IWMI International Water Management Institute

IWMI is a member of the CGIAR Consortium and leads the: CGIAR RESEARCH PROGRAM ON Water, Land and Ecosystems

Developing Fortified Excreta Pellets for Use in Agriculture

Final Report

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Excreta are rich source of essential plant nutrients and organic matter that can be recycled as fertilizer-cum-soil conditioner – an effect not shared by chemical fertilizers and of dare need in tropical soils. Such material improves soil structure; increases water holding capacity, reduce pests and diseases and neutralize soil toxins and heavy metals. Between 2002 and 2010, IWMI worked on the understanding of the principles that underlie the use of excreta in agriculture (e.g. to optimize the removal of pathogens as well as the recovery of nutrients) and assessed the associated benefits. Despite several indisputable benefits in terms of agricultural productivity, it was observed that use of excreta was constrained by the cost of transportation and handling as well as negative perception of communities with regards to using FS in agriculture. To address both challenges, this project hypothesized that producing excreta pellets (*Fortifer*) could be the solution.

1 Activities

The project started in May 2011 and ended in April 2013 (Table 1).

Table 1: Overall Project design and implementation plan.

No.	Activity Description	Contributors [1]	Beginning	End	Output
Task 1	***Selection of binding material***				One scientific paper – Under review (Annex 1)
1.1	Screening of suitable materials	IWMI, BNARI, UI	2011-Jun	2011-Nov	
1.2	Physical and biochemical analysis of selected binding materials	IWMI, BNARI	2011-Nov	2012-Jan	
1.3	Supply chain analysis of the 2 selected binding materials	IWMI	2011-Sep	2012-Jan	
Task 2	***Design of pelletizing unit***				
2.1	Design of a pelletization unit	IWMI, BNARI, CSIR	2011-Aug	2012-Jan	Report
2.2	Pre-testing of the pelletization unit	IWMI, BNARI, CSIR	2011-Dec	2012-Jan	
Task 3	***Irradiation, Composting, Enrichment and pelletization***				One scientific Journal paper – Under review; 1 Conference paper (Annex 2)
3.1	Drying of fecal sludge	IWMI, TMA, BNARI	2011-Aug	2011-Sep	
3.2	Irradiation, co-composting and composting	IWMI, BNARI	2011-Nov	2012-Feb	
3.3	Enrichment of co-composts and composts	IWMI, UG	2012-Mar	2012-Jul	
3.4	Optimization of the process, production and characterization of pellets (including incubation study)	IWMI, BNARI	2012-Mar	2012-Dec	
Task 4	***Agronomic trials***				One scientific paper – Under preparation (Annex 3)
4.1	Testing of *Fortifer* pellets in the greenhouse	IWMI, VVU, UG	2012-Aug	2012-Nov	
Task 5	***Market, costs, benefits analysis***				Report (Annex 4)
5.1	Cost-benefit analysis	IWMI	2012-Jun	2012-Oct	
5.2	Exploratory market analysis	IWMI	2012-Jun	2012-Oct	

[1]: **IWMI**: International Water Management Institute; **BNARI**: Biotechnology and Nuclear Agriculture Research Institute, Ghana; **UI**: University of Ibadan, Nigeria; **UG**: University of Ghana; **VVU**: Valley View University; **TMA**: Tema Metropolitan Assembly, Ghana; **CSIR**: Council for Scientific and Industrial Research, Ghana.

1.1 Selection of binding material (Task 1)

This task aimed at identifying a cost-effective and locally available binder for the pelletization of fecal sludge based materials. Addition of a binder to composts is necessary in order to form strong pellets, i.e. able to maintain their shape when some mechanical pressure is exerted on them during e.g. packaging and transportation.
Following our investigation, cassava starch and clay were selected as potential binders. Parameters considered for selection included total available amounts, availability in time and in each region of Ghana, ease of use during pelletization, handling and storage requirements, binding ability and strength, costs, etc. Cassava starch (has to be pretreated in order to increase its binding properties; through pregelatinization - in the presence of hot water - or gamma irradiation) and clay were analyzed for their nutrient content. The supply chain analysis further confirmed that available amounts of clays are high while current uses are limited. This situation suggests a guarantee for consistent supply over coming years. In the case of cassava, even though it is a staple food in the country, the current market does not absorb all the production. Creating a new use for cassava (through starch production) is also in line with the government's development agenda.

1.2 Design of pelletizing unit (Task 2)

The objective of this task was to design and construct a pilot scale pelletizing unit for production of pellets using the different compost products. To minimize the costs involved and increase the chance of successful uptake, local expertise was favored. Table 2 presents photos and characteristics of the equipment fabricated in Ghana by CSIR.

Table 2. Components of the pelletizing unit

<table>
<tr>
<td>Grinder
Capacity: 450 kg/hr
Power requirement: 3 phase, 4 kW motor

Outside dimensions:
• Length: 1 m
• Width: 0.5 m
• Height: 1.2 m</td>
<td></td>
<td rowspan="2">Mixer
Capacity: 20 kg per batch (up to 240 kg/hr)
Power requirements: 3 phase, 1.5 kW motor

Outside dimensions:
• Length: 1.56 m
• Width: 0.5 m
• Height: 0.95 m
</td>
<td rowspan="2"></td>
</tr>
<tr>
<td>Pelletizer
Capacity: 100 kg/hr
Power requirements: 3 phase, 1.5-4 kW motor
Diameter of pellets: 8-12 mm
Outside dimension:
• Length: 1.2 m
• Width: 0.5 m
• Height: 1.35 m</td>
<td></td>
</tr>
</table>

To validate the design and calibrate the equipment, a series of conducted pretests allowed us to identify key pelletization factors as follows:

- Moisture content; it was observed that addition of suitable amount of water improves the fluidity of the fecal compost and aids in pellet formation.
- Binder type; for pelletization, compost containing starch requires less water than the one containing clay (kaolin). On the other hand, pellets obtained using starch were better and stronger (even after 1 month) than those from clay which crumble during storage. Based on that observation, starch was preferred to clay.
- Binder concentration affected the visual quality of pellets produced. For compost samples containing starch as binder, ability to form pellets of high visual quality and strength increased with increased starch concentration but was not consistent in the case of clay.

The pre-testing also allowed the optimization of the protocol for handling of pellets after production.

1.3 Composting, enrichment, irradiation and pelletization (Task 3)

1.3.1 Materials

To obtain the dewatered fecal sludge (DFS), FS from public toilet (retention time at source: 2 – 4 weeks) and from household septic tank (retention time at source: 1 – 3 years) were collected and mixed in volume ratio 1:2 on a drying bed at the TMA's treatment plant. About 2,100 kg of DFS were generated, packaged in polypropylene bags and sent to the composting site within BNARI. The sawdust used was a 3-day old waste obtained from a timber sawmill at Ofankor, Accra. The market waste was obtained from Madina market in Accra.

1.3.2 Production process

The objective of this task was to produce the fecal sludge based materials needed for *Fortifer* production.

- Three heaps were prepared; 1) C-SDFS [co-compost: DFS + sawdust; mass ratio = 1:3]; 2) C-MDFS [co-compost: DFS + market waste; mass ratio = 1:3]; 3) C-DFS [compost: DFS only]. Each heap was turned and moistened twice a week. Heap temperature was monitored daily over > 90 days. The maturity of the C-DFS and C-SDFS was confirmed through germination tests with seeds of tomato, cucumber and water melon. C-MDFS failed the germination test and was therefore eliminated from further work. Matured composts, with 1.2-1.7% N, were enriched with sulphate of ammonium to raise the N content to 3% as previously recommended.
- The irradiation consisted of subjecting 200 kg (packaged in polypropylene bags of 20 kg each) of DFS to 20 kGy of gamma rays for 2 days. Irradiation causes atoms and molecules to become ionized, which leads to the production of free radicals causing the breakage of chemical bonds and/or creation of new chemical bonds and cross-linkages. In a sanitation context, these lead to injury to living tissue and deactivation of molecules that regulate vital cell processes (e.g. DNA, proteins). As a consequence, organisms, originally in the treated material, become unable to grow or reproduce. I-DFS was then obtained.

For each pelletization test, at least 4 kg of material was used. This was mixed with the required amounts of starch (irradiated (IR) or pregelatinized (PG)) and water. The mixture was fed into the pelletizer to produce pellets of 8 mm in diameter. Final step involved sun-drying and sieving (5 mm grid).

1.3.3 Results

The objective was to optimize the pelletization process and characterize the physical (Table 3), chemical and biological parameters of *Fortifer* pellets. Therefore, influence of operating parameters such as binder type and concentration, as well as moisture content was studied. Starch at an optimal level of 3% was selected.

Table 3. Results of pelletization

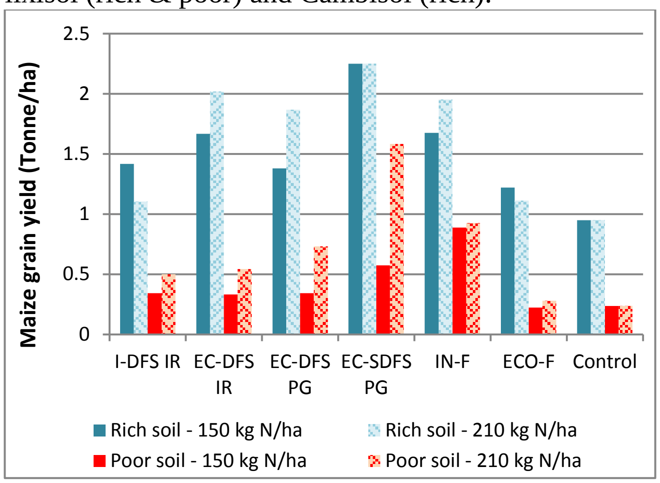
Parameter / Selected products		C-DFS	EC-DFS	I-DFS	C-SDFS	EC-SDFS	Most significant factors
Moisture content (%) when using starch		27-31	18-25	27-31	39-46	39	• Type of pelletized material • Type of binder • Concentration of binder
Percentage of fines following production and drying		10-15	2-23	6-17	-	19	• Starch concentration • Moisture content • Type of pelletized material
Typical pellet length (cm) distribution (%)	0.5-1.0	71	21	24	-	-	• Starch pretreatment method • Type of pelletized material
	1.0-1.5	24	49	64	-	-	
	1.5-2.0	4	24	9	-	-	
	2.0-2.5	1	4	3	-	-	
Bulk density (dried materials)	Raw	0.71	N/A	N/A	0.37	N/A	• Type of pelletized material • Starch pretreatment method • Moisture content
	Ground	0.77	N/A	0.58	0.39	N/A	
	Pelletized	-	0.91	0.88	-	0.47	
Disintegration time in the presence of water		-	28-73 hrs	7-50 hrs	-	50 hrs	• Starch content • Type of pelletized material
Stability (% of pellets keeping a length > 5 mm after shaking (300		87-90	88-98	85-92	-	92	• Shaking time duration • Type of pelletized material • Binder concentration

motion/min, 2 hr)						• Moisture content

C-SDFS [co-compost: DFS + sawdust; mass ratio = 1:3]; I-DFS [Gamma irradiated DFS]; C-DFS [compost: DFS only]; EC- [enriched compost]

1.4 Agronomic trials (Task 4)

The objective of this task was to test the efficiency of the fertilizer pellets and compare them with competing fertilizers. A greenhouse having 225 m^2 of surface area was constructed on the campus of VVU and used to test the effectiveness of the pellets on plant growth and yield. Open field experiments were also conducted in parallel to validate the greenhouse tests and also allowed testing of additional products. Measured parameters included number of leaves per plant, plant height, leaf area, leaf, stem and root weights, pest incidence, etc. Soils and plant nutrient levels were also analyzed. Results confirm that pellets performed better. Yields of cabbage and maize were comparable or higher than the tested inorganic fertilizer and the commercial organic fertilizer.
Tested products were: 1) EC-SDFS with 3% PG starch; 2) EC-DFS with 3% PG starch; 3) EC-DFS with 3% IR starch; 4) I-DFS with 3% IR starch; 5) Inorganic fertilizer (IN-F); 6) Commercial organic fertilizer (ECO-F) or poultry manure (PM)[1]; 7) Soil only (control). **Application rates were**: 150 & 210 kg N/ha; **Soil types were**: Ferric lixisol (rich & poor) and Cambisol (rich).



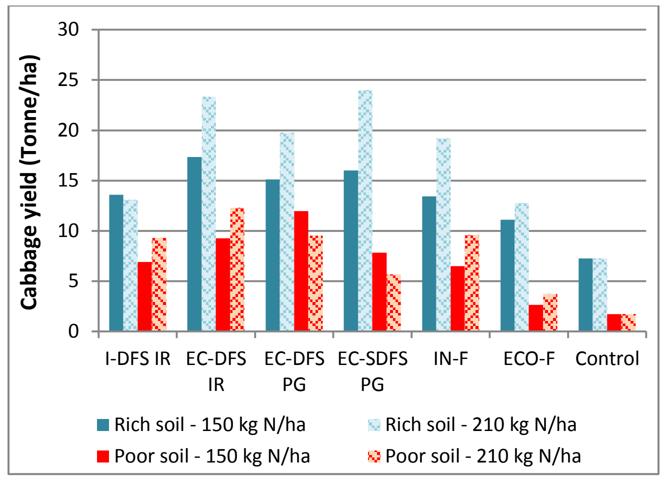


Figure 1. Maize and cabbage yields following the greenhouse trial (Ferric lixisol – poor – and Cambisol)

1.5 Costs, benefits, market analysis (Task 5)

This study estimated that the current production cost of *fortifer* was about **10 US$ per bag of 50 kg for composts and co-composts** and 34 US$ per bag of 50 kg when irradiation[2] is involved. These costs could be lowered following further optimization of the processes.
An exploratory market research was also conducted to 1) identify and quantify the alternative/competing fertilizer materials in Ghana; 2) estimate the potential demand for the product and possible market share; 3) identify and map out the potential actors in a *Fortifer* pellets market chain; and 4) identify possible channels for up-scaling and competitive positioning of *Fortifer* pellets. These have been done through extensive desktop search and engagement with key pre-identified and snow-balled stakeholders in four key administrative regions in Ghana – Ashanti, Greater Accra, Northern and Western. The results show that in all the four regions surveyed, NPK, Urea and Sulfate of ammonia featured as prominent fertilizer types. The main organic fertilizer types observed from the study are poultry manure which is quite popular with vegetable farmers. In all four regions, most farmers and Ghana agri-input dealers association (GAIDA) members indicated their willingness to purchase fecal sludge based pellets. The Western, Ashanti and Northern region presents great potential demand for *Fortifer*. In the Northern region, this willingness was conditional to the demonstration of the efficiency of the pellets. The main channel for

[1] In the greenhouse, the commercial organic fertilizer was tested but showed an overall performance below that of our products. Poultry manure was tested during open field experiments.
[2] The cost of gamma radiation will reduce if the use of the equipment was optimized. In addition, gamma irradiation allows the production of 40 % more and 50 % less bags than composting and co-composting, respectively.

up-scaling *Fortifer* is through private-public partnerships such as inclusion of *Fortifer* onto the Fertilizer Subsidy programme.

1.6 Conclusion

All hypothesis/assumptions formulated in the beginning of the project were confirmed throughout the research (Table 4). It was established that pelletization of enriched composts or irradiated DFS is a suitable way to reduce disease incidence, volumes (and therefore improve transportation and handling) and contribute to addressing perception issues. This project also allowed a better understanding of the challenges related to pelletization of fecal sludge products and prepared for a scaling up of the production of pellets in Ghana.

The pellets were found to be suitable as fertilizers following greenhouse and field trials (different soil types tested for cabbage and maize growth).

Table 4. Main conclusions

Challenge	Addressed?
Disease incidence	*Fortifer* is found to be safe.
Transport	Pelletization increases the bulk density, i.e. less volume (50-80 % of the initial volume) is needed to transport *Fortifer*
Handling	*Fortifer* pellets are strong and do not easily break down even when roughly shaken for up to 2 hours
Perception	Preliminary market analysis confirmed that there is no barrier to the fact that *Fortifer* is derived from fecal sludge in 4 selected regions of Ghana
Use	No dust generated, as when powder materials are used. Still, *Fortifer* pellets will decompose and release the nutrients gradually in the soil

2 Challenges

Most challenges were in connection with analytical capabilities of national laboratories in Ghana. The laboratory of BNARI that was planned to be used could not be completed in time forcing us to rely on an external laboratory for chemical analysis, which increased the delays in analysis and costs. On the other hand, it was not possible to get a laboratory equipped for analysis of some properties of the binders (e.g. plasticity); we had to rely on literature. Similar situation was encountered for pellets analysis (strength, etc.). As a result, some of the parameters could not be quantified using standard methods. Instead, they were assessed using indirect methods and available equipment. Finally, it was not possible to access a greenhouse early to conduct the experiments involved in this research. Therefore, a greenhouse was constructed leading to delay in the field trials and justifying a no-cost extension.

3 Other sources of project support

The main additional contributions to this project are given in Table 5.

Table 5. Additional sources of support and amounts

Activity	Objective	Funding source/amount
Installation of the pelletizing unit	Connect the facility to the 3-phase electricity needed by the equipment and secure the location	IWMI: 5000 $
Greenhouse construction	Draw plans and supervise the construction	VVU: In kind
Composting platform in BNARI (SAFISANA/CHF sponsored)	Produce composts and co-composts needed for the production of *Fortifer*	30,000 $

4 Annex

- Annex 1: Binding materials; http://onlinelibrary.wiley.com/doi/10.1002/ep.11790/abstract
- Annex 2: Pelletization; Nikiema, Josiane; Cofie, Olufunke; Impraim, Robert; Adamtey, N. 2013. Processing of fecal sludge to fertilizer pellets using a low-cost technology in Ghana. Environment and Pollution, 2(4):70-87. [Open access]
- Annex 3: Agronomic trials (Greenhouse/field experiments)
- Annex 4: Market analysis
- Annex 5: Experience from Nigeria