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Terra Preta Sanitation: a new tool for sustainable sanitation in urban areas?

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Terra Preta (Black Soil) is highly fertile soil, which was produced in the Amazon region until around 500 years ago. It is a result of sanitation and biowaste management which can give direction in developing a sustainable future. Ongoing research indicates that addition of ground charcoal and lactic acid fermentation are probably the main components in producing terra preta. These discoveries were used to develop Terra Preta Sanitation, which is not one fixed type of sanitation but rather a set of processes: collection under lactic acid fermentation and transport to a semi-central site for thorough vermicomposting. The addition of lactic acid bacteria and powdered bio-char eliminate faecal smell, facilitate sanitization and increase user friendliness. In this way sanitation can help produce rich soil, which in turn improves water availability, food security and the regional climate. The avoidance of smell and opportunities for business development make TPS an obvious choice in urban contexts.

Introduction

More than half of the world's population is living in urban centres. The number is increasing by an alarming rate of around 180,000 every day. To keep pace with population growth the sanitation and waste management sector has to think 'outside the box', and explore new sustainable technologies and find flexible service models. Ecological sanitation already addresses the challenges with the right approach: understanding urban sanitation as a business opportunity rather than a bare civic and administrative necessity. The developed technologies, mainly UDDT systems, are following a waterless and resource oriented approach. However, UDDTs still face problems mainly because of the difficulties in usage, the frequently observed odours, the difficulties experienced in secondary treatment, and challenges in marketing the end-products. The discovery of the anthropogenic black soils (terra preta) in the Brazilian Amazon region and the findings of terra preta research on ancient solid waste management, involving the conversion of biowaste and faecal matter into long-term fertile soils, has given new life to the development of resource oriented sustainable sanitation options.

Terra Preta

Terra Preta is anthropogenic black soil consisting of organic matter including excreta and charcoal. It covers around 10% of the Amazonas region around Manaus (Glaser, 2007). These areas were mostly used for food production. Terra Preta soils are of pre-Columbian nature and were created by humans from around 7.000 until 500 years ago (Glaser, 2007). It is very stable and remains in the soil for thousands of years (Sombroek et al., 2002). Terra Preta is highly fertile even until today with little or no addition of fertilizer. It owes its color to very high charcoal content. According to archaeologists, Terra Preta was generated by incorporating large amounts of charred residues (charcoal) into the soil together with nutrient-rich material such as human and animal manure, bone, ash residues of incomplete combustion, and plant biomass (Glaser, 2007). The addition of charcoal resulted in high contents of soil organic matter. The black carbon content of terra preta soils can be up to 70 times higher than surrounding, mostly infertile, soils with approximate average values of 50mg/ha/m (Glaser et al., 2001). Terra preta, therefore, acts as a longterm carbon sink.

Most researches on terra preta point out that intentional or unintentional additions of charred material with different organic wastes including human excreta resulted in the formation of terra preta. It also seems that lactic acid fermentation was applied (Pieplow 2008). The challenge is to utilize the findings of the terra preta research and mimic the process to generate modern terra preta soils. The application of the terra preta concept to sanitation offers new possibilities for the treatment of human faeces and household wastes. Terra Preta Sanitation (TPS) is developed based on these concepts.

Terra Preta Sanitation

Terra Preta Sanitation is a dry sanitation system, which refers to the Amazonian black soil (terra preta). TPS aims to produce this carbon and nutrient rich soil, by adding a lactic acid bacteria (LAB) mix, waste sugar, and a charcoal mixture to the excreta (Otterpohl, 2012). TPS is anaerobic but oxygen tolerating, develops no smell, and therefore operates without ventilation pipes. It is an integrated solution, which is currently being developed to address poor sanitation, in particularly the problems of urban sanitation, food insecurity and soil degradation. Table 1 illustrates the different development lines of Terra Preta Sanitation.

Table 1. Development lines of Terra Preta Sanitation

Development lines	Upgrading pit latrines	Modification of UDDTs	High- and low-tech TPS toilets	
			UD	Non UD
Additives during collection	LAB mix, waste sugar, possibly charcoal mix	LAB mix*, waste sugar, charcoal mix	LAB mix*, waste sugar, charcoal mix	LAB mix, waste sugar
Treatment during collection/ storage	Lactic acid fermentation			
Effect	No smell			
Additives before secondary treatment	-	None	None	Charcoal mix
Secondary treatment	None	Composting	Vermi-Composting**	
End product	None***	Nutrient rich compost	**Terra preta**	**Terra preta**

* The LAB mix should also be added to the urine collection container to prevent smell.
** Organic materials such as garden waste, woody biomass and biowaste can be added with charcoal.
*** Even though there is no reuse of end products the soil under the pit latrine will be rich in nutrients and organic matter.

TPS toilet systems

Terra Preta Sanitation systems comprise of three steps: collection, lactic acid fermentation (LAF) and vermi-composting. Lactic acid fermentation is initiated during collection in the TPS toilet and continues during the subsequent storage of the material collected from TPS toilets for a period of 2 to 3 weeks to allow the last collected excreta to be subjected to the LAF process (Yemaneh et al, 2012). After the storage period the lactic acid fermented material is vermi-composted for three months (Factura et al., 2010; Buzie, 2010). TPS toilet systems can be waterless or low-flush systems with solid-liquid separation. They can be designed for urine diversion or combined collection. LAB mix and waste sugar sources are added to TPS toilets to initiate lactic acid fermentation (Yemaneh et al, 2012). The LAB mix and the waste sugar source for feeding the bacteria has to be added at the start of the filling process and if necessary between start and filling of the collection container, depending on the type of waste sugar source. Depending on the TPS toilet system and the type of waste sugar source, the charcoal mixture can be added after each use, once a day, or before vermi-composting. Sources of waste sugar can be spoilt fruit, kitchen waste, fruit waste and bread.

Collection – toilet design

The main treatment process in TPS systems, lactic acid fermentation is an anaerobic process. Therefore the main feature of a TPS toilet is an airtight lid, to prevent oxygen from entering the collection chamber. No gas and hence no odour is produced. Consequently no ventilation of the collection chamber is needed. Any UDDT, abor loo, fossa alterna or composting toilet design is possible. Single vault is preferred over double chamber UDDTs. The construction cost of double chamber systems is too high and the handling of unsafe material through the users is not acceptable in an urban setting. Regarding user friendliness, the favoured design will be a single vault system without urine diversion, which will be pumped out once a week.

High-tech options

High-tech options have to be well designed and comfortable. Urine diverting or non urine diverting dry toilets with optional automatic addition of the additives have to be developed. Photograph 1 shows the non urine diverting sit-squat Terra Preta Toilet with a 1-week storage tank developed by S. Schober for TUHH and WTO. The design received the 2012 WTO Toilet Design Award and still has to be optimized.

Photograph 1. Sit-squat Terra Preta Toilet developed by S. Schober, Triften Design, Germany

Source: terra-preta-sanitation.net

The main features different from conventional toilets and UDDTs are: an airtight sealing lid between bowl and container, a manual stirrer inside the container for cutting and mixing, separate additives opening for LAB mix and bio waste, openings for emptying. The handle on the right side moves the lid and the stirrer through an up and down movement.

Low-tech options

Any sealable bucket with or without urine diversion can provide a low cost TPS toilet option as long as air tightness is secured to maintain anaerobic conditions for lactic acid fermentation.

Lactic acid fermentation (LAF)

LAF is an anaerobic process in which lactic acid bacteria and some fungi metabolize easily degradable carbohydrates, such as glucose, fructose, and sucrose to pyruvate by glycolysis. The pyruvate is then converted mainly to lactic acid and few other metabolic by-products depending on the type of LAB involved. Two distinct pathways exist for carbohydrate metabolism by lactic acid bacteria, homolactic and heterolactic. Homofermentative LAB only form lactic acid as metabolic end product. For one mole of glucose, two mole of lactate are formed. Heterofermentative LAB, on the other hand, produces in addition to lactic acid, carbon dioxide and ethanol or acetate in equimolar quantities. The most common applications of lactic acid fermentation are the production of silage in agriculture and sauerkraut.

Lactic acid bacterial mix (LAB mix)

To start the LAF process in TPS systems LAB inoculum has to be added. LAB grow anaerobically, but they also grow in the presence of O_2 as "aerotolerant anaerobes". LAB are restricted to environments in which sugars are present since they obtain energy only from the metabolism of sugars. The LAB mix can either be obtained from a third source or produced and stored at home. From research at Hamburg University of Technology (TUHH), a mixed culture LAB inoculum consisting of the three strains *lactobacillus Plantarum, lactobacillus Casei* and *Pediococcus Acidilactici* was identified to be effective for LAF of human faecal matter. The commercially available microbial mix, effective microorganism (EM), can also be used as inoculum. But it is less effective for LAF of human excreta compared to LAB mix (Yemanah et al., 2012) and more difficult to duplicate. Another effective and easy way to obtain LAB mix is an inoculum from Sauerkraut (Factura et al. 2010), or any similar fermented local food, such as Korean Kimchi, Nigerian Gari, Kenyan Uji, or Egyptian Kishk. More research on the optimum LAB mix is needed.

Waste sugar source

For proper LAF process a sugar source has to be added to the TPS toilet. All organic wastes that provide simple sugars like spoilt fruit, kitchen waste and bread can be used as a source of sugar for LAB. It is found that adding 5-10% molasses (Yemaneh et al., 2012) or 40-50% kitchen waste (Schmale, 2013) per weight of collected material results in efficient LAF process.

Vermicomposting

After LAF of either urine and feaces collected together or of urine and feaces collected separately these have to be vermicomposted to form the fertile terra preta compost. Vermicomposting is a process of composting using various worms. Compared to conventional composting, it composts organic materials more quickly (as defined by a higher rate of carbon-to-nitrogen ratio increase) and the composting process is easier to control. Faecal matter should be vermicomposted for a minimum of 3months to be converted to an odourless earth-like material (Buzie, 2010). The temperature should be between 20°C and 35°C and the humidity of faecal matter between 65% and 85% (Shalabi, 2006; Buzie, 2010). Organic materials such as garden waste, woody biomass and biowaste can be added with charcoal during vermicomposting. The end product of the digestion of organic matter by an earthworm, the vermicast is rich in nutrients. There are several features of vermicompost which make it more beneficial to plants than normal compost: lower salinity levels; content of easy to absorb water soluble nutrients for plants; and the creation of a living soil environment due to microbes added to the compost from the digestive system of the worms. Because of the easy to maintain conditions for vermicomposting and the shorter treatment periods, vermicomposting is more suitable and easier to realize as a safe treatment method for faecal matter than composting without worms.

Charcoal mixture

The most stable humus is that formed from the slow oxidation of black carbon, after the incorporation of finely powdered charcoal into the topsoil. This process is at the origin of the formation of the fertile terra preta (Glaser et al., 2001). The co-composting of ground charcoal, around 10% of the total mass, is therefore essential for TPS to produce a product with similar characteristics to terra preta. The charcoal mix should contain charcoal (black carbon), stone dust, soil and any bulking agent (e.g. wood chips) to raise the C/N ratio and thus facilitate vermicomposting. (Factura et al. 2010)

TPS toilets – a sustainable solution?

Desiccation as an effective treatment process has to be questioned. Desiccation processes in UDDTs are often accompanied by operating problems such as slight smell. Desiccation is a conservation technique for some pathogens and also hinders the composting process, which should follow as a second treatment step. With LAF offering an odourless and more trouble free sanitation process new possibilities of waste and excreta management can be explored. However, five main parameters should be considered when judging sanitation systems: hygienic safety of system; operation and maintenance; acceptance and adaptability; quality of end product; and cost/input.

Hygienic safety of system

TPS as such is still very much in its infancy with much research still on-going. Therefore limited results on pathogen die-off rates are available so far. However, vermicomposting and LAF both have sanitizing effects. The combination of the two processes could make TPS superior to other combined processes.

Sanitization through vermicomposting

According to Shalabi (2006) and Buzie (2010), vermi-composting alone is highly efficient for treating faecal matter. Buzie (2010) monitored the reduction of six sanitation indicator bacteria in test units (with earthworms) and in controls (without earthworms) over a 60 days period. The reduction is more significant when earthworms participate in the stabilization process: *Escherichia coli* (99.98% vs. 45.46% reduction), *Faecal coliforms* (99.98% vs. 49.26% reduction), *Enterococcus faecalis* (99.99% reduction vs. 24.72% increase), *Salmonella spp.* (99.76% vs. 74.57% reduction), *Shigella spp.* (99.69%vs. 99.71% reduction), and *Enterobacter spp.* (99.98% vs. 56.81% reduction).

Hygienization through lacto-acid fermentation

The antimicrobial effect of LAF is widely reported as it plays an important role in food processing and preservation, silage preservation and in management of different organic wastes. Acidification is the first factor for hygienization as many pathogenic micro-organisms do not survive in a media with low pH. Action of antagonistic constituents produced by LAB also increases the antimicrobial effect. Based on laboratory and field experiments Scheinemann and Krüger (2010) reported that LAF facilitates the die-off of most pathogens in faecal waste from veterinary hospitals. Pathogenic bacteria like *Listeria monocytogenes*, *Salmonella Anatum*, *Salmonella Senftenberg*, acid tolerant *E. coli O157* strain and *Straphylococcus aureus* were inactivated through fermentation within 3 days. Itchon (2010) also reported that LAF could effectively kill off parasite eggs in faecal matter collected from UDDTs with LAF treatment. However, the sample size and the number of analysed Ascaris eggs were too small to allow any general conclusion. To fully assess the hygienic safety of a sanitation system, a risk assessment/multi barrier approach (WHO, 2006) should be used. The difference between TPS and other ecosan solutions is that there are more stages, including the mixing and co-composting of the material, hence there is the potential for multiple-barriers to infection.

Operation and maintenance of TPS toilets

The main processes of TPS, namely lactic acid fermentation and vermicomposting, need to be monitored but this requires little effort. The LAF will be initiated at household level, whereas vermicomposting will ideally be done in semi-central sites though it could also be managed at household level. As with every sanitation system, well organised operation and maintenance (O&M) is crucial. Particularly in urban settings, a business has to be created around the O&M. The business would be responsible for emptying/collection and reuse. This approach minimizes the hygienic risk.

The general tasks to be done at household level include making sure the lid closes airtight, and supplying and adding the charcoal mixture during the filling of the collection container. Ideally a service provider would be responsible for the following tasks:

- Supplying and adding the LAB inoculum to the toilets during emptying process,
- TPS with urine diversion: collecting and changing the airtight containers,
- TPS without urine diversion: emptying of the airtight collection tank with pump,
- Airtight storage of the material for 2 to 3 weeks,
- Vermicomposting for three months, and
- Marketing of end products.

A weekly collection/emptying of the containers is advisable to ensure a hygienically safe system.

Acceptance and adaptability

The TPS principle can and should be applied to existing designs by adding the LAB mix to the different collection systems. In the case of UDDT the addition of the LAB mix to the urine collection prevents the bacterial urease process and therefore prevents smell (Yemaneh, 2012). However, TPS toilets do not need to be designed for urine diversion. Therefore complicated toilet seat designs and the often challenging change of behaviour when using the toilet are not needed. Familiar conventional toilet seats can be used. TPS systems are waterless, and can be installed above ground, in single or multi-storied buildings. They do not produce gases or smells, as the process is anaerobic, hence a ventilation system is not needed. All this would suggest an easy acceptance at household level. Particularly with the odourless operation, an indoor installation is more likely than with UDDTs. However, TPS toilets are not yet tested large scale.

Quality of end product

Terra Preta, the end product of TPS systems, has the same characterisitcs as terra preta soils from ancient times and therefore has several advantages over normal compost, mainly because of its high carbon content. It improves the long-term fertility of soils since the nutrients get trapped in the micro pores and cracks of the charcoal. Terra preta therefore holds the nutrients in the soil and prevents them from being washed out. Furthermore terra preta contributes to carbon sequestration from the atmosphere.

Cost/input

The basic design of a low-tech TPS toilet is similar to a single chamber UDDT except for the urine diverting toilet seat, which is replaced with an airtight toilet seat. A tank connected to the toilet seat will be used for excreta collection. Therefore, the construction cost of a low-tech TPS toilet should be slightly less than, or the same as, the cost for the construction of a single chamber UDDT. Kitchen biowaste can provide the required sugar source. Biochar has to be produced from low value excess biomass. At household level it can be produced by avoiding open biomass burning and using biochar producing stoves, such as the highly efficient woodgas stoves. Larger units can combine power-heat/cooling and biochar production. The sugar input for large scale production of LAB mix has to be quantified. A detailed cost study is needed considering all aspects of the sanitation system including the short and long-term benefits from the use of the final sanitation product as soil conditioner and fertilizer.

Conclusion

TPS is a recently developed sanitation system and more research is needed. Research has to address several issues such as the use of low value excess biomass for production of biochar, different sources of waste sugars, hygienic safety, and life cycle assessment. However, application of LAB together with the addition of waste sugar to let the LAB grow is a breakthrough in sanitation in general. The main advantage of TPS compared to other sustainable sanitation technologies, is its odourless operation, the low maintenance, and the higher quality of the end product, which facilitates the generation of rich soils. Rich soils improve water availability, food security, the regional climate and are, in addition, the key element for reversing desertification which creates more poverty and further unsustainable urbanisation. The avoidance of smell and opportunities for business development make TPS an obvious choice in urban contexts.

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