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Investigating the Applicability in Emergency Situations of Terra Preta Sanitation System using Lactic Acid Bacteria

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Abstract

Malawi experiences emergency situations whose response does not prioritize faecal sludge management challenges. This research adopted a redefined Terra Preta Sanitation (TPS) system that replaced vermicomposting with Lactic Acid Bacteria (LAB) inoculation. The research aimed at determining possibility of on-site LAB procedure upscalling and safe separation of urine and lacto-fermented sludge as useful agricultural by-products. The study site was Crown Ministries, Blantyre, Malawi. A fermented mixture of15L pasteurized milk, 30ml of Yakult and 1.5g cane molasses was added to a 200L faecal sludge collection drum before use. After defecation, 100cm^3 charcoal and 2g molasses were added. Urine was anaerobically collected in 50L drum. Random grab samples results indicated that COD for urine (868.4mg/l) and Lacto-fermented sludge (431.2mg/l) were above 60mg/l Malawi Standard and *E. coli* (1.05 x10^7) and Total coliforms (2.18 x 10^7) for Lacto-Fermented Sludge went above <10^3 CFU/100ml.

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LAB failed to keep lacto-fermented sludge's pH (6.7) and TAN (11.8mg/l) below 4.2 and within 15-30 mg/l respectively. This is despite registering promising results in pH (9.6) and TAN (16.6mg/l) for urine. The results challenged on-site LAB procedure in terms of stabilizing and sanitising faecal sludge possibly due to differences in sludge age, charcoal addition and different environmental factors. Therefore TPS combined with LAB inoculation could not be the best sanitation option for an immediate phase but rather second and third stages of emergency situations.

Keywords: Emergency situation; Lactic Acid Bacteria; Lacto-Fermented Sludge; Terra Preta Sanitation; Urine.

1. Introduction

An emergency is defined as a situation or state characterised by a clear and marked reduction in the abilities of people to sustain their normal living conditions, with resulting damage or risks to health, life and, livelihoods [1]. For Malawi, most natural disasters arise from weather related events such as winds hailstorms and heavy rain, which results in floods. Amongst these events floods are the most occurring and have impacted Malawi more than 157 times since 1946 [2]. The districts which are most hit by floods include Nsanje, Chikwawa, Thyolo, Mulanje Zomba, Machinga, Balaka , Mangochi, Blantyre, Chiradzulu, and Phalombe (in the south), Salima, Ntcheu, and Nkhotakota (in the central region), and Karonga, Rumphi, and Nkhatabay (in the north) [2, 3, 4]. The provision of clean water and hygienic sanitation, which are essential services for safeguarding public health, are often disrupted upon the event of a disaster or emergency situation [5]. Outbreaks of diarrhoeal diseases including dysentery and cholera are common in emergencies [6, 7, 8, 9]. Containment and Treatment of faecal matter is a vital barrier against the spreading of diarrhoeal diseases in particular during emergencies when the population is more vulnerable. The sanitation response to the emergency situation in Malawi, highlights the limitations of current emergency sanitation options within humanitarian response [3]. As such there is need for more suitable approaches and technologies that can be rapidly deployed and are effective under challenging physical conditions such as unstable soils, high water tables and flood-prone areas.

It is worth mentioning that an ideal emergency sanitation system should be one that would either not require expensive reticulation systems or conserve water and allow the safe recovery and recycling of nutrients from human excreta for soil fertility improvement [10]. One such approach and technology is the Terra Preta Sanitation (TPS) system. The idea of Terra Petra Sanitation (TPS) is to produce fertile soils of human excreta and includes urine diversion away from faeces via a specially designed pedestal (Figure4), addition of a charcoal mixture and is based on lactic-acid-fermentation with subsequent vermicomposting[11, 12]. In this study TPS was preferred because of the following reasons;(1) it uses little or no water and the excreta is not discharged or buried in deep pits thus making it better than the conventional latrine-based systems commonly used in most emergency camps as it enables the hygienic recovery of faeces and urine for possible use as soil amendments [10], (2) it produces no gas and odour in so doing reducing vector attraction in emergency camps, (3) it transforms the carbon and nutrients into the deep black, fertile and stable soil that can be utilized in agriculture, and (4) No ventilation or external energy is required[11], just to mention but a few.

However, the challenge for an emergency situation is how to make TPS sanitise, and stabilise faecal sludge and

generate useful by-products, which are acceptable, affordable and sustainable for an early stage of an emergency as it takes too long to be completed. To address this challenge, and for the purpose of this study, the final stage of vermicomposting was left out and replaced by the addition of LAB inoculum which according to [13], while carrying off-site batch experiments, can successfully sanitise and stabilised faecal sludge. However, [13]'s findings at the time this study commenced had no on-site faecal sludge treatment literature back up. Hence this paper sought to determine the possibility of up-scaling the off-site lactic acid faecal sludge treatment procedure, established through small scale experiments, to on-site treatment in a pit latrine. Finally, the paper seeks to determine if the separately collected urine and Lacto-fermented sludge could be safe and useful by-products for sustainable agriculture in emergencies.

2. Materials and Methods

2.1. Study Sites

The TPS Toilet was built at the site of Crown Ministries in the vicinity of Chigumula, Blantyre, Malawi. Physically, the toilet was raised and consisted of four elements: (1) toilet superstructure, which provided shelter for the user and the toilet itself; (2) a urine diversion seat placed on a slab; (3) a 50L urine collection Drum and (4) a 200L faecal sludge collection Drum (see Figures 1,3,4,5 and 6 below).

2.2. Sample preparation

LAB inoculum, made by mixing 15L pasteurized milk, 30ml of Yakult and 1.5g of cane molasses then fermented at room temperature for 48 hours [13], was added to a 200L drum before the toilet was in use. Immediately after each defecation, 2g of cane molasses and approximately 100 cm^3 Charcoal, from corncobs, bamboo and other waste material, prepared by using a specially made anaerobic Pyorolysis Stove [14] as cited by[11,15], (see Figure 2 below). were added to the Lacto-fermented sludge in order to remove the bad odour of the faeces, provide stable organic matter for the Terra Preta soil production and increase the black carbon source. The addition of cane molasses was done to ensure that there was enough glucose for the LAB to continue multiplying [16]. Urine was diverted from faecal sludge using a specially designed pedestal (see Figures 3 and 4 above), via a plastic pipe to a 50L plastic drum (see Figure 5) where it was kept under anaerobic conditions in order to prevent the hydrolysis of the urea and its transformation to volatile ammonia and CO_2, which would result in the loss of nitrogen and CO_2 into the atmosphere and bad odour [17] as cited by [11]**.** Faecal sludge fell into a 200L drum, placed airtight underneath the toilet seat's slab (see Figure 6) to allow for anaerobic conditions in the drums. Although the lid was frequently opened this was not expected to affect the treatment outcome as LAB are aero tolerant [13].

2.3. Sample Collection

Using randomly selected days of the study period (May,201 to August, 2014) grab samples, in 1 litre sterilised plastic sampling bottles, were taken from both urine and Lacto-fermented sludge and then transferred from the sampling site (Crown Ministries) to Soche Pollution Control Laboratory for analysis. Before the samples were taken, urine and faecal sludge were mixed using a manually driven stick in order to ensure uniformity of the

samples collected.

2.4. Chemical Analysis

To assess the TPS systems' stabilisation and useful by-product generation the following parameters were analysed: pH, Temperature, Chemical Oxygen Demand (COD) and Total Ammonia Nitrogen (TAN). pH, Temperature, and COD for stabilisation while TAN was done for useful by-product generation. Parameters such as COD and TAN were analysed in triplicates while Temperature and pH were measured in situ immediately after collecting the samples. Table 1 below shows the specific methods for determining each parameter adopted from [18].

Figure 1: TPS toilet structure

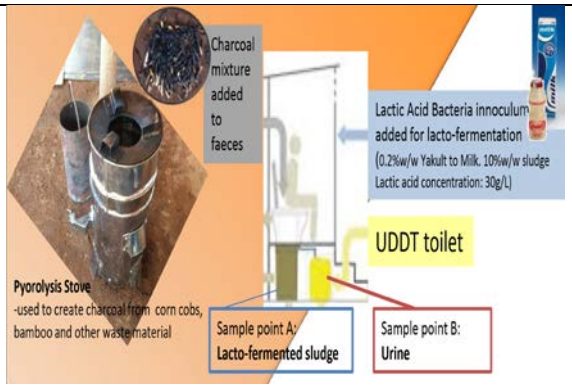

Figure 2: TPS toilet Model

Figure 3: TPS toilet inside

Figure 4: TPS Pedestal inside

Figure 5: TPS urine drums

Figure 6: TPS faecal sludge drum

Table 1: Analysed parameters and the respective methods for analysis

No.	Parameter	Method
1	PH	Potentiometric SM-4500-H+
2	Temperature (^{o}C)	SM-2550B
3	Total Ammonia Nitrogen (TAN)	Indophenol blue method Hach LR/HR TNTN tube test
4	Chemical Oxygen Demand (COD)	Hach tube test HR Oxidation by Potassium dichromate

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2.5. Microbial Analysis

Chromocult Coliform Agar was used for the enumeration of Total Coliforms and Escherichia coli in both urine and Lacto-fermented sludge samples according to the methods used by [18]. Chromocult Coliform Agar was used because it is a selective and differential chromogenic culture medium which contains Tergitol 7 as an inhibitor of Gram-positive bacteria which has no negative effect on the growth of the targeted coliforms/ *E. coli*, the character which makes it an ideal medium for the detection of coliforms/ *E. coli* in wastewater [19]. Both *E. coli* and Total Coliforms were analysed in duplicates with averages of the duplicates analysed reported. Most of the analysis for *E. coli* and Total Coliforms were done within six hours from the time samples were taken and those that were not analysed within the six hours were refrigerated at 10^{o}C till the next day

2.6. Data Analysis

Laboratory results were analysed using excel. The means for each analyte were calculated and graphs were produced. The means for both urine and Lacto-fermented sludge were compared with wastewater discharge limits set by Malawi Bureau of Standards [20] and World Health Organisation guidelines on surface water and effluents [21].

3. Results and Discussion

The redefined TPS toilet, as an on-site sanitation system, targeted an early stage of an emergency. It was anticipated that it would demonstrate stabilization of faecal sludge, generation of useful by-products from faecal sludge and most importantly reduction of pathogens that are found in human waste. To achieve this, parameters such as pH, Temperature and Chemical Oxygen Demand were analysed for stabilisation whereas Total Ammonia Nitrogen was tested for useful by-product generation and *E. coli* and Total Colony Forming Units were assessed for pathogen reduction and the obtained results are shown in Table 2 below.

3.1. Stabilisation

Stabilisation of the toilet was assessed with an aim of determining whether the treated sludge and urine could not attract vectors as they are carriers of faecal oral related diseases, a challenge quite often in emergency camp

sites. In order to achieve this, the following parameters were assessed: pH, Temperature, and COD.

3.1.1. Chemical Oxygen Demand (COD)

Table 2 indicates that the average COD value (868.4mg/l) for urine was two times higher as compared to that of Lacto-fermented faecal sludge (431.2mg/l). This could be due to high concentrations of TAN that was found in urine. The bigger difference in the COD values for the two samples suggest the addition of both charcoal and LAB inoculum did not have a significant impact on the stabilisation of Lacto-Fermented faecal sludge because the observed results went above the stabilisation optimal limit of 60mg/l [20]. The failure of the system to stabilise both urine and Lacto-fermented faecal sludge explains why the toilet attracted flies. The attraction of flies defeated the whole purpose of having a vector free toilet in emergency camps. The attraction of vectors by the terra preta toilet was contrary to what was reported elsewhere surrounding treating human waste using Terra Preta Sanitation and LAB [12, 13]. While [12] and [13] reported successful treatment/stabilisation of faecal sludge using LAB and terra pretta, the current study has shown the contrary. This could be attributed to differences in both age and source of sludge. The studies by [12]and [13] were conducted off-site and involved desludging of faecal sludge from existing pit latrines while this study was done on-site and targeted fresh faecal sludge. The other possible reason could be that in the study conducted by [13], LAB inoculation was not combined with addition of charcoal which was the case with the current study. The addition of Charcoal was inevitable as it is key to Terra Preta's long organic matter residence times and continuing fertility if emergency dwellers were to practice sustainable agriculture [22] as cited by [11]. One would also argue, on the part of Lacto-Fermented Sludge, that the failure could be as a result of frequent opening of the pedestal's lid that may have continuously disturbed the required anaerobic conditions. This would be contradicting literature which says that LAB is aero-tolerant [13]. However, despite LAB being aero-tolerant, there is a possibility that seat cover was not consistently covered after use

3.1.2. Temperature

The average temperature for both urine and Lacto-Fermented Sludge, as indicated in Table 2, was 16.1 ^{o}C and 17.6 ^{o}C respectively. The recorded temperatures for both samples were below what [13] recorded as the temperatures (21^{o}C – 26^{o}C) that supported the required anaerobic conditions for LAB inoculum to successfully sanitised faecal sludge. It is not surprising seeing that pathogen reduction in Lacto-fermented sludge did not meet the set standards. The lower temperature could be thought to have contributed to the failure of LAB dependent TPS system.

3.1.3. pH

The results indicate that urine was alkaline (mean pH 9.6) while the Lacto-fermented sludge was acidic (pH 6.6), Table 2. This could be attributed to the fact that the main proportion of the nitrogen in urine is excreted as urea, which increases the pH to 8.8 - 9.0 during its transformation into ammonia in the collection tank. The alkaline pH of urine is advantageous because it is critical in as far as getting substantial amount of TAN is concerned [10] and suggests that it can be a good source of soils conditioning especially if the soils in the

emergency camps were acidic**.** According to [13], in order to successfully sanitise lacto-fermented sludge, pH of 4.2 was required. However, the observed pH (6.6) of lacto-fermented sludge was higher than that reported by [13] while sanitizing faecal sludge off-site. This probably explains why the Terra Preta sanitation system failed miserably in reducing pathogen concentrations in faecal sludge. Although the pH of both urine and Lacto-Fermented Sludge fell slightly within the optimal stabilisation limits of 6.5 – 9 [20], it would be misleading to say that the two were stabilised because the toilet still attracted a lot of flies.

3.2. Useful by-product generation

3.2.1. Total Ammonia Nitrogen (TAN)

The average TAN of urine (16.6mg/l), as seen in Table 2 below, was slightly higher than that of lacto-fermented sludge (11.8mg/l). This is in agreement with observation that urine has a high content of readily available nitrogen to such an extent that its fertilising effect is similar to that of nitrogen rich chemical fertiliser [24] and [26] as cited by [11]. The observed higher TAN in urine justifies the importance of keeping urine under anaerobic conditions. This is because, according [11] keeping urine under such conditions helps to prevent the hydrolysis of urea and its transformation to volatile ammonia and CO_2, which would result in the loss of nitrogen and CO_2 into the atmosphere and bad odour. The lacto-fermented sludge has, however, lower TAN than urine because its nitrogen content is slowly released as it is organically bound in undigested food remains of the sludge [10]. This suggests that urine could be a better by-product for sustainable agriculture as compared to Lacto-fermented sludge. However, it is advisable that urine be diluted in the safe dilution ratio of 1 to 8 (one part urine-7 parts water) for all plants before it is actually added to plants [26].

3.3. Pathogen Reduction

3.3.1. E. coli and Total Colony Forming Units

The results of bacteriological analysis in both Lacto-Fermented faecal sludge and urine samples are indicated in the Table 2 and Figures 7 and 8. The microbial analysis showed that urine did not contain pathogenic micro-organisms unlike Lacto-Fermented sludge which contained high amounts of indicator pathogens. This finding agrees with what was reported in literature surrounding urine [10, 27]. This observation suggested that the separation of urine from faecal sludge was efficient as the contrary observation would mean ocurance of direct or indirect faecal cross-contamination between the two.

The fact that both *E. coli* and TCFU were no detected in urine suggests that there is no need of urine storage which would in turn not overstretch the already scarce resources in emergency situations. It further suggests that urine can be directly applied in the fields without causing both dysentery and cholera in emergency camps. This also suggests that the pedestal was a good separating device for both urine and faecal sludge. The high concentrations of *E. coli* and TCFU in the Lacto-Fermented sludge suggests that the addition of LAB inoculum did not yield any better results in as far as sanitisation of faecal sludge was concerned. It is evident that LAB inoculation failed to sanitise Lacto-Fermented sludge on-site despite doing so off-site. However, it is also

Table 2: Results for pH, Temperature, Total Ammonia Nitrogen (TAN), Chemical Oxygen Demand (COD), *Escherichia coli* (*E. coli*) and Total Colony Forming Units (TCFU).

	N	Mean		Std. Deviation
	Statistic	Statistic	Optimal Limit	Statistic
Stabilisation				
COD (mg/l)				
Lacto-Fermented Sludge	13	431.2262	**60**	294.39212
Urine	13	868.3854		248.69606
Temperature(^{o}c)				
Lacto-Fermented Sludge	13	17.546	**21 – 26**	3.5491
Urine	13	16.1154		3.59185
PH				
Lacto-Fermented Sludge	13	6.6515	**<4.2**	0.63166
Urine	13	9.5808	**6.5 – 9**	0.16204
Useful By-Product				
TAN (mg/l)				
Lacto-Fermented Sludge	13	11.7777	**15 - 30**	6.22589
Urine	13	16.5792		5.69111
Pathogen Reduction				
***E. coli*/100ml)**				
Lacto-Fermented Sludge	13	1.05 x10^{7}	**<10^{3}**	4.1 x 10^{1}
Urine	13	<10^{3}		
Total coliforms/100ml)				
Lacto-Fermented Sludge	13	2.18 x 10^{7}	**<10^{3}**	9.0 x 10^{0}
Urine	13	<10^{3}		

possible that the higher pathogen concentrations in the Lacto-Fermented sludge could have been, at least partially, contributed by the addition of charcoal which was often used as a dehydrating/sanitising agent while the toilet was in use. These findings suggest that there is need for further studies as there is still the possibility that LAB inoculation could significantly reduce pathogens on-site. However, if charcoal were not added it would mean defeating the whole purpose of having a by-product that would successfully sustain agriculture [28] as cited by [29].

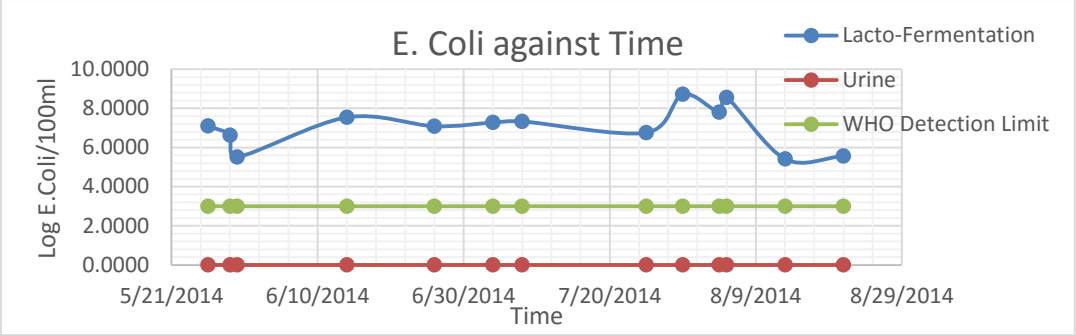

Figure 7: *E. coli* - time graph for both urine and Lacto-Fermented sludge

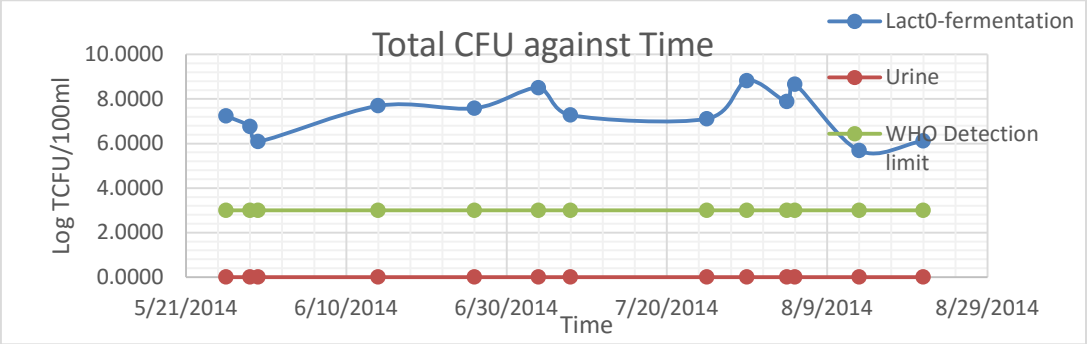

Figure 8: TCFU – Time graph for both urine and Lacto – Fermented Sludge

4. Conclusion

Although not stabilised, urine produced better results than Lacto-Fermented Sludge in terms of both pathogen free and useful by-product generation. The fact that both *E. coli* and TCFU were no detected in urine has suggested no need for urine storage as doing so would in turn overstretch the already scarce resources in emergency situations. It further suggested that urine can be directly used for sustainable agriculture in emergency camps sites without causing both dysentery and cholera. The better agronomic potential of Urine when compared to Lacto-fermented sludge was attributed to its higher TAN value suggesting that, for greater agronomic effectiveness, Lacto-Fermented terra preta should be co-applied with urine. Finally, the research based On-Site TPS system demonstrated that, minus vermi-composting, a lot needed to be done, on top of adding LAB inoculum, to have both a sanitised and stabilised Lacto-Fermented terra preta sanitation system. This failure of the early emergency stage targeted TPS system implied that the system, despite having a lot advantages over other sanitation systems, can only be adopted when targeting the second and third stages of an emergency situation.

5. Recommendations

The aim of this study was to find solutions to faecal sludge management challenges that are frequently met during emergency situations. Looking at the results it has been shown that this focus has been challenged. However, for purposes of targeting the early phase of an emergency situation, while brushing aside issues of

having the soils that have an improved water-holding capacity, increased organic matter content, and increased availability of nutrients, further studies on the use of LAB on-site should not involve the addition of charcoal.

The performance of LAB depends partly on the availability of enough glucose. It should be recommended that the toilet be further modified to a point at which the molasses would be poured on top of the faecal sludge using a specially made device so as to ease the application of the molasses by the users after each defecation. There is a high possibility that some users hardly followed the instructions.

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