Faecal Sludge Reuse in Birendranagar, Nepal: A Case Study of the World Health Organisation's Multiple Barrier Approach

Short title : Faecal sludge reuse in Birendranagar, Nepal: A case study of the WHO's multi-barrier approach

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Abstract:
This case study presents an innovative initiative to facilitate safe reuse of faecal sludge (FS) by introducing the World Health Organisation's multi-barrier approach within a Farmer Field Schools framework for participatory experiential learning. A novel FS treatment process based on fermentation by 'effective organisms' (EM) was piloted to test the feasibility, safety and acceptability of the resulting fertilizer. Fermented FS in agricultural application was found to perform at least as well as other common fertilizers it was compared with, while its lower cost delivered higher profits per cultivated hectare. Participating farmers found it easy to prepare and use, and viewed it favourably overall. EM-based fermentation was, however, found to be insufficient as an FS treatment to render safe reuse, particularly with respect to helminth inactivation. The paper discusses strengthening the treatment barrier, and improving the application of the multi-barrier approach by the systematic consideration of non-treatment barriers using guidance from the WHO's Sanitation Safety Planning Manual. Further research to enable effective monitoring and support systems for maintaining treatment and non-treatment barriers, and for understanding long term impacts of fermented FS application is recommended. In combination, adequately treated fermented FS may be a candidate for scale up necessary for meeting the Sustainable Development Goals.

Keywords: Faecal sludge reuse, multi-barrier method, farmer field school, fermentation treatment, effective microorganisms, sanitation safety planning

INTRODUCTION

Linking safely managed sanitation with productive agricultural reuse can support multiple Sustainable Development Goals (SDGs) to improve food security, support farmers' livelihoods and reduce pollution of water resources. In order to maximize benefits from reuse of human waste, it is necessary to address risks to public health and the safety of sanitation workers, farmers, local communities and consumers of produce (WHO 2015).

Facilitating safe, effective and long-term faecal sludge treatment and reuse/disposal is one of the components of the SNV Netherlands Development Organisation's *Urban Sanitation and Hygiene for Health and Development (USHHD)* program. The USHHD program in Nepal has included work in Birendranagar Municipality in Surkhet District, where peri-urban farmers sometimes purchase raw faecal sludge (FS) from private septic tank emptying service providers to fertilize their farm lands. SNV identified the opportunity to improve the health and safety around FS reuse in Nepal through piloting the introduction of the multiple barrier or 'multi-barrier' approach recommended by the World Health Organisation (WHO 2015).

The pilots implemented by SNV were modelled on an innovative approach to faecal sludge reuse trialled by GIZ in Afghanistan (GIZ 2012a,b), which was novel in two key aspects. Firstly, the multi-barrier approach was introduced within a *Farmer Field School framework* – a well-established participatory and experiential learning approach for farmer groups to explore new agro-technological innovations (Khisa et al. 2014). Secondly, a simple, low cost fermentation-based process based on 'effective microorganisms' (EM) was used for faecal sludge treatment. Explanations of the multi-barrier approach, EM-based faecal sludge fermentation and the Farmer Field School framework are provided below, following a brief introduction of the pilot projects that form the basis of this paper.

This paper reflects on two pilots conducted by SNV in Birendranagar Municipality that make up the case study. The pilots investigated the viability, safety and social acceptability of fertilizing off-season crops using FS treated on-site using the relatively unknown fermentation-based treatment process based on effective organisms (EM). EM is a common additive in composting cow dung and crop wastes (green manure) in Nepal where it is believed to enhance the decomposition process and improve soil fertility, and its use is promoted by the District Agriculture Development Office (DADO) – key reasons for choosing this treatment in the pilots.

The pilots were designed to investigate a broad range of questions for indicative answers rather than a more scientifically rigorous study of a narrow set of issues. They included testing crop response, financial viability (relative production costs and harvest revenues), indicative hygienic properties of the treated FS fertilizer and harvested crop samples, and farmer perceptions. The first pilot (October 2014 - March 2015) was a preliminary investigation modelled on the GIZ approach, while the second pilot (February - July 2016) included adaptations and improvements based on lessons from the first pilot. The collaborating authors are SNV practitioners, who developed and undertook the two pilots in Nepal, and researchers from the Institute for Sustainable Futures at the University of Technology Sydney, who drew on the data after the fact to facilitate analysis of the pilots and presentation of the case study.

The case study is structured around the following research questions with respect to the two pilots:

- How safe is fermented FS for reuse in terms of pathogen levels?
- How effective is the multi-barrier approach in reducing exposure to pathogens?
- What are potential gaps in the application of the multi-barrier approach, and how can they be addressed?
- How well does fermented FS perform as a fertilizer relative to other commonly used fertilizers, and in terms of farmer acceptability?

A brief overview of the multi-barrier approach, EM-based FS fermentation treatment, and the Farmer Field School framework follows, to situate the features of the case study with reference to literature. The methodology section then explicates how these aspects were applied through the arrangements for each pilot.

The multi-barrier approach

Health risks around wastewater and sludge reuse need to be managed without requiring wastewater treatments that are prohibitively expensive for developing countries. To this end, the WHO's Wastewater Reuse Guidelines (2006) considers multiple strategies to eliminate or reduce risks to an acceptable level, further elucidated in the multi-barrier approach in the WHO Sanitation Safety Planning manual (2015). The multi-barrier approach comprises of a series of control measures along exposure pathways and transmission routes in order to limit human contact with FS pathogens. These include both *treatment controls* to reduce the pathogen hazard, and *non-treatment controls* which are a range of appropriate interventions to safeguard all people identified as at risk of exposure – sanitary workers, farmers, local communities and consumers.

The multi-barrier approach to agricultural FS reuse includes consideration of a range of controls such as appropriate selection of crops, irrigation methods, and providing allowance for pathogen die-off in the timing of harvesting. For at-risk groups, examples of barriers include: use of personal protective equipment and tools that limit exposure, and good hygiene behaviours to safeguard farmers and sanitation workers; physical barriers to treatment facilities (e.g. fencing, warning signage) and irrigation buffer zones to safeguard local communities (WHO 2015). For situations where a FS treatment process does not reduce the pathogen hazard with sufficient certainty, the additional (non-treatment) multi-barriers for reducing exposure are critically important for protecting human health.

FS treatment by fermentation with effective microorganisms

Effective microorganisms (EM) consists of mixed cultures of naturally occurring, beneficial microorganisms – predominantly lactic acid bacteria, yeasts, actinomycetes and photosynthetic bacteria (Yamada & Xu 2000). Lactic acid fermentation is identified as the dominant biochemical process occurring with the addition of EM (Factura et al. 2010, Spit 2016). The use of EM as an inoculant to soil and plants is documented as improving the microbial diversity of soil, thereby improving soil quality, crop quality and crop yields (see for example, Journal of Crop Production 2000, Vol 3 No 1 (Special Issue on nature farming research)). EM has been most effective as an agricultural soil additive when applied in combination with organic amendments that provide carbon, nitrogen and energy for the microorganisms – for example, fermentation of organic fertilizers with EM and molasses (Yamada & Xu 2000).

There is limited documentation on EM fermentation of faecal sludge (FS), compared to the extensive literature on EM fermentation of organic fertilizers noted above. Much of the available literature relates to testing claims that the addition of EM to septic tanks and pit latrines can reduce volumes of faecal sludge build-up - claims which are refuted (e.g. Szymanski & Patterson 2003; Grolle 2015, SuSanA Forum 2015). Pathogen inactivation by EM fermentation is not discussed by these sources.

To protect public health, FS treatment needs to reduce the hazard from a range of endemic faecal pathogens – including bacteria, viruses, protozoa and helminths (Feachem et al. 1983). The limited published pathogen studies using EM fermentation as a FS treatment process have predominantly focussed on indicator bacterial pathogens. These studies suggest it may be effective in inactivating bacterial pathogens under specific laboratory conditions (Anderson et al. 2015; Factura et al. 2010; Scheinemann et al. 2015; Soewondo et al. 2014). Anderson et al. (2015) report that lactic acid fermentation (using a culture created from the fermented milk drink *Yakult*) was effective in reducing *Escherichia coli (E.coli)* to undetectable levels after 168 hours (7 days) of treatment in plastic drum reactors at 'room temperature' (assumed to be 20 ^{o}C). Six types of indicator bacteria tested by Factura et al. (2010) were inactivated adequately to meet US EPA standards for biosolids after 4 weeks of lactic acid fermentation at 20 ^{o}C followed by vermicomposting. Scheinemann et al. (2015) found that lactic acid fermentation of FS at 37^{o}C under laboratory conditions reduced indicator bacteria within 3 days and indicator viruses in 7 days, but took 56 days to inactivate indicator helminth eggs (Ascaris). They identify holding temperature as the critical factor affecting the viability of Ascaris eggs in sludge, with greater inactivation at warmer temperatures.

The Birendranagar pilots used a locally available preparation on EM, understood to be derived from *EM-1 MICROBIAL INOCULANT (Dr. Teruo Higa's Original Effective Microorganisms),* which was the EM product used by the GIZ project on which the pilots were modelled. Before adding EM to the FS, a pre-culture was prepared by adding molasses and water to the EM and allowing it to develop in a warm environment for 5-14 days. A similar pre-culture was prepared by Anderson et al. (2015) who explain that this enables exponential growth of the lactic acid bacteria population.

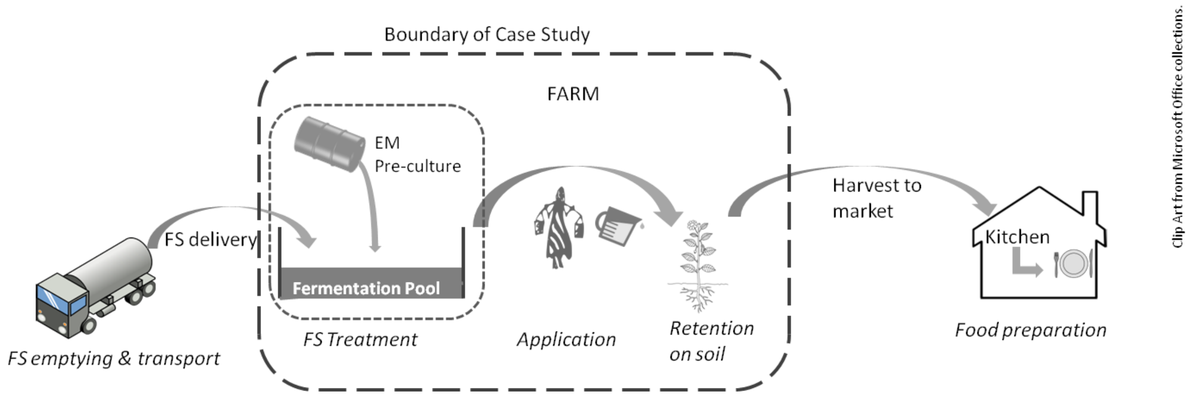
The field conditions for FS fermentation treatment in the Birendranagar case study, where winter temperatures ranged from 20-36 °C by day and 5-16 °C by night, suggest less effective pathogen reduction than what is reported through the literature on EM fermentation under controlled laboratory conditions and steady temperatures of at least 20 °C. Soil-transmitted helminths are endemic in Nepal (Global Atlas of Helminth Infections 2015), so helminth inactivation needs to be a particular treatment priority (WHO 2006). In summary, the literature indicates the need for fermented FS to be handled with caution as a pathogenic substance that requires additional barriers to protect public health.

Farmer Field School framework

The Farmer Field School (FFS) framework was developed by the UN Food and Agriculture Organisation (FAO) in 1989 and used successfully with farmers adopting integrated pest management practices (Khisa et al. 2014). A FFS typically comprises a group of 20-25 farmers who meet weekly (or other regular interval) to experiment with and evaluate new practices under the guidance of a trained and qualified facilitator. The FFS approach uses experiential and participatory learning techniques, allowing farmers to merge their own traditional knowledge with external information to identify and adopt the practices and technologies most suitable to their livelihood system and needs (Khisa et al. 2014).

The case study boundary for piloting the multi-barrier approach with EM fermentation within the FFS setting was defined by the geographical boundaries of the farm land (Figure 1).

Figure 1: Case study boundary relative to potential pathways and points for exposure to pathogens in FS reuse



METHODS

The methods section is broadly structured around the order of implementation beginning with high level details followed by specific techniques used.

The methodology for the pilots was developed by SNV Nepal, with advice on the fermentation treatment technology from the agricultural specialist and Farmer Field School (FFS) master trainer from the GIZ project in Afghanistan. SNV partnered with the local NGO *Sundar Nepal Sanstha (BNA)* who entered into agreements with the FFSs, recruited Master Facilitators and provided technical and logistical support, monitoring and supervision for the first pilot. Additional partners supported the second pilot, including Birendranagar municipality who ensured provision of fecal sludge, and DADO who provided technical support to the farmers through its Master Facilitator, and farmers, while BNA staff supported data collection.

The first pilot was conducted on land leased in two peri-urban municipal wards, Raharpur and Tilpur, with two Farmer Field School groups as detailed in Table 1.

Table 1: Key details of the first pilot

	Raharpur	Tilpur
Cultivated extent of land for pilot	2000 sq. m	1400 sq.m.
FARMER FIELD SCHOOL (FFS) Integrated Pest Management (IPM) Farmer groups	Shramjyoti IPM Farmer School (25 farmers)	Integrated Pest Management Cooperative (24 farmers)
Off-season crops grown	Potato (*Cardinal*), (Cauliflower crop destroyed in bad weather)	Cauliflower (*Snowcrown*) Cabbage (*Green Coronet*)
Planting date	31 Oct 2014	1Dec 2014 (cauliflower) 8 Dec 2014 (cabbage)
Final harvest date	20 Feb 2015	20 Mar 2015 (cauliflower) 14 Mar 2015 (cabbage)

In the second pilot (Table 2), the same FFS farmer group from Rahapur participated, with land provided for the pilot by one of the FFS farmers. A commercial farmer from Nayagaun was included in the second pilot at the request of the DADO, who allocated a plot on his commercial farm to the pilot.

Table 2: Key details of the second pilot

	Raharpur (Farmer Field School)	**Nayagaun** (commercial farmer)
Cultivated extent of land for pilot	700 sq. m	300 sq.m.
Farmers	Shramjyoti IPM Farmer School (25 farmers - same group as first pilot)	Commercial farmer (1 farmer)
Off-season crops grown	Cow pea (*Chinese Tane-320*) Bottle gourd (*Namdhari*) Pumpkin (*Green Blum House*)	Bitter gourd (*Pali*)
Planting date	31 Mar 2016	22 Feb 2016
Final harvest date	2 Jul 2016	25 Jul 2016

Farmer training in the multi-barrier approach

In line with the FFS framework, each farmer group was supported by a Master Facilitator (an FFS-IPM trained resource person) and a trained local facilitator (lead farmer) drawn from the FFS group. The commercial farmer in the second pilot received training and support from the Master Facilitator and the local facilitator of the Rahapur FFS group.

The FFS curriculum (already adopted by DADO for integrated pest management) was updated with guidelines for safe use of fermented FS based on internal resources provided by GIZ Afghanistan. The participating farmers had 18 weekly sessions with the facilitators following the FFS curriculum in conducting experimental trials and monitoring results using 'Agro Eco System Analysis' methodology.

The farmers were provided training in conducting FS treatment by EM fermentation, and the following non-treatment controls of the multi-barrier approach:

- *Use of personal protective equipment when handling raw and treated FS*:
  Gloves and face masks were provided for each individual, and shared gumboots and aprons

(one set per 10 farmers in the first pilot; one set per five farmers in the second pilot; separate set for the commercial farmer)

- *Safe practices for applying fertilizer to crops*:
  Training in the preparation of furrows for pouring fermented FS; instruction in 'fertigation', a method of mixing fertilizer with pumped irrigation water that is distributed using open channels (as used by GIZ Afghanistan); and training in safe use of plastic buckets for distributing fertilizer where suitable pumped irrigation is unavailable
- *Timing of irrigation*:
  Education and training on ceasing application of fertilizer a month before crops were harvested to allow pathogen die-off, as recommended by WHO (2015).

While all farmers received instruction on fertigation, it was not widely available – only the Tilpur farmer group used it with one of two fermented FS preparations trialled.

Farmers made the decisions regarding the crops to be planted, and determined when to apply the fermented FS to crops any time after a minimum period of FS treatment by fermentation (around 7 days) - for example, to follow recommended fertiliser application periods or to suit weather conditions.

Regular field observations were made in accordance with the standard FFS methodology. That is, farmers made regular group visits to fields accompanied by a facilitator, to make observations and discuss aspects such as plant health, growth, incidence of disease and pests and any control actions required, and made their own evaluations about the new practice of using fermented FS.

Preparation of EM-based fermented faecal sludge

At each site, FS fermentation pools (see Figure 1) were constructed by digging earthen pits (capacity 3-9 m^3) and lining them with 200 GSM UV plastic. In the second pilot in Raharpur, a cemented pond was made instead of a lined pit as the farmers wanted to continue with the practice of fermentation when the pilot ended. For the first pilot, FS was purchased from the single private-sector domestic septic tank emptying service provider in Birendranagar at the time. In the second pilot, sludge was delivered by the municipality's contracted primary desludging service provider, as the city's contribution to the pilot.

A pre-culture of Effective Microorganism (EM) was prepared ahead, by adding EM and molasses to a 200 litre plastic drum filled with water. After mixing, the drum was covered with a lid and placed in sunlight to develop. In the first pilot, a local fungicide ('jivatu') was also added while preparing the pre-culture solution; in the second pilot, 'jivatu' was mixed directly into the fermentation pool on DADO's recommendation. The pre-culture was mixed into the FS in the fermentation pool together with other additives (see Table 3 and Table 4 for details of additives and variations in fermentation treatments). The mixture was manually stirred daily to assist uniform FS fermentation in the pool, and covered by the plastic at other times.

A second type of fermented FS fertilizer was prepared in the first pilot (FS2 in Table 3), where FS was co-fermented with a 'compost mix' of composted cow dung and green manure (composted crop residues). In the second pilot, a single preparation of fermented FS was used at each location (see the comparative study section for further details). The second pilot prepared smaller quantities of fermented FS, commensurate with the smaller land areas used for test plots (see Tables 1 & 2).

Table 3: Methods for fermented FS preparation in the first pilot

	Raharpur		Tilpur	
EM pre-culture preparation	20 L EM + 20 kg molasses + 150 ml fungicide, topped with water in 200 L drum Covered with lid and cultured for 12 days by placing in sunlight		10 L EM + 10 kg molasses + 150 ml fungicide topped with water in 100 L drum. 2 x 100L drums prepared. Covered with lid and cultured for 14 days by placing in sunlight	
FS and additives in fermentation treatment	FS1	7300 L faecal sludge 100 L EM pre-culture 7.5 kg ash	FS1	3600 L faecal sludge 100 L EM pre-culture 15 kg ash
	FS2	3600 L faecal sludge 100 L EM pre-culture 7.5 kg ash 750 kg 'compost mix'	FS2	1900 L faecal sludge 100 L EM pre-culture 15 kg ash 750 kg 'compost mix'
	Fermentation for one week minimum before use.			

In the second pilot, some variations in preparing fermented FS were introduced for comparing microbial quality of the different treatments. These included adding urea 3 days before commencing EM fermentation (as a measure to improve sanitisation and nitrogen content of the fertilizer), increasing the time of fermentation from 7 to 10 days (to allow more time for microbial die-off), and varying the quantity of EM per quantity of sludge treated. However, only one of these (FS1 in Table 4) was used in the trial plots as a fertilizer; the others (A1, A2, A3 in Table 4) were spread on barren land after samples were taken for analysis.

Table 4: Methods for fermented FS preparation in the second pilot

	Raharpur		Nayagaun	
EM pre-culture preparation (in 200L drum with water)	6L EM + 6 kg molasses, topped with water to make 200 L. Covered with lid and cultured for 5 days in sunlight		6L EM + 6 kg molasses, topped with water to make 200 L. Covered with lid and cultured for 5 days in sunlight under plastic cover	
FS and additives in fermentation *(used as fertilizer in trial plots)*	FS1	2000 L faecal sludge 10 kg urea. *Left for 3 days before adding:* ~15 kg ash 200 L EM pre-culture 300 ml Jivatu (fungicide) Fermentation for 10 days before use (and lab analysis)	FS1	1000 L faecal sludge 200 L EM pre-culture 150 ml Jivatu (fungicide) ~15 kg ash Fermentation for 7 days before use (and lab analysis)
Alternative preparations of fermented FS (not used in field applications)	A1	1000 L faecal sludge ~15 kg ash 200 L EM pre-culture (of 3L EM + 3 kg molasses) 150 ml Jivatu (fungicide) Sampled for laboratory analysis after 7 days fermentation (A1)	A2	1000 L faecal sludge 200 L EM pre-culture (6L EM + 6 kg molasses) 150 ml Jivatu (fungicide) ~15 kg ash Sampled for laboratory analysis after 9 days fermentation (A2)
			A3	1000 L faecal sludge 5 kg urea. *Left for 3 days before addition of:* ~15 kg ash

				200 L EM pre-culture (6L EM + 6 kg molasses) 150 ml Jivatu (fungicide) Sampled for laboratory analysis after fermentation of 10 days (A3)

For the first pilot, the fermented FS was deemed 'ready for use' after 7 days fermentation. For the second pilot, the different preparations of fermented FS experimented with varying treatment times of between 7 – 10 days, and the first fertiliser application was done as soon as practically possible after completion of the treatment period.

Laboratory testing for pathogens

Sampling for fermented FS

One sample of each type of fermented FS was sent to the Environmental and Public Health Organisation (ENPHO) laboratory in Kathmandu for analysis within 18 hours of collection in the first pilot, after approximately 7 weeks of fermentation. Microbial analysis tested for *E.coli* levels*,* and for presence/absence of *Salmonella* spp. and helminth eggs (Ascaris or Hook worm)*.* Sampling protocols were not strictly controlled (collected in unsterilized bottles, no temperature control in transferring samples).

In the second pilot, one sample of each type of fermented FS was collected after 7-10 days of fermentation to reflect microbial profile at the time deemed 'ready for use' (see Table 4). The samples were delivered to Nepal Environmental & Scientific Services (P) Ltd. (NESS) in Kathmandu within 15-24 hours after collection. Improved sampling protocols were specified by the laboratory, including stirring the fermentation pool before sample collection, collection in plastic bottles washed in boiled or mineral water, and transfer to laboratory in ice packaging. Samples were analysed for levels of *E.coli* and helminth eggs, and presence/Absence of *Salmonella* spp.

Testing of harvested produce

One sample from each crop grown from each batch of fermented FS was transported to the laboratories by the same procedures as above. In the second pilot, samples grown with the other fertilizers used in the pilot were also sent for microbial analysis, for comparison. While samples were analysed for presence/absence of the three indicator pathogens as before, the second pilot included quantitative analysis for helminth egg levels, the main safety concern identified through analysis of fermented FS.

Application of fermented FS

In the first pilot, both fermented FS preparations FS1 and FS2 in Raharpur, and FS2 in Tilpur, were applied manually using buckets, after dilution in water (1:2). FS1 in Tilpur was applied by fertigation, using a 2" motor for pumping water into the fermentation pool for dilution and using a 1" motor for pumping the diluted fermented FS into irrigation furrows. For the second pilot, fermented FS was diluted in water (1:3) and applied manually using buckets in both locations.

The amount of fermented FS applied by bucket to each plant was based on volume: approximately 1 L per plant for crops with low-demand for fertilizer, and 2-3 L per plant for crops with high demand. The amount of fermented FS applied by fertigation was estimated as a total for the test plot by calculation after the fact.

In line with the multi-barrier approach, personal protective gear was worn by farmers during application of fertilizers containing fermented FS, and hygienic practices were observed (hand washing etc).

Application of fermented FS was ceased with strict observance of withholding periods before first harvest, namely 26 days (Raharpur: potato) and 47 days (Tilpur: cauliflower and cabbage) in the first pilot, and 26-28 days (Raharpur: cow pea, bottle gourd and pumpkin) and 30 days (Nayagaun: bitter gourd).

Comparative study of fermented FS and other common fertilizers

Each pilot compared the plant response to fermented FS against other fertilizer combinations as decided by the farmer groups.

The first pilot compared:
1. FS1: Faecal sludge, fermented (as in Table 3)
2. FS2: Faecal sludge and 'compost mix' co-fermented (as in Table 3)
3. 'Compost mix'
4. Traditional fertilizer: NPK chemical fertilizer and composted cow dung
5. Diluted urine

N.B.: 'Compost mix' is a compost made with cow manure and green manure – the proportions of the mix varied in the pilots. Compost was made by layering organic matter with EM in a plastic-covered composting pit.

The second pilot compared:
1. FS1: Faecal sludge, fermented (as in Table 4)
2. FS1 with 'compost mix'
3. Traditional fertilizer*:* NPK chemical fertilizer and 'compost mix'
4. No fertiliser (only with Nayagaun bitter gourd crop)

For each crop, the trial plots had equal planting density to allow results such as a yield per hectare to be comparable across the plots. These were typically based on DADO's guidelines except for the Nayagaun bitter gourd crop where the distances were greater than those recommended by DADO (they were however the same across all the trial plots).

Designated areas of the crop field (trial plots) received one type of fertilizer each, applied as top dressings (i.e., not dug in). Each plant within a trial plot received an equal amount of fertilizer. The quantity of fertilizer applied to each plant was determined by the FFS farmers who broadly followed DADO guidelines for the compost mix and traditional fertilizer applications, although the actual nutrient quantities in any of the fertilizers were unknown. Fermented FS was applied as diluted liquid as noted previously, while the 'compost mix', cow dung compost and mineral fertilizers (NPK, urea) were applied in dried form. Urine in the first pilot was diluted in water (1:5) and applied manually using a plastic measuring jug.

Fermented FS was applied on three occasions during the growing period, while the other fertilizers were applied 1-3 times. FS was also applied in land preparation of three trial plots at Nayagaun in the second pilot, that inadvertently included the plot for traditional fertilizer (this was taken into account in the analysis of results). Nayagaun also included a trial plot that received no fertilizer.

For comparison of yields, the harvest from a 'sample collection area' was weighed, allowing the production volume to be calculated in kilograms per hectare. Income and production costs and net income were calculated for each crop/fertilizer combination, with net income expressed as the difference between revenues from sale of harvested produce and production costs (excluding capital costs). Yields were used to estimate the income per hectare based on the seasonal market price for harvested produce. Production costs per hectare were estimated based on the cost of materials and labour inputs per hectare. Unit costs for fertilizer (per liter or kg for liquid or solid forms) were calculated from the cost of individual ingredients (sludge, EM, compost etc).

Elicitation of farmer perceptions

Structured surveys were used to elicit how farmers rated specific aspects of their experience in the two pilots (as good/moderate/bad etc.) In addition, qualitative data was collated by the respective FFS Master Facilitators together with a BNA supervisor in the first pilot and by BNA staff hired for data collection in the second pilot, as comments and views of the strengths and weaknesses of the pilots.

RESULTS AND DISCUSSION

The presentation and discussion of results are structured in line with the four research questions.

Safety of fermented FS in terms of pathogen levels

The pathogenic quality of fermented FS indicates the effectiveness of the *treatment barrier* in the series of controls that form the WHO's multi-barrier approach. Results of microbial analysis from the two pilots provided an indication of pathogens present in the treated FS fertilizer when handled by farmers. These results deliver valuable indicative information despite their statistical significance being limited. Improving statistical significance by analysing multiple samples of each product would have increased laboratory costs significantly.

The results presented below show that EM-based fermentation in the pilots did not provide adequate reduction of analysed FS pathogens to safe levels, with improvements to helminth inactivation identified as a treatment priority.

Preliminary microbial analysis in the first pilot, testing for indicator bacteria and helminth pathogens in fermented FS samples (FS1 and FS2 in each of Raharpur and Tilpur) showed *Escherichia coli* (*E.coli)* levels ranging from 18x 10^3 – 9x10^4 CFU/1 mL. The samples were drawn after 47 days of fermentation treatment (at the time of final fertilizer application), so pathogen levels are likely to have been higher when farmers first applied it on crops. *Salmonella* was 'absent' in both samples from Tilpur, but 'present' in both samples from Rahapur. Helminth eggs (species identified as Hookworm and/or Ascaris) were 'present' in both samples from Tilpur and in the FS2 sample from Raharpur, but 'absent' in the FS1 sample. The indicative presence of helminth eggs in fermented FS was a particular concern since soil transmitted helminths are endemic to the Surkhet region as noted earlier. The results from the first pilot informed more targeted microbial analysis for the second pilot.

The results of microbial analyses from the second pilot (Table 5) for indicative pathogen levels at the time of first use (after 7-10 days of fermentation treatment), showed:

- *E. coli* levels below 10^5 (MPN index)/100 ml
- Helminth egg levels ranging from 4000-100,000/litre (species not identified)
- *Salmonella* spp. presence in all samples.

Table 5: Lab results of fermented FS from the Second Pilot

Sample analysed	*E. coli* MPN index/100 ml	*Salmonella spp.* (Present/Absent)	Helminth eggs #/L
Raharpur Fermented FS	900	present	1.01×10^5
Nayagaun Fermented FS	1.1×10^5	present	2.64×10^5
Alternative treatment A1 Raharpur (not used in field application)	4600	present	4000
Alternative treatment A2 Nayagaun (not used in field application)	3.75×10^4	present	5.75×10^4
Alternative treatment A3 Nayagaun (not used in field application)	900	present	6.1×10^4

The current WHO Wastewater Reuse Guidelines (2006) imply that detected *E. coli* levels may represent sufficient risk reduction when applied with adequate post-treatment multi-barriers. The Guidelines do not specify absolute pathogen standards for treated wastewater to be used in agriculture, instead suggest taking a Quantitative Microbial Risk Analysis (QMRA) approach to determine the ultimate risk of pathogens at exposure. Earlier Guidelines (1989) state that the quality of effluent for unrestricted irrigation of salad and vegetable crops normally eaten uncooked could safely be 1,000 *E. coli*/100 ml., reflecting a 7 log reduction in total (Shuval 2008). Irrigation and exposure to sun and soil following treatment could result in additional pathogen reduction (typically 2 log reduction), and further removal resulting from simple home rinsing of salad crops and vegetables in potable water (around 1 log reduction), indicating that with such additional measures, a 4 log pathogen reduction from wastewater treatment would provide adequate safety (Shuval 2008). Accordingly, < 10^5 *E. coli/100 ml* following treatment is considered adequate for restricted irrigation (Blumenthal et al. 2000).

Indicative helminth levels, however, significantly exceeded safe levels, since very low doses (e.g. 1-10 eggs for Ascaris) can cause infection (Feachem et al. 1983). Safe limits for wastewater reuse are considered to be < 1 helminth egg/L to adequately protect farmers and their families (Blumenthal et al. 2000), and even lower if children are exposed (WHO 2015). Post-treatment multi-barriers need to consider the infection routes and life cycle stage of helminths (discussed briefly in next section), but are likely to be inadequate in light of the persistence of helminths in the environment (Feachem et al. 1983). The results indicate the need for much greater inactivation of helminths in fermented FS.

In the absence of quantitative data, it is difficult to assess the implications of *Salmonella* spp. detected in all samples. The EM-based fermentation literature suggests, however, that inactivation of *Salmonella* spp. could be similar to *E. coli* (e.g. Scheinemann et al. 2015). Furthermore, effective treatments for inactivating helminths can be effective in inactivating *Salmonella* spp. at the same time (e.g. urea and ammonia in Fidjeland et al. (2016)).

Although different treatment variations were prepared in the hope that analysis may reveal the effect of different treatment parameters (addition of urea, different fermentation periods, different quantities of EM), the baseline pathogen levels at the beginning of fermentation were not measured, which makes it difficult to correlate pathogen inactivation with the specific fermentation treatment process. Furthermore the literature suggests the need for longer treatment for helminths than the 7-10 days allowed before sampling and use.

While fermented FS has potential as a low cost fertilizer (discussed later below), its current helminth pathogen quality must be addressed before scale-up is considered. Improved treatment needs to preserve the simplicity and low cost advantages of fermented FS that farmers in the pilots viewed as incentives to FS reuse. We suggest exploring a low cost *pre-treatment* before subjecting it to EM-based fermentation, for example, by holding FS with suitable helminth-inactivating agents such as urea in the treatment pool for an extended period commencing in the summer months. Sources of FS with low presence of viable helminth eggs could also be explored. Dry FS from urine diverting dry toilets after an adequate period of storage is an example, if this toilet technology is widely adopted in Nepal. There may also be opportunities for sourcing FS with low helminths by leveraging the WHO's global target to 'eliminate morbidity due to soil-transmitted helminthiases in children by 2020' (WHO 2017). This would involve coordination with health agencies who implement periodic medicinal (deworming) treatment for the community living in endemic areas, while FS reuse implementing suitable *treatment* and *non-treatment* controls of the multi barrier approach reduce risk of re-infection.

Effectiveness of the multi-barrier approach

While farmers showed engagement and learning through the process of implementing the *non-treatment/non-technical control measures* of multi-barrier approach considered in this section, the case study showed these control measures were not completely effective in limiting risks of FS pathogen exposure for farmers and consumers. Each element of the implemented multi-barrier approach is discussed below, while improvements are considered in the section that follows.

Use of Personal Protective Equipment (PPE)

The training of farmers in the use of PPE mainly targeted risks around the *application of fermented FS* to the test plots. The Master Facilitators reported that both FFS farmer groups in the first pilot wore gum boots, gloves, face masks and aprons when handling fermented FS. In the second pilot, however, only the wearing of gumboots was strictly observed by all farmers; some FFS farmers reportedly did not use gloves or aprons.

While slippage in PPE use was partly due to these materials being torn, it also exposes the challenge of maintaining behavioural controls over time, and highlights the need for regular reinforcement of safety and hygiene requirements, including processes and budgets for inspection and replacement of protective gear. It would be useful to monitor farmer attitudes to using PPE and target training appropriately.

Application of fertilizer to crops

Farmers were reported to have observed practices in line with their training at all times when applying fermented FS to the test plots, including cessation allowing for pathogen die-off period before harvest. While fertigation using pumped irrigation has the advantage of lowering exposure risk by contact, compared to manual application by buckets, it requires pumped irrigation to be available near the fermentation pools – which was not feasible in most cases.

Crop selection

Although crop selection was not introduced to FFS farmers as a possible barrier, the FFS experiential learning processes led them to recognise risks from produce coming into direct contact with fertilizer. They switched from cultivating ground-level crops (potato, cauliflower, cabbage) in the first pilot, to more crops with elevated produce (peas and gourds) in the second pilot.

Pathogen levels on harvested produce

Sufficiently low pathogen levels on the harvested end product indicates the effectiveness of the multi-barrier approach in limiting pathogen exposure to consumers, given the presence of pathogens in fermented FS at the time of application discussed earlier.

In the first pilot, no helminth eggs or salmonella was detected in the analysis of any of the vegetable samples, but *E.coli* was present on some of the samples. While there were questions regarding the reliability of laboratory results, the indicative presence of *E.coli* prompted further improved analysis in the second pilot.

The results from the second pilot (Table 6) showed the presence of helminth eggs on the pumpkin sample – not entirely surprising given the ease for ground level produce to become contaminated by fertilizer and soil. The helminth contamination of cow pea samples grown using both fermented FS and traditional fertilizer was more unexpected (helminths were not detected on other above-ground level produce samples, as expected). *E.coli* was present on all samples grown using fermented FS, as well as on most samples grown using traditional fertilizer or using fermented FS + compost mix. *Salmonella* was present in some of the produce grown in Raharpur, but not on samples grown with fermented FS alone.

Table 6: Pathogen results for uncooked produce in second pilot

Crop	*Fertlizer used on crop*	*E. coli* (P/A)	*Salmonella* spp. (P/A)	Helminth eggs #/kg
Bottle gourd (Raharpur)	*Fermented FS*	*presence*	*absence*	*nil*
	Traditional (Chemical NPK +compost mix)	absence	presence	nil
	Fermented FS + compost mix	*absence*	*absence*	*nil*
Cow pea (Raharpur)	*Fermented FS*	*presence*	*absence*	*360*
	Traditional (Chemical NPK +compost mix)	presence	absence	346
	Fermented FS + compost mix	*presence*	*presence*	*nil*
Pumpkin (Raharpur)	*Fermented FS*	*presence*	*absence*	*48*
	Traditional (Chemical NPK +compost mix)	presence	presence	nil
	Fermented FS + compost mix	*presence*	*presence*	*nil*
Bitter gourd (Nayagaun)	*Fermented FS*	*presence*	*absence*	*nil*
	Fermented FS + compost mix	*presence*	*absence*	*nil*
	No fertilizer	presence	absence	nil

The results suggest there may be additional routes of contamination of harvested produce, that were unaffected by multi-barrier interventions such as withholding irrigation to allow die-off before harvest in line with the Sanitation Safety Planning (SSP) Manual (WHO 2015). It is difficult to explain the similar levels of helminth contamination in harvests fed by fermented FS and traditional fertilizers. It is also difficult to explain the positive bacterial presence or to establish potential impacts to health without quantitative measures. Diagnostic analysis of practices and potential routes to produce contamination are needed to improve practices since some vegetables could be eaten raw.

Addressing gaps in the application of the multi-barrier approach

Attention in implementing the multi-barrier approach in the two pilots was focussed primarily on the farmers applying fertilizer to the crops, that left some gaps in consideration of the system comprising the pilot as illustrated in Figure 1. A more complete set of potential risks and control barriers can be identified through a systematic process that follows the materials flow sequence for wastewater and sludge through the system. The SSP Manual (WHO 2015) provides valuable guidance for using such a process to consider a wide range of hazards and control measures.

To demonstrate the potential for such a process to identify and address hazards and controls, an example considering *microbial hazards* along potential exposure pathways within the case study was developed drawing on the authors' knowledge, presented in

Table 7 below.

This process could be enhanced by collaborating with farmers and other stakeholders to better identify local risks and develop appropriate locally owned control measures. A further step to consider common/likely failures in controls (e.g. gloves not used), demonstrated in the SSP Manual, can help avoid pitfalls, address gaps and validate controls. The FFS platform is seen to be effective for diagnosing and improving practices (WHO 2008).

Table 7: Possible framework for systematic identification of on-farm control measures for fermented FS reuse

Microbial Hazard	Hazardous events leading to exposure	Groups at risk of exposure	Possible control measures
Pathogens in fermentation pool	Accidental falling into pool	Farmers, when • covering/uncovering plastic covers • stirring mix daily during treatment phase • removing treated product in buckets	• Safety barriers • Appropriate tools with long handles
		Community and animals wandering into area	• Restricted access to area • Adequate fencing and warning signage
Pathogens in treated fermented FS during application to crops	Accidental dermal contact with hazardous product	Farmers, when • Lifting and carrying buckets filled with product • Pouring product onto plants	Personal protective gear • Gloves • Boots • Aprons • Face masks
	Contamination of crop produce	Consumers of produce	• Withholding time before harvest • Choice of crops with lower risk for produce contamination • Hygienic practices (e.g. hand washing before and after handling produce)
Soil transmitted helminths on land fertilized with	Hook worm infection through penetration of	Farmers, community members walking in bare feet and/or handling soil on affected land	• Advice to local community to restrict access of children • Protective footwear

fermented FS	bare feet/skin		• Gloves when performing tasks such as weeding
	Ascaris infection through ingestion of eggs from water that is contaminated by run off from fertilized land	Community members exposed to receiving waters from affected land	• Run off management (e.g., appropriate barriers, holding ponds and filtration media to minimise helminth eggs in run off)

The SSP Manual suggests disinfection of produce as a further control, e.g. washing in potable water and drying produce before sending to market. While it may be feasible in commercial packing houses, washing and drying produce adequately to prevent spoilage is likely to be less feasible for small scale urban farmers in Nepal.

While the boundary of the pilots was the farm, FS re-use over the long term would need to also consider safety controls for sludge emptying services as well as post-farm controls such as consumer information of safe food preparation methods (washing, peeling, cooking times).

The ability of non-treatment multi-barriers discussed here to effectively limit risks of high levels of helminth eggs surviving FS treatment needs closer examination. While transmission of helminths from inadequately treated FS can in theory be controlled by non-treatment barriers like those in Table 1, these barriers could be difficult to maintain over the long term (e.g. footwear, restricted entry, run off management during extra heavy rains) while helminths can persist in the soil for months or years. There may be uncertainties around scaling up the multi-barrier approach outside the supportive FFS environment, and high risk that the approach may slacken over time (such as failures to using PPE experienced in the case study) – indicating that non-treatment controls of the multi-barrier approach cannot be relied on for mitigating the risks of inadequate FS treatment.

Comparison of fermented FS against other commonly used fertilizers

The results of the comparative study, presented below, indicate fermented FS is a potentially valuable fertilizer that is *at least as good* as other fertilizers in terms of crop response and financial feasibility, and is broadly acceptable to user farmers.

Crop Response

The response of the crops to fermented FS, as assessed by standard FFS group observation processes and agro eco system analysis, suggest it performed better than traditional fertilizer against most measures (Table 8).

Table 8: Measures of crop response to fermented FS, traditional and other fertilizers in pilot

Health of plant (leaf colour, height, growth)	*First pilot:*	Fermented FS fertilizers (FS1 and FS2) showed better results in terms of plant health than traditional fertilizer for all three crops
	Second pilot:	Fermented FS (without compost) delivered the best plant health outcomes
Resistence to disease	*First pilot:*	Fermented FS fertilizers (FS1 and FS2) in the first pilot appeared to perform better than traditional fertilizer, and as well as or better than the other fertilizers
	Second pilot:	All crops at Raharpur in the second pilot were disease free; Bitter gourd plots fed by traditional methods at Nayagaun were afflicted

		by downy mildew whereas those fed by fermented FS alone appeared to have resisted the disease, while the other two plots (combination of fermented FS and compost mix, and no fertilizer plot) were less afflicted
Incidence of insects	*First pilot:*	Fermented FS fertilizers (FS1 and FS2) appeared to perform better than traditional fertilizer, and well as or better than the other fertilizers.
	Second pilot:	There was no difference in insect incidence across all the Raharpur crops in the second pilot. Fruit fly was present in the Nayagaun bitter gourd crop; the FS-fed plot was least afflicted and the 'no added fertilizer' afflicted worst.
Quality, appearance and size of product	*First pilot:*	Fermented FS fertilizers (FS1 and FS2) showed better results for produce quality/appearance and size than traditional fertilizer for all crops; Small scabs appeared on potatoes fed by fermented FS
	Second pilot:	Fermented FS (alone, and mixed with compost) performed as well as or better than traditional fertilizer in terms of size and quality/appearance for all products; Fermented FS appeared to cause some surface staining/markings on pumpkins.
Taste of product	*First pilot:*	Traditional fertilizer appeared to perform worst in the first pilot, while fermented FS performed as well or better than urine and compost mix.
	Second pilot:	The three Raharpur products in the second pilot given traditional fertilizer were considered 'less tasty' than the fertilizers with fermented FS.

In both pilots, crop yields from using fermented FS also compared relatively well against other fertilizers (Table 9 and Table 10). While FFS farmers followed DADO recommendations for planting densities so results are broadly comparable against published average yields, the use of greater than recommended plant spacing by the commercial farmer at Nayagaun was noted by the Facilitator as a factor for the lower yield reported there.

All crops in the first pilot were affected by unseasonal rains and flooding, with the Raharpur plots further suffering from drainage issues. Furthermore, Rahapur farmers in the first pilot reported applying less compost mix than the DADO-recommended rate (22,200 kg/ha against 35,500 kg/ha) which may have been a further factor in reduced potato yields (Table 9). Delayed plantings in Tilpur are thought to have affected the cauliflower yields.

In the second pilot, the farmers noted 'extraordinarily high' yields for cow pea with all fertilizers, while pumpkin production was noted to be lower than normal.

Table 9: Agricultural yields (harvested produce in kilograms per hectare) for crops using different fertilizers in First Pilot

	FS1 Fermented FS *(kg/hectare)*	**FS2** FS and compost mix, co-fermented *(kg/hectare)*	**Compost mix** *(kg/hectare)*	**Traditional** (chemical NPK + cow manure compost) *(kg/hectare)*	**Human Urine** *(kg/hectare)*	**DADO published average production** *(kg/hectare)*
Potato (Raharpur)	25,000	30,000	20,000	15,000	18,500	36,000
Cauliflower (Tilpur)	16,000	16,667	15,333	13,333	14,667	22,000

Cabbage (Tilpur)	35,294	35,294	n.a.	21,176	29,412	35,000-38,000

Table 10: Agricultural yields (harvested produce in kilograms per hectare) for crops using different fertilizers in Second Pilot

	Fermented FS *(kg/hectare)*	**Fermented FS and Compost mix** *(kg/hectare)*	**Traditional (Chemical NPK + compost mix)** *(kg/hectare)*	**No added fertilizer** *(kg/hectare)*	**DADO average production** *(kg/hectare)*
Cow pea (Rahapur)	27,500	27,000	26,000	n.a.	16,000
Bottle gourd (Raharpur)	25,667	25,333	23,667	n.a.	27,000
Pumpkin (Raharpur)	22,667	23,333	25,333	n.a.	35,000
Bitter gourd (Nayagaun)	16,214	15,000	14,021	10,357	22,000

Financial aspects

Fermented FS was shown to deliver higher profits than traditional fertilizer in the net profit analysis for each crop in both pilots (Table 11 and Table 12). The low cost of raw FS contributed to the lower production cost for fermented FS fertilizers compared to more costly cow dung and green manure composts. Urine fertilizer, considered only in the first pilot, delivered relatively high profits due to very low production costs with virtually no costs for urine collection or treatment (by storage).

Table 11: Revenues and production costs for crops using different fertilizers in First Pilot in Nepalese Rupees

	FS1 Fermented FS *(NRs/hectare)*	**FS2 Co-fermented FS + Compost mix** *(NRs/hectare)*	**Compost Mix** *(NRs/hectare)*	**Traditional** *(NRs/hectare)*	**Urine** *(NRs/hectare)*
Raharpur potato					
Revenue	825,000	990,000	660,000	495,000	610,500
Production cost	479,873	493,181	356,509	410,962	256,213
Net profit	**345,127**	**496,819**	**303,491**	**84,038**	**354,287**
Tilpur cauliflower					
Revenue	400,000	416,667	383,333	333,333	366,667
Production cost	337,451	371,289	292,275	395,118	150,888
Net profit	**62,549**	**45,377**	**91,058**	**(61,785)**	**215,779**
Tilpur cabbage					
Revenue	529,412	529,412	n.a.	317,647	441,176
Production cost	325,662	359,595	n.a.	343,905	139,053
Net profit	**203,750**	**169,816**	n.a.	**(26,258)**	**302,123**

Table 12: Revenues and production costs for crops using different fertilizers in Second Pilot

	Fermented FS *(NRs/hectare)*	Fermented FS and Compost mix *(NRs/hectare)*	Traditional (Chemical NPK + compost mix) *(NRs/hectare)*	No added fertilizer *(NRs/hectare)*
Raharpur: Cow pea				
Revenue	1,100,000	1,080,000	1,040,000	n.a.
Production cost	306,133	377,789	410,658	n.a.
Net profit	**793,867**	**702,211**	**629,342**	n.a.
Raharpur: Bottle gourd				
Revenue	513,333	506,667	473,333	n.a.
Production cost	300,129	353,875	390,034	n.a.
Net profit	**213,204**	**152,792**	**83,299**	n.a.
Raharpur: Pumpkin				
Revenue	453,333	466,667	506,667	n.a.
Production cost	285,071	338,963	352,038	n.a.
Net profit	**168,263**	**127,704**	**154,628**	n.a.
Nayagaun: Bitter gourd				
Revenue	729,643	675,000	630,964	466,071
Production cost	330,341	377,393	378,901	237,303
Net profit	**399,302**	**297,607**	**252,063**	**228,769**

Excluding the capital costs (materials and labour for fermentation pool construction) in the financial analyses above may be justified in the pilot study context, since the extent to which the fermentation pools would be reused and lifetimes for plastic pit liners and other data to determine annualised capital costs were unknown. For fair comparison, costs for construction of composting pits were also excluded from the analysis. If fermented FS is likely to transition beyond pilot stage, a robust approach to annualising capital costs should be developed.

A caveat to the 'better' agricultural performance of fermented FS reported here is that the fertilizer quantities applied to each test plot did not correspond to a standard amount of any specific nutrient since nutrient concentrations in each fertilizer were unknown. Crops receiving fermented FS may have been advantaged by receiving more nutrients due to greater and more frequent applications, made possible by its lower cost. Higher yields from the plots that received fermented FS in both pilots also corresponded with relatively lower incidence of disease that may have been advantaged from organic fungicide ('jivatu') used in fermented FS preparation. Thus the results are indicative rather than scientifically rigorous. Nevertheless they suggest fermented FS as a promising low cost alternative to traditional fertilizer.

Farmer perceptions

The results from eliciting farmer perceptions revealed broad acceptance of fermented FS for a range of characteristics they viewed very favourably, while identifying a need for further efforts to address their concerns.

The 49 participant FFS farmers in the first pilot, and 19 farmers interviewed from the 26 participants in the second pilot, selected the most positive options for their survey responses in most cases, conveying a positive perception towards using fermented FS, including willingness to use it again in the future. A participant farmer's contribution of land for the second pilot, with the fermentation pool constructed from permanent materials to enable subsequent use, may be interpreted as further evidence of their receptiveness.

In identifying benefits or strengths of using fermented FS over common alternatives, farmers in both pilots noted improved plant health and growth, improved yields, reduced disease and insect presence. Improved soil texture in terms of loose soil structure and productivity were also noted in both pilots, with moisture retention and ease for ploughing mentioned in the first pilot. Low production costs and ease of applying fertilizer in liquid form were further strengths identified by farmers in the second pilot.

In identifying concerns, farmers interviewed in both pilots expressed uncertainty about whether the produce was safe for consumption, and expressed the desire for further research to determine safety.

The investment costs for FS fermentation (construction of fermentation pool with plastic lining or cement) was identified as a further concern, particularly in the second pilot where 17 (of 18) farmers rated it 'expensive', in contrast to the first pilot where almost all farmers rated it 'cheap'. It was noted that the high capital cost may be feasible for commercial farmers but not for non-commercial small hold farmers, and that coordination and support from DADO and the Municipality could help reduce costs for small farmers. The commercial farmer in Nayagaun rated investment costs as 'moderate'.

Unreliable supply of FS was noted as a difficulty in both pilots. This was largely due to erratic and highly variable demand for emptying services. The Facilitator believed there may have been perverse incentives with the emptying service used in the second pilot, that may have led to emptiers dumping FS in the forested areas in preference to delivering it to farmers. The variable quality of FS was noted as another challenge. In the second pilot, a consignment of FS from a hotel was considered too weak for use on Rahapur test plots, and had to be disposed in fallow land following fermentation treatment. There were some difficulties in vehicle access for FS delivery to the fermentation pools at Tilpur, although careful project design can avoid such issues in the future.

Most farmers noted a light or moderate 'foul smell', while 3 rated it 'strong foul smelling' in the second pilot. The foul smell was observed to be strongest at the time the FS was deposited and during the first 7 days when uncovered for stirring the pools. Supply of less fresh FS (from longer retention in septic tanks) may have less malodours, although it would be difficult for emptiers to deliver on such a criterion given the uncertainties around demand for emptying services.

The surveys did not explore views specifically about the multi-barrier approach such as attitudes to using PPE such as gloves and footwear. It would be helpful for future studies to be more explicit in exploring farmer perceptions to specific aspects of the multi-barrier approach, to improve understanding of their acceptance of new behaviours and practices. Without their acceptance and commitment, the multi-barrier approach is likely to fail at scale and in the long term.

In summary, fermented FS in the two pilots presented as a feasible and mainly acceptable low cost alternative to other common fertilizers, making it worthy of further investigation for improving safety before considering potential scale up. A long term monitoring study on soil impacts of fermented FS could be of value, as excessive application of fertilizer that can lead to nutrient overloading with negative environmental impacts. Redwood (2008) points to Farmer Field Schools as a particularly useful forum for implementing good agricultural practices and research into effective training to help minimise possible negative environmental impacts on farmers, soil and downstream water resources.

CONCLUSIONS

Reuse of nutrients contained in human waste for food production, in ways that consistently and reliably protect public health and the environment over the long term, is important for delivering on the Sustainable Development Goals to meet the fundamental human rights of everyone everywhere. This case study reviewed the experience of using the multi-barrier approach in two pilots in Birendranagar, Nepal, to share learnings with the broader sector towards progressing the agenda for safe reuse of faecal sludge. The participatory learning orientation of Farmer Field Schools was a particularly conducive environment for piloting agricultural reuse leading to evidence-based learning.

The case study indicated that faecal sludge treatment by fermentation with effective microorganisms (EM) may provide adequate reduction of bacteria indicated by *E.coli,* but presence of high levels of helminth eggs that made it unsafe for reuse without further treatment. The paper proposed that although the multi-barrier approach implemented in the two pilots within the Farmer Field School environment may, in theory, be strengthened to provide adequate non-treatment controls against human exposure to helminths in fermented FS fertilizer, such controls cannot be relied upon over the long term in practice, as the necessary behaviours and practices that provide the controls can slacken over time. *Non-treatment controls* of the multi-barrier approach cannot therefore replace the need for *adequate treatment controls* for producing a fertilizer with safe pathogen levels. Improved treatment targeting helminths is likely to improve inactivation of *Salmonella* at the same time. When seeking improved treatment options, it would be of value to extend the scope to include other endemic pathogens that may be of concern that were not explored in the current study.

Further investment in research is warranted to ensure the safety of EM-based fermented FS fertilizer through systematic application of treatment and non-treatment controls of the multi-barrier approach, as the study indicated fermented FS could be a cost-effective fertilizer that farmers reported as easy to prepare and use, that appeared to deliver a range of positive results including improved plant health, reduced incidence of pests, improved soil quality and improved harvest yields for the piloted crops compared to conventional fertilizers used. It is also potentially a readily available replacement for farm yard manure compost which is increasingly more difficult and costly to obtain.

Additionally, further research could support effective monitoring and support systems for maintaining controls and understanding long term impacts of fermented FS application, changes to agriculture practices and hygiene behaviours. While improved treatment may allay farmers' concerns about safety of consuming produce, further investigation for building farmer and public confidence on safe FS reuse is also indicated.

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