BioLitter Toilet as a valorisation and management strategy for human excreta: Practices, challenges and opportunities

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Bio-engineering Master's Degree
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Summary Human excreta, i.e. faeces and urine, can both be a resource and a health hazard. Thus, a treatment to ensure health protection can combine with the objective of resource recovery. This statement respects the Ecological Sanitation principle, i.e. sustainable sanitation approach closing the loop between sanitation and agriculture. In BioLitter Toilets, excreta are mixed with carbon-rich substrate, then composted to be recycled. Composting is a well-known process widely used to recycle organic matter. However, its seems that composting has not been studied yet for human faeces and urine regarding low-tech household-scale systems in Belgium. The first objective of this work is thus the identification of management practices regarding BLTs operators using the snowball sampling method. The second objective consists of characterization of raw feedstocks and composts of different ages and inputs to collect quantitative data and discuss them regarding (a) the practices and process, (b) the agronomic value, (c) the potential health hazards. These results highlighted a broad range of management practices regarding dry toilets, with or without resource recovery, treatment, and thermophilic composting as a treatment. While technical aspects concerning the process and the logistics are theoretically easier to spot and solve, social reluctance and inconsistent practices are the main barrier to the development of this sanitation technique. Furthermore, quantitative characterisation suggest that thermophilic stage was not reached in several of the sampled composts, which impacts its sanitation potential. This result is confirmed by Enterococci values. Neither Salmonella nor Listeria monocytogenes pathogenic load were found in any sample. Management practices suggested include temperature monitoring and associated turnings and co-composting to increase volumes and potentially heat insulation and thermophilic conditions. Moreover, risk management strategies are considered to dismiss health hazard. An overview of the current state of the management practices in Belgium is finally proposed using the SWOT approach.

Résumé Les excréments humains, c'est-à-dire les fèces et l'urine, peuvent être à la fois une ressource et comporter un risque pour la santé. Ainsi, leur traitement pour supprimer le risque sanitaire qu'ils représentent peut être combiner avec un objectif de revalorisation des ressources. Cela respecte principe de l'assainissement écologique, c'est-à-dire une approche d'assainissement durable refermant la boucle des nutriments et des matières entre l'assainissement et l'agriculture. Dans les Toilettes à Litière Bio-maitrisée (TLB), les excréments sont mélangés à un substrat riche en carbone, puis compostés pour être recyclés. Le compostage est un processus bien connu et largement utilisé pour recycler les matières organiques. Cependant, il semble que le compostage n'ait pas encore été étudié pour les fèces et l'urine humaines en ce qui concerne les systèmes domestiques low-tech en Belgique. Le premier objectif de ce travail est donc l'identification des pratiques de gestion concernant les opérateurs de TLB utilisant la méthode d'échantillonnage en boule de neige. Le second objectif consiste à caractériser les matières premières et les composts de différents âges et compositions. Les données quantitatives sont discutées en termes de (a) pratiques et de processus, (b) valeur agronomique, (c) risques pour la santé. Ces résultats ont mis en évidence un large éventail de pratiques de gestion concernant les toilettes sèches, avec ou sans revalorisation des ressources, avec ou sans traitement, avec compostage thermophile comme moyen de traitement ou non. Alors que les aspects techniques concernant le processus et la logistique sont théoriquement plus faciles à repérer et à résoudre, la réticence sociale et les pratiques incohérentes sont le principal obstacle au développement de cette technique d'assainissement. En outre, la caractérisation quantitative suggère que le stade thermophile n'a pas été atteint dans plusieurs des composts échantillonnés, ce qui impacte la capacité d'hygiénisation du processus de compostage. Ce résultat est confirmé par les valeurs d'Enterococci. Aucun échantillon n'a révélé de charge pathogène de Salmonella ou de Listeria monocytogenes. Les pratiques de gestion

suggérées comprennent la surveillance de la température et les retournements associés et le co-compostage pour augmenter les volumes et potentiellement l'isolation thermique et donc les conditions thermophiles. En outre, des stratégies de gestion des risques sont envisagées pour écarter les risques pour la santé. Un aperçu de l'état actuel des pratiques de gestion en Belgique est finalement proposé en utilisant l'approche SWOT.

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1 Introduction

1.1 Human excreta, a resource and a health hazard

Human excreta, i.e. faeces and urine, have always been linked to soil fertility and food production through the application to soil. It is thought to have been a factor of humans survival [Gotaas, 1956]. Despite this use as a fertilizer [Schmid Neset et al., 2008], this practice is also associated with disease transmission [Tran-Thi et al., 2017, World Health Organization, 2006].

Thus, a treatment to ensure health protection can be combined with the objective of resource recovery. This statement respects the Ecological Sanitation principle, i.e. sustainable sanitation approach closing the loop between sanitation and agriculture [Langergraber and Muellegger, 2005, Tilley et al., 2014].

Furthermore, improving sanitation access and resource recovery is linked with the Millenium Development Goals of eliminating extreme poverty and hunger and ensuring environmental sustainability. Indeed, excreta management is linked to health status through its pathogenic load and to nutrient status improvement through its fertilizing value. It is also associated with diminishing the pressures on fresh water resource and energy and resource demand for mineral fertilzers production [World Health Organization, 2006].

1.2 BioLitter Toilets

BioLitter Toilets (BLTs) respect the principles of Ecological Sanitation (Eco-San), i.e. the alternative approach to Conventional Sanitation based on waterflush toilet and mixed-wastewater collection. Eco-San is resource-oriented through the closure of material flow cycles. Instead of the traditional sewage disposal, it aims to "drop and reuse" instead of "drop-flush-forget" [Haq and Cambridge, 2012, Langergraber and Muellegger, 2005]. This system thus allow to treat and recover human excreta.

1.3 Composting

Composting is one of the best-known processes for solid organic wastes biological stabilisation. Compost produced is a safer and more stabilised material usable in agriculture as a source of nutrients and soil conditioner [Michel et al., 1996]. Composting is low cost and low tech process that pursues the three main goals of volume reduction, sanitation and organic matter and nutrients recycling. Composting also has a potential regarding mitigating climate change and improving sustainability in agriculture (See Foreword section).

BioLitter Toilets are used by few people in Belgium. The practice is neither very widespread nor very recorded. Some sociological approaches such as [Chamel, 2017] dug into the philosophy of such practices, or non scientific literature exists, like websites[1].

Its seems that composting has not been studied yet for human faeces and urine regarding low-tech household-scale systems in Belgium. A question thus concerns the becoming of excreta and urine, this unusual flux commonly dealt with principally through dark water management and wastewater treatment plants.

[1] see http://eautarcie.org/

1.4 Objectives

Considering what has been stated above, the first objective of this work is the identification of management practices by BLTs operators and the study of dry toilet excreta flux to understand its becoming. People who manage a BLT system in Belgium will be called "operators". This management notion makes the distinction with a simple user. As excreta represent a health hazard and a potential resource, the hypothesis tested is "Bio Litter Toilet operators practice compost to sanitize the excreta and urine for recovery purposes."

The second objective is to characterize raw feedstocks and composts of different ages and inputs to collect quantitative data and discuss them as followed :

Characterize and discuss :

- the practices and process,
- the potential health hazard.

Provide data :

- on agronomic value of TLBs composts

These results will then allow to get an overview of the management practices and conclude by an assessment of the system using the SWOT method.

To ensure optimal understanding of this work, the foreword section will previously present several notions. First, it will precisely define what BLT exactly means in the context of the current work. Second, it will present the interest of faeces and urine in agriculture due to their composition. Third, it will define what is composting and explain parameters of interest for that process and the end-product called compost. It will finally link the interests sought through the study of parameters in regard to process quality and considering health hazard aspects.

2 Foreword

2.1 Definition of BioLitter Toilet

BioLitter Toilets (BLTs) are one possible approach to Eco-San. The compendium of Sanitation Systems and Technologies [Tilley et al., 2014] defines sanitation systems based on five functional groups that can be combined to form a whole sanitation system :

1. user interface
2. collection and Storage
3. conveyance
4. (semi-)centralised treatment
5. use or disposal

BLT user interface (1) is composed by a BioLitter dry toilet (Figures 1 and 2). It is important to note that dry toilets simply mean water-less toilets and this term can cover a huge variety of more or less technological devices. In the case of the low tech BLT considered here, excreta, urine and toilet paper are collected in a receptacle (2) under the toilet seat (Figure 3). A C-rich bulking agent, the cover material, or "Litter", is used to cover the fresh matter (Figure 4) [Del Porto Steinfeld, 2000] IN [Funamizu, 2019].

Once the collector (2) is full, it is emptied and reconditioned before reuse. Its rather small size requires regular emptying. Thus no treatment is considered to happen inside the collector, which is only a storage system. Indeed, BLT are not "composting" toilets as the composting process does not occur inside the toilet, but the user interface only serves for toilet use and collection purpose. The conveyance to the composting area, either on-site or off-site, is human-powered or mechanical (3). The treatment (4) itself is based on composting of faeces and urine, with the triple objective of volume reduction, sanitation of hazardous organic material and recovery of a resource (5).

The great amount of possible combinations of Eco-San functional groups makes the classification rather complex. Thereby, low tech BioLitter toilets as defined here are not exactly considered in [Tilley et al., 2014]. However, composting is thought as an option for treatment, with the difference that it is treated in a pit under the toilet, during step (2), contrarily to BLT where composting is separated from the collection step. The BLT toilet defined here is the one expected to be encountered and managed at the household-scale.

Figure 1 – Exemple of a TLB system inside of a house. Sawdust is available as C-rich cover material.

Figure 2 – TLB is a seating model comparable to a small piece of furniture.

Figure 3 – The collection container is located under the seat. Here, a rubber bib ensures that there is no leakage outside of the container.

Figure 4 – Example of C-rich cover material : commercial wood shavings.

2.2 Snowball sampling for qualitative research

Snowball sampling method is a way to conduct exploratory research. It provides qualitative data that allow the understanding of a system and its qualitative analysis. This way of sampling has the advantage to identify and sample populations hard to reach [Naderifar et al., 2017]. It is important to keep in mind that the sample can never be considered representative. These approaches allow better understanding of practices but can not be considered as an exhaustive representation of field practices. In the present case, this method is interesting as it makes it feasible to identify BLTs users and managers and dress a picture of different practices encountered in Belgium.

2.3 Faeces and urine composition

Faecal wet mass value is estimated at 128 $g.cap^{-}1.day^{-}1$, with a dry mass of $29g.cap^{-}1.day^{-}1$. Median water content is 74.6%. Mean pH is 6.64. 84-93% of dry matter is organic (Feachem et al., 1978 IN [Rose et al., 2015]), [Nwaneri et al., 2008, Bai and Wang, 2011]. 25-54% of it is microbial biomass and the remainder of is composed of undigested carbohydrate, fiber, protein and fat [Rose et al., 2015].

Carbon content of feces is between 44% and 55% of dried solids (Feachem et al., 1978 IN

[Rose et al., 2015]; [Strauss, 1985].

14% of N is voided through faeces, i.e. 1.8g.cap^{-1}.day^{-1}) and the majority is excreted in urine (10.7 g.cap^{-1}.day^{-1}) according to [Calloway and Margen, 1971]. [Bender and Bender, 1997] stated that nitrogen excretion will equal ±5% of intake in healthy humans in nitrogen equilibrium.

Fraction	% of dry mass	absolute mass (g)
microbial biomass	25-54%	7.3 - 15.7
proteins or N-compounds	2-25%	0.58 - 7.3
carbohydrates	25%	7.25
undigested lipids	2-15%	0.58 - 4.35

Table 1 – Faeces composition

C:N ratio of faeces can be computed as 7.1 using the values from [Rose et al., 2015].

[Gotaas, 1956] indicates C:N ratios between 5 and 10.

Urine Median urine generation is evaluated at 1.42L.cap$^-$1.day$^-$1 with a dry solids content of 59g.cap$^-$1.day$^-$1. pH is 6.2. Urine contains the largest fractions of N, P, and K released by the body. 10.7 g N.cap$^-$1.day$^-$1) are dominantly excreted as urea (>50% of total solids) [Rose et al., 2015].

2.4 Composting

2.4.1 Interests of compost in agriculture

Agricultural practices Intensive agricultural practices such as frequent and deep tillage lead to a decrease in soil organic matter levels, which is associated with the degradation of soil properties: risks of compaction, erosion, decrease in chemical fertility, etc. Organic matter diminution in soils has been identified as a threat by the European Commission (COM/2006/0231). More sustainable practices should increase agricultural production and meet the ever-increasing demand for food and fibers, restore soil fertility and participate in climate change mitigation through carbon sequestration [Lal, 2008].

Compost application is suggested, among other organic residual fertilisers, as a recommendation to alleviate fertility diminution [Marmo, 2008]. This practice can participate in a more sustainable agriculture on the condition that compost quality does not adversely affect agroecosystems or aquatic environments [Houot et al., 2014].

Expected effects of compost application The double advantage of compost application is its fertilizing value due to the nutrients brought to soils and its soil additive value through the increase of soil organic matter through time or the increase of acidic soils pH [de Guardia, 2018].

Compost inputs potentially contribute to all three components of soil fertility :

– chemical fertility: OM content and potential availability of nutrients (N, P, K, Ca, Mg, Na), neutral pH, cation exchange capacity;

– biological fertility: biological activity and biodiversity;

– physical fertility: porosity, structure, water holding capacity. These properties regulate the plants ability to develop their rhizosphere and to uptake water. Structure stability regulates soil loss risks due to its capacity to improve soil erosion resistance.

Effects of application can be immediate (< one month), short-term (< one year), mid-term (about 10 years), or long-term (> 10 years). Composts usually are used to increase the soils organic matter content at mid- to long term. This increase has an indirect effect on soil fertility such as biological activity or nutrient bio-availability of N. Furthermore, physical properties like water holding capacity, CEC and structure are closely related to OM content. It is to note that these effects depend on the pedoclimatic conditions in which compost applications are made, as well as on the doses and the frequency of application.

Although, improper use management of residual fertilizers can lead to air contamination through ammonia or greenhouse gas emissions, or nitrates and phosphorous contamination of water bodies, causing eutrophication. This phenomenon is described as the anthropogenic enrichment of water in nutrients, causing the development of algae and other superior plants with undesirable effects on water environments [Csathó et al., 2007].

2.4.2 Composting process

Composting is an aerobic biological process in which microorganisms use organic matter as a substrate and decompose it into a stable and humified product, called compost [Epstein, 1997]. Composting is mainly driven by bacteria, actinomycetes, and fungi whose populations evolve greatly spatially and temporally. Their metabolic activity releases heat, generally involving thermophilic conditions [Swan et al., 2002].

Organic matter is converted into microbial biomass, humified i.e. turned into stable organic molecules or mineralised into by-products including carbon dioxyde (CO_2), ammonia (NH_3), and water vapour (H_2O) [de Bertoldi et al., 1983].

Timeline The process is divided into four "successive" phases : mesophilic, thermophilic, cooling and curing phases (Fig. 5). One commonly considers two phases : the active phase corresponding to the mesophilic, thermophilic and a part of the cooling phase, on one hand. The maturation phase includes the end of the cooling phase and the curing phase, on the other hand.

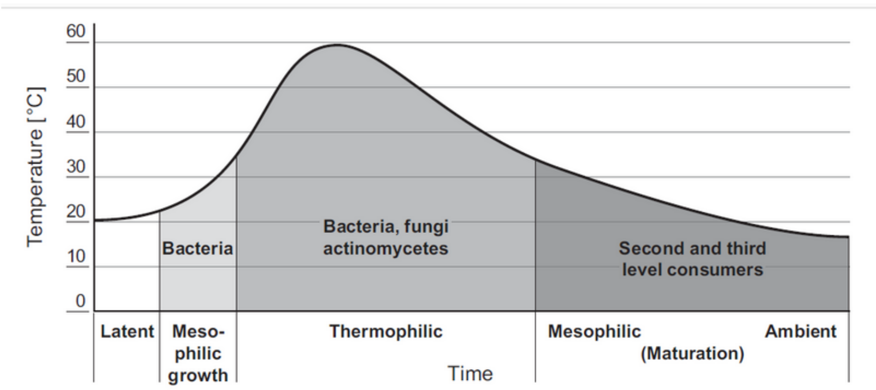

Figure 5 – Evolution of organisms and temperature through time during the composting process. Adapted from [Polprasert, 2007]

Biodegradation is the main process during the active phase. Easily degradable organic matter is degraded by microorganisms. The first step of the active phase is mesophilic. The temperature range is inferior to 40°C for a few hours to a few days. Endogenous microbes break down easily degradable matter such as sugars and starches. Their proliferation releases metabolic heat, causing a temperature increase in the waste [Ryckeboer et al., 2003b].

As temperature raises over 40°C, thermophilic phase occurs. A switch happens in the microbial populations. Thermophilic organisms develop as mesophilic become dormant or die. This step lasts for weeks. High temperature enhances complex compounds degradation and allows sanitation of the organic matter [Ryckeboer et al., 2003a]. The third and last step of the active phase, the cooling, starts with the temperature decline and ends when the oxygen consumption is low and at temperature below 40°C. The maturation phase is characterised by the rearrangement of the residual organic matter and the humification of aromatic and aliphatic compounds. Biodegradation becomes minor while the major process is now the biosynthesis of macromolecules.

2.4.3 Key parameters for composting

As composting is a microbial process, its overall performance results from the combined activity of every individual driving it. The most important parameters for microorganisms development are substrate composition, especially C:N ratio, oxygen availability, water content, pH, and temperature [Epstein, 1997, Miller, 1992, Gao et al., 2009].

C:N ratio Proportion of C to N is among the key factors influencing composting process and quality [Michel et al., 1996]. About one third of carbon is used as building bricks of cells, while two thirds of that is used serves for energy [Gotaas, 1956]. Nitrogen (N) is a constituent of the cells protoplasm. Since C is necessary both for energy and cells components, micro-organisms use more C than N.

If C:N is too great, the biological activity diminishes once all the N has been used up. Micro-organisms die, making N available again. Microbial growth then happens again, until N is limiting. Several cycles of die-off, N liberation and regrowth are needed to burn up most of the C. The process is thus very slow [Gotaas, 1956, Gao et al., 2009].

If C:N is too low, N excess can be lost by leaching or volatilization as ammonia [Gao et al., 2009].

[Huang et al., 2004] suggest that the optimal C:N ratio is 28 to ensure ideal thermophilic composting, when moisture and oxygen are not limiting. Furthermore, many composting tested for C:N ratios between 14 to 29 showed that the more complete stabilisation occurred for the highest ratios, [Gao et al., 2009, Wang et al., 2013, Nada, 2015] while lowest ratios led to the highest N loss [Zhou, 2017, Guo et al., 2012].

Many waste materials like animal manure, sewage sludge or food waste have too high moisture contents and too low C:N ratios for efficient composting [Chang and Chen, 2010]. C:N ratios for faeces are 7.1, or between 5 to 10. (see section. In addition, urine is liquid and rich in N (See above section 2.3).

To address these too low ratios and deal with N brought by urine, C-rich bulking agents are used to balance C:N as well as water content [Haug, 1993, Gea et al., 2007] This is the role of sawdust used in BLTs [Lin et al., 2018].

Oxygen OM degradation occurs more or less quickly and liberates a certain quantity of energy depending on thermodynamic laws and oxidation-reduction. In the case of sufficient oxygen supply, electron donors are organic matter and reduced mineral compounds, to a smaller extent.

The final electron acceptor is O_2. In that case, the principal metabolism reaction is aerobic respiration:

$$C_nH_{2n}O_n + nO_2 \longrightarrow 2nH_2O + nCO_2 + \text{Energy}$$

Mineralisation of OM is then maximum and the compost is stabilised [Haug, 1993].

However, in anoxic zones, i.e. zones without free O_2, other electrons acceptors such as NO_3, SO_4^{2-} or CO_2 intervene and metabolic reactions become denitrification, sulfato-reduction, methanogenesis or acetogenesis. The energy released by these reactions is lower than that released by aerobic respiration. The smaller release of heat can cause insufficient temperature raise and prevent the thermophilic phase to take place.

Water content All living organisms need water, so moisture is essential for the function of the composting process. For the microorganisms there is no upper limit for the water content as such, but excessive moisture reduces the air space in the compost matrix and thus causes oxygen limitation [Miller, 1992].

Below 40 to 45%, the nutrients are no longer in aqueous medium and they are not easily available to microorganisms [EPA - Environmental Protection Agency, 1994]. As a consequence, microbial activity diminishes and composting slows down. Conversely, anoxic conditions prevail when high moisture impedes the oxygen flow, which occurs near 65% of moisture [Rynk et al., 1992]. Common recommended range is 50-65% [Horisawa et al., 2001].

[Lopez Zavala and Funamizu, 2005] found that moisture content below 64% ensured aerobic decomposition of faeces, while both anerobic and anaerobic degradation occurred at >=64%. They suggest to keep water content near the optimum value of 60% and to care not to exceed levels near or higher than 65%. Staying below this limit will avoid odors, anaerobic emissions, nitrite formation, and increase of sulphate concentrations [Lopez Zavala and Funamizu, 2005]. In fact, certain gaseous compounds have a high greenhouse gas effect, and others are responsible for odours. Water content dynamics the matrix is determined by the water input, itself linked to the moisture and water retention capacity of OM to compost, and to its drying rate. Windy conditions can accelerate the water content decrease and increase heat loss.

pH The broad spectrum of microorganisms involved usually makes the composting process operational within a large range from 5.5 to 9, the optimal pH values lying between 6.5 and 8. However, N-rich inputs will encounter high N conversion into ammonia at pH above 8.5. This implies a loss through gaseous emissions, and further adds to the alkalinity. Ensuring a pH value below 8 limits the quantity of N lost through ammonia volatilisation [Rynk et al., 1992].

The pH value generally decreases below 7 in the beginning of the composting process because of organic acids forming then rises above neutral as acids are consumed and ammonium is produced [Beck-Friis et al., 2003].

Temperature Composting is self-heating process driven by the heat generated by microorganisms metabolism. Target temperature ranges are reached by managing the substrate properties. Chemical factors include C:N, moisture, and pH. Physical parameters are the porosity and the particle size, which influence the access to OM by microorganisms and the oxygen availability. Biological conditions, such as nutrients bioavailability, are mainly defined by the nature of the substrate. The process might not reach thermophilic stage if one factor is not controlled. Furthermore, thermophilic stage, also called sanitation stage, is of higher importance in terms of pathogen agents inactivation.

2.5 Stability and maturity

Stable and mature compost application on agricultural land can improve the soil structure by increasing soil organic matter (OM), suppressing soil borne plant pathogens, and enhancing plant growth [Haga, 1999, Mehta et al., 2014].

Converslely, unstable and immature compost application can cause N starvation to plants [Willson and Dalmat, 1986], or phytotoxic effects related to pathogens [Fang et al., 1999] or to the emission of ammonia and other substances like phenolic compounds and low molecular weight organic acids [Bernal et al., 2009].

Maturity and stability are used as quality indicators to ensure safety of compost use in agricultural application [Moral et al., 2009].

Several authors use the microbial activity rate to evaluate stability in composts [Bernal et al., 1997],

Maturity is 'the degree or level of completeness of composting', according to the California Compost Quality Council (CCQC, 2001). Mature compost implies improved qualities resulting from 'ageing' or 'curing' of a product. A mature compost does not have any negative effect on seed germination or plant growth [Iannotti et al., 1993]. It also implies the absence of pathogens and weed seeds [Gao et al., 2009]. [Bernal et al., 1997] described maturity as implying 'a stable OM content and the absence of phytotoxic compounds and plant or animal pathogens'. Similar definitions were notably proposed by [Iannotti et al., 1993]. It is to be noted that maturity requires stability as suggested by [Bernal et al., 1997], since phytotoxic compounds are produced by microorganisms during the active phase of composting [Gao et al., 2009].

High amounts of free ammonia, certain organic acids or other water-soluble compounds can be present in immature composts and potentially limit seed germination and root development [Bernal et al., 2009].

Stability and maturity assessment Stability can namely be evaluated by respirometric measurements [Gao et al., 2009], while assessment of maturity can by made through biological methods involving seed germination tests and plant growth bioassays [Gao et al., 2009].

2.5.1 Maturity and stability indicators

NO_3^-:NH_4^+ ratio serves as a maturity indicator under certain conditions as NO3 increases and NH4 decreases during the process (See below).

Moreover, NH_4^+:NO_3^- ratio (expressed in mg NH4+/kg DM and mg NO3-/kg DM) can be obtained from the measurements in N-NO3-/kg (FM) and N-NH4+/kg. This ratio is another indicator of the maturity level of a compost [Wichuk and McCartney, 2010].

After conversion into mg NH_4^+/kg (DM), NH4 concentration values alone can also serve as a maturity indicator based on the following classification [Wichuk and McCartney, 2010]:

- > 500 : immature,
- 75-500 : mature,
- < 75 : very mature.

Self-heating test The principle is based on the fact that mature compost has a low microbial activity and few easily degradable organic matter left. Thus, if put in a vase Dewar, i.e. a container with very effective thermic isolation, in optimised and ideal moisture conditions, the temperature of mature compost should not rise much. Maturity is thus assessed based on the maximal temperature reached by the sample. Moisture conditions have to be adjusted to an ideal value, as too wet or too moist samples limit the heating, causing an overestimation of maturity.

Respirometry test is based on the principle that mature compost has a low oxygen consumption and a low CO_2 production. Stability is estimated through the microbial activity, expressed in consumed oxygen.

Phytotoxicity is another maturity indicator, as cured compost is expected not to entail plant development or growth.

Weed germitation capacity Maturity of composts can be established by verifying their absence of weed germinative power. Indeed, proper composting should have inactivated weed seeds, thus the smallest number of weed seeds should germinate.

2.6 Agronomic parameters

Aerobic conditions, influenced by bulk density and porosity, C:N ratio and moisture content are the three main parameters to control for an optimal composting process.

Apart from C:N ratio, oxygen availability, water content, pH, and temperature, related to the process control, and stability and maturity tests, several other characteristics are useful to assess.

Organic matter plays a major role in soil fertility and crop production [Loveland and Webb, 2003].

Nutrients Nitrogen (N), especially nitric (NO_3^-) and ammoniacal (NH_4^+) forms, Phosphorous (P), Potassium (K), Sodium (Na), Calcium (Ca) and Magnesium (Mg) are nutrients essential for plant growth. Their availability is strongly linked to soil conditions such as organic matter content, pH or texture.

Fertilising value of composts its linked to its nutrients content [Steiner et al., 2007]. They are key agronomic parameters because they influence the application rate of mature composts. It is also relevant to quantify the potential resource humanure represents as composts fertilising effect depends on the feedstocks used.

In addition, nitrogen and phosphorous are of particular importance as their leaching can lead to eutrophication [Csathó et al., 2007].

Nitrogen dynamics In the initial feedstock, N is mainly present in organic (N_org) and ammoniacal (NH_4^+/NH_3) forms [de Guardia, 2018]. N_org is partly mineralised in ammoniacal N. This pool (NH_4^+/NH_3) is partly immobilised as microrganisms biomass, partly emitted as NH_3 gas into the atmosphere, and partly nitrified into NO_2^- and NO_3^-. The remaining fraction accumulates in the compost. Volatilisation of NH_3 is an important parameter and can be as high as 40%.

Kjeldhal nitrogen doses N from the ammonium, nitrate, nitrite and organic fractions.

Nitric nitrogen, Ammoniacal nitrogen Plants N uptake occurs in the form of nitrates ions, NO_3^- and to a lesser extent NH_4^+.

$NO_3^-/NH_4^+ < 1$ indicates an oxydation (thus a mineralisation) of the substrate, more precisely, a nitrification reaction due nitrifying bacteria activity.

NH_4^+:NO_3^- (mg NH_4^+.kg/mg NO_3^-.kg) (Dry Mass) After conversion from mg N/kg (FM) to mg NH_4^+/kg and mg NO_3^-/kg (Dry Mass), the NH_4^+:NO_3^- ratio classifies composts as very mature (<0.5), mature (0.5-3) or immature (>3).

Electric conductivity is a measurement of the ionic concentration in the liquid phase of a medium using its property of conducing electricity proportionally to its ionic concentration. It provides an indication about the water soluble electrolyte content.

Organic carbon is both an important parameter for the C:N ratio and the organic matter content, strongly linked to soil fertility and C storage.

Bulk volumic mass (kg/m^3) is related to porosity, itself linked to oxygen availability. Bulk volumic mass of a material is the ratio between its mass and the total volume it fills. This includes the pore volume. Less than 700kg/m^3, preferably 400-600kg/m^3 are recommended values for bulk volumic mass [Coker et al., 2019]. For the record, another porosity indicator is the free air space (FAS) expressed in %. Reasonable range includes 40-60% free air space, while optimal range is 50-60%.

2.7 Microbiological parameters

2.7.1 Soil conditioner sanitary quality

Poor microbial quality of raw agricultural products can be associated with the presence of pathogens in food and diseases outbreaks [Beuchat, 1996, De Roever, 1998]. Moreover, Listeria monocytogenes, Salmonella or E. coli pathogens transfer from amended soil to fresh agricultural products have been demonstrated by [Al-Ghazali and Al-Azawi, 1990, Islam et al., 2004], including migration inside lettuce tissues [Solomon et al., 2002].

To control the risk of food-borne disease caused by contaminated compost, soil additives should be safe regarding microbial pathogens [De Roever, 1998].

Faeces contain many pathogens and need to be sanitised to be suitable for valorisation without causing a health issue [World Health Organization, 2006]. Time-temperature criterion is commonly used in legislation to ensure compost safety before marketing and use. Indeed, pathogen inactivation was demonstrated during thermophilic phase of composting [Sunar et al., 2014]. Low levels of faecal coliforms and no Salmonella spp. were found in several Municipal Solid Waste (MSW) composts [Dimambro et al., 2007]. However, E. coli and Salmonella survival for more than 5 days at 55°C was stated in a mixed compost of biosolids, food waste and yard trimmings. Furthermore, these two pathogenic agents have been discovered to increase their thermal tolerance if exposed to sub-lethal heat shock, making them able to reinfect compost in the maturation phase [Droffner and Brinton, 1995]. This is why monitoring process and ensuring that sufficient temperature rise for a sufficient time in addition to control microorganisms levels is a preconised strategy, as legislation shows. Indeed, time-temperature criteria for process control are common in many countries regulation.

2.7.2 Indicator or pathogenic organisms

It is virtually impossible to count every species of anykind of pathogen that can be found in composts. This is the reason why only certain µorganisms are studied.

Indicator or index µorganisms are organisms, toxins or metabolites which presence or concentration is correlated to hygienic conditions of the processes. They can indicate initial contamination of raw products, treatment process "efficiency", hygiene conditions and conservation conditions. A single indicator can be used for different criteria depending on the link of the food chain surveyed.

Pathogen µorganisms can cause illness to humans through consumption of contaminated foodstuffs. These pathogen agents can be bacteria such as Listeria monocytogenes, Salmonella, shigatoxin-producing E. coli (STEC); viruses; or bacterial toxins, e.g. toxins of Clostridium perfringens [Agence Fédérale la pour la Sécurité de la Chaîne Alimentaire, 2020].

2.7.3 Belgian standard for commercialisation of composts made with animal by-products

Belgian and European Regulation

Belgian Federal legislation relative to production and commercialisation of soil improvers made out of animal by-products are summurised in [Swillens et al., 2018]. For composts, pathogens levels have to be assessed and can not exceed standards of the Commission Regulation (EU) n° 142/2011[2].

Process monitoring Five representative samples taken during process or at its immediate end must comply with the standard:

- Escherichia coli < 1000 CFU/g, with maximum one sample < 5000 CFU/g
  - OR
- Enterococcaceae < 1000 CFU/g, with maximum one of the five samples < 5000 CFU/g

Pathogen control Five representative samples taken during or on withdrawal from storage must comply with the standard:

- Salmonella absent in 25g in all five samples

Belgian FASFC standards Similarly, the Belgian Federal Agency for the Security of the Food Chain (BFASFC or AFSCA-FAVV) uses Enterococcae as an indicator organism and testes Salmonella as a pathogen for soil conditioners control [Agence Fédérale la pour la Sécurité de la Chaîne Ali

Other regulations

[2]see Annex XI, ch. 2, section 1.5

US EPA (Biosolids Rule 503) uses thermotolerant coliform bacteria (TtC) and Salmonella for process control and pathogen testing, respectively.

French standard for organic soil conditioners (NF U44-051) use E. coli and Enterococcae as treatment indicators. Pathogenic risk is assessed through Salmonella and viable helminth eggs. Compost made out of wastewater treatment plants residues (NF U44-095) uses the same, plus Clostridium perfringens for treatement control and Listeria monocytogenes for pathogen assessment.

It is to be noted that none of the precited legislation includes human excreta or urine as a admitted feedstock for composting.

2.7.4 Index microorganisms

Thermotolerant coliforms are a treatment indicator more that a pathogenic risk assessor. Indeed, they are present in many media in higher concentrations than pathogens, and not all of them are a health hazard. They are also distributed more evenly in feedstocks, contrarily to pathogens (CCREF, 2019). Apart from being easily and inexpensively measured, their main interest in this study is their abundance in human faeces and their densities declining in about the same proportion as enteric bacterial pathogens. Thus, a significant decrease in TtC could mean that other enteric pathogens are of no concern (EPA 2003).

correlation between coliforms and E coli Microbiology literature contains many studies that depict a correlation between TtC levels and the presence of E. coli including several recent examples that advocate the TtC test as an acceptable indicator in manure composts and foods. For example, [Brinton et al., 2009] found excellent correlation between fecal coliforms and E. coli in composts. E. coli is however considered a better indicator for faecal contamination in compost in general as thermotolerant coliforms also include a wide range of non faecal-borne bacteria [Doyle and Erickson, 2006].

Enterococci are found in concentrations between 10^4 and 10^8/g fresh mass of human faeces [Slanetz and Bartley, 1957, Zubrzycki and Spaulding, 1961]. They have been chosen as index µorganism due to their presence in human fecal matter and persistence in the environment.

Clostridium perfringens presents a higher resistance to various treatment conditions among index organisms. It makes it a indicator of choice to control the process of sanitation and pathogens removal especially in sludge treatment [Hirata et al., 1991].

Salmonella sp. and Listeria monocytogenes Salmonella and Listeria are searched for as pathogenic agents as their presence can lead to food-borne diseases outbreaks. Nearly one in three food-borne outbreaks in the EU was caused by Salmonella in 2018 [Food and Authority, 2019].

Purpose	Microorganism	Standard	Value (CFU/g)
Sanitation process control	Thermotolerant coliforms (TtC)	US EPA	< 1000 MPN/g
	E. coli	EU 142/2011 & BFASFC NFU 44-095 NFU 44-051	< 1000* $< 10^3$ or 10^4** $< 10^2$
	Enterococci	EU 142/2011 & BFASFC NFU 44-095 NFU 44-051	< 1000* $< 10^5$ $< 10^4$
	Clostridium perfringens	NFU 44-095	$< 10^5$
Pathogenic agent	Salmonella	EU 142/2011 & BFASFC FR NFU 44-051 FR NFU 44-095	Absence in 25g
	Listeria monocytogenes	NFU 44-095	Absence in 1g OT 25g

Table 2 – Treatment and pathogenic microorganisms standards

3 Material and methods

3.1 Qualitative characteristics of TLB operators

As no study could have been found over BLT operators in Belgium, this section prospected to answer the following questions :

- collect information on the operator's profiles,
- identify technical parameters,
- state real cases management practices, considering excreta and urine treatment and recovery

The objective was to conduct exploratory research over BLTs operators. Users' profile, technical aspects and management practices were studied through 28 semi-directive interviews with both closed and open questions.

Operators are identified and surveyed using the snowball sampling method. The hypothesis tested is that "Bio Litter Toilet operators practice compost to sanitize the excreta and urine for recovery purposes."

Contacting respondents by email was chosen by default if no phone number was available, while phone and direct contacts were preferred in order to have more precise information and be able to get more details or nuances. Written contacts could be chosen in the case of exchanges not in French, i.e. either in Dutch or in English with Flemish operators.

Searching for potential operators was made through the experimenter's acquaintances and by contacting organisations and networks assumed to have a contact book of potential users. When accessible, these lists of members where used to increase the size of the sample. Semi-structured interviews with respondents occurred mainly in French by the phone or in face-to-face meetings. English was sometimes used if it was easier for native Dutch speakers.

Framework Criterion of self-management has been considered. The emphasis was put on the fate and management of excreta as it represent both a potential resource and a health hazard. Thus their flows within system compartments were investigated. As an example, event organisers dealing with companies renting BLTs were not surveyed, while these companies were tried to be reached in order to establish the becoming of human excreta. Both users that currently have or have had toilets were surveyed.

More than 100 assumed or confirmed users were contacted, and 28 ended up in the sampling. Most of those not selected did not answer the first request. Some did not have such toilets and others did not fall into the criteria of a self managed toilet.

An analysis grid was built a posteriori, as a function of the different responses content during the coding part of the data analysis. Categories of answers were made : User information and habits, technical or logistic considerations, sociological considerations.

3.2 Quantitative characterisation of raw and composted BLTs inputs

Objectives A second objective was to assess feedstocks and composted materials from case studies BLTs with varying ages and inputs. Several aspects were investigated : practices, process, agronomic parameters, stability and maturity indicators, pathogens as treatment indicators and potential health hazard.

3.2.1 Sampling

Samples were made at several places and contain different inputs. Figure 6 summarises the composition and age of the collected composite samples.

Code	Inputs			
	toilet material	cover material	other	Age
KT0	FTU(1)	wood shavings	kitchen waste	0 month, fresh
KT6	FTU	wood shavings	kitchen waste	6 months
KT18	FTU	eucalyptus bark	kitchen waste	18 months
KT 30	FTU	wood shavings	66% commercial potting soil	30 months
T6	FTU	wood turning scraps (mainly tuya, cherry wood and linden tree)	grass clippings, peat moss, straw	6 months
T8-Top	FTU	wood shavings (mainly douglas, spruce)	n.a.	8 months(2)
T8-Bot	FTU	wood shavings (mainly douglas, spruce)	n.a.	8 months(2)

(1) FTU = Faeces, Toilet paper and Urine

(2) 8 months in bin, matter between 9 to 17 months old since production

Figure 6 – Characteristics of the composite samples

Three case studies compost sites were investigated. Toilet material was faeces, urine and toilet paper in every sampled material.

KT0, KT6, KT18 and KT30 The first site investigated is a household of one inhabitant who co-composts kitchen wastes with BLT material (KT). 5 and 10L composite samples were taken from 0 (code KT0, 5L), 6 (KT6, 10L), 18 (KT18, 5L) and 30 (KT30, 5L) months old materials. The cover material used was commercial dust free wood shavings conceived for horse bedding, except for KT18 where eucalyptus bark was used. KT0 and KT6 came from the same pile. KT0 was sampled from the top of the pile delimited by wire mesh, as fresh materials were added up. KT6 was sampled from the bottom. The pile was turned over using a shovel, then a composite sample was taken at the bottom, not too close from the borders, where it was possible to see that degradation did not occur. Centering the sampling was meant to avoid edge effect influences. KT18 was sampled from a second pile of older composted material. KT30 was sampled from a vegetable bin. It is composed of one third of 30 months-old kitchen and toilet material compost and two thirds of potting soil.

T6 The second site is a household of two inhabitants which co-composts BLTs material with green wastes, mainly glass clippings, peat moss and a few straw. The sampling was made on 6 months old matter, extracted from the centre bottom of the pile. Excreta, urine and toilet paper (EUTP) are covered in the toilet using wood-turning scraps. These are thin corkscrew-shaped wood pieces from cherrywood (Prunus avium), tuya (Tuya spp.), taxus (Taxus spp.) and linden (Tillia spp.). Water used to clean the bucket after emptying it is added on the pile as well, increasing its moisture content. The pile is exposed to precipitations. When forming the stack, bucket material is always covered with either moss, grass clippings or straw in order to avoid olfactory nuisances.

T8-Top and T8-Bot The third site is an off-site composting pile of BLTs used during events. Two composite samples were taken from an Intermediate Bulk Container (IBC). The bottom and walls are airtight. A removable roof covers the top, (Figure 16) keeping it mostly preserved from rainfall. Two zones were identified and sampled. The upper part (T8-Top) had forest-like smells and was dry on the top (Figure 18), otherwise moist but not soggy. A composite 10L sample was taken from it (Figure 19). The lower part was soaked in liquid 17. as there was no exit for liquid to percolate. Strong ammonia smells escaped when disturbed during the composite sampling of a 10L bucket, using a shovel (T8-Bot).

Sampling limitations Compost piles were very variable spacially. Thus the samples, even if they were tried to be as representative as possible, were heterogeneous, due to the intrinsic nature of the feedstocks. Moreover, volumes to sample were rather small; less than a cubic meter. These small volumes did not permit to make repetitions. The most homogeneous samples were T8-Top and T8-Bot. Indeed, co-composting of large pieces of vegetables or green waste made the sample more heterogeneous.

3.3 Analyses

Quantitative parameters studied As presented in the foreword, some parameters are key for the composting process to happen in the best conditions. The most important are C:N, oxygen availability, moisture content and temperature rise. The latter should occur if other key factors are in proper range. pH is important as well but is usually not problematic. Maturity and stability tests insure compost quality and readiness. Microbiological analyses assess the health risks through pathogen load measurement. Index µorganisms are treatment monitoring tools, especially to ensure that thermophilic stage was reached. Finally, agronomic parameters are evaluated as no assessment seems to exist yet for case studies BLTs composts in Belgium.

3.3.1 Physico-chemical analyses

Specific protocols for compost analyses are recommended by the belgian Public Service Scientific Institute (ISSeP). Analyses were conducted by the Bureau Environnement et Analyses of Gembloux Agro-Bio Tech (B.E.A.Gx).

pH water (/) is measured using a glass electrode in a diluted 1:5 (V/V) suspension of sample in water (protocol : S-II-6.1V3 - ISSeP).

Dry matter and water content (% of fresh mass) of a sample are determined by weighing before and after drying it, the difference in mass indicating the water loss through evaporation (protocol : S-I-3V3 - ISSeP).

Organic matter (% of fresh mass) is measured by gravimetry after calcination at 550°C. The loss of mass of the 105°C-dried sample is compared to the initial fresh mass. The difference is an estimation of the organic matter content.

Organic carbon (% of dry mass) is estimated by the quantification of its reducing power using sulphochromic oxidation. Organic carbon and organic matter being estimated by different methods, the ratio linking them is not a constant.

Kjeldhal nitrogen (% of fresh mass) doses N from the ammonium, nitrate, nitrite and organic fractions. These compounds are mineralised into ammonium. The latter is then distilled by addition of soda into gaseous ammonia, which is finally dosed by titration (protocol : S-II-9.3V2 - S-II-9.2V2).

C:N ratio is computed from C organic ratio to Kjeldhal N.

Ammoniacal nitrogen : NH_4^+ and nitric nitrogen : NO_3^- (mg N/kg of fresh matter) are isolated and steam distilled before titration with an indicator dye (protocol : S-II-11V3).

NO_3^-:NH_4^+ ratio is computed from previous values.

Phosphorous, Potassium, Magnesium and Calcium (% of fresh mass) are extracted using EDTA, then dosed by molecular (P) or atomic (K, Mg, Ca) absorption spectrophotometry (protocol S-II-12V2).

Electrical conductivity ($S.cm^{-}1$ at 20°C) : Sample is water extracted at 1:5 (m/V) at 20°C to dissolve electrolytes. Electrical conductivity of the filtered extract is measured using a conductivity meter (protocol S-II-7V3).

Bulk volumic mass (kg/m^3) is obtained by measuring the weight and the volume of the sample then computed from these values.

3.3.2 Maturity and stability tests

OxiTop® method is used to determine composts stability through the measurement of oxygen consumption in standardised conditions inside a closed respirometer. The compost is mixed with mineral substrate and agitated for five days in the hermetically sealed container. The drop of pressure measured in the container is correlated to the oxygen consumption (protocol S-IV-6V1). Based on this, class of stability, ranking from one to five, assess the stability.

Self heating test is similar to the OxiTop® respirometry method, expect that the temperature rise is the criterion to establish a class of stability for the sample.

Phytotoxicity or a delay in plant growth is evaluated through a germination test of cress (Lepidium sativum L.) under standardised conditions. Sand and fresh material are mixed in such proportions that it avoids adverse effects of saline concentrations (measured through the electric conductivity). Germination capacity is compared to the one of the control, exclusively made of sand. Phytotoxicity is expressed as the % of inhibition compared to the control after ten days at about 10°C (protocol S-IV-4V1).

$P(\%) = (K_c\text{-}K_s)*100/K_c$

P(%): Phytotoxicity for 1:s proportion, with s the sand:substrate volume ratio,

K_c: germination capacity of cress in the control substrate,

K_ss: germination capacity of cress in the analysed substrate.

Weed germinative capacity is tested by preincubating 500mL of fresh material mixed with 2L of white peat at 4°C for 3 days. After that, it incubates at 21°C for 14 to 21 days with 100% relative humidity under natural light. A 5-seeds cress line is sown over the width of the tray to ensure that mixing was properly made. The germination of these control seeds validates the results of the tests. Indeed, if cress germinates, the absence of weed seeds germination is not due to any phytotoxicity of the compost (protocol S-IV-2V1).

3.3.3 Microbiology

In the current study, several µorganisms have been chosen due their interest as indicators or pathogenic nature and presence in several regulations. As human excreta is not included in official regulations, the choice made was based on several of them. Table 2 summarises the µorganisms studied, the interest sought and the standards referred to.

Thermotolerant coliform bacteria, E. coli, Enterococci and Clostridium are analysed as index µorganisms to assess treatment efficiency. Salmonella and Listeria are studied to evaluate the health risks.

4 Results

Foreword As results can not be considered representative, when referring to certain tendencies, one has to keep in mind that these trends are the sample's trends.

4.1 Qualitative results

These results are the answers collected from the 28 surveyed operators. Categories of answers can be inclusive or exclusive, i.e. operators can fit inside more than one or only one category[3]

4.1.1 Operator's profiles

Number and type of toilets The number of toilet is rather low, with either one (16), two (10), four or a variable number of toilet used (2). 14 users use both water toilet and dry toilet, 7 only have dry toilet and 7 did not mention it. Places and uses are variable : households with a daily use, one-off events, in fields, in rented lodge, and/or for outside activities. Some uses are combined.

Number of users The number of users can be classed between one to 6 regular users (19) or zero regular users (7), i.e. only punctual or seasonal use. Moreover, a seasonal increase in the number of users is to be reported for 19 users. Indeed, fifteen interviewees said that four to about 20 people used the toilets in summer time and on weekends. Four declared that about 100 to 150 users were to be counted especially for events, or activities organised in daytime. Otherwise, 7 say that the number is rather constant through the year. Two interviewees could not estimate the number of users.

4.1.2 Technical aspects

Inputs and cover material Six users completely separate or limit urine from contact with faeces and cover material. They either urinate directly on the compost pile or outside. 22 users mix faeces and urine. C-rich substrates used vary widely. 23 users recover wood or green waste and seven buy wood shavings used for animal bedding. A wide range of waste types is recycled ; 12 use carpentry or planer shavings, 10 use sawmill residues, 9 use waste from their own trees or woodwork. 27 use a source that varies through year, depending on what is available or have changed the main source they use. 23 do not know all the wood species they use. More than 13 wood species are known to be used.

Wood shavings, wood chips, shed, sawdust, chainsaw waste, pellets, twigs, wood turning wastes. Apart from wood, one user stated using flax straw as the main bedding material. Two mentioned employing leaves or straw if nothing else is available.

Co-composting Many different substrates are added to the mix faeces/urine + carbonaceous material by 15 of the users while 13 treat this mix aside. Materials added for co-composting include kitchen waste (9), green waste (15), other waste (9) such as potting soil remains, cow, horse, chicken or rabbit manure, paper, cardboard, carcass and farm waste.

[3]Example for co-composting : 28 people have been surveyed (n=28). Exclusive category of adding (15) or not (13) supplementary material to toilet material (=cover material+exceta) => sum of answers = n = 28. A contrario, inclusive categories of kitchen waste, green waste etc., i.e. type of co-composting material make the total of answers > 28, because operators can use several types of material.

Water inputs When water is used to rinse the bucket, 9 users pour it at the same place as excreta and cover material, while 14 do not. 5 could not answer. Three of these places are not exposed to rain, 19 are and 6 partly receive precipitations.

Transportation Collection receptacles are generally buckets. They are either emptied by foot (22) or using a wheelbarrow (2) at the treatment place or eventually emptied in larger containers and loaded on a trailer (3) to be carried there. In one case, a pit was dug as the collection receptacle. It is planned to be emptied using a shovel into a bucket before being carried on a wheelbarrow to the treatment site. Excreta management is mainly dealt on-site (26), rarely off-site (2). The distance between the toilet and the treatment place is less than about 30m (14), between about 30 and 60m (6), between about 60 and 100m (5). Off-site treatment occurs in a range of about 100m to a hundred kilometers. Two interviewees could not estimate the distance from the toilet to the pile, but it is likely to be smaller than 100m since it was on-site treatment.

Composting spot Compost process either occurs in a well defined and compartmentalized (14), in a pile without walls (9), on a large area of ground (3), in a hole (1), or is to be defined (1).

Faeces and urine management strategies Many patterns were revealed by the survey on how people manage faeces and urine. It appears that 5 users do not manage it sensus stricto. Indeed, they deposit the waste at a storage location and do not interfere with it anymore once it is done. They do not plan to use it. Some reasons evoked were a lack of time to take proper care of it, or a too great amount of material to handle and manage. Such big volumes were from horse manure, while humanure is negligible in that case. For another manager, it was not about recycling it, but about avoiding water to be contaminated then required to be treated.

Recovery pathways Practices are very different in terms of total duration, turnings, co-composting inputs, composting location,... Figure 7 illustrates all the different paths excreta can take from production to final use or disposal. Note that this is really specific to the sample and can not be generalised. Some other variations may certainly exist.

Process duration Duration between production of excreta and use can last under 9 months (2), 9 months to one year (3), one to two years (3), one to two years after the last adding of fresh material (8), or two years (5). Seven durations are technically "zero" because either continuous as a deposit practice, or direct application to land, and the decomposition process is expected to occur straight at the spreading place. A rather long period is generally privileged. In the case of shorter periods, a stated reduction of volume occurring in plant pots, where plantations, including plants for human consumption are grown on a layer of breeding ground on top of the layer of "humanure" .

Monitoring Most interviewees were not especially monitoring the process (24). Two said that they add C-rich materials such as straw or other ligneous materials as needed, based on visual and experience criteria. One said that piles were covered during heavy rains in the winter and to avoid evaporation. One said that piles were watered when judged too dry. None of them measure temperatures or conduct analyses on the product.

Excessive water management When asked what they do if the piles are too wet, 16 say that they would not add anything special, seven say that they never encounter this problem, three would add C-rich materials to the pile intuitively. Three mentioned problems of dryness rather then excessive moisture, one made a bedding of straw to absorb excess water as a bottom layer previous to stacking a new pile. One who directly spread fresh organic waste mixed with sawdust explained that he distributed it over a great surface of grassland so liquids would not be too concentrated at one spot.

Contact with the soil 24 compost sites were spread directly on bare ground, while 4 had at least a part of the process occurring on a waterproof surface. At one site, an IBC container was used as the processing tank, and it could be observed that the bottom was soaked in liquid. Two others mentioned that they had a slurry recovery tank preventing leaching. These two had a lot of organic waste to manage from their farms, and they mixed small humanure volumes into large amounts of cattle manure.

Timeline of system implementation Dry toilets systems were implemented since less than one year (4), 14 were between 2 and 6 years old, and 10 were eight or older.

Annual volume production estimation Annual volumes of fresh matter, i.e. unprocessed, produced are rather small, with a maximum volume of 10 m^3 a year (1). Eleven users have one or less cubic meter a year, and 17 two or less. Six users produce between 2 and 5 m^3 a year and three cannot tell.

Volume reduction 19 users could not tell about a volume reduction between the fresh versus the composted matter. Others noticed a diminution of >=50% to 66% (6), >=66 to 75% (2), or over 75%.

Reported problems When asked if they had any problem related to dry toilet use or management, 17 spontaneously answered that they had not, and that they are satisfied with the system. They mentioned the advantages and problems that they do not have. Eleven mentioned solutions or strategies they use to solve some problems they have encountered. Ten cited problems that they may have without explaining a solution they found. Ten of them mentioned a regular reluctance from family members or visitors, sometimes a refusal of use.

Encountered problems can be classified based on their type :

- Compost process : too wet, too low C:N, undegraded matter,...
- Logistics : e.g. big collectors too heavy when full, or too heavy when not enough cover material compared to urine
- Social acceptance : reluctance or refusal to use, avoided when possible,... It was mentioned by one third of the surveyed operators.

Product use The final product is used on food crops on vegetable garden (13), at the base of fruit trees (8), in grasslands (1), in lawn or flowerbeds (5), as basement layer in vegetable pots (3), around trees or hedges (7), on field crops (1) or is not used (5). A user mentioned that the end product was not used for sowing, not because of a fear of pathogens but because this product was insufficiently sterile in terms of seed germination.

End product characterisation Technically speaking, the end product is not always "compost", as defined as the product of aerobic biological degradation of organic matter with a thermophilic stage.

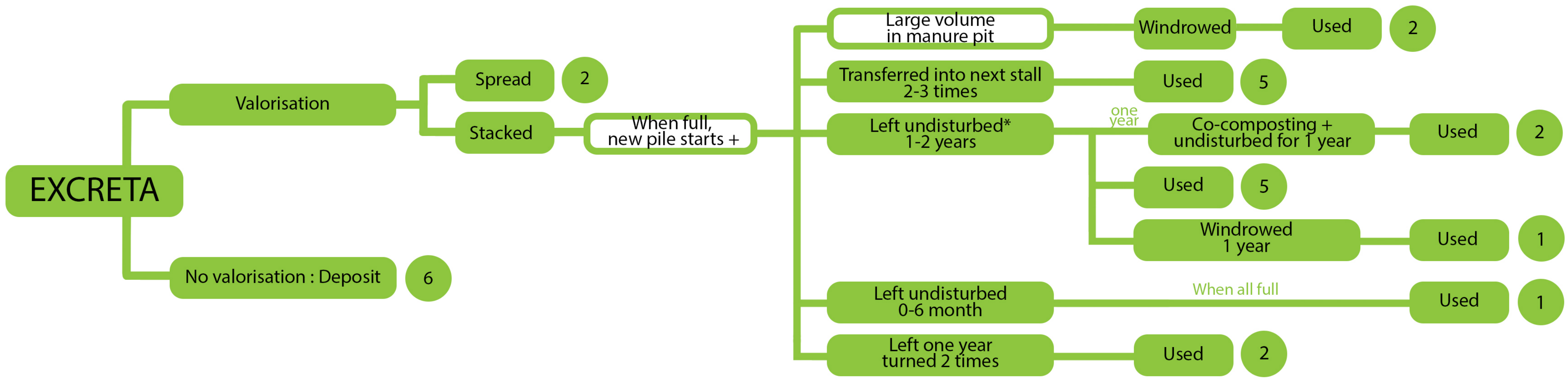

Figure 7 – Management practices diversity. Number into brackets give the number of operators having this practice. Excreta is either deposited without valorisation (6) or is aimed to be valorised. If so, it is either spread on the ground or at the bottom of trees (2), or stacked. When the stacking spot is full, a) in the case of large volumes mixed with cattle manure in manure pit, compost is placed into windrows either inside a hangar or on a field, then used 9 to one and a half year later (2). Or, b), the matter is moved into the next stack, being turned over. When the first stack is full again, matter is again moved from stack 2 to 3, and from stack 1 to 2, etc. It is then piled up in stack 4. When stack four is full, the compost is then used (5). Or, c), the matter is left undisturbed* for one to two years. *:possible turning by rodens. c1) Then after one year, material is co-composted and left undisturbed for one more year before use (2). c2) the matter is used. c3) the matter is windrowed for one year then used (1). Or, d) the matter is left undisturbed and new pile start, until every container aimed to "compost" is full. Once it is done, all the collected material (aged 0-6 months) is used in cultivation trays. (1). Or, d) the material is composted for one year with at least two turnings before use (2).

Spontaneous remarks Some users questioned the fate of drugs and hormones in compost (4). Some questioned the unknown medication of their guests, or wonder their fate in compost (4). Some guess that some medication should end up in the pile, and thus in the compost. Other(s) brought the fact that septik tank spreading was practiced decades ago, but that increased consumption of chemicals and medicines makes him wonder if using human excreta on soils is acceptable. A user asked what was the protocol to follow to ensure proper sanitation, limit risks, where and how apply it, what were the use applications or restrictions. A user explained that she stopped using her dry toilet compost in her garden as she used to because she does not know medication status of her guests and does not want drugs to end up in her vegetables garden. To deal with concerns or interrogations over medication fate, strategies of application use are implemented, such as avoiding application on food crops. Relatively long duration of treatment is another strategy used to diminish the risk associated with medication content. Some also invoke composting human excreta aside from cattle manure, to avoid contamination.

Reflections on water use Seven users spontaneously expressed reflections about water consumption. One said that water was becoming a scarce resource and that should not be used for toilets. "Dry toilets save tap water" ... ["You absolutely have to talk about this in your work".] Someone explained that they feel less guilty to have water toilets in their home as they are supplied with rain water and that they have an individual lagoon-based wastewater treatment plant. They add that fresh water can cover other uses than that (referring to water toilet use). This argument of a more relevant use was put forward by other users. Another interviewee said that it allows significant water savings but that he did it for ecological rather than economical reasons. He did not want to use water for faeces (management), and contaminate it (by doing so). Another user who installed BLTs in her garden because she gives workshops to groups and wanted to avoid dozens of people coming inside and using her bathroom said that now she no longer sees the point of using water toilets anymore. Another said he was angry that ["we build huge wastewater treatment plants to treat piss"]. He finds that fresh water should not be used for that. ["It (BLT) requires space and management, but it is worth it."] Ecological reasons were invoked by several operators.

4.2 Quantitative characterisation of raw feedstocks and compost samples

4.2.1 Aspect of the samples

KT0 and KT6 aspect Large and various pieces of matter, such as whole vegetables, illustrated a spatial heterogeneity in the compost pile, making it very complicated to take a representative composite sample. The fresher the matter, the more the heterogeneity was obvious. Figures 8 and 9 picture the texture of the KT0 and KT6 samples, respectively.

KT18 aspect KT18 was really woody and a drier than KT0 and KT6. According to the BLT operator, volume was smaller than at the beginning. Large wood pieces were still easy to distinguish in the pile (Figure 13).

KT30 aspect KT30 is a mix of one third of 30 months old compost and two third of potting soil. It is the finest particle size encountered. Material is very dark, rather homogeneous but still with larger pieces (Figure 14).

T6 aspect The compost pile can be accessed easily by removing the pallet delimiting the front wall. A irregular layered structure of co-composting and cover materials was easy to identify (Figure 10). Plus, vertical lines of the pallets show were the wood was in contact with the organic matter. Spatial heterogeneity was marked by recognizable elements such as peat moss, straw, grass clippings, wood shavings, forming distinct zones (Figure 15).

White mushrooms were observed at the upper surface of the pile. They regularly break the surface and grow at the top of the pile. They are picked then burried under fresh material again.

The sampling targeted the bottom layer which corresponds to the oldest material added (Figure 12). It presents a darker color, a relatively more homogeneous structure and a higher moisture content than the upper layers. Wood pieces were still very recognisable (Figure 11).

T8-Top and T8-Bottom aspects The upper part of the IBC container (Figure 16) presented a forest-like smell while returned and explored during the sampling of T8-Top. The second composite sample, T8-Bot, made out of compost from the bottom of the IBC, was soaked in liquid (Figure 17). Unpleasant ammonia smells escaped when the material was disturbed during the sampling. Material was rather homogeneous. The top of the pile was drier (Figure 18), then digging into it discovered moister organic matter (Figure 19). Wood pieces were clearly identifiable in the 8-month-old compost.

Figure 8 – KT0 sample : fresh (0-month old) kitchen waste and BLT material sampled from the top of the KT pile.

Figure 9 – KT6 sample : 6 months old kitchen waste and BLT material. Moisture content is higher than KT0.

Figure 10 – Side of T6 compost pile. Spatial heterogeneity is remarkable, plus a gradient of darkness from top to bottom. Vertical ligns show pallet contact with organic matter.

Figure 11 – KT6 : 6-month-old large wood pieces were not highly decomposed and were easily recognisable.

Figure 12 – Composite sample from the bottom darker and moister 6-month-old layer.

Figure 13 – KT18 C-rich material. The part of recalcitrant carbon must be high.

Figure 14 – KT30 samples where taken from 3 vegetable trays. KT30 has the finest particle size, even though it still presents larger particles that are recognisable, but they are diluted in the potting soil volume.

Figure 15 – T6 : Many different feedstocks form pockets of local heterogeneity. Darker, more decomposed matter layers are still distinguishable by variable textures and colours.

Figure 16 – T8 IBC composting container with watertight floor

Figure 17 – Outside view of the bottom (T8-Bot) soaked in liquid due to waterproof floor, at the level of the metal bar. Upper part (T8-Top is moist but not soggy.

Figure 18 – T8 Pile before sampling : Surface is relatively dry compared to the center of the pile. Wood piece are still obvious to identify.

Figure 19 – T8 composite sampling using a shovel

Table 20 presents the values for physico-chemical and agronomic parameters studied on the samples. Table 21 summarises the stability and maturity tests results. Table 22 depicts the microbiological analyses results carried out on the samples.

Parameter	Unit	KT0	KT6	T6	KT18	T8-Top	T8-Bot	KT30
pH (water)	-	7.9	6.7	7.4	6.2	6.9	**8.7**	7
Dry matter	(%) (FM)	27.26	30.33	**24.88**	52.54	33.33	**21.22**	65.43
Water content (WC)	(%) (FM)	**72.74**	69.67	75.12	47.46	66.67	78.78	34.57
Organic matter (OM)	(%) (FM)		**15.61**	20.06	**18.3**	31.79	20.14	-
			22.40562653					
Total nitrogen (TN)	(%) (FM)	0.381	0.357	0.71	0.674	0.396	0.306	0.476
Nitric nitrogen (NO3-)	(mg N/kg) (FM)	10	63	<10	44	102	46	37
	(mg N/kg) (DM)	37	208	40	84	306	217	57
	(mg NO3-/kg) (DM)	162	920	178	371	1355	960	250
Ammoniacal nitrogen (NH4+)	(mg N/kg) (FM)	116	<10	203	<10	206	220	<10
	(mg N/kg) (DM)	426	33.0	816	19.03	618.1	1037	15.3
	(mg NH4/kg) (DM)	523	40.5	1002	23.37	759.0	1273	18.8
NO3-/NH4+ ratio	-	0.0833	0.006	-	4	0.476	0.227	0.004
NH4:NO3 ratio	-	**3.22**	0.04	**5.63**	0.06	0.56	1.33	0.07
Phosphorous (P)	(% P2O5)*	-	0.308	0.462	0.319	0.376	0.208	-
Potassium (K)	(% K2O)*	-	0.358	0.489	0.207	0.199	0.189	-
Magnesium (Mg)	(%MgO)*	-	0.227	0.219	0.261	0.1	0.071	-
Total Calcium (Ca)	(%CaO)*	-	0.675	0.531	0.754	0.406	0.19	-
Electrical conductivity (EC)	(µS.cm-1 at 20°C)	723	812	917	159	559	547	499
Carbon	(% DM)	48.9	25.19	37.65	19.02	47.82	49.01	11.38
C/N	-	36.2	21.9	15.2	15.2	42.3	35.7	15.8
Density	g/100 ml	-	44.95	32.5	21.52	14.45	24.85	-

Figure 20 – Physico-chemical and agronomic parameters of the samples

Self-heating test	Unit	KT0	KT6	T6	KT18	T8-Top	T8-Bot	KT30
H2O	H2O%DM	-	217.6	283.1	90.3	176.8	608.5	-
Water holding capacity	H2O%DM	-	240.2	714	196.6	384.5	372.2	-
Rehydration		-	no	yes	yes	yes	no	-
Maximum temperature	°C	-	28.6	24.7	24.4	25.2	31.7	-
Time	days	-	14	6	6	10	10	-
Stability class		-	5	5	5	5	4	-
Oxitop Respirometry(R)	**Unit**	**KT0**	**KT6**	**T6**	**KT18**	**T8-Top**	**T8-Bot**	**KT30**
Respiration	mmol O2.kg.MV-1.h-1	-	9.5	6.6	4.1	3.2	5.1	-
Class	-		4	4	5	5	4	-
Phytotoxicity - weed germination capacity	**Unit**	**KT0**	**KT6**	**T6**	**KT18**	**T8-Top**	**T8-Bot**	**KT30**
Mean seedlings ratio after 4 days (Pt4)	%	-	77	74	95	85	0	-
Reference Pt4	%	-	90	89	89	86	86	-
Mean seedlings ratio after 4 days (Pt10)	%	-	84	93	98	89	7	-
Reference Pt10	%	-	97	96	96	93	93	-
Phytotoxicity		-	13	3	<1	4	92***	-
Germination capacity of weeds	seeds/500 ml	-	1	2	18	0	0	-

Figure 21 – Stability and maturity tests results

Microbiology	Unit	KT0	KT6	T6	KT18	T8-Top	T8-Bot	KT30
Thermotolerant coliforms (TC)	CFU/g	2,4.10^6	3,8.10^4	2,4.10^4	150	10	<10	360
Escherichia coli (E. coli)	CFU/g	**2,4.10^6**	**2,1.10^4**	230	50	<10	<10	<10
Enterococci (E)	CFU/g	**4,4.10^4**	**1,6.10^5**	**5,0.10^4**	1,1.10^3	330	200	4,0.10^4
Clostridium perfringens (WW uniquement)	CFU/g	400(1)	<100(1)	<100(1)	200(1)	<1000(1)	**3,0.10^4**	1,8.10^3
Salmonella sp.	A or P/25g	A	A	A	A	A	A	A
Listeria monocytogenes (WW uniquement)	A or P/25g	A	A	A	A	A	A	A

* in % of fresh mass

** Pt10 of the sample compared to the Pt10 of the reference.

*** highly significant difference

Figure 22 – Microbiological characterisation of the samples

4.3 Quantitative analyses

4.3.1 Physico-chemical and agronomic parameters

pH (unitless) KT18, KT6 and T8-Top are under neutral with values of 6.2, 6.7 and 6.9. KT30 is at 7, T6 is at 7.4, KT0 at 7.9. T8-Bot has the highest value of 8.7.

Water content (WC, %) Water content ranges from 34.6 to 78.9%. KT30 presents the lowest value and T8-Bot the highest. KT18 is at 47.5%, while KT0 and KT6 are around 70%. T8-Top is 66.7, T6 is 75.1.

Organic matter content (OM, %) (fresh mass (FM)) OM contents range around 15.6 to 20.1 % for KT6, KT18, T6 and T8-Bot. Only T8-Top is about twice as big as the smallest value (KT6) with 31.8%.

Total nitrogen (% FM) Values vary between 0.31 to 0.71, with T8-Bottom being the lowest, (highest ammonia losses), and the T6 the highest. T8-Bot, KT6, KT0 and T8-Top have similar total N content with 0.31, 0.36, 0.38, 0.40 %, respectively. KT30 is next with 0.48%, then KT18 (0.67), and finally T6 (0.71%).

Nitric nitrogen NO_3^- (mg N/kg) (FM) T6 being < 10, presents the lowest value. Then KT0 is 10, KT30 is 37, KT18 is 44 and T8-Bot is 46, KT6 is 63. T8-Top presents a value of 102, higher than ten times the smallest.

Ammonical nitrogen NH_4^+ (mg N/kg) (FM) KT6, KT18 and KT30 are below 10. KT0 is 116, and T6, T8-Top and T8-Bot range about the same values of 203, 206 and 220. With values under 75, KT6, KT18, KT30 are considered very mature. KT0, T6 and both T8 samples are classified mature.

NO_3^-:NH_4^+ (-)(FM) Ratios range from 0.004 (KT30) to 4 (KT18). KT6 (0.006), KT0 (0.083) T8-Bot (0.227), T8-Top (0.476), range in between. T6 could not be determined. According to the criteria of NO_3^-:NH_4^+ $>$ 1 for mature composts, only KT18 can be considered mature.

NH_4^+:NO_3^- (DM) KT0 value of 3.2 and T6 value of 5.6 classify them as immature. T8-Top and T8-Bot are mature while KT6, KT18 and KT30 are very mature.

Phosphorous (P) ranges from 0.208 to 0.462% P_2O_5)(FM).

Potassium (K) ranges from 0.189 to 0.489 % K_2O)(FM).

Magnesium (Mg) ranges from 0.071 to 0.261 % MgO (FM).

Total Calcium (Ca) ranges from 0.19 to 0.754 % CaO)(FM).

Electrical conductivity (EC) ranges from 159 to 917 (ţS.cm^{-}1).

Organic Carbon (% DM) varies from 11.4 to 48.9%.

C:N (-) ranges from 15.2 to 48.9.

Bulk volumic mass ranges from 145 to 450 kg/m^3.

4.3.2 Stability and maturity indicators

Self-heating test categorised KT6, T6, KT18, T8-Top into class 5, i.e. very stable. T8-Bot was class 4, i.e. rather stable.

Oxitop Respirometry test classed KT6, T6 and T8-Bot as "stable with limited activity" (class 4) and KT18 and T8-Top as "very stable" (class 5).

Phytotoxicity (%) Phytotoxicity tests showed no significant relative difference between control and KT6, T6, KT18 and T8-Top, with corresponding germination rates between 84 and 98%. A contrario, with an absolute value of 7% germination, T8-Bot is the only to presents a very highly significant difference of 92% with control ($alpha$<0.001).

Weed germination capacity (Seeds number/500ml) shows the absence of germinated seeds for T8-Top and T8-Bot. KT6 and T6 have one and two seeds. KT18 has a high number of weed contamination with 18 germinated seeds/500ml.

4.3.3 Microbiology

Thermotolerant coliforms (TtC - Colony Forming Units/gram : CFU/g KT0, KT6 and T6 present values over $2.4.10^4$ and up to $2.4.10^6$. KT18, T8-Top, T8-Bot and KT30 have low values from under 10 to 360.

Escherichia coli (E. coli - CFU/g KT0 and KT6 show high values of E. coli, $2{,}4.10^6$ and $2{,}1.10^4$ respectively. T6 is 230, KT18 is 50. Finally, T8-Top, T8-Bot and KT30 are all < 10. KT0 and KT6 do not pass the standard for E. coli (EU No 142/2011). Indeed, their value is over 5000, which is eliminatory.

Enterococci (Ent. - CFU/g) KT0, KT6, T6, KT18 and KT30 fail the test for Ent. with values ranging from $1{,}1.10^3$ to $1{,}6.10^5$. Except for KT18, all of the failing samples exceed the eliminatory value of 5.10^3. T8-Top and T8-Bot are below the 10^3 standard for Ent.

Clostridium perfringens (C. perfringens - CFU/g) Low counts from <100 to <1000 for KT0, KT6, T6, KT18 and T8-Top are of poor accuracy. T8-Bot values and KT30 are $3{,}0.10^4$, and $1{,}8.10^3$. T8-Bot and KT30 are both under the 10^5 standard of the NF U 44-095.

Salmonella (Slm.) and Listeria monocytogenes (L. mono) - A/25g) All of the studied samples contained neither Salmonella nor Listeria in 25 grams.

5 Discussion

5.1 Qualitative results

Preliminary remarks Qualitative results analysis from snowball sampling method provides information which is not representative and can thus not be generalised or statistically treated. However, it allows a better understanding in qualitative and exploratory research. This analysis is neither exhaustive nor representative of practices in Belgium. Yet it gives a first idea of practices as no similar studies treating the technical aspects have been conducted yet. Moreover, this preliminary description allows to bring reflections over these practices.

5.1.1 Various profiles

The qualitative survey highlighted that user's and operator's profiles were extremely variable in use, frequency of use, number of users,... A trend exists concerning an increase of use in the summer, common in farms and locations where seasonal workers and guests come. Some common points can still be made. All users have some outside space to manage it. Volumes are very small, maximum a few cubic meters. When co-composted with animal manure, the volumes of "human manure" are really negligible in comparison. Most people manage dry toilets as a choice; it is a voluntary action.

5.1.2 Fate of excreta

Since urine and faeces are both a resource and a health hazard, the hypothesis was made that "Bio Litter Toilet operators practice compost to sanitize the excreta and urine for recovery purposes."

The survey results actually show that this hypothesis may be true for some users, but that practices vary so widely that this hypothesis is clearly not the main path. Divergence from that are the following :

- No everyone considers excreta and/or urine as a resource. Some simply dispose of it. In such case, the BLT system is simply a dry toilet, as the Litter is not "Biologically controlled".
- Moreover, when managed for recovery, not everyone sanitize it. Fresh fecal matter is sometimes used directly on the ground, in pastures or at the foot of trees.
- It was assumed that faeces and urine where both composted together, urine increasing the moisture and nitrogen contents. However, some operators limit urine content in the collector as much as possible.
- Not everyone practice aerobic thermophilic composting for faeces and urine before recovery. Indeed, some really short periods of time to no time at all is sometimes left before reuse as culture substrate.

5.1.3 Inputs

As previously said, practices are really different from one operator to another. What participate in this variations is the nature of cover material, that can change through the year. None of the operator had trouble getting C-rich litter for their dry toilet in Belgium. Resource is available, especially by-products that are recyclable from sawmill or other wood work. Buying animal litter wood shavings is another option.

5.2 Motivations of TLB use

Dry toilet use is not especially common. This is even more true as Belgian Regulation requires houses to be connected to the sewer or a sewage system so as not to be considered unsanitary. People that make the choice to have dry toilets have a personal will and commitment, as they think that it is preferable option to water toilets.

Water considerations Many interviewees spontaneously mentioned water consumption and contamination and ecological reasons when talking about dry toilets. Arguments in favour of dry toilets include the waste it represents. Water was for example considered to have to be used for more important uses than carriage of human excreta. Some mentioned the waste of energy and water they think it is to build huge centralised wastewater treatment plants because water has been polluted by human excreta. Water is thought to be not used for this purpose from the start. Remarks were made citing the context as an example as some interviews occurred during the heat wave of the 2020 summer. Why water should especially not be used for toilets was underlined as vegetation was experiencing drought.

Generic and personal unknowns Interviewees also rose concerns regarding the fate of drugs or contraception pills that either are known to be taken by users or are questioned to be taken. Several studies were able to demonstrate pharmaceuticals in urine and faeces. However, effect of composting on these molecules is barely known. Further research could provide better information.

5.3 Issues management

Several categories of problems were identified by the operators.

Compost process and logistics are rather technical criteria that are easy to solve. Reducing the weight of collectors by more frequent emptying, adding more cover material, turn piles, temperature measurement, ... Basically, composting is a very well known process and improving compost quality can be performed by best practices application. Social acceptance is harder to address as this is subjective. Moreover, it is interesting to note that the reluctance is only for users. These reticent actors do not have to manage it, simply the fact of using dry toilet seems problematic to them.

Social acceptance is one of the main barrier for the development of the practice. However, inadequate practices can also be a risk and so, a barrier as well.

Composting quality and risk management As these systems are very different from one to another, it is hard to assess compost quality or risks linked to the practice in general. To do so, case study scale should be considered. Applying composting best practices should increase the probability of producing a good quality compost. For example, some operators reported weed seeds germination in their garden after use of compost. Best practices and monitoring of temperature could help avoid that kind of problem.

5.3.1 Factors influencing management practices

Figure 23 is an analysis proposed based on the gathered data from the surveys. This grid of factors influencing the practices does not only consider really technical aspects and parameters, but also to have a more systemic view by integrating psychological identified factors influencing the practices and external factors such as legislative framework, hardware available for the operator, empirical trial and error method making the reflections over the practice to evolve. Here is the gap : although knowledge about composting is well established, best practices are known and widely studied, and the method is low cost and simple to implement, these are not sufficient pros or drivers for the practice to spread. This is why this is really important to not only understand the technical aspects, but also include sociological or legal aspects.

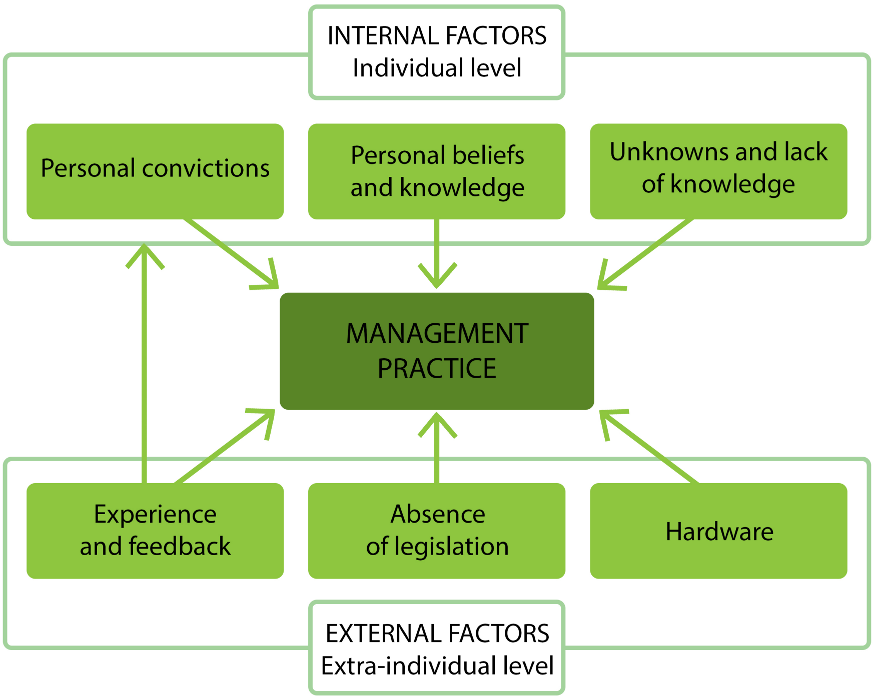

Figure 23 – Factors influencing the practices of management of BLTs. Individual factors are related to a) convictions, b) knowledge or beliefs, the difference depending on the scientifically admitted accuracy of a piece of information. c) unknowns are generic, i.e. no data is available, while lack of knowledge is available information that are not known by the operator. External factors depend on the frame, e.g. legislation and hardware, but also from data gather from others (feedbacks) and from experience due to practicing.

Another illustration is that some practices are based on the belief of what is thought to be adequate, but lack of knowledge regarding the composting process makes these practices unfavourable to plant growth and constitutes a higher health risk. The fact that observation of volume reduction in cultivated pots could be done to the naked eye by an interviewee encourages to think that decomposition is still happening. It would then be more desirable to avoid using such an immature compost as a substrate since it is likely that it has a high phytotoxicity. Knowledge is availalble regarding composting best practices. A interesting question is "how to transfer it to operators ? How to make accessible and understood ?"

Volumes Volume estimations are very tricky because quantitative data collected was made based on operator's estimation. They are neither accurate nor This can only provide orders of magnitude. Produced volumes are very small, a few cubic meters at most. Furthermore, as cover material and co-composting feedstocks vary widely in structure and input quantities, as well as number of users and frequency of use, it is impossible to accurately estimate a precise volume mean production per person per year. Yet this practice is still really negligible compared to sewage sludge fluxes. In 2013, around 183.10^3 tons of dry matter are estimated to have been spread in agricultural land [SWE and Sol Environnement Wallonie,].

5.4 Raw and processed inputs characterisation

5.4.1 KT0

Microbiological analyses KT0 has high TtC, E. coli and Enterococci contents, which was expected since all three are treatment indicators. No reduction has occured yet on this fresh matter.

KT0 process Comparison between theoretical ideal initial parameters and measured values can help predict if the composting process will occur successfully. %73WC is very high. If porosity is filled with water, it may cause anaerobic conditions and prevent heating. Plus GHG and N losses are of bigger importance in the case of anaerobic metabolism. C:N ratio and pH are acceptable. Information over volumic mass would have helped evaluating oxygen availabilty. Low NO_3^- compared to NH_4^+ in KT0 corresponds to an expected trend, as initial N in manure mainly comes from organic and NH_4^+ pools and form nitrates through composting.

KT0 management Monitoring temperature over time is a simple measurement that could improve the composting process, namely by indicating when it would be relevant to turn over the pile. these values are approximate, since they are necessarily not representative due to the very high spatial heterogeneity

5.4.2 KT6

Maturity and stability KT6 shows low phytotoxicity, and few microbial activity through the self heating and respirometry tests. It seems that easily degradable matter has been used up. If hypothesis that KT6 parameters were in the same order of magnitude as KT0 at the beginning of composting, C_org was divided by 2, and C:N also clearly decreased, which comfort SH and R tests. Like those indicators, few weed seeds also pleads for KT6's maturity. NO_3^-:NH_4^+ and conversely show opposite results, only NH_4^+: NO_3^- suggesting maturity.

Composting process However, high levels of E. coli, Enterococci and TtC clearly suggest that thermophilic phase might have not been reached everywhere in the pile. This is a hypothesis consolidated with the high water content. Anaerobic conditions are more likely to happen in that case, and this could have prevented the pile to heat up. Moreover, C:N is still high for "cured" compost. Too big C to N slows the process and can also be linked with an absent thermophilic stage, as microbial activity is not sufficient to raise the pile's temperature. However, wood as cover material is pretty rich in lignin which is a recalcitrant form of C. This would explain the C:N value higher than 15, the available C:N ratio may be lower. Making the hypothesis that N fractions of KT6 were similar to KT0 when it was itself fresh, a decrease in NH_4^+ and an increase in NO_3^- seem normal N conversions.

Agronomic parameters Small volumes and no wind blocks on side plus continuously-fed pile such as the KT0-KT6 may struggle to reach hot temperature, as border effect is constantly displaced. This is something that could be observed with dried out material such as toilet paper along side the wire mesh.

Heterogeneity may have impacted the composting process due to big particle size (e.g. big pieces of cabbage), and different heat transfer properties. Big size particles can not be decomposed in the center, as microorganisms live on the biofilm at the surface of organic matter.

5.4.3 T6

Composting process Very high water content, low density and high TtC and Enterococci lead to think that thermophlic phase did not occur either. Indeed, compaction can occur at pile's bottom, and this phenomenon is emphasised at higher moisture contents.

Maturity and stability $NH_4+:NO_3^-$ can be used when C:N is below 15 to indicate maturity. Considering the C:N at 15.2, this indicator suggests immaturity. However low NO_3^- content makes this ratio not very accurate. NH4:NO3 ratio indicates immaturity, but SF and R tests suggest the opposite along with Pt and WG that foresee low risks for plants too.

Agronomic parameters pH suits for land application. MO

Low nitrates suggests that either nitrification has not occurred (yet?), or leaching have happened. NH_4^+ can have been rather high from the start or due to mineralization of organic N.

5.4.4 KT18

Composting process Pathogens are low in KT18 except for Enterococci, which exceed the EU standard by 10%. In the similar case of no thermophilic phase having occurred in small volume of kitchen waste and TLB material, time could be a parameter that played a role in pathogen elimination. It is impossible to establish if thermophilic raise occurred, though.

NO3/NH4 >1 show logical trends in nitrates enrichment and NH4 diminishing for cured compost. This indicator is finally in adequation with the rest. C:N $<$ 15 makes it usable. Indeed, it is a requirement to be able to.

Maturity and stability KT18 have the highest stability class in both self-heating test and respirometry. It also has a low phytotoxicity. However, it has a important weed seeds contamination. Either composting occurred at high temperature and weed contamination happened after one year, when green wastes were mixed with the one year old material. Then thermophilic temperatures did not occur during the last 6 months, and seeds brought can still germinate. The second hypothesis might be more likely, since KT6 is not so weed-seeds-rich and that it can not simply be attributed to phytotoxicity. Plus, regarding the initial feedstocks, the only difference is linked to the cover material, which is eucalyptus bark for KT18. Low weed seeds in KT6 might be due to the presence of few weed seeds from the start. KT18 is the one with high weed contamination, and also the only one mixed with other material after one year.

KT18's 47% WC, i.e. lower than KT6 or KT0 might be explained by properties of the cover material. Indeed, the owner explained that eucalyptus barks were not satisfactory in terms of moisture absorption. Moreover, as evaporation occurs during composting, water content might have been higher at the beginning of the process.

Recommendations Avoiding mixing green waste residues to cold cured compost could prevent recontamination of weed seeds.

5.4.5 T8-Top

Composting process Low TtC, low E. coli and low Enterococci suggest low risk for health hazard, and suggest that thermophilic phase occurred. This is reinforced by the field observation. Indeed, the IBC container walls might have diminished wind effects causing both cooling down and drying. Moreover, it is probable that it provided a better thermal insulation as well and diminished heat losses. WC is at the upper limit of reasonable range. Plus, field observation showed a rather homogeneous woody media, which suggest a well distributed and sufficient porosity.

Maturity and stability Respirometry, self-heating and phytotoxicity tests suggest stability and maturity. No weed seeds germinated, but this was very likely due to the absence of weed seeds in the feedstocks. Thus this indicator is not relevant for maturity in this case.

Agronomic parameters T8-Top is very rich in Carbon and C/N is over 42. This is in adequation with field observations that stated a very wood-rich substrate. Heating phase could have occurred with sufficient available C. The final high C:N could be explainable by the recalcitrance of remaining C. Its low biodegradability is confirmed by self-heating test : readily available C has been burnt up.

Rather high NH_4^+ suggests that this fraction could be further converted into nitrates and thus that composting could keep going. However, maturity having been reached, This NH_4^+ is the final value, giving a ammonium ion-rich compost.

5.4.6 T8-Bot

Composting process As the sample was soaked into liquid, which is confirmed by the almost 80% WC, and the H_2O content exceeding the water holding capacity, both computed for the Self-Heating test. It shows that macroporosity was filled with water.

In such case, it is extremely likely that anaerobic conditions have prevailed, causing no temperature rise, N loss and GHG such as CH_4.

Comparison between T8-Top and T8-Bottom is interesting because initial conditions were identical except for the water immersion. It caused difference in water content, obviously, and in oxygen availabilty. With similar C_org contents, C:N ratio is lower for T8-Bot. Total N is 25% lower, nitrates are 50% lower, and ammonium is about the same. High pH confirms the hypothesis of N loss. pH higher than 8.5 encourages conversion of N compounds to ammonia, which further adds to the alkalinity. Unpleasant smells at sampling also confirm the anaerobic conditions, leading to odourous molecules release. P and Ca also are in a smaller order of magnitude than T8-Top.

Anaerobic decomposition also caused very high phytotoxicity. It seems that indicator organisms for aerobic composting did not survive in such anaerobic and alkaline conditions. Yet stability and respirometry tests show a little µbial activity.

This product should not be used on soil, as it would kill plants. A possible way to handle the excessive moisture would be to evacuate the liquid in a slurry pit, then increase porosity, by adding bulking agent and mixing to homogenize moisture. A supplementary action could be to put it as a layer on a waterproof surface and allow it to dry a bit. Easy rules of thumb exist to quickly estimate water content. Measuring temperatures after piling up the parameter-adjusted feedstocks could monitor its rise and decrease, giving indication of the degradatation process timeline. Nonetheless, if the new volume is to small to permit proper composting, due to poor heat retaining quality, another option would be to dilute this small volume in a great amount of animal manure, for example. This way high moisture and phytotoxicity would become negligible in this larger mass.

5.4.7 KT30

KT30 sample was taken from a cultivation tray. Neither TtC nor E. coli are of concern. Though, Enterococci and C. perfringens are present. As tomatoes and basil are grown in the tray, risk management strategy consists of hand-washing after gardening, before cooking, and vegetable careful washing. Heating or cooking them would add a supplementary protection.

KT18, T8-Top, T8-Bot and KT30 have very low TtC concentrations, which are correlated with a reduction in E. coli, still this does not work for T6 which high TtC value would mean that E. coli values are also high, giving a false positive result by overestimating E. coli presence. This is something already shown in the literature.

Five representative samples should have been tested but the very small volumes prospected made it impossible. Thus the five required repetitions were not made. This weakens the possibility of interpretations, except for values over the upper tolerance, which are "directly" discarded. However, as samples were hard to be representative under such heterogeneous materials, conclusions have to be considered carefully.

5.4.8 C. perfringens

KT0, KT6, KT18 and T8-Top C. perfringens concentrations are chosen not to be commented due to their poor accuracy. T8-Bot and KT30 values below standards plus the absence of testing for this parameter under other standards suggest that C. perfringens is of little concern in the tested samples.

5.4.9 Pathogenic agents

Salmonella and Listeria monocytogenes No concern is to be raised about neither Salmonella nor L. monocytogenes as none of them could be detected in any of the samples. Salmonella contamination mainly occurs through cross contamination from animals or foodstuffs while Listeria is present in plant matter and soil as well. Salmonella and Listeria are usually not present in healthy humans. Thus composting healthy human faeces should not be a cause of Salmonella nor Listeria infections. However, contamination from human to human can happen from ill individuals [AFSCA, 2015]. This is due to the fact that pathogens concentrations in faeces are correlated with infection prevalence in a population.

Recommendations about KT6 handling and use would be to wait longer in order to increase pathogens die-off. Other measure such as avoiding its use for crops that can be eaten raw, proper vegetable cleaning and hand washing after gardening are effective barriers to avoid contamination.

If KT18 is used in the garden as well, same measures apply.

Time is interesting to observe. Indeed, it seems that a 6-month treatment is not sufficient in the case of degradation of organic matter with no thermophilic phase to fullfill the standards regarding pathogens. However, it seems that 18 to 30 months had an importance in reducing E.

coli. However, both still have high Enterococci concentrations respectively slighly and largely over the EU standard.

Maturity and stability interpretations Considering that maturity tests gave results of "stablilty" for several samples, the very high associated C:N could either suggest

- Or that "compost" is/are indeed mature and that C:N is made of much recalcitrant carbon,
- Or that compost is stable but not mature, as few microbial activity has been recorded, but that there is still available carbon not mobilised because of N limitation.

Co-composting the products with N-rich material and monitoring of temperature variation could answer that question. The second option seems intuitively likely.

Limitations of the interpretations These conclusions have to be considered carefully because of the limited representativity of the samples. Indeed, small volumes did not allow to make repetitions, even if composite samples have been made from matter of approximately the same age. Moreover, the homogeneity of the composite samples was hard to respect due to the great intrinsic heterogeneity of the products themselves. The microbiological analyses could be performed again to see if the trends observed here happen again. If so, the time criterion is interesting to consider before valorisation.

6 Conclusions

6.1 Conclusions

6.1.1 Dry toilet management in Belgium

BLTs management practices in Belgium vary widely. The hypothesis made that "Bio Litter Toilet operators practice compost to sanitize the excreta and urine for recovery purposes." might be accurate for some operators but is not so common. Here are the main alternative patterns:

- Disposal of excreta and urine
- Direct use of raw fresh matter for recovery
- separation of faeces and urine for treatment or disposal
- Inadequate conditions were sometimes spotted by operators or based on their practices description.

Operators chose to use TLBs on a voluntary base. Personal convictions regarding toilet water pollution, water waste and use, and ecological reasons were reasons invoked spontaneously by the interviewees. Personal beliefs and knowledge and personal lack of knowledge and unknowns also had an impact on TLBs management practices, as individual factors. Extra-individual factors such as hardware, the absence of legislation, experience and feedbacks also influence the management. Questioning over drugs and hormones fate in compost were regular and spontaneous. Further research of the fate of medication degradation through composting should be investigated.

One of the barriers to the development of the practice is related to inadequate composting practices, sometimes due to a lack of knowledge or to personal belief. However, logistics or practice issues are easy to solve by using composting best practices. Absence of legislation may contribute to empirical and diverse management strategies. Another barrier, which is more complicated to handle, is the social reluctance. Indeed, faeces and urine are taboo despite fulfilling a vital and daily need.

Second objective showed that thermophilic phase has probably not occurred in several sampled composts, probably due to inadequate initial conditions, heterogeneity of the matrix and small volumes. Too high moisture contents are suspected to have limited the self-heating of the pile, while very high C:N ratios suggest a N limitation, which could cause a slow degradation. This hypothesis is supported by Enterococci concentration results.

6.1.2 Management practices recommendations

Process control is certainly a huge challenge in BLTs development. Wide variety of management practices, cover material, composting time, makes it really complicated to compare "composts" obtained, and assess the success of sanitation.

As shown by the qualitative data, the type and bulk density and characteristics of C-rich materials varies so widely that it is impossible to suggest a single recipe.

Solutions for process control and best practices are well known, but the gap is located between the theoretical best practices and the real-case management practices. Documentation like a clear user guide with best practices and risk management strategies is missing, even if some books exist on the topic.

Composting best practices Based on the results of both quantitative and qualitative data, the implementation of several simple recommendations could significantly improve process and process control, at least for the surveyed and sampled operators of this study.

Temperature Simple monitoring such as temperature measurements could provide information on the efficiency of sanitation. Material turning in active phase every time there is a significant temperature drop will help homogenize and increase the likelihood of thermophilic temperatures reached for every material in the pile.

Co-composting of toilet material associated with kitchen waste, animal manure or other N-rich substrate will diminish the C:N ratio, increasing the probability that N is not limiting. Furthermore, it will increase the volumes, which are often small. Bigger volumes will improve the heating insulation and help keep piles reach and maintain thermophlic temperature. Mixing humanure in the heart of big manure piles seems a good practice, as high temperatures may increase the probability to inactivate pathogens.

Composting duration should keep going if a reduction of volume is still perceptible. It shows immaturity and it can have phytotoxic effects on plants.

Health hazard risk management In addition to compost best practices application, especially ensuring thermophilic conditions, risks can be lowered by combining it with hygiene measures; hand-washing after handling, gardening, before cooking, vegetables washing and cooking, and compost application far from the harvest, not on edible plants that grow in or on the the soil, etc...

6.1.3 Unknowns

Concerns were risen about the fate of human hormones and drugs during composting. While faeces and urine are known to contain drugs residues after absorption, few information are available regarding their fate if submitted to composting process. Further research is needed regarding this concern.

6.2 SWOT analysis

The SWOT analysis overviews the current situation, its challenges and opportunities for BLTs in Belgium.

Strengths:

- low cost low tech sanitation system
- resource recovery
- cover material available

Weaknesses:

- requires knowledge
- household development requires commitment
- gap between theory and practice
- change of habits needed
- wide variety of practices : hard to standardize a recipe

Opportunities:

- composting is a well-known process
- applicable wherever there is a garden or outside space

Threats:

- lack of social acceptance
- no legislation
- not recommended - no awareness
- taboo
- unknowns : especially fate of drugs and hormones

References

[AFSCA, 2015] AFSCA (2015). Report on Zoonotic Agents in Belgium - trends and sources 2012-2103. Technical report.

[Agence Fédérale la pour la Sécurité de la Chaîne Alimentaire, 2020] Agence Fédérale la pour la Sécurité de la Chaîne Alimentaire (2020). RAPPORT D ' ACTIVITÉS 2019 Contaminants microbiologiques. Technical report.

[Al-Ghazali and Al-Azawi, 1990] Al-Ghazali, M. R. and Al-Azawi, S. K. (1990). Listeria monocytogenes contamination of crops grown on soil treated with sewage sludge cake. *Journal of Applied Bacteriology*, 69(5):642–647.

[Bai and Wang, 2011] Bai, F. and Wang, X. (2011). Study on dynamics model of biodegration property of organic matter in aerobic thermophilic composting reactor for sanitary disposal of human feces. *Advanced Materials Research*, 281:291–295.

[Beck-Friis et al., 2003] Beck-Friis, B., Smårs, S., Jönsson, H., Eklind, Y., and Kirchmann, H. (2003). Composting of source-separated household organics at different oxygen levels: Gaining an understanding of the emission dynamics. *Compost Science and Utilization*, 11(1):41–50.

[Bender and Bender, 1997] Bender, D. A. and Bender, A. E. (1997). *Nutrition : a reference handbook*. Oxford University Press, Oxford ; New York, [1st ed.]. edition.

[Bernal et al., 2009] Bernal, M. P., Alburquerque, J. A., and Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment. A review. *Bioresource Technology*, 100(22):5444–5453.

[Bernal et al., 1997] Bernal, M. P., Paredes, C., Sánchez-Monedero, M. A., and Cegarra, J. (1997). Maturity and stability parameters of composts prepared with a wide range of organic wastes. *Bioresource Technology*, 63(1):91–99.

[Beuchat, 1996] Beuchat, L. R. (1996). Listeria monocytogenes: Incidence on vegetables. *Food Control*, 7(4-5):223–228.

[Brinton et al., 2009] Brinton, W. F., Storms, P., and Blewett, T. C. (2009). Occurrence and levels of fecal indicators and pathogenic bacteria in market-ready recycled organic matter composts. *Journal of Food Protection*, 72(2):332–339.

[Calloway and Margen, 1971] Calloway, D. H. and Margen, S. (1971). Variation in endogenous nitrogen excretion and dietary nitrogen utilization as determinants of human protein requirement. *The Journal of nutrition*, 101(2):205–216.

[Chamel, 2017] Chamel, J. (2017). « On est tous des composts » Discours et pratiques écologistes autour des déchets organiques et des toilettes sèches. *Tsantsa*, 22:89–94.

[Chang and Chen, 2010] Chang, J. I. and Chen, Y. J. (2010). Effects of bulking agents on food waste composting. *Bioresource Technology*, 101(15):5917–5924.

[Coker et al., 2019] Coker, C., Franciosi, F., Black, G., Cotton, M., Gage, J., Gregory, C., Powell, K., Ozores-Hampton, M., Thompson, W. H., and Ziegenbein, J. (2019). Compost Operations Training Course. Technical report, Compost Council Research and Education Foundation, Monterey, CA.

[Csathó et al., 2007] Csathó, P., Sisák, I., Radimszky, L., Lushaj, S., Spiegel, H., Nikolova, M. T., Nikolov, N., Čermák, P., Klir, J., Astover, A., Karklins, A., Lazauskas, S., Kopiński, J., Hera, C., Dumitru, E., Manojlovic, M., Bogdanović, D., Torma, S., Leskošek, M., and Khristenko, A. (2007). Agriculture as a source of phosphorus causing eutrophication in Central and Eastern Europe. *Soil Use and Management*, 23(SUPPL. 1):36–56.

[de Bertoldi et al., 1983] de Bertoldi, M., Vallini, G., and Pera, A. (1983). The Biology of Composting: a Review. *Waste Management & Research*, 1(1):157–176.

[de Guardia, 2018] de Guardia, A. (2018). Compostage et Composts Avancées scientifiques et techniques.

[De Roever, 1998] De Roever, C. (1998). Microbiological safety evaluations and recommendations on fresh produce. *Food Control*, 9(6):321–347.

[Dimambro et al., 2007] Dimambro, M. E., Lillywhite, R. D., Rahn, C. R., and Dimambro, M. E. (2007). The physical, chemical and microbial characteristics of biodegradable municipal waste derived composts. *Compost Science and Utilization*, 15(4):243–252.

[Doyle and Erickson, 2006] Doyle, M. P. and Erickson, M. C. (2006). Closing the door on the fecal coliform assay. *Microbe*, 1(4):162–163.

[Droffner and Brinton, 1995] Droffner, M. L. and Brinton, W. F. (1995). Survival of E. coli and Salmonella populations in aerobic thermophilic composts as measured with DNA gene probes. *Zentralblatt für Hygiene und Umweltmedizin = International journal of hygiene and environmental medicine*, 197(5):387–397.

[EPA - Environmental Protection Agency, 1994] EPA - Environmental Protection Agency (1994). *Composting Yard Trimmings and Composting of yard Trimmings and Municipal solid Waste*. Number May.

[Epstein, 1997] Epstein, E. (1997). *The Science of composting*. Technomic, Lancaster.

[Fang et al., 1999] Fang, M., Wong, J. W., Ma, K. K., and Wong, M. H. (1999). Co-composting of sewage sludge and coal fly ash: Nutrient transformations. *Bioresource Technology*, 67(1):19–24.

[Food and Authority, 2019] Food, E. and Authority, S. (2019). The European Union One Health 2018 Zoonoses Report. Technical Report 12.

[Funamizu, 2019] Funamizu, N. (2019). *Resource-Oriented Agro-sanitation Systems - concept, business model, and technology*.

[Gao et al., 2009] Gao, M., Liang, F., Yu, A., Li, B., and Yang, L. (2009). Evaluation of stability and maturity during forced-aeration composting of chicken manure and sawdust at different C/N ratios. *Chemosphere*, 78(5):614–619.

[Gea et al., 2007] Gea, T., Barrena, R., Artola, A., and Sánchez, A. (2007). Optimal bulking agent particle size and usage for heat retention and disinfection in domestic wastewater sludge composting. *Waste Management*, 27(9):1108–1116.

[Gotaas, 1956] Gotaas, Harold Benedict, W. (1956). Composting : sanitary disposal and reclamation of organic wastes / Harold B. Gotaas.

[Guo et al., 2012] Guo, R., Li, G., Jiang, T., Schuchardt, F., Chen, T., Zhao, Y., and Shen, Y. (2012). Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. *Bioresource Technology*, 112:171–178.

[Haga, 1999] Haga, K. (1999). Development of composting technology in animal waste treatment - review. *Asian-Australasian Journal of Animal Sciences*, 12(4):604–606.

[Haq and Cambridge, 2012] Haq, G. and Cambridge, H. (2012). Exploiting the co-benefits of ecological sanitation. *Current Opinion in Environmental Sustainability*, 4(4):431–435.

[Haug, 1993] Haug, R. (1993). The practical handbook of compost engineering.

[Hirata et al., 1991] Hirata, T., Kawamura, K., Sonoki, S., Hirata, K., Kaneko, M., and Taguchi, K. (1991). Clostridium Perfringens, as an Indicator Microorganism for the Evaluation of the Effect of Wastewater and Sludge Treatment Systems. *Water Science and Technology*, 24(2):367–372.

[Horisawa et al., 2001] Horisawa, S., Sakuma, Y., Tamai, Y., Doi, S., and Terazawa, M. (2001). Effect of environmental temperature on a small-scale biodegradation system for organic solid waste. *Journal of Wood Science*, 47(2):154–158.

[Houot et al., 2014] Houot, S., Pons, M., and Pradel, M. (2014). Valorisation des matières fertilisantes d'origine résiduaire sur les sols à usage agricole ou forestier (Valorisation of fertilising materials from waste on agricultural and forest soils). *Expertise scientifique collective INRA-CNRS-Irstea*, (May 2020):1–108.

[Huang et al., 2004] Huang, G. F., Wong, J. W., Wu, Q. T., and Nagar, B. B. (2004). Effect of C/N on composting of pig manure with sawdust. *Waste Management*, 24(8):805–813.

[Iannotti et al., 1993] Iannotti, D., Pang, T., Toth, B., Elwell, D., Keener, H., Hoitink, and H.A.J. (1993). A Quantitative Respirometric Method for Monitoring Compost Stability. 1(3).

[Islam et al., 2004] Islam, M., Morgan, J., Doyle, M. P., Phatak, S. C., Millner, P., and Jiang, X. (2004). Fate of Salmonella enterica Serovar Typhimurium on Carrots and Radishes Grown in Fields Treated with Contaminated Manure Composts or Irrigation Water. *Applied and Environmental Microbiology*, 70(4):2497–2502.

[Lal, 2008] Lal, R. (2008). Soils and sustainable agriculture. A review. *Agronomy for Sustainable Development*, 28(1):57–64.

[Langergraber and Muellegger, 2005] Langergraber, G. and Muellegger, E. (2005). Ecological Sanitation - A way to solve global sanitation problems? *Environment International*, 31(3):433–444.

[Lin et al., 2018] Lin, L., Xu, F., Ge, X., and Li, Y. (2018). Improving the sustainability of organic waste management practices in the food-energy-water nexus: A comparative review of anaerobic digestion and composting.

[Lopez Zavala and Funamizu, 2005] Lopez Zavala, M. A. and Funamizu, N. (2005). Effect of moisture content on the composting process in a biotoilet system. *Compost Science and Utilization*, 13(3):208–216.

[Loveland and Webb, 2003] Loveland, P. and Webb, J. (2003). Is there a critical level of organic matter in the agricultural soils of temperate regions: A review. *Soil and Tillage Research*, 70(1):1–18.

[Marmo, 2008] Marmo, L. (2008). EU strategies and policies on soil and waste management to offset greenhouse gas emissions. *Waste Management*, 28(4):685–689.

[Mehta et al., 2014] Mehta, C. M., Palni, U., Franke-Whittle, I. H., and Sharma, A. K. (2014). Compost: Its role, mechanism and impact on reducing soil-borne plant diseases. *Waste Management*, 34(3):607–622.

[Michel et al., 1996] Michel, F. C. J., Forney, L. J., Huang, A. J.-F., Drew, S., Czuprenski, M., Lindeberg, J. D., and Reddy, C. A. (1996). Effects of Turning Frequency, Leaves to Grass Mix Ratio and Windrow vs. Pile Configuration on the Composting of Yard Trimmings. *Compost Science & Utilization*, 4(1):26–43.

[Miller, 1992] Miller, F. C. (1992). Composting as a process based on the control of ecologically selective factors. page applications in agricultural and environmental man.

[Moral et al., 2009] Moral, R., Paredes, C., Bustamante, M. A., Marhuenda-Egea, F., and Bernal, M. P. (2009). Utilisation of manure composts by high-value crops: Safety and environmental challenges. *Bioresource Technology*, 100(22):5454–5460.

[Nada, 2015] Nada, W. M. (2015). Stability and maturity of maize stalks compost as affected by aeration rate, C/N ratio and moisture content. *Journal of Soil Science and Plant Nutrition*, 15(3):751–764.

[Naderifar et al., 2017] Naderifar, M., Goli, H., and Ghaljaie, F. (2017). Snowball Sampling: A Purposeful Method of Sampling in Qualitative Research. *Strides in Development of Medical Education*, 14(3).

[Nwaneri et al., 2008] Nwaneri, C. F., Foxon, K. M., and Buckley, C. A. (2008). Biological Degradation Processes within a Toilet. *WISA 2008 Conference, Sun City, 19-22 May 2008*, (May 2008).

[Polprasert, 2007] Polprasert, C. (2007). *Organic Waste Recycling : Technology and Management - Third Edition*. IWA Publishing.

[Rose et al., 2015] Rose, C., Parker, A., Jefferson, B., and Cartmell, E. (2015). The characterization of feces and urine: A review of the literature to inform advanced treatment technology. *Critical Reviews in Environmental Science and Technology*, 45(17):1827–1879.

[Ryckeboer et al., 2003a] Ryckeboer, J., Mergaert, J., Coosemans, J., Deprins, K., and Swings, J. (2003a). Microbiological aspects of biowaste during composting in a monitored compost bin. *Journal of Applied Microbiology*, 94(1):127–137.

[Ryckeboer et al., 2003b] Ryckeboer, J., Mergaert, J., Vaes, K., Klammer, S., De Clercq, D., Coosemans, J., Insam, H., and Swings, J. (2003b). A survey of bacteria and fungi occurring during composting and self-heating processes. *Annals of Microbiology*, 53:349–410.

[Rynk et al., 1992] Rynk, R., van de Kamp, M., Willson, G. B., Singley, M. E., Richard, T. L., Kolega, J. J., Gouin, F. R., Laliberty, L. J., Kay, D., Murphy, D. W., Hoitink, H. A. J., and Brinton, W. F. (1992). On-Farm Composting Handbook. *Monographs of the Society for Research in Child Development*, 77(January):132.

[Schmid Neset et al., 2008] Schmid Neset, T. S., Bader, H. P., Scheidegger, R., and Lohm, U. (2008). The flow of phosphorus in food production and consumption - Linköping, Sweden, 1870-2000. *Science of the Total Environment*, 396(2-3):111–120.

[Slanetz and Bartley, 1957] Slanetz, L. and Bartley, C. (1957). Numbers of Enterococci in water, sewage and feces determined By the Membrane Filter Technique With an Improved Medium. *Journal of Bacteriology*, (74):591–595.

[Solomon et al., 2002] Solomon, E. B., Yaron, S., and Matthews, K. R. (2002). Transmission of Escherichia coli O157:H7 from contaminated manure and irrigation water to lettuce plant tissue and its subsequent internalization. *Applied and Environmental Microbiology*, 68(1):397–400.

[Steiner et al., 2007] Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., De MacÊdo, J. L. V., Blum, W. E., and Zech, W. (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and Soil*, 291(1-2):275–290.

[Strauss, 1985] Strauss, M. (1985). Health Aspects of Nightsoil and Sludge use in Agriculture and Aquaculture, Part II: Pathogen Survival. (04):87.

[Sunar et al., 2014] Sunar, N. M., Stentiford, E. I., Stewart, D. I., and Fletcher, L. A. (2014). The Process and Pathogen Behavior in Composting: A Review. pages 78–87.

[Swan et al., 2002] Swan, J., Crook, B., and Gilbert, E. (2002). Microbial emission from composting sites. *Issues in Environmental Science and Technology*, 18:73–101.

[SWE and Sol Environnement Wallonie,] SWE and Sol Environnement Wallonie, S. Boues d'épuration.

[Swillens et al., 2018] Swillens, L., Van Nerum, I., Van Autreve, J., and AFSCA (2018). Circulaire relative aux engrais / amendements du sol / substrats de culture contenant des sous-produits animaux.

[Tilley et al., 2014] Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., and Zurbrügg, C. (2014). *Compendium of Sanitation Systems and Technologies. 2nd Revised Edition.*

[Tran-Thi et al., 2017] Tran-Thi, N., Lowe, R. J., Schurer, J. M., Vu-Van, T., MacDonald, L. E., and Pham-Duc, P. (2017). Turning poop into profit: Cost-effectiveness and soil transmitted helminth infection risk associated with human excreta reuse in Vietnam. *PLoS neglected tropical diseases*, 11(11):e0006088.

[Wang et al., 2013] Wang, Z., Gao, M., Wang, Z., She, Z., Hu, B., Wang, Y., and Zhao, C. (2013). Comparison of physicochemical parameters during the forced-aeration composting of sewage sludge and maize straw at different initial C/N ratios. *Journal of the Air and Waste Management Association*, 63(10):1130–1136.

[Wichuk and McCartney, 2010] Wichuk, K. M. and McCartney, D. (2010). Compost stability and maturity evaluation - a literature review. *Canadian Journal of Civil Engineering*, 37(11):1505–1523.

[Willson and Dalmat, 1986] Willson, G. B. and Dalmat, D. (1986). Measuring Compost Stability. *BioCycle*, 27(7):34–37.

[World Health Organization, 2006] World Health Organization (2006). *Guidelines for the safe use of wastewater, excreta and greywater*, volume IV : EXCRE.

[Zhou, 2017] Zhou, J. M. (2017). The Effect of Different C/N Ratios on the Composting of Pig Manure and Edible Fungus Residue with Rice Bran. *Compost Science and Utilization*, 25(2):120–129.

[Zubrzycki and Spaulding, 1961] Zubrzycki, L. and Spaulding, E. H. (1961). Studies on the stability of the normal human fecal flora. *J. Bacteriol.*, 83:968–974.