS should be co-composted within two days to avoid creating anaerobic pockets (with odor). • DFS with low moisture content (less than 40%) may generate dust during handling.
	Step 3: Extended storage in bags. • As much as possible, DFS and compost production should be aligned to minimize DFS storage. • Only adequately dried FS (≤ 40% moisture content) can be bagged (e.g., in polypropylene bags) and stored in a low-moisture and UV unexposed area. • The DFS contains pathogens. Therefore, handling of the waste should be done carefully. • Each DFS bag must be properly sealed and labelled before storage to avoid cross-contamination with matured compost. • Note the expiry date of woven polypropylene bags, which might be around 12 months.

Do	Do not
- Allow FS to be sufficiently dried (i.e., when it shows cracks, it can be easily removed from the sand surface) without excessive sand collection. - Opt for manual DFS collection to minimize sand removal and bed compaction.	- Remove excessive amounts of sand with the DFS. Presence of sand in co-compost lowers its quality and increases wear, e.g., of the pelletizing machine. - Use heavy equipment/machines to remove DFS from the drying bed. - Disturb the drying bed surface and layers during DFS removal.

Maintenance and troubleshooting		
Problem photograph	**Issue**	**Solution**
	Old bags are rotting, releasing the DFS.	Replace the bags in time to avoid spillage of DFS. **Remember:** At this stage of the process (without composting), the DFS still contains pathogens. Therefore, handling of the waste should be done carefully.

3.4 Final Work on the Drying Bed

Following collection of the dried FS, the drying bed needs to be prepared for a new cycle of drying. Therefore, all foreign materials remaining on the drying bed need to be collected (see section 3.1).

Do	Do not
- Remove any remaining waste from the drying bed. - Top-up the sand if needed.	- Leave waste on the drying bed. - Allow weeds to grow on the drying beds.

Maintenance and troubleshooting	
Issue	**Solution**
Sand is gradually lost after continuous drying cycles.	Once a year, a layer of sand should be added on top of the drying bed to cater for loss and to maintain good filtration ability. The exact amount should be locally determined (measuring the depth of the sand layer) as sand loss depends on various factors, including the frequency of use of drying beds, the DFS removal system and so forth.

4. CO-COMPOSTING OF THE DFS

Compost preparation from a blend of two or more organic feedstocks of different nature is termed co-composting. DFS can be composted alone, but unnecessarily high losses of the most valuable plant nutrient (nitrogen) will occur due to the relatively narrow carbon to nitrogen ratio (C:N) of DFS (see below). Therefore, co-composting with another organic waste that is rich in carbon is recommended. For example, this can be food waste, straw or sawdust, but not farmyard or poultry manure. A mass ratio of 3:1 (food waste to DFS) is the combination used in this manual (Table 2).

There are different types of composting systems which are described in detail by Cofie et al. (2016). In this manual, the heap (or pile) composting system will be addressed.

TABLE 2. TYPICAL EXAMPLE OF DIMENSIONS RELATED TO DFS CO-COMPOSTING.

Material input	
Target ratio of organic market waste to DFS	Ca. 3:1
Amount of DFS obtained from 12,000 m^3 of mixed liquid FS (in MT; see Table 1)	228
Required volume of organic waste (sorted food waste in MT $year^{-1}$)	Ca. 700
Total amount of waste (DFS and organic waste) to be co-composted (MT $year^{-1}$)	928
Single compost heap mass on co-composting day 0 (MT)	2-3
Duration of co-composting (weeks)	At least 12
Co-composting process	
Weight loss during co-composting (%)	40-50
Maximum amount of co-compost produced (MT $year^{-1}$)	464
Amount of DFS to be processed per 12 weeks (MT)	55
Amount of organic waste to be processed per 12 weeks (MT)	165
Production unit dimensions	
Waste sorting and storage bay total surface area (m^2)	400
Composting platform total surface area (m^2)	1,200
• **Thermophilic stage (m^2)**	740
• **Intermediate stage (m^2)**	150
• **Maturation area (m^2)**	310

Sources: Data obtained or extrapolated from earlier IWMI research, such as Nikiema et al. 2013, 2014; Cofie at al. 2016; Adamtey 2010.

4.1 Selection of Suitable Organic Waste

The feedstock to complement DFS should be carefully selected. Generally, a blend of feedstock is more likely to provide optimum conditions for composting than a single feedstock. Moreover, single feedstock is only common in agricultural and timber industries, and not among urban domestic or market waste sectors. The general rule is that the added organic waste should not have contaminants (such as high levels of heavy metals) while showing an appropriate carbon content for an optimal C:N ratio after feedstock mixing (Table 3). Microorganisms that digest compost need about 30 parts of carbon for every part of nitrogen they consume. If there is too much N, such as in manure (a low C:N ratio), the microorganisms cannot use it all and the excess N (over 60%) can be lost in the form of noxious ammonia gas. If the C:N ratio is too high (excess carbon), decomposition slows down.

Wastes that can be potentially used in co-composting

Municipal wastes (organic fraction: 60-95%)

Household/food waste

Market waste

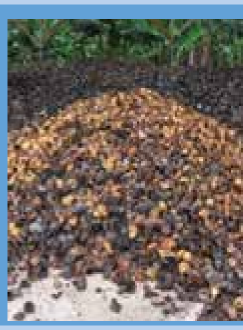
DFS

Agro-industrial wastes (organic fraction: > 95%)

Empty fruit bunches

Rice husks

Sawdust



Cocoa pod husks

TABLE 3. COMMON C:N RATIOS OF SELECTED ORGANIC WASTE SOURCES.

Feedstock	C:N ratio
High in carbon	
Wood chips	400-700:1
Cardboard (shredded)	350:1
Sawdust	325-500:1
Newspaper (shredded)	175:1
Pine needles	80:1
Straw	75-90:1
Corn (maize) stalks	60-75:1
Leaves	60-80:1
Rice straw	60:1
Peanut shells	35:1
Garden waste	30:1
Fruit/market waste	25-40:1
Relatively high in nitrogen	
Ash, wood	25:1
Vegetable scraps	25:1
Clover	23:1
Coffee grounds	20-25:1
Food waste	17-20:1
Grass clippings/fresh weeds	17-20:1
Seaweed	19:1
Livestock manure	15-20:1
Alfalfa	12:1
DFS	7-10:1
Mature poultry manure	7:1

Sources: https://www.planetnatural.com/composting-101/making/c-n-ratio/; http://www.homecompostingmadeeasy.com/carbonnitrogenratio.html and unpublished IWMI data.

Annex 1 presents other typical characteristics of co-compost feedstock in Ghana and Burkina Faso.

Maintenance and troubleshooting		
Problem photographs	**Issue**	**Solution**
	Contamination of feedstock: The organic material contains contaminants such as batteries, medications, fats / oils / grease, and colored paper, with potentially toxic elements or material that will disrupt smooth composting.	Waste that was presorted at source should preferably be used as feedstock. Alternatively, sorting before composting is required. Eggs and meat might not compost but could rot, and the smell would attract animals.
	Compost pile stinks: There are several reasons that affect the expected microbial activities: the compost is too wet, it is compacted with low oxygen levels, it contains rotten meat, eggs or fats, or the C:N ratio is too low and nitrogen is lost in the air in the form of ammonia gas.	Maintain a C:N ratio of somewhere around 25 to 30 parts carbon to one part nitrogen (or 25-30:1); turn the compost pile regularly to keep it well aerated; do not add too much water.

4.2 Sorting of Organic Waste

If the additional organic waste is obtained from markets or households, it usually contains a mix of compostable and non-compostable materials, such as plastics. To a lower extent, this is also the case where the organic waste has been separated at the household or market level. To remove non-compostable items, the waste has to be spread on a platform. Spreading on a sun-exposed concrete platform has the additional advantage of allowing fresh (fruit and vegetable) waste to lose some water, which might otherwise negatively affect the composting process (more leachate; anaerobic conditions).

Tools	
Shovel	To collect and handle the organic waste
Wheelbarrow	To transport the waste
Rake	To spread the organic waste on the platform and turn it regularly
Pickaxes, machetes	To shred organic waste into smaller pieces
240-L dustbin	For plastics, etc.
Water hose	For wet cleaning of the platform
Broom	For sweeping

Whereas too little moisture (<30%) inhibits bacterial activity, too much moisture (>65%) results in slow decomposition as well as odor production in anaerobic pockets. The moisture content of compostable organic materials ranges widely from waste newspapers (5%) to fruit and vegetable waste (80-90%).

Description of the process	
	Step 1: Spread the organic waste on the sorting platform using rakes. • All organic solid wastes arriving at the plant should be deposited on the concrete platform at the sorting bay. • Record the volume and/or weight of waste. • Remove the bags/sacks which contained the waste. • The height of the waste on the platform should be 10 cm or less to minimize anaerobic conditions and odor generation.
	Step 2: Sorting of the organic waste. • Manually remove nonorganic materials using standard PPE. • Safely collect and dispose of the undesired fractions which should subsequently be sent to the landfill.
	Step 3: Dewatering/resting period. • Leave the organic solid waste with high moisture on the platform to be slightly dewatered. • Use a rake/spade to turn lower and upper parts once a day. • The ‘dewatering’ period ends when there is **no free** moisture visible, which might be after 1-2 days. • Extended exposure to sun (or rain) will negatively affect composting. • Possible leachate might evaporate.
	Step 4: Shredding of organic waste (optional). • Shredding or crushing allows a reduction in particle size of the organic waste. The increased surface area exposed to microbial degradation will reduce the co-composting period. • Shredding can be done mechanically or manually. • The recommended particle size for co-composting is about 5 cm (or 2 inches). • Excessively fine particle size may impede the co-composting process through inhibition of aeration.

Description of the process	
	Step 5: Transport to the co-composting area. • Use rakes, shovels and wheelbarrows to collect the organic waste and send it to the co-composting platform.

Do	Do not
- Remove all plastics and undesired waste before co-composting. - Record the initial volume or mass of the feedstock used. - Use mesh to protect the platform from the intrusion of birds and other animals.	- Over-shred the waste to be co-composted. - Leave solid waste on the platform for unnecessarily long periods.

Maintenance	
Cleaning	Safely dispose of the unwanted solid waste at a designated disposal site.

4.3 Sorting of the DFS

The DFS should be sorted well and broken into smaller pieces (2 inches or 5 cm).

Tools	
Spade	To collect and handle the waste
Wheelbarrow	To transport the waste
Rake	To spread the organic solid waste on the platform and turn it regularly for partial dehydration
Pickaxes, machetes or shredders	To shred the waste into smaller pieces
240-L dustbin	To collect unwanted waste
Water hose	For wet cleaning
Broom	For dry cleaning

Description of the process	
	Spread the DFS waste on the co-composting platform using rakes. • If the DFS comes from a store, remove bags/sacks. • Break large lumps of DFS into smaller pieces. Avoid crushing into fine particles or powder, as this will inhibit aeration when the compost heap is formed. • Remove all foreign materials, such as stones, plastics and pads, which could be present in the DFS.

Do	Do not
- Remove all unwanted waste in the DFS.	- Pulverize the DFS into pieces that are less than 5 cm (or 2 inches) in size.

Maintenance	
Cleaning	Safely discard the unwanted solid waste at a designated disposal site.

4.4 Formation of Initial Compost Heaps

As mentioned above, feedstock should be blended to create an optimum C:N ratio of about 25-30:1. This can be achieved by combining materials relatively high in carbon (like garden or market waste) with materials high in nitrogen (like DFS) at a ratio of **3:1** (for example) as illustrated below.

In mass:	 1,500 kg of sorted organic waste (e.g., a mix of vegetable/food waste)	+	 500 kg of DFS	=	2,000 kg (2 MT) of feedstock

or

In volume:	 38 wheelbarrows of sorted organic solid waste (a mix of vegetable/food waste)	+	 16 wheelbarrows of sorted DFS	=	About 2,000 kg (2 MT) of feedstock

Tools	
Spade/shovel	To collect and handle the organic waste
Wheelbarrow	To transport the waste
Weighing scale	To quantify the required amount of waste
Waste container (30 L)	To hold the waste during quantification
Watering container	To add water to the heap
Watering hose	To distribute water
Notebook, pens	For record keeping
240-L dustbin	For unwanted waste collection
Broom	For cleaning
Graduated wooden rod (long measuring stick)	To measure the height of the heap
Flexible measuring tape/rope	To measure the circumference of the heap

The composting area should include two main sections: the 'thermophilic stage' area and the 'maturation stage' area. There can be an 'intermediate stage' area between both these areas.

After the first four weeks of heating and volume reduction in order to free space, heaps of the same age may be merged into one compartment located at the other side of the platform (intermediate stage area) and heaped again for four to five additional weeks. Thereafter, the co-compost is moved to the maturation area for the remaining co-composting time.

Photo: IWMI

Description of the process

Weighing of waste to ensure adequate proportions are subsequently mixed

Waste is applied in layers and the mixing is started

Step 1: Mixing the right amounts of DFS and organic solid waste on the co-composting platform.

- Initially, a mass ratio should be used to establish the amounts of each material to be added, until staff have sufficient experience.
- In the case of a mass ratio, mix 500 kg of DFS with 1,500 kg of organic solid waste to form one 2-MT co-compost heap.
- If a scale is not available for weighing materials, it is possible to use a volume ratio.
- In the case of a volume ratio, mix (for example) 16 wheelbarrows of DFS with 48 wheelbarrows of organic solid waste to form about 2 MT of co-compost heap.
- Use shovels and spades to mix the feedstock thoroughly.

Step 2: Adjusting the moisture level.
Water is added during the mixing stage and the moisture of the mixture is gradually increased to the desired level.

- The moisture content of the newly formed heap should range from 50 to 60%.
- Add the required volume of water while mixing the feedstock. This typically corresponds to 30-50 watering cans (13-L capacity each) depending on the initial water content (e.g., dry sawdust, wet market waste).

1. Finalize the heap formation.

2. Measure the height and validate it is correct.

3. Measure the circumference and validate it is correct.

4. Label each co-compost heap.

Step 3: Forming the heap.

- The heap size should create optimum conditions for air and temperature regulation.
- A co-compost heap must be of sufficient size (see photographs) to prevent rapid dissipation of heat and moisture, yet small enough to avoid compaction and limited air circulation.
- Optimum heap sizes range from 1.2 to 1.6 m for height and 6-9 m for circumference.
- Polyvinyl chloride (PVC) pipes/bamboo poles (with holes) could be mounted in each heap for measuring temperature and to aid aeration.
- Each co-compost heap should be labeled indicating the date of formation, volume of water added, next turning date (see below) and expected maturation date.

Do	Do not
- Use a blend of feedstock which provides the optimum C:N ratio. - Mix the feedstock thoroughly before heap formation. - Record the volume or mass of initial feedstock used in forming the co-compost heap.	- Build heaps of sizes below the minimum or above the maximum limit provided. - Add excess water to the heap. - Combine co-compost heaps that were formed on different days.

Maintenance and troubleshooting		
Problem description	**Issue**	**Solution**
Housekeeping standards	Cleaning	• In order to minimize odor and flies, the platform must be cleaned with water after each batch. • The co-composting platform must remain neat after the heap is formed.

4.5 Monitoring of the Co-compost Heap

The four main monitoring indicators are the temperature and moisture level of a compost heap, as well as its odor and visual characteristics. From experience, one person can take care of three to four heaps per day.

Tools	
Spade/shovel	To collect and handle the organic waste
Wheelbarrow	To transport the waste
Thermometer (90-cm long)	To monitor temperature of the heap
Watering container	To add water to the heap
Watering hose	To distribute water
Notebook, pens	For record keeping
240-L dustbin	For unwanted waste collection
Broom	For cleaning

During the co-composting process, the material undergoes a physical and chemical transformation, which also affects the characteristics of the maturing product and compost management. For example, there will be organic matter (carbon) losses with up to 40% mass and 50% volume reduction, which also affects carbon and nitrogen concentrations (Table 4).

TABLE 4. CHANGES IN THE CHEMICAL CHARACTERISTICS OF A MUNICIPAL SOLID WASTE (MSW) AND DFS CO-COMPOST HEAP DURING CO-COMPOSTING.

Composting week	Carbon (%)	Nitrogen (%)	C:N
0	28.4	1.58	18
2	27.4	1.61	17
4	23.7	1.58	15
6	22.2	1.48	15
8	20.0	1.46	14
10	17.8	1.48	12
12	22.3	1.49	15

Composting **temperature** is an important indicator of the transformation and quality of the composting process that has to be monitored and can be steered.

The first (thermophilic) phase is characterized by temperatures commonly reaching 50 to 60 ˚C which eliminate harmful pathogens. When the temperature drops below about 50 ˚C, and the addition of water will not raise the temperature again, the compost pile needs to be turned to transfer the less-composted (cooler, outer) material into the center of the heap. According to the United States Environmental Protection Agency (USEPA 1994), in order to achieve a significant reduction of pathogens during biosolids composting, the compost should be maintained at minimum operating conditions of 40 °C for five days, with temperatures exceeding 55 °C for at least four hours during this period. After this, the heap has to be turned inside out and the moisture level readjusted so that the outer material will be composted. Turning the heap will usually result in a new temperature peak because of the replenished oxygen supply and the exposure of organic matter not yet thoroughly decomposed.

After the thermophilic phase, the temperature of the compost drops and is not restored by turning or mixing. At this point, decomposition is taken over by mesophilic microbes (the maturation phase). Chemical reactions continue to occur that make the remaining organic matter more stable and suitable for use with plants.

Attention is needed when the temperature starts exceeding 65 ˚C. Most species of microorganisms, including those that are beneficial cannot survive at temperatures above 60-65 °C.

Description of the monitoring process

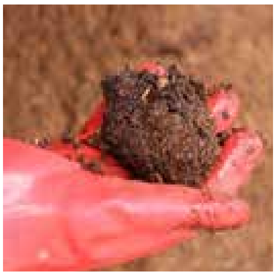
Step 1: Record the temperature of the heap daily.

- Insert the thermometer probe into the co-compost heap (at least 30-cm deep) and wait for the reading to be stable before recording the value.
- Record the temperatures at five different spots of the co-compost heap. The spots should be at different sides and heights, targeting a depth of 30 and 90 cm each time (12 inches; 3 feet).

Description of the monitoring process (continued)

× BAD

The compost crumbles (too dry) or water drips out (too wet).



✓ GOOD

The fist releases a very small amount of moisture and the compost remains compact.

Step 2: Monitoring the moisture level.
Squeeze a handful of co-compost for a few seconds and release the pressure.

- Good: Squeezing releases a little moisture and the compost remains compact (moisture level 60-65%).
- Bad: The compost crumbles. This means that the amount of water is insufficient (<60%).
- Bad: Water drips or filters out of the fist while squeezing the compost. This means that the amount of water is too high (>70%).

A co-compost heap being turned. The easiest way to do this is by moving the heap from one spot to another just next to it, taking care that outer material will now become inner material.

Step 3: Turning (aeration) and watering the heap.

- To support a good air supply, the heap should be turned during the thermophilic stage at 3-5 day intervals or even earlier in case the temperature drops below approximately 50 °C or starts exceeding 60-65 °C.
- The turning frequency should gradually be reduced to once a week, if the temperature no longer climbs above 45-50 °C even after turning.
- When multiple co-compost heaps are to be turned on a given day, it is best to start turning the most-matured heaps before moving to the least-matured compost, in order to minimize the risks of recontamination of mature compost.

Addition of water

Excess water flowing out of a heap

- It is important to ensure that the co-compost heap remains moist (50-60% moisture content by weight) throughout the co-composting period. Biological activity is inhibited when the heap dries out.
- Moistening of the co-compost heap should preferably be done during turning.
- Add the required volume of water starting from the top of the co-compost heap.
- Water should be sprinkled, preferably from a watering can with a rose.
- During moistening, ensure that water is not added excessively to the heap.
- On site, treated leachate from the composting area can be used to moisten heaps that are less than a week old. Beyond this time, water reuse should **not** take place to avoid recontamination of the co-compost with pathogens.

Step 4: Moving feedstock from a large compartment to a small one.
Given the volume and mass reduction, the co-compost heap may be moved from a large compartment to a smaller one after one month. It is also possible to combine the two reduced heaps initially formed **on the same** day and from the same feedstock composition to build a new heap of more reasonable size.

<table>
<tr><th colspan="2">Description of the monitoring process (continued)</th></tr>
<tr><td>
</td><td>Step 5: Monitoring of co-compost quality
Table 5 presents typical quality standards that could be considered for the co-compost products in the absence of national standards. The parameters to be analyzed could include the following:

Macronutrients (e.g., N, P and K) - to establish the nutrient value of the compost, if applied in addition or as an alternative to a fertilizer. Also, to establish the amount of inorganic fertilizer required to enrich the compost to a certain standard.
Minimum frequency required: Once for each bulk of co-compost to be enriched.
Pathogens, especially, for example, helminth eggs and E. coli - to ensure that the World Health Organization (WHO) guidelines for the safe recycling of waste are met (see Table 5).
Minimum frequency required: Once for each bulk of co-compost to go through post-processing; twice a year for pellet samples (microbial risks are lower with pellets than with basic compost).
Heavy metals (e.g., nickel [Ni], chromium [Cr], lead [Pb], mercury [Hg], cadmium [Cd]) to ensure permitted levels are not exceeded.
Minimum frequency required: Twice a year.
Germination tests - to ensure the co-compost is mature (no active weed seeds left) but also not toxic to crops (see Boxes 1 and 2).
Minimum frequency required: Once for each bulk of co-compost to be enriched or bagged.
pH and electrical conductivity (salinity).
Minimum frequency required: Once for each bulk of co-compost to be enriched or bagged.
</td></tr>
<tr><td></td><td>Step 6: Once matured, spread co-compost to dry and for sieving.

Spread the co-compost thinly on the co-composting platform or designated drying point using washed shovels and spades to avoid contamination.
Turn/stir the co-compost intermittently to facilitate drying.
Dried co-compost should be sieved using a 6-8-millimeter (mm) grid.
The coarse co-compost fraction may be added to a new co-compost heap, mildly ground and added to the compost product or be discarded (for example, non-composted fruit parts).
Record the final weight of the co-compost produced.
</td></tr>
</table>

The internationally used standards in Table 5 could be considered as guidelines.

TABLE 5. SELECTED MAXIMUM CONCENTRATIONS OF CONTAMINANTS IN CO-COMPOST.

Heavy metal	Concentration (mg per kg dry matter)						
	UK standard	ECN standard	Swedish standard	Austrian limits A+	Austrian limits A	EU eco label	Canadian limits A
Cr	100	60	100	70	70	100	210
Ni	50	40	50	25	60	50	62
Cd	1.5	1.3	1	0.7	1	1	3
Hg	1	0.45	1	0.4	0.7	1	0.8
Pb	200	130	100	45	120	100	150
Cu	200	300	100	70	150	100	400
Zn	400	600	300	200	500	300	700
Pathogens							
E. coli	1,000 per gram (g) of total solids in treated feces and FS						
Helminth eggs	Less than 1 viable egg per gram of total solids in treated feces and FS						

Source: Cofie et al. 2016.

Note: ECN: European Compost Network.

Do	Do not
- Turn the co-compost heap according to the schedule. - Wash shovels/spades thoroughly for each heap turned to avoid cross-contamination between younger and older heaps. - Add some water during the turning process. - Use a container (e.g., watering can with a rose) that showers/sprinkles the water on the heap. - Record the volume of water added to each heap. - Reduce the volume of water added as the co-compost matures (the curing stage). - Stir matured co-compost that is spread on the platform intermittently (e.g., once a day, depending on climatic conditions) using rakes to speed up drying.	- Add fresh feedstock to an already maturing co-compost heap. - Use wastewater for moistening the co-compost heap that is more than a week old. - Add water in excess. - Use unclean spades/shovels for turning co-compost heaps. - Allow contact between mature co-compost and immature co-compost or waste, and provoke cross-contamination.

Maintenance and troubleshooting

Problem description	Issue	Solution
	Unclean composting platform	After each batch, the platform must be cleaned with water and small amounts of mild soap to minimize odor and flies Excess water from the co-compost heap attracts flies and generates a foul odor. Only the required volume of water should be to the co-compost heap. Excess water should be removed and reused if possible.

Troubleshooting the co-composting process		
Problem	**Possible causes**	**Recommendations**
Low temperature: Only hot in the middle of the heap	• The heap could be too small or of the wrong heap dimensions. • Poor aeration and low moisture content. • Feedstock with large particle size resulting in heat escape.	• Reconstruct the heap to the appropriate size. • Turn (mix) the co-compost heap and add adequate water in the process. • Shred large feedstock to be used, such as plantains and pineapple suckers.
High temperature: Exceeds the limit of 65 ˚C	• Inadequate aeration. • Low moisture content. • Large heap.	• Turn the co-compost heap (to improve air circulation) and add adequate water in the process. • Reduce the heap size, if needed.
The heap will not heat up, nothing is happening	• Inadequate oxygen. • Inadequate moisture. • Inadequate nitrogen content, i.e., wrong feedstock ratios used in heap formation.	• Turn the co-compost heap and add adequate water in the process. • Add nitrogen-rich feedstock such as DFS, and green fruit and vegetable waste. • Form the co-compost heap using the right ratios of carbon-rich and nitrogen-rich feedstock. Ensure that this is also done during initial heap formation.
Ammonia odor	• High level of nitrogen and low level of carbon (low C:N ratio below 20:1).	• Add carbon-rich feedstock such as sawdust, shredded dried grass or leaves. • Turn the co-compost heap.
Foul odor (not similar to the ammonia odor)	• Excess moisture. • Inadequate oxygen.	• Turn the co-compost heap without adding water in the process.
Continuous draining of water from the co-compost heap	• Excess water was added to the co-compost heap. • The compost heap contains fresh fruit and vegetables with no partial dehydration being done before its use.	• Turn the co-compost heap without adding water in the process. • For recently formed heaps: Add feedstock low in moisture content such as sawdust and well-dried DFS. • For old heaps: Trap and store drained water and reuse for that specific heap during the turning process.
Flies and larvae	• High moisture content causing excess water to drain. • Foul odor. • Low temperature around the base of the co-compost heap.	• Avoid adding excess water during the turning process. • Turn the co-compost heap and ensure exposed food is buried within the heap.

4.6 Sieving Co-compost

Sieving of co-compost is a common practice to enhance the marketing of co-compost. It ensures that a uniform product, which is visually appealing, is sold to the farmers or other users. A common sieve size is 6-8 mm.

If the compost is to be pelletized later, the optimal sieve size will depend on the specifications of the pelletizing machine. In general, a sieve with openings suitable for passage of particles up to 5-mm in size is usually sufficient for safe pelletizer operation. The resulting coarse material can enter the co-composting process from the beginning or be ground.

Tools	
Spade/shovel	To collect and handle the co-compost
Wheelbarrow	To transport the co-compost
Sieve (6-8 mm)	To sieve the co-compost
Notebook, pens	For record keeping
Broom	For cleaning

The sieved co-compost may be heaped on the co-composting platform for up to several months, but ideally be sold as soon as possible (see section 5.4).

Do	Do not
- Sieve co-compost that has a moisture content of 40% or more to reduce the formation of dust. - Store sieved and dried co-compost in a dry and low-moisture area. - Wear suitable PPE to minimize dust threat to operators.	- Allow co-compost with mostly fine particles < 2 mm (e.g., particles) to be stored under windy conditions, and the wind blowing the fine particles away.

4.7 Grinding Co-compost

The coarse material obtained after sieving can reenter the co-composting process from the beginning. However, it may be discarded, if its quantity and quality are insufficient for further processing. Alternatively, it could undergo a grinding process, which will contribute to a reduction of the particle size. The mixture from the sieved and ground portions could feed the mixer and then a pelletizer (see below).

Do	Do not
- Wear suitable PPE to minimize the dust threat to operators. - Grind the co-compost outdoors or utilize ventilation to ensure that it will minimize exposure of workers to dust. - Only grind the refuse of sieved co-compost if its quantity is sufficient.	- Subject the co-compost to excessive grinding, as small particles tend to form dust. - Sieve the material that was ground, as the particle size is already small, resulting in additional dust.

4.8 Storage of (non-enriched) Co-compost

Tools	
Spade/shovel	To collect and handle the co-compost
Wheelbarrow	To transport the co-compost
Weighing scale	To quantify the final co-compost mass
Notebook, pens	For record keeping
Broom	For cleaning
Woven polypropylene bags	To eventually bag the compost for 6-12 months
Storage room/shelter	To keep the heaps or bags cool and dry

Description of the process

- Only matured, adequately dried (moisture content of < 40%) co-compost should be stored. At this point, the product is safe and should be protected from (re)contamination by unsafe wastes or fresh co-composts.
- Co-compost for sale should be bagged in a way that it is protected from moisture but allows its content to breathe, for example, in woven polypropylene bags.
- Throughout the storage period, the co-compost, bulked or bagged, should remain dry.

Do	Do not
- Store matured and dried co-compost only. - Store co-compost in a dry and low-moisture area. - Use woven polypropylene bags, but note their shelf life sensitivity to sunlight.	- Store matured co-compost and waste in the same area. - Bag co-compost intended for long-term storage but for quick sale. - Smoke in compost storage areas.

Maintenance and troubleshooting

Problem description	Issue	Solution
The co-compost is accidentally put in contact with water.	The co-compost becomes moist or wet.	Remove the co-compost from the bag and dry it by spreading it on a platform.

5. PRODUCT QUALITY ENHANCEMENT

Normal MSW composts can have the reputation of being lower quality than horticultural composts sold on the free market, which are often produced with farmyard manure and/or other nutrient sources. The production of a co-compost using human manure (FS) is an important step to address this challenge apart from introducing circular processes in the sanitation sector. To be even more competitive, the compost or co-compost can be further enriched with nutrients and also pelletized.

5.1 Enrichment of Co-compost

A compost or co-compost is an organic soil ameliorant which supports soil structure and aeration, as well as nutrient and water-holding capacity and soil biology, for example, by supplying soil microbes with carbon as an energy source. **Therefore, composts should not be compared with a chemical fertilizer**, which consists of highly concentrated plant nutrients such as nitrogen, phosphorus and potassium, without organic matter and its carbon content.

Composts, and certainly co-composts enriched with FS or manure, also contain plant nutrients, but the amounts are much lower than in an industrial fertilizer, while the variety of macronutrients and micronutrients is larger. Thus, (co-)composts and fertilizers can complement each other and should not be regarded as alternatives.

However, there are many situations where farmers cannot afford fertilizer or their soils only need a relatively low amount of additional plant nutrients. In these situations, and to avoid two separate applications, the (co)compost can be 'topped up' (enriched, fortified) with a defined amount of nutrients. Usually, these nutrients will be immediately plant available and can support competitive marketing of the created 'superior' compost. Topping up also allows responding to local needs by adding the nutrient(s) most commonly demanded; in business terms, this improves the value proposition and allows a higher price to be charged for the additional input.

Depending on the type of crop and its growing period, crop nutrient demands vary, and also in terms of the time the nutrients are most needed. Extreme examples are (i) a lettuce crop which matures in up to six weeks and needs significant amounts of nitrogen within this period to develop green leaves, in comparison to (ii) a perennial rubber tree, where nutrient demands are influenced by the long-term nutrient-supplying capacity of the soil, and factors like clonal variation, stage of growth, intensity of exploitation, ground cover management, etc. Thus, very different nutrient needs are possible, depending on the farming system.

The following overview shows some of the advantages and disadvantages of enriching compost:

Advantages	Disadvantages
– Adds nutrients to the soils, and these can be derived (based on demand) from fast- or, if required, slow-release fertilizers as well.	– Requires access to chemical fertilizer, bone meal or rock phosphate, for example.
– Reduces the need for a separate fertilizer application, unless this is required in particular growing stages.	– Adds additional capital, fertilizer and labor costs at the compost station. A mixer is required to homogenize the co-compost and the dry inorganic fertilizer minerals.
– Allows tailoring of the added fertilizer in amounts and compositions suitable to local soil quality and crop demands.	– More laboratory analysis is necessary, if the extra nutrients are to be tailored to customer demands, building on the existing compost quality.
– Some nutrients, like nitrogen, can facilitate a faster compost breakdown if the compost is low in nitrogen.	– Care has to be taken with a rock phosphate addition as it can include heavy metals.
– Can add additional control of pathogens as, for example, urea will increase soil alkalinity and kill pathogens.	– High risk of nutrient loss during storage (ammonia volatilization) after nitrogen enrichment (see Annex 2).

Annex 2 provides data for the enrichment process, for example, on how to calculate the amount of fertilizer to be added to raise the existing nitrogen level of the compost.

5.2 Transformation into Pellets

Several factors motivate the production of pellets from co-compost. First, it can help logistically, because pelletization reduces the bulkiness of the co-compost through densification of the biomass. The increased bulk density (Table 6) and lowered volume can reduce the space needed for storage or transportation (increasing cost-effectiveness), and ease the handling of the product during application.

Note: Pelleting and pelletizing are two terms often used interchangeably, although their processing methods differ. Pelleting commonly refers to forcing material through a die or mesh to create a unique size. Pelletizing, on the other hand, can include the use of a binding agent and densification using a rotary drum or a pan pelletizer. In our context, we refer to pelletizing.

TABLE 6. IMPACT OF PELLETIZING ON THE BULK DENSITY OF THREE DFS CO-COMPOSTS.

Non-composted but Gamma-[a] irradiated DFS		DFS compost				Co-compost of DFS and sawdust (mass ratio = 1:3)			
Raw	Pelletized	Basic	Ground and enriched	Pelletized by machine[b]		Basic	Ground and enriched	Pelletized by machine[b]	
				A	C			A	C
0.58	0.88	0.71	0.77	0.90	0.84-0.93	0.37	0.39	0.54	0.71-0.90

[a] See Nikiema et al. 2014.

[b] See Annex 3 for a description of both machines, A and C (C is used in Ghana at the *Fortifer* plant).

Advantages	Disadvantages
• A less bulky and easier to handle organic product.	• Pelletization results in additional capital and operational costs, and requires the possibility of having to purchase/ import a pelletizing machine of the right capacity and strength, as well as having access to electricity and water.
• Commercial appearance resembles fertilizer and thus improves marketing potential.	• Requires technical skills to adjust the machine to local materials, as well as to operate and maintain the machine.
• There is the possibility of combining with 'fortification' to support the homogenization of compost and fertilizer, and to steer pellet stability for slow or fast breakdown.	

Do	Do not
• Handle the newly formed pellets with care as they are weak and can be hot. • Store pellets indoors or under low moisture conditions to avoid breakdown of pellets into fine particles.	• Pelletize compost with high sand levels (> 5%) as this results in accelerated wear of the pelletizer. • Pelletize sawdust-rich co-composts if possible, as these are difficult to process. • Do not store enriched compost for longer than a few months as its nitrogen content can decrease by 50%.

Pellets can be easier to apply on the farm than co-composts. For example, the use of pellets reduces the formation of dust. It also enables the use of mechanized equipment for land application through broadcasting. This reduces labor requirements and the time needed for the operation. Finally, pellets – depending on the binding agent and densification – can more quickly or more slowly release nutrients and thus meet crop requirements, and minimize nutrient loss through (for example) leaching after land application (Nikiema et al. 2013; Hettiarachchi et al. 2016). This implies that pelletization can help to achieve higher fertilizer efficiency, and long-term (residual) benefits, as opposed to non-pelletized co-compost.

5.3 Required Machinery for Value Enhancement

The machinery required is shown in the example of the *Fortifer* plant in Ghana (Tables 7 and 8; Figures 6 and 7), where matured compost can be sold either from the heap, or sieved and packed, or processed further into enriched composts and subsequently into pellets.

TABLE 7. EQUIPMENT INSTALLED OUTDOORS IN THE COMPOST MATURATION AREA.

Grinder	Capacity (kg hour^{-1})	500
Sieve (rotating drum)	Capacity (kg hour^{-1})	1,500
Water tank (connected to pelletizer)	m^3	1
Conveyors (in and out of the sieving drum)	Numbers	2
Surface occupied	m^2	79

FIGURE 6. PROCESSING EQUIPMENT INSTALLED NEAR THE COMPOST MATURATION AREA AT THE *FORTIFER* PLANT IN GHANA.

TABLE 8. EQUIPMENT INSTALLED WITHIN THE WAREHOUSE.

Indoor machinery space	m^2	175
Mixer	Capacity (m^3)	5.5
	Mixing time per batch (minutes)	20
Pelletizer	Capacity (kg $hour^{-1}$)	300-750 (depending on feedstock)
Bagging device	Capacity (kg $hour^{-1}$)	500
Storage space for compost bags	Area (m^2)	300

FIGURE 7. PROCESSING EQUIPMENT INSTALLED INDOORS AT THE *FORTIFER* PLANT IN GHANA.

Basic technical criteria for the selection/construction of a pelletizer include the following:

1. The motor should be robust, able to tolerate frequent ‘on and off’ periods, and possibly variable feedstock characteristics (with the percentage of fine particles produced during pelletization remaining below 5-10% when optimal operating conditions are enforced).
2. Cleaning of the pelletizer die/disc should not be difficult. Removing materials from the hole of the die should be simplified.
3. Pellet size (diameter) is often 6-10 mm. The die/disc hole size of the pelletizer must be designed accordingly.
4. Some machines require the use of a binding material (such as starch).

Do	Do not
• Test the pelletizer with available types of composts before purchase. • Optimize the operation of the pelletizer using the exact material(s) being locally processed. • Consider that the pelletizer should offer connection points for other equipment (such as an air compressor or a water pipe).	• Install the pelletizer in a fully enclosed area as dust may be generated during the pellet production process.

The newly produced pellets may be weak for a few seconds or a few minutes. The receiving plate and its subsequent transfer into a different processing unit (for example bagging) must consider this fact. Poor handling will result in the formation of fine materials and constitute an increase in processing cost.

Annex 3 provides detailed information on different types of pelletizing equipment.

5.4 Storage and Labeling of enriched Co-compost

	Tools
Wheelbarrow	To transport the bagged products
Weighing scale	To quantify the required amount of each product
Notebook, pens	For record keeping
Broom	For cleaning
Labeled sacks	To protect and describe the products for sale
Storage room/shelter	To keep the bags cool and dry

Bagging is required for short-term storage (from a few weeks to a few months, or more) and distribution of the final products. Generally, bagged composts will last well for few years provided that they are stored in dry conditions. However, especially nitrogen-enriched compost can lose nitrogen to the air (ammonia volatilization). Over two years of storage using nylon bags in an experiment in Ghana, a non-enriched co-compost lost 13% of its nitrogen content, while an ammonium sulfate-enriched co-compost lost 24-46%, and a urea-enriched co-compost 47-59% (Adamtey 2010). Especially for the enriched composts, the observed changes make the nitrogen content, as specified on the bag label, outdated.

Bagging requirement	Type of bag required	Storage condition
Compost	Polypropylene, nylon or recyclable bags.	Store products in a shelter or room to ensure that they remain dry and not exposed to heat above 35 °C or direct sun (UV) light.
Enriched (co-) compost/ pellets	A bag that has a plastic lining to exclude moisture and humidity.	

Labeling: The label to be used (see Figure 8) should meet the requirements of the country in which the product is to be marketed. In Ghana, the label must be approved by MoFA as part of the fertilizer certification process (see Annex 4 for details).

FIGURE 8. THE *FORTIFER* PRODUCT LABEL APPROVED BY MoFA IN GHANA.

Source: IWMI

It might be 'safer' to state a nutrient range on the bags rather than a certain percentage, as the waste composition (and final compost quality) can vary and volatile nutrients might be lost during storage. Stating a range can also reduce the frequency of laboratory analyses required to verify the nutrient content of the final product.

Sell/use the bagged co-composts ideally within 12 months after bagging, and N-enriched compost within 6 months. Older N-enriched compost bags do not have to be discarded, but can still be sold/used with a note of caution (and, for example, discount) to serve purposes such as landscaping and forestry, where nitrogen demand is low.

Do	Do not
– Bag the co-compost products for easy handling and (short-term) storage. – Stack the bagged products on wooden pallets in the storage area to promote air circulation around the co-compost (including 1 m distance from walls). – Aside the pallets, store the bags at least 5 m away from any potentially flammable product. – Use approved labels on bags stating verified nutrient ranges. – Create walkways and space for equipment used in moving co-compost. – Practice good housekeeping and monitor bags for pests, etc. – Ensure first in, first out product movement because nitrogen-enriched co-compost, in particular, will lose its mineral nitrogen during storage.	– Over-pile pellets to avoid crumbling into fine particles. – Permit smoking near compost (bags). – Leave bagged products under high-moisture conditions (e.g., outdoors) for extended periods. – Sell enriched compost, which was stored for more than 6 months without informing customers that the nitrogen content is likely to be lower than stated on the label.

6. RECORDING OF OBSERVATIONS AND DATA

Good data management allows for (a) benchmarking processes (quantities, efficiencies, quality) for improvement (for example, to become more cost-effective); and (b) tracing reasons for possible failures or shortcomings. Therefore, accurate recording of all observations and measurements (or in short 'data') at the co-composting facility is important to establish and maintain operating records which can be verified or referred to when needed. Both soft (electronic) and hard (printed) copies of records as well as pictures should be kept at a site designated for data storage.

Activities or measurements on which records should be kept include feedstock management, general observations and incidents (like heavy rainfall) that potentially (or de facto) affect the co-composting processes, pelletization processes and machinery, co-compost quality assessment (including physical/chemical analyses) and staff management dynamics.

As much as possible, data management should include the raw materials entering the plant (amounts, sources, quality observations) as well as the quantities and dates of production of the material ready for sale.

Monthly reports on all observations, product quality data and activities have to be prepared and stored safely and appropriately. Detailed but simple templates, based on standard operating procedures should be developed for respective activities to ensure uniformity or formalized for easy reporting requirements.

Tools	
Notebook, pens	For record keeping on site
File	For storing hard copy records
Computer	For data transfer, analysis and long-term storage
External drive	For safeguarding data

7. USE OF FECAL SLUDGE-BASED CO-COMPOST IN FARMING

7.1 The Product and Added Value to Soils and Plants

The main difference between an inorganic fertilizer (like NPK) and compost is that, while compost enhances the soil to create a beneficial environment for plants, fertilizer feeds plants with nutrients. 'Beneficial environment' refers to improving the physical and biological characteristics of the soil (structure/aeration, water- and nutrient-holding capacity, etc.).

Although a compost contains plant nutrients, some nutrients like nitrogen and phosphorus are, to a large extent, organically bound and will only be released to the soil slowly through compost mineralization. The slow release of nutrients might last for several seasons. It is therefore not recommended to directly compare the nutrient content of a compost and fertilizer in relation to crop needs, as a compost primarily serves a different purpose, which is the long-term improvement of soil organic matter content and structure.

Examples of the nutrient content of an FS-based co-compost are presented in Table 9. As the nutrient content of FS and organic MSW varies geographically between sources and treatment, the variation shown in Table 9 is possible. Comparing local fertilizer recommendations with the nutrient content of the compost will help to identify the remaining nutrient gap. The gap can be closed through a separate fertilizer application or by blending (enriching) the compost.

TABLE 9. COMPOSITION OF FS-BASED CO-COMPOSTS IN GHANA AND SRI LANKA.

Parameter	FS-based co-compost in Ghana	FS-based co-compost in Sri Lanka
Organic matter (%)	44.3 ± 7.9	53.0 ± 3.4
Total carbon (%)	25.7 ± 4.6	18.6 ± 5.6
Total nitrogen (%)	1.5 ± 0.5	2.3 ± 0.5
Total phosphorus (as % P_2O_5 equivalent)	3.6 ± 0.9	1.3 ± 0.2
Total potassium (as % K_2O equivalent)	1.3 ± 0.6	1.1 ± 0.3
Total sulfur (%)	1.9 ± 0.7	0.6 ± 0.1
There are many more essential plant nutrients (e.g., magnesium, calcium, zinc, iron, boron, copper and manganese), which a compost will provide, but none of the common industrial fertilizers will do likewise.		

Source: IWMI (unpublished data).

From a fertilizer perspective, a finished (and not enriched) compost can be considered as a weak slow-release fertilizer, having an NPK composition of about 1-1-1 (N-P_2O_5-K_2O) plus certain amounts of the other macronutrients and micronutrients that a crop needs. An industrial NPK fertilizer has a 15-15-15 composition, for example, but lacks other nutrients; 15-15-15 means equal percentages of 15, or in other words, 15 kg of each nutrient (N, P and K) in a 100-kg bag.

7.2 Guidelines for Compost Field Application

FS-based co-compost can be used for any type of crop as an organic soil ameliorant or conditioner, or to add value to a particular growing medium, like coconut coir, as well as for long-term cultivation in the horticulture or plantation sectors. Yields can increase by 20-50% compared to using only inorganic fertilizer. In general, composts show highest returns on very light or also heavy soils. In sandy ('light') soils, compost binds sand particles, creating smaller (and better) water-holding pores. It also improves the nutrient storage capacity and provides crop nutrients. In clayey ('heavy') soils, compost loosens the soil by creating wider pores for better aeration and less compaction, which plant roots and soil organisms will appreciate. The improved soil structure increases water infiltration and leads to more stable aggregates, mitigating the risk of waterborne and wind-borne erosion.

Compost can also be applied in combination with other soil amendments (biochar, rice husk, manure, etc.) to further improve the soil fertility.

Tools	
Weighing scale	To quantify the required amount of each FS-based co-compost product
Rake or hoe	To incorporate the compost into the top layer of the soil

There are two common methods: Broadcasting and point application (placement). The choice of method used depends on the crop and its growing stage, but can also be influenced by the type and amount of the co-compost.

	**Broadcasting** is used for field crops, vegetables, maize, cereals, etc. It consists of distributing the required amount of compost evenly on to the field. The compost then needs to be incorporated into the topsoil (maximum 10-cm deep) using, for example, a rake. The system works well with powder compost before planting or at an early crop growth stage.
	**Placement** is commonly used for compost pellets, or perennials, fruits and vegetables (such as tomatoes, eggplants), by placing a calculated specific amount of compost at a 5+-cm distance around each plant. The compost is then incorporated into the topsoil (approximately 5-10 cm) using a hoe or rake. If the compost is for whatever reason still immature and made from nitrogen-rich feedstock, wider spacing is needed so that the ammonium will not be toxic to plant growth and 'burn' its tissue, including roots.

7.3 Recommended Application Rates

Common application rates of FS-based composts range between 5 and 25 MT of co-compost per hectare (ha). The precise quantity is soil- and crop-dependent, and defined by the gap between crop requirements and what the local soil can provide over the cultivation period, taking into account the nutrient-release characteristics of any applied soil input (crop residues, manure, fertilizer, compost). Lower application rates are possible if the co-compost has been enriched (Table 10). However, as noted in the right column of Table 10, a nitrogen-enriched compost might still require an extra application of other nutrients, like phosphorus or potassium. This is particularly common on sandy or highly weathered soils, and can be addressed with additional fertilizer.

TABLE 10. RECOMMENDED FS COMPOST APPLICATION RATES (ENRICHED AND NON-ENRICHED) IN GHANA FOR REGIONAL FINE-TUNING.

Crop	Quantity required of an enriched (3% N) FS-based co-compost (MT ha^{-1})	Quantity required of a non-enriched FS-based co-compost (MT ha^{-1})	Possible additional P and K fertilizer needs depending on soil fertility
Cabbage	3.4	10.8	
Maize	3.0-4.0	10.0	
Okra	2.5	5.7	
Carrot	2.5		P
Watermelon	2.0		P, K
Tomato	3.2	8	K
Onion	2.5		
Eggplant	3.7	7.5-9.5	K
Cucumber	2.0		
Lettuce	4.3-5.0	12.5	
Banana	3.7		
Rice	3.2	7-8	

Moreover, while a chemical fertilizer has only the function to supply nutrients, which simplifies the calculation of its application rate based on crop nutrient requirements, a compost can support various soil functions over a longer time frame, and the best application rate will vary locally. **Farmers are therefore encouraged to test different co-compost application rates starting with the 5 to 25 MT range mentioned above.**

The final application rate will also be influenced by other factors, like the availability and costs of the right fertilizer or compost, climatic conditions, input effectiveness (organic matter breakdown, possible nutrient loss through leaching, etc.) in delivering their values, and farmers' limitations in terms of transport and labor for land application.

Annex 5 provides more information on fertilizer and compost application and release rates.

Do	Do not
– Apply matured (well-composted) FS-based products only. – Ensure even application of FS-based compost/pellets. – Incorporate FS-based products into the top layer of the soil. – Test different (co-)compost application rates starting with the range of 5-25 MT ha^{-1}.	– Apply non-mature compost as this could have possible negative side-effects ('burning'), especially on young crops. – Enrich a compost with mineral fertilizer in (semi)arid regions, where soil salinity could increase, if compost rates are high.

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ANNEXES

Annex 1. Composition of Solid and Liquid Waste

The physical-chemical composition of some solid wastes used in co-compost production in Ghana and Burkina Faso is presented in Tables A1 to A3.

TABLE A1. TYPICAL CHARACTERISTICS OF CO-COMPOST FEEDSTOCK IN GHANA.

Parameters	Unit	Dewatered FS	Market waste
pH		7.45 ± 0.04	9.04 ± 0.37
Acidity	cmol kg^{-1}	No data	2.15 ± 1.48
Moisture	%	35.4 ± 5.2	68.1 ± 1.3
C	%	12.3 ± 5.2	32.8 ± 19.1
N	%	2.66 ± 0.02	1.25 ± 0.93
C:N		8.4 ± 3.4	28.5 ± 6.0
K	%	0.61 ± 0.05	0.94 ± 0.03
P	%	1.24 ± 0.03	0.54 ± 0.07
E. coli	10^8 CFU g^{-1}	4.07 ± 2.04	5.70 ± 3.54
Total bacteria	10^8 CFU g^{-1}	6.10 ± 1.05	2.71 ± 2.40
Total fungi	10^6 CFU g^{-1}	4.67 ± 1.54	5.75 ± 5.02
Clostridium	10^8 CFU g^{-1}	4.93 ± 1.48	4.50 ± 3.82
Helminths	Eggs gTS^{-1}	25-83	No data

Source: Nikiema et al. 2014.

TABLE A2. CHARACTERISTICS OF DIFFERENT TYPES OF LIQUID FS DISPOSED OF IN THE GREATER ACCRA REGION, GHANA.

FSTP	Origin		pH	EC	TSS	TS	COD	BOD	$N\text{-}NO_3$	$N\text{-}NH_4$	OC	OM	TN	TP	TK	*E. coli*	T. coli
				µS cm^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	%	mg L^{-1}	mg L^{-1}	mg L^{-1}	*E+05 CFU 100 mL^{-1}*	*E+05 CFU 100 mL^{-1}*
Lavender Hill	Households	Av.	7.5	6,326	3,723	7,103	9,378	1,969	2.1	529	3,190	0.55	1,320	176	196	53	1,517
		SD	0.2	3,127	3,028	5,153	8,212	1,493	1.5	233	2,693	0.46	239	124	137	26	1,202
	Institutions	Av.	7	9,628	22,447	29,727	20,953	3,331	2.8	797	12,216	2.11	3,008	856	258	331	1,517
		SD	0.3	1,269	20,096	26,090	13,561	2,326	3.4	191	8,596	1.48	1,932	679	121	277	1,202
Nungua Farm	Households	Av.	7.5	3,331	2,643	4,789	6,935	1,278	2.5	1,572	2,756	0.48	1,720	146	92	10	273
		SD	0.1	1,748	1,702	1,275	2,618	409	2.5	1,752	969	0.17	1,635	67	34	3	335
	Institutions	Av.	7.7	9,388	21,621	34,230	28,248	4,164	5.2	1,304	7,600	1.34	10,410	414	620	34	170
		SD	0.3	8,728	13,748	12,232	12,395	1,083	5.6	294	1,673	0.30	11,396	298	342	20	154

Notes: FSTP (fecal sludge treatment plant), Av (average), SD (standard deviation), EC (electrical conductivity), TSS (total suspended solids), TS (total solids), COD (chemical oxygen demand), BOD (biological oxygen demand), $N\text{-}NO_3$ (nitrate), $N\text{-}NH_4$ (ammonium), OC (organic carbon), OM (organic matter), TN (total nitrogen), TP (total phosphorus), TK (total potassium), *E. coli (Escherichia coliforms)*, T. coli (total coliforms).

TABLE A3. CHARACTERISTICS OF DIFFERENT TYPES OF LIQUID FS DISPOSED OF IN OUAGADOUGOU, BURKINA FASO.

FSTP	Origin		pH	EC	TSS	TS	COD	BOD	$N\text{-}NO_3$	$N\text{-}NH_4$	OM	TN	TP	TK	*E. coli*	Helminths
				µS cm^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	%	mg L^{-1}	mg L^{-1}	mg L^{-1}	*E+05 CFU 100 mL^{-1}*	Eggs L^{-1}
Kossodo	Households	Av.	8.6	1,053	1,801	2,974	939	502	63.2	28.7	1.56	430	44.1	644	13	2,139
		SD	0.1	28	53	12	26	35	3.7	2.5	0.81	418	3.5	121	22	1,786
	Institutions	Av.	8.4	1,940	2,631	4,458	1,319	640	93.3	48.8	1.69	640	68.4	588	7	981
		SD	0.2	34	115	141	74	25	4.3	3.4	1.41	121	5.3	59	11	561
Zagtouli	Households	Av.	8.4	1,236	2,165	3,157	976	454	78.2	36.9	1.39	596	61.2	734	1	817
		SD	0.1	39	487	324	42	30	6.5	3.3	1.39	369	2.1	125	1	670
	Institutions	Av.	8.3	1,981	3,004	5,256	1,614	640	94.5	56.6	0.58	672	82.4	680	1	1,572
		SD	0.4	11	67	252	306	42	3.2	2.5	0.23	425	2.7	177	1	1,234

Notes: For abbreviations, see Table A2. For alternative data, visit: https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/publikationen/EWM/FS_Quantification_Characterisation/Characterization_FS_Ouaga.pdf

Annex 2. Enrichment Options

Different methods can be employed for co-compost enrichment:

Dry enrichment	Paste enrichment	Liquid enrichment
This consists of mixing both components, i.e., co-compost and crop nutrients (minerals) in their dry forms.	The minerals may be converted into a paste through the addition of a reduced amount of water before it is incorporated into the co-compost.	The inorganic fertilizer is fully dissolved in water and the mixture is incorporated into the co-compost.

Source: Adamtey 2010.

Of the three methods (dry, paste or liquid enrichments), dry enrichment is the easiest to perform using a mixing machine, which will reduce manual labor requirements and ensure uniformity of the mixture.

Table A4 shows how nitrogen enrichment can affect the chemical characteristics (e.g., C:N ratio) of the compost for the three enrichment methods discussed above, and via an increase in pH through urea, also lowers the coliform count.

TABLE A4. CHEMICAL AND MICROBIOLOGICAL CHARACTERISTICS OF AN MSW-BASED CO-COMPOST BEFORE AND FOUR MONTHS AFTER ENRICHMENT.

	Before enrichment	After enrichment with urea			After enrichment with ammonium sulfate		
Enrichment method		Dry	Paste	Liquid	Dry	Paste	Liquid
pH	8.8	9.2	8.7	9.2	7.7	8.0	8.0
Total C (%)	24.2	22.3	19.3	20.3	23.5	19.6	16.0
Total N (%)	1.60	3.13	3.73	3.30	3.53	3.27	3.47
C:N	15.3	7.2	5.2	6.0	6.8	6.0	4.7
N - NH_4^+ (mg g^{-1})	0.60	1.65	1.72	4.80	16.4	14.8	12.9
N - NO_3^- (mg g^{-1})	0.15	0.05	0.06	0.05	0.13	0.11	0.17

	Before enrichment	After enrichment
Fecal coliforms (MPN 10g TS^{-1})	2.3×10^6-26.3×10^6	0
Helminth eggs, viable (number of ova 10 g TS^{-1})	2-3	0-2

Source: Adamtey 2010.

Note: MPN: Most probable number; TS: total solids.

Enrichment increases the fraction of non-organically-bound nitrogen, which is quickly plant available but also at a high risk of loss during storage (ammonia volatilization) or soil application (leaching).

Enrichment will not affect heavy metal concentrations in the co-compost unless the fertilizer addition contains metals like certain types of rock phosphate.

Table A5 helps to estimate the amount of urea or (preferably) ammonium sulfate required for enriching co-composts with mineral nitrogen to reach a content of 3% N. Similar calculations would be needed if particular P or K levels are targeted.

TABLE A5. AMOUNTS NEEDED TO ENRICH CO-COMPOST USING AMMONIUM SULFATE OR UREA.

To enrich to 3% N: ...		...10 kg of co-compost		...50 kg of co-compost	
Concentration of N in co-compost (in mg g^{-1} and %) before enrichment		Ammonium sulfate addition (kg) to 10 kg	Urea addition (kg) to 10 kg	Ammonium sulfate addition (kg) to 50 kg	Urea addition (kg) to 50 kg
10.0 mg g^{-1}	1.00%	0.97 kg	0.44 kg	4.86 kg	2.21 kg
12.0	1.20	0.88	0.40	4.38	1.99
14.0	1.40	0.78	0.35	3.89	1.77
16.0	1.60	0.68	0.31	3.40	1.55
18.0	1.80	0.58	0.27	2.92	1.33
20.0	2.00	0.49	0.22	2.43	1.11
22.0	2.20	0.39	0.18	1.95	0.88
24.0	2.40	0.29	0.13	1.46	0.66
26.0	2.60	0.19	0.09	0.97	0.44
28.0	2.80	0.10	0.04	0.49	0.22
30.0	3.00	0.00	0.00	0.00	0.00

Formula used:

X is the amount of fertilizer in kilograms to be added for the enrichment of 1 kg of co-compost, with y being the actual percentage of total N of the non-enriched co-compost, and 3% the target:

$$X[kg] = \frac{(3-y)}{\mathrm{A}}$$ A = 20.564 for ammonium sulfate, and 45.241 for urea

For example, if the results of the laboratory analysis show that the nitrogen content in the co-compost is 1.5%, and you have ammonium sulfate for the enrichment, then:

$$X[kg] = \frac{(3-1.5)}{20.564} = 0.073\ kg$$

This means that you have to add 0.073 kg (73 g) of ammonium sulfate to enrich 1 kg of such co-compost to contain 3% N.

Annex 3. Pelletization Machinery Options

There are different types of pelletizers. Two common examples are disk and extruder pelletizers (Table A6), which differ in price and effectiveness (Table A7). However, the specific co-compost characteristics also affect the performance of even the best pelletizers, and attention to detail is important when selecting the equipment.

TABLE A6. TYPES OF PELLETIZER, MODES OF OPERATION, ADVANTAGES AND LIMITS.

	Disk pelletizer	Extruder pelletizer
Subtypes	• Roller ring die type • Roller disk die type • Double die type	N/A
Design	Have dies with many holes and a roller or two disks	Have a barrel and a screw extruder
Input method	Compost is fed between disks and rollers	Compost is fed into the barrel and forced by a screw
How pellets form	Disk or roller turns and co-compost is forced into the holes to form pellets	Material is compressed into the die installed at the end of the machine by the screw to form pellets
Advantages	• Does not get blocked easily • Suitable for substances with low moisture content (20-30%) • Does grinding simultaneously	• Die temperature can be controlled • Pressure applied can be adjusted • Die replacement is easy • Able to produce pellets of various shapes
Disadvantages	• Damage to the dies and rollers is severe due to foreign bodies • Demand for frequent replacement of machine components	Machine easily blocked by foreign bodies such as long fibers and small stones
Key operating parameters	Feeding rate of the material	• Speed of the screw • Moisture of the fed material

Source: Hara 2011.

TABLE A7. PERFORMANCE OF SELECTED PELLETIZERS TESTED BY IWMI WITH FS-BASED COMPOSTS AND CO-COMPOSTS.

Machine	A. Extruder pelletizer	B. Roller disk die type	C. Roller disk die type
Country	Ghana	Sri Lanka	Ghana
Source	Locally manufactured	Imported from India	Imported from Europe
Pelletizers			
Dimensions	Specifications: 380 V, 1.5 or 4 kW Length: 1.2 m Width: 0.5 m Height: 1.4 m	Specifications: 415 V, 22.4 kW Length: 2.18 m Width: 1.00 m Height: 1.85 m	Specifications: Pellet Mill IOTA 25, 400 V, 18.5-30 kW Length: 1.25 m Width: 1.20 m Height: 2.50 m
Material processed during tests	FS compost, co-composts with other organic waste and/or sawdust	Co-composts with other organic waste	FS compost, co-composts with other organic waste and/or sawdust
Pellets produced			
Price (USD)	Ca. 3,000	Ca. 10,000	Ca. 40,000
Operational observations	• High failure rate • Effect of the presence of sand not obvious • Binder/grinding required • Pellet quality affected by binder type/concentration • Could barely process some materials • Fine particles represent 5-15% of feed products • Moisture content is critical and dependent on the type of feedstock	• Roller maintenance is an issue • Low sand level is essential to prevent high wear rate • No binder required • Production rate much lower than expected • Fine particles represent 5-15% of feed products • No grinding required for sieved co-compost	• Required trained labor staff to install and operate • Sand level must be below 5% per specification • No binder required • Able to produce pellets from various feedstock • Fine particles represent 5-15% of feed products • Moisture content can be auto-adjusted (dependent on the die compression value)

(Continued)

TABLE A7. PERFORMANCE OF SELECTED PELLETIZERS TESTED BY IWMI WITH FS-BASED COMPOSTS AND CO-COMPOSTS. (CONTINUED)

Machine	A. Extruder pelletizer	B. Roller disk die type	C. Roller disk die type
Country	Ghana	Sri Lanka	Ghana
Disintegration time[a]	34-120 hours (h)	72-330 h	4-10 h
Bulk density increase	20-50%	20-30%	20-100%
Theoretical production rate	100 kg h^{-1}	300 kg h^{-1}	500 kg h^{-1}
Real production rate[b]	60-100 kg h^{-1}	30-130 kg h^{-1}	300-750 kg h^{-1}
Energy consumed	36-57 kWh MT^{-1} of pellets[c]	172-740 kWh MT^{-1} of pellets[d]	67-73 kWh MT^{-1} of pellets[d]
Pellet shape	Dimensions varied with feedstock and binder type; did not vary with moisture content and binder concentration.	Dimensions varied with feedstock. Initial temperature of pellets was 45-50 °C.	Dimensions varied with feedstock. Initial temperature of pellets was 45 °C.

Source: Modified from Nikiema et al. 2013.

Notes:

[a] Disintegration time varied depending on the type of binding agent and the raw materials selected for co-composting.

[b] Co-composts with sawdust were the most difficult to pelletize, while FS compost was the easiest to pelletize. Other operating parameters, such as the moisture content, concentration of binder and the process temperature, also influenced the pelletization flow rate.

[c] Solar drying of pellets was carried out. Energy requirement was not considered in the given data.

[d] No drying of pellets was required.

Annex 4. Registration and Certification Processes: The Ghana Example

The registration procedure of the *Fortifer* business can broadly be divided into three main stages:

1. Registration with the Registrar General's Department.
2. Registration with the Environmental Protection Agency (EPA).
3. Registration with the Plant Protection and Regulatory Services Directorate (PPRSD) of Ghanaian MoFA.

1. Registration with the Registrar General's Department

The Companies Act 1963 (Act 179) requires that, before starting a business in Ghana (in this case the *Fortifer*™ fertilizer business which falls under agricultural inputs), the business must be registered with the Registrar General's Department in order to obtain the Registrar of Companies' ***Certificate of Incorporation*** and ***Certificate to Commence Business***. However, registration is not needed if the production company already has a certification that permits it to engage in the sale of agricultural inputs. The same department also allowed the registration of a 'Trademark' for the name *Fortifer*.

2. Registration with the Environmental Protection Agency (EPA)

This registration is required to obtain environmental clearance for *Fortifer* production at the exact location where the plant will be established. This implies that the (often long-lasting) land search and acquisition processes have to be completed before the EPA application. The actual procedure involves filling an Environmental Permit (EP) Form, which allows the EPA to decide whether the proposed development (i.e., the *Fortifer* production facility) should be subjected to an environmental assessment and the level of possible impact/assessment that is required. A site inspection by EPA officers will be conducted and a screening report presented to a Technical Review Committee (TRC) for decision-making within 25 days from the time the report was submitted to the TRC. The results of the screening will determine the next cause of action.

3. Agricultural input accreditation

The governmental institution responsible for registration of the **fertilizer producer** and the new **fertilizer product** in Ghana is MoFA through its PPRSD unit. The application has to be made through the Minister of Food and Agriculture, separately for the company and each co-compost product. With respect to the product(s), the applicant is required to send the following (IWMI 2017):

- Technical Dossier of each product to be registered, describing its organic materials and nutrient content (standard form provided).
- Proposed label for each product, which was designed by taking into consideration the product name, its uses and safety precautions.
- Certificate of Incorporation for the company.
- Certificate to Commence Business for the company (including the EPA permit).

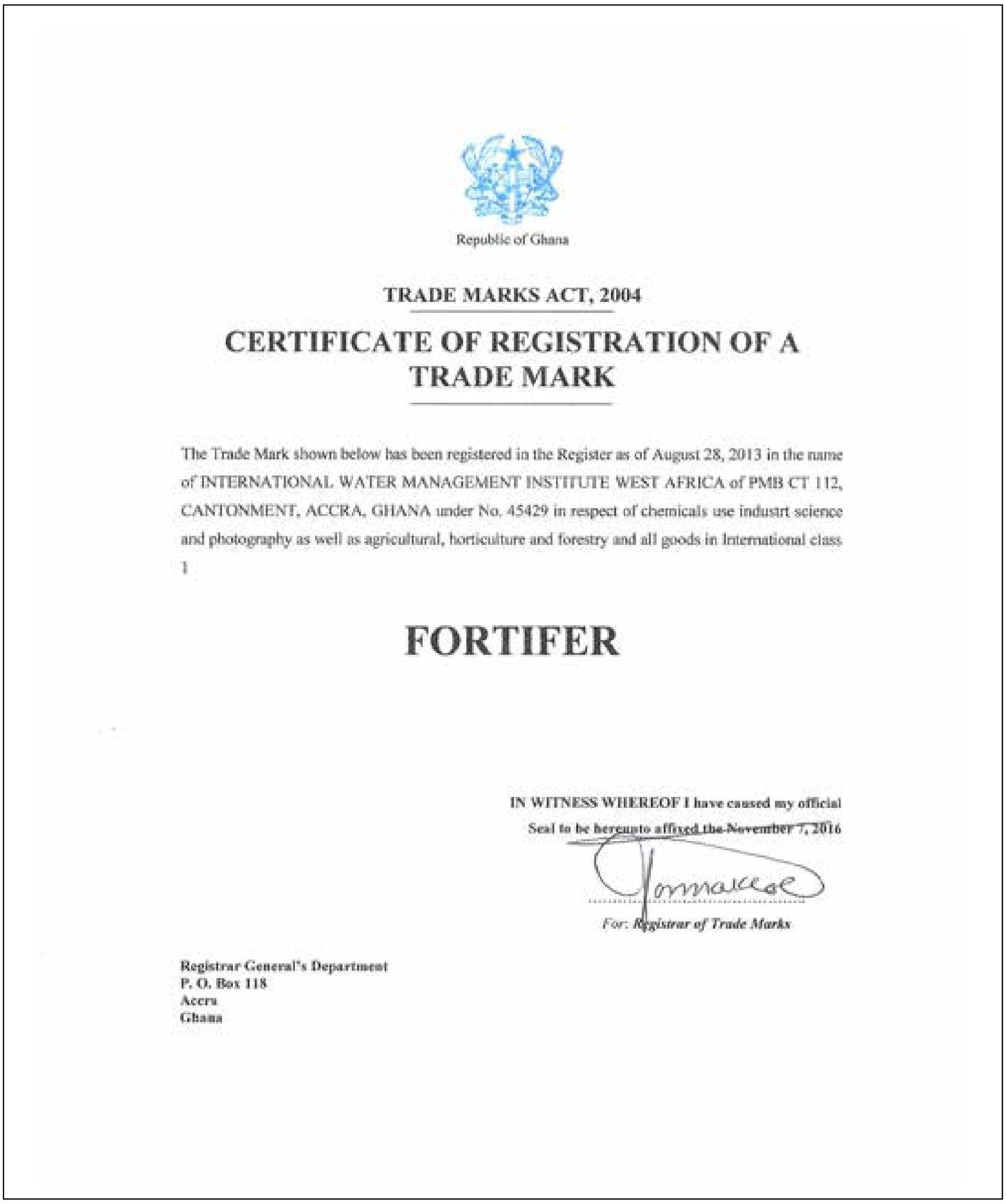
Once these documents are submitted, the procedure involves the following (IWMI 2017):

- Verification of the contents (organic materials, nutrients and pathogens) of the dossier presented by the applicant. A specific quantity of the product (about 2 kg) has to be submitted to PPRSD for laboratory analysis.
- A field trial (efficacy trial) to assess the effectiveness of the product. This is carried out for two agronomic seasons and using two or more crops by an independent research team engaged by PPRSD. After the trial, the research team submits a report, which also includes the recommendation on the product's effectiveness, to PPRSD. *Fortifer* was tested in view of its nutrient supply (i.e., like a fertilizer) and its effectiveness was determined by crop yield. As control, an industrial fertilizer (NPK + sulfate of ammonia) was used. *Fortifer*™ application rates were 6-20 MT ha^{-1}.
- PPRSD reviews the results and takes a decision on approval or otherwise, and also provides necessary recommendations where necessary. At this point, feedback is also provided on the designated 'label' of the product for finalization.

Various fees are payable at the different stages. Apart from the laboratory fee and field trial cost, which depend on the number of product formulations and the range of analysis/trials required, there are fixed rates for the other fees, which are periodically reviewed by PPRSD.

The entire *Fortifer*™ certification process in Ghana took **three years**, i.e., longer than expected for the following four formulations:

1. DFS compost enriched with inorganic nitrogen.
2. DFS and organic solid waste co-compost enriched with inorganic nitrogen.
3. Pellets of DFS compost enriched with inorganic nitrogen.
4. Pellets of DFS and organic solid waste co-compost enriched with inorganic nitrogen.



Republic of Ghana

TRADE MARKS ACT, 2004

CERTIFICATE OF REGISTRATION OF A TRADE MARK

The Trade Mark shown below has been registered in the Register as of August 28, 2013 in the name of INTERNATIONAL WATER MANAGEMENT INSTITUTE WEST AFRICA of PMB CT 112, CANTONMENT, ACCRA, GHANA under No. 45429 in respect of chemicals use industrt science and photography as well as agricultural, horticulture and forestry and all goods in International class 1

FORTIFER

IN WITNESS WHEREOF I have caused my official Seal to be hereunto affixed the November 7, 2016

For: Registrar of Trade Marks

Registrar General's Department
P. O. Box 118
Accra
Ghana

Annex 5. Fertilizer and Compost Application and Nutrient Release

Recommendations for **fertilizer** application rates for specific crops and fertilizers to be used are based on the knowledge of the local soils and can be obtained from local universities, research institutions, or the extension service of the ministry of agriculture. Table A8 shows a typical recommendation for fertilizer application in Sri Lanka. The nutrients applied are readily available, although care has to be taken that especially N and K will not be excessively lost through leaching following irrigation or heavy rains.

TABLE A8. FERTILIZER APPLICATION RATES (IN KG HA^{-1}) AS RECOMMENDED FOR MAIZE IN SRI LANKA.

Crop	Urea (N)	Superphosphate (P)	Muriate of potash (K)
Maize (rainfed)	225	100	50
Maize (irrigated)	325	100	50

As discussed in 7.2.2, providing a similar numerical recommendation for a **compost** is difficult, as its primary function is to improve soil structure. As a nutrient source, compost has the advantage of providing a larger variety of different crop nutrients compared to commercial fertilizers, but the amounts are much lower, and will only be released over a longer period:

a] Replacing, theoretically, 100 kg of urea would require between 1,500 and 3,000 kg of compost, depending on its quality and ability to match the total nitrogen content (Table A9). However, as only a certain percentage of this nitrogen is easily plant available, a much higher amount of compost would be needed to supply the first crop with its dose of fertilizer needed.

TABLE A9. EQUIVALENT NITROGEN AMOUNTS BETWEEN DIFFERENT CO-COMPOSTS AND NITROGEN FERTILIZERS.

Fertilizer (N/P/K) (kg)	Co-compost (1.5% N)	Co-compost (2.3% N)	Enriched co-compost (3% N)
The nitrogen content of 100 kg of urea (46-0-0) is equivalent to about the same in:	3,000 kg	2,000 kg	1,500 kg
The nitrogen content of 100 kg of ammonium nitrate (33-0-0) is equivalent to the same in:	2,200 kg	1,450 kg	1,100 kg
The nitrogen content of 100 kg of ammonium sulfate (21-0-0) is equivalent to the same in:	1,400 kg	900 kg	700 kg
The nitrogen content of 100 kg of NPK (15-15-15) is equivalent to about the same in:	1,000 kg	650 kg	500 kg

b] Different climates, sludge treatments and types of compost can result in the release of different amounts of nitrogen. A faster compost breakdown is more common in warmer than colder climates. The likelihood of having plant-available nitrogen in the soil will increase with a decreasing C:N ratio of the composts used, from a standard MSW compost to a compost which contains manure or FS, and to a co-compost enriched with nitrogen. A higher release rate is also common from fecal sludge produced through aerobic rather than anaerobic digestion. In general, the mineralizable nitrogen fraction decreases with increasing biological stabilization of the sludge. As a result, nitrogen release rates from different types of compost reported under tropical conditions vary between **10 and 40%** in the first year; while in temperate climates, up to 25% of the total nitrogen might become available within the first three years.

c] Similar to nitrogen, a significant amount of phosphorus in compost is not readily available through mineralization. Moreover, in certain iron-rich soils, a part of the mineralized fraction can be bound by metals, making it unavailable for crops. Thus, the range of actually available phosphorous for the first or second crop can differ between **10 to 50%. Potassium**, on the other hand, does not get incorporated in large organic compost molecules and so, in principle, it is **100%** readily available to plants. However, it is also very soluble in water, and rain or ambitious watering can easily leach potassium out of the root zone in the topsoil.

In summary, composts differ significantly from chemical fertilizers and a comparison based on their crop nutrient content is not appropriate. However, organic and chemical inputs can complement each other very well as established and promoted since the late 1980s in various research programs on Integrated Soil/Plant Nutrient Management (e.g., Vanlauwe et al. 2001, 2015).

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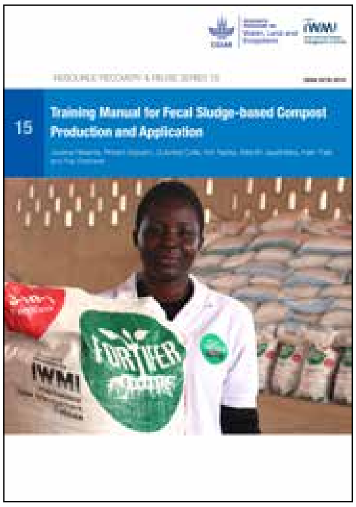

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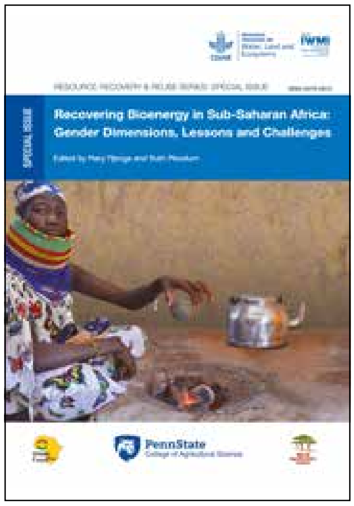

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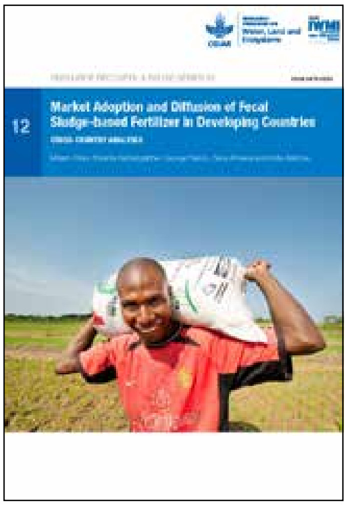

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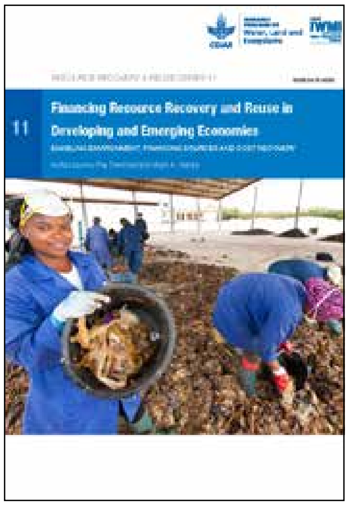

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CGIAR Research Program on Water, Land and Ecosystems (WLE)
International Water Management Institute (IWMI)
127 Sunil Mawatha, Pelawatta
Battaramulla, Sri Lanka
Email: wle@cgiar.org
Website: wle.cgiar.org
Thrive Blog: wle.cgiar.org/thrive

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