Composting toilets a misnomer: Excessive ammonia from urine inhibits microbial activity yet is insufficient in sanitizing the end-product

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ABSTRACT

End-product from 16 public mixed latrine style composting toilets (CTs) at 12 sites between 50 and 2100 m.a.s.l. in Western North America was tested in order to evaluate the effect of composting variables (TS%, NH_3–N, temperature, and material age) on compost quality and hygiene (VS%, *Escherichia coli*, NO_3^-–N, and pH). Principal component analysis indicated that TS%, temperature, and material age equally contributed to reduction in VS%. NH_3–N had the greatest effect on NO_3^-–N, *E. coli*, and pH. Nitrification was significantly inhibited above 386 mg/kg NH_3–N, but no such limit was found for *E. coli*, despite a significant ($p = 0.016$) but weak ($r^2 = 0.11$) negative relationship. It may be possible to amplify the sanitizing effect of ammonia and overcome pathogen resistance due to low temperatures and re-contamination (caused by poor design) with generous dosing of urea and ash. However, even sanitized, the fertilization effect of discharged material on the natural environment may not be desired or permitted in parks or protected areas where many CTs were found. To this end, operators of CTs need to evaluate their primary management objectives and ensure congruency with proven system capabilities.

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1. Introduction

Composting is the managed aerobic decomposition of organic waste into stable, mature, and sanitized end-product low in contaminants and foreign matter, which would not cause deleterious environmental impacts if land applied (Haug 1993, Wichuk and McCartney, 2010). In order to develop end-product material that meets this definition and passes relevant jurisdictional standards, feedstocks are conditioned and the process managed to induce a rapid temperature rise, which stimulates thermophilic microbial consumption of organic matter. To sustain thermophilic composting, organic matter must have an appropriate ratio of biodegradable carbon and nitrogen (~30/1) (Kayhanian and Tchabanoglous, 1992) despite the consumption of carbon, oxygen and water; all of which must be continuously available or replenished through forced aeration, periodic mixing and watering in order to prevent process

inhibition and premature cooling (Haug 1993). Temperatures are expected to reach 55 °C or more for three days to three weeks (depending on which composting process is used) to kill and adequately sanitize pathogens (CCME, 2005; British Columbia Regulation 198, 2007). The World Health Organization (WHO) guideline recommend that composting of toilet waste should be performed at 50 °C or higher one week to month followed by two to four months curing time (WHO, 2006). Once the majority of rapidly degradable organic matter has been consumed the rate of oxidation drops, heat production slows, and the curing phase begins. This phase is less actively managed and is characterized by mesophilic microorganisms such as fungi and bacteria including nitrifiers, which convert remaining ammonium to nitrate, an essential process in the production of mature compost.

Composting toilets (CTs) are used in North America for the decentralized, waterless, treatment of human waste despite the WHO (2006) recommendation that the difficult process of fecal matter composting be conducted off-site as a centralized secondary treatment. CTs are commonly perceived and advertised as being capable of producing 'compost' onsite, a notion, which may be

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traceable to product literature. As a result, the disposal/land application of untested end-products into public park environments is prevalent. The objectives of nutrient reclamation and organic matter re-use add complexity to the primary objective of material sanitation, which is itself difficult to accomplish (Cilimburg et al. 2000). Numerous composting toilet studies indicate a failure to produce sanitized material let alone stable and mature compost low in foreign matter as defined above due to a variety of causes including: poor design, overuse, insufficient maintenance, low temperatures, anaerobic conditions, and excessive urine (Matthews, 2000; Redlinger et al. 2001; Holmqvist and Stenstrom, 2002; WHO, 2006; Tønner-Klank et al. 2007; Jensen et al. 2009; Hill and Baldwin, 2012). Land application of 'compost' failing to meet standards can result in pathogen transmission, eutrophication of aquatic ecosystems, and phytotoxic impacts (Wichuk and McCartney, 2010) and should be removed to appropriate treatment facilities according to most regulations pertaining to public operators on publically accessible land in North America (WSDOH, 2007). This can be labor intensive, offensive, expensive, and dangerous and at remote sites (Hill and Henry, in press; Hill and Baldwin, 2012).

The following explanatory factors have been explored in narrow CT field studies and laboratory experiments: operations and usage by Matthews (2000) and MWH (2003); moisture content by Zavala and Funamizu (2005), Tønner-Klank et al. (2007), Redlinger et al. (2001) who determined that 40%TS was optimal, below which anaerobic conditions developed and sustained pathogens; thermodynamics and temperature by Chapman (1993), Holmqvist and Stenstrom (2002), and Zavala et al. (2004) who reported that most in-field CTs operated at or near ambient air temperatures; storage time by Gibbs et al. (1997), Guardabassi et al. (2003), Vinnerås (2007), Jensen et al. (2009), and Sherpa et al. (2009), all of whom found storage time alone unreliable in the destruction of pathogens; and feedstock conditions by Chapman (1993), Vinnerås et al. (2003), Tønner-Klank et al. (2007), Niwagaba et al. (2009) each of whom showed that the addition of food-waste or diversion of urine can improve decomposition. But as far as the authors know, a comprehensive exploration of root causes of failure from in-field public, mixed latrine style microbial composting toilets (MLMCs) has not been conducted in North America.

We apply multivariate statistics to a comprehensive data set of end-product quality and process variables from public and in-field MLMCs in Western North America in order to evaluate underlying causes of variability and those most impactful on compost quality. By isolating consistent root causes of system failure: the management of in-situ systems could altered for improved sanitation and end-product quality; the most appropriate new sites can be chosen for systems currently on the market; and adaptations and advancements in product designs can be stimulated.

Based on the literature and variables measured in our study the following key variables (and their impact on the compost process) were chosen: TS% (moisture and ability to deliver oxygen); material age (residence time within treatment system); ambient site temperature (rate of biochemical reaction); and ammonia concentration (urine content). Compost quality was indexed by pH (general quality), nitrate (maturity), VS% (stability), and *Escherichia coli* (pathogen content).

2. Methods

2.1. Sites

Agencies operating public mixed latrine style composting toilets in Washington, USA, British Columbia, Alberta, and Northwest Territories, Canada were contacted requesting permission to extract samples of end-product for analysis. All those granting permission were visited. Twelve sites, with 16 chambers in total, were visited between 2009 and 2011. Nine were found in remote national, provincial, and regional park sites. Two were found in public buildings; only one site was housed within a heated utility room. All toilets sampled were commercial units, sized and installed professionally. Despite some differences in tank size all systems were used and maintained in a similar fashion by each agency according to operational manuals provided at the time of purchase. Sites were found scattered between 50 m and 2100 m elevation and between 46°N and 61°N. The sites received 500–45,000 uses per year per toilet with a concentration of usage in summer months and minimal usage in the winter months except at the toilet within the public building where usage was more consistent throughout the year. A summary of site characteristics can be found in Hill and Baldwin (2012).

2.2. Collection and maintenance

Both fecal matter and urine are collected through a single toilet hole. Pine shavings or peat moss bulking agent (40–200 ml) were added each use along with toilet paper. Site operators performed weekly and monthly maintenance according to the CT manufacturers' instruction manuals. During maintenance additional bulking agent was added if the pile was too wet, a judgment likely to differ considerably by operator. When a chamber filled up, end-product was removed from the bottom. A description of compost toilet chamber design and characteristics can be found in Hill and Baldwin (2012).

New chambers were started 2/3–3/4 full with bulking agent. Depending on use, chamber size, and operational procedures, this bulking agent will dominate the material removed for 1–8 years before true 'end-product' (fecal matter, trash, 'compost') could be observed.

2.3. Samples

Only samples from the oldest end-product in each chamber ware investigated. The material sampled was deemed 'finished' end-product as all material was older than six months and as old as eight years, which is in accordance with NSF/ANSI Standard 41 where testing of end-product is made after six months of system operation. Not all samples were tested for the complete suite of chemical analyses, resulting in minor variations in sample size by assay.

Two to five replicate grab samples were extracted from each compost chamber during 21 site-chamber visits, with a gloved hand from the oldest sections of the material pile according to NSF/ANSI Standard 41 (2011). Samples were extracted from the grab sample directly with a sterile 200 ml glass sample jar. Samples were placed into sterile glass jars in a cooler with ice packs for overnight transport by courier to the commercial laboratory for analysis. In the majority of cases samples were received by the laboratory within 48 h of sampling and a minority in 72 h.

2.4. Biochemical analyses

Benchmark Labs in Calgary, Alberta, an ISO 17025 accredited Lab, analyzed solid end-product samples according to Table 1 (Table 2).

2.5. Statistics

JMP version 8 (SAS 2009) was used to: perform Principal Component Analyses, univariate ANOVA tests when assumptions