Environmental Science & Technology

Article

Cite This: Environ. Sci. Technol. 2018, 52, 11803−11812

pubs.acs.org/est

Can Sanitation Technology Play a Role in User Perceptions of Resource Recovery? An Evaluation of Composting Latrine Use in Developing World Communities in Panama

Colleen C. Naughton,[†] Patricia Akers,[‡] Danielle Yoder,[‡] Roberta Baer,[§] and James R. Mihelcic*,[‡]

[†]Department of Environmental Engineering, University of California Merced, 5200 N. Lake Road, Merced, California 95343, United States

[‡]Department of Civil and Environmental Engineering, University of South Florida, 4202 E. Fowler Avenue, Tampa, Florida 33620, United Sates

[§]Department of Anthropology, University of South Florida, 4202 E. Fowler Avenue, Tampa, Florida 33620, United States

Supporting Information

ABSTRACT: There remains a large unmet need for sanitation access throughout the world that compromises both human and environmental health. Opportunities exist to employ sanitation systems that better utilize and recover scarce resources from excreta such as water, energy, and nutrients. However, technologies such as a composting latrine may require more maintenance and close handling of feces compared to other sanitation technologies. This study aims to evaluate how use of on-site composting latrine technology and other demographic characteristics are associated with users' perceptions of excreta for resource recovery. Field observations and interviews of composting latrine users (N = 201) and 200 perceptions surveys were administered to composting and non-composting latrine users in Indigenous and Latino communities in Panama. Of the completed composting latrines, 78% were in use and 65% of these were used properly. Compost latrine design and operational factors identified to improve were: anal wash capability, desiccant supply, children usage, and clogging urine tubes. Demographic categories associated with positive perceptions toward resource recovery ($p < 0.05$) were ethnicity (14 out of 16 total statements) and sanitation type (11) then community origin (7), occupation (5), education (4), age (3), and gender (1).

1. INTRODUCTION

Currently 946 million people still open defecate and 2.4 billion people lack access to basic sanitation.[1] Lack of sanitation contributes to diarrheal disease (second leading cause of death for children under five)[2] and environmental degradation (one-third of the rivers in Africa, Asia, and Latin America are severely contaminated by pathogen pollution).[3] Thus, in 2015 the United Nation's established 17 Sustainable Development Goals (SDG) to follow the Millennium Development Goals. SDG 6 aims to achieve equitable access to safely managed water and adequate sanitation for all by halving the proportion of wastewater that goes untreated and ending open defecation.[4]

Human excrement and domestic wastewater are increasingly seen as a valuable resource that can provide fit-for-purpose water, energy, and nutrients.[5−7] While achieving greater recovery of resources from wastewater is seen as a preferred path forward,[8,9] the wastewater sector has not fully integrated this strategy with established goals of protecting human health and the environment. Challenges to achieving this strategy at primarily larger centralized facilities include lack of consideration of social-political and other external macroeconomic factors,[10,11] lack of incentives,[12] a need to spur innovation that accelerates adoption of reliable technologies,[13] and the costs associated with doing something different.[14]

In a developing world context, where there is still a large unmet need for basic sanitation, there are significant opportunities to develop sanitation systems that better utilize and recover scarce resources. Already, advances have been made in developing on-site technologies to obtain safe water and embedded nutrients (e.g., ref 15), manage fecal sludge,[16] and produce energy.[17] Related to this way to view "wastewater" as a resource, on-site sanitation technologies, which collect excreta, sanitize it, and reuse the embedded resources from excreta for beneficial purposes, are dubbed ecological sanitation (EcoSan). One such technology is the double alternating pit composting latrine.[18] If maintained properly, a composting latrine can lessen

Received: May 7, 2018
Revised: August 2, 2018
Accepted: September 10, 2018
Published: September 10, 2018

Table 1. Demographic and Sample Size Information of Communities Surveyed for Their Perception of Excrement and Use of Feces for Resource Recovery

Community		Filo Verde	Norteño	San San Puente	Quebrada Honda	Altos de Cristo
Ethnicity		Indigenous	Indigenous	Indigenous	Latino	Latino
Human Development Index[a]		0.499	0.499	0.668	0.769	0.769
Sample Size (N)		36	62	25	37	40
Approximate Total Population		375	1000	600	600	400
Age	Range	17−72	15−65	15−70	18−77	18−72
	Average	39.2	32.0	37.3	42.0	39.0
Gender	Male	38.9%	38.7%	32.0%	32.4%	15.8%
	Female	61.1%	61.3%	68.0%	67.6%	84.2%
Education	No Schooling	61.1%	16.1%	28.0%	10.8%	2.5%
	Schooling	38.9%	83.9%	72.0%	89.2%	97.5%
Primary Occupation	Farmer	80.6%	58.6%	4.0%	44.4%	33.7%
	Non-farmer	19.4%	41.4%	96.0%	55.6%	66.7%
Latrine Type	Composting	41.7%	16.1%	16.0%	37.8%	15.0%
	Non-composting	58.3%	83.9%	84.0%	62.2%	85.0%

[a]Human Development Indices were retrieved from UNDP (2014)[38] for the geographic regions of each community. The HDI for Panama is 0.788.

water demand associated with sanitation provision[19] and promote nutrient recycle for food production.

The double vault alternating composting latrine[18,20] is one type of EcoSan technology. It is constructed aboveground, provides urine-diversion (for collection or routing to the subsurface), and requires addition of dry bulking material (e.g., wood ash, sawdust, grass) after each use.[21] This improves aeration and the carbon-to-nitrogen ratio to support aerobic biodegradation of organic materials that create heat.[21] After it is filled, the contents of a pit are recommended to sit and compost for at least six months to promote pathogen inactivation while the other side is put into use. The composting latrine technology assessed in this study requires more maintenance compared to a dry pit latrine or flush toilet and may require more frequent and close handling of feces by the user; therefore, we expect that perceptions of feces, their use, and their management strongly influence the latrine user's behavior and resulting resource recovery.

Adoption and use of household latrines has been researched systematically and on large scales; however, these studies do not include composting latrine technologies.[22−24] There are some qualitative studies that evaluate user satisfaction, use, and knowledge of composting latrines with smaller sample sizes that took place in Uganda,[25] South Africa,[26] Malawi,[27] Mexico,[28] and Europe.[29] Findings showed much variation. In one study users had high satisfaction because a composting latrine can be built above ground in rocky terrain where it is difficult to dig pits and can be used for resource recovery as fertilizer[25] while another study had very low satisfaction where 95% of respondents (N = 146) aspired to a flush toilet.[26] Other studies focus on evaluating potential user perceptions of ecological sanitation or using human excreta as a fertilizer before an intervention. For example, Nawab et al. (2006)[30] found that respondents were not receptive to composting latrines because it would limit their ability to cleanse with water and it had higher maintenance.

This study aims to fill a knowledge gap of how use of on-site ecological sanitation technology is associated with users' perceptions of excreta and the opportunities for resource recovery in different socio-cultural settings. To date studies that have evaluated ecological sanitation use did so through surveys of respondents[25−27] which can have a response bias toward positive behavior[31] as opposed to direct observations. Accordingly, the objectives of this research were to (1) quantify the usage of completed composting latrines and the composted feces through interviews and direct observations, (2) identify design and operational factors that may impede full resource recovery potential and health improvements, and (3) evaluate how use of resource recovery technology and other demographic factors (sanitation type, ethnicity, age, gender, and occupation) play a role in user perceptions of resource recovery from excreta. Our hope is that this study's findings will assist in greater basic sanitation coverage and more widespread, safe, and better adoption of innovative resource recovery technologies.

The study was conducted in Indigenous and Latino rural areas of Panama. In Panama, 77% of the urban population has access to improved sanitation facilities, while only 54% of the rural population has access.[32] Indigenous groups represent approximately 12% of the total population.[33] However, there is a significant disparity between Indigenous and non-Indigenous populations in Panama as in other countries throughout the world. Indigenous populations have much lower access to sanitation (less than 50%)[34] and Human Development Index rankings compared to the average Panamanian (see Table 1). With large unmet needs for sanitation particularly in rural and Indigenous areas and a large amount of agriculture and high water tables,[35] there is a great potential for implementing resource recovery sanitation technologies in many areas of the world similar to our study location.

2. MATERIALS AND METHODS

Three research phases were employed in this study: (1) field observations of compost latrines and initial interviews of users, (2) informal interviews regarding the likes and dislikes of composting latrines, and (3) oral survey of composting and noncomposting latrine users' perceptions of human and animal feces and the use of composted human feces for resource

DOI: 10.1021/acs.est.8b02431
Environ. Sci. Technol. 2018, 52, 11803−11812

recovery. Phases 1 and 2 were conducted between August 2013 and January 2014 while phase 3 was conducted from January–April 2014. All communities had implemented composting latrine (Double Vault Urine Diverting) development projects starting in June 2003 through 2014 that were designed, funded, and implemented by Peace Corps with community contribution of in-kind labor and materials. For example, Peace Corps provided funding for cement for the vaults while the household built the superstructure and took ownership of the latrine and future maintenance including emptying the vault. Two secondary authors performed this research (and made all observations regarding proper/improper latrine usage) while they were serving as development engineers in Panama as part of their graduate education.[36] All research methods employed were approved by the Institutional Review Board at the University of South Florida which required consent from local community leadership and individual respondents.

2.1. Community Backgrounds. Phase 1 was implemented in 23 communities of the Indigenous Comarca Ngäbe-Buglé in the province of Bocas del Toro and Ñö Kribu regions in Panama where there had been Peace Corps composting latrine projects. Eighteen of these communities were chosen for phase 2 based on respondent availability of the same households in phase 1. For phase 3, three of these indigenous communities (Filo Verde, Norteño, and San San Puente) as well as two Latino communities (Quebrada Honda and Altos de Cristo) were surveyed in the Darién and Eastern region in Panama for sample comparison between ethnic groups (see Supporting Information (SI) Figure S1 for a map of the communities and Table 1 for sample sizes and demographics). The major source of income for the majority of these communities is subsistence agriculture (cacao, bananas, plantains, tropical fruits, and root vegetables). Along the coast, fishing, and lobstering are major sources of income. Additionally, men often leave their community to find work in nearby banana plantations, construction in larger cities, or work on coffee fields in another province or neighboring country. See Wilbur (2014)[37] for more information on the 23 Indigenous communities, their culture, occupations, and sample sizes. This study focused on Indigenous populations to better understand this disadvantaged population in the country but also surveyed Latino communities for comparison. Both Latino communities were located near the Pan-American Highway and had a higher percentage of non-agricultural employment such as concrete masons and chauffeurs.

2.2. Composting Latrine Observations and Interviews. Of the 23 communities visited in phase 1, observations of 201 composting latrines and interviews with their households were performed. Unannounced visits were conducted typically with the aid of another community development worker, the original leader of the composting project, or latrine owners in that community. No respondents refused to participate. Interviews and surveys were conducted in Spanish and each family would select the appropriate respondent with the most knowledge of the composting latrine. The interview consisted of 26 questions (included in the SI). These questions inquired about compost latrine operation, maintenance and responsibility, location of compost use, training composition and retention, cleansing materials, project origin, and potential rate of disuse. After interviewing the user, permission was requested to enter their latrine to make observations for presence and type of desiccant inside and outside of the composting chamber, levels of odor, moisture of latrine contents and cleanliness, and physical status of the latrine (e.g., broken urine separation tubes, unsealed rear doors, missing seats, and structural failures). A composting latrine was classified as improperly used if one or more of the previous items were not present or functioning (e.g., no desiccant, bad odor, dirty, etc.). For phase 2, in 18 of these 23 communities an additional informal interview segment was performed about likes and dislikes of their composting latrine for one respondent in each community. Phase 2 was conducted immediately following the phase 1 survey and observations. Respondents could list multiple advantages and disadvantages.

2.3. Perceptions of Feces and the Use of Composted Human Feces for Resource Recovery. In phase 3, an in-depth survey including demographic information (age, education, gender, occupation, and sanitation type) and perceptions of excreta and the use of composted human feces for resource recovery was administered in three Indigenous and two Latino communities. These five communities were selected because of their diversity in demographic characteristics based on the authors' experience in the field. While income information was not collected, the Human Development Indices for each region[38] were noted and important factors potentially related to income, education, and occupation, were compared. From a review of the literature and field experience, elaborated further in each demographic category in the Results and Discussion section, we hypothesized that the following demographic characteristics of respondents would lead to more positive perceptions of resource recovery: (1) Indigenous, (2) more formally educated, (3) male, (4) farmers, (5) compost latrine owners, and (6) older age groups. In contrast, the following demographic characteristics of respondents would have more negative perceptions of resource recovery: (1) Latinos, (2) less formally educated, (3) female, (4) non-farmers, (5) pit latrine and flush toilet owners, and (6) younger age groups.

The phase 3 survey consisted of 40 questions adapted from Mariwah and Drangert's (2011)[39] survey to peri-urban farming communities without composting latrines on their attitudes and perceptions toward human feces and their knowledge and utilization of human excrement as fertilizer (see SI for all 40 questions). Sixteen of these questions were statements such as "1. Human feces is a waste and should only be used for disposal." where respondents were asked to respond with (1) agree, (2) disagree, or (3) do not know.

2.4. Data Analysis. Data for all phases were recorded in the field and then entered and summarized in excel spreadsheets. For phase 2, the frequencies of the different likes and dislikes stated by the respondents were totaled.[37] For phase 3, IBM SPSS version 23 software was used to conduct the Pearson's Chi-squared test for independence to determine if there was an association between the demographic information collected (ethnicity, sanitation type, education, etc.) and responses to the 16 statements for perceptions of excrement in general and for resource recovery. A 95% confidence interval with alpha threshold of 0.05 ($p < 0.050$) was chosen to determine significance. The Pearson's Chi-squared test for independence was chosen for data analysis as it is used to compare categorical and non-continuous variables. Furthermore, the chi-squared test does not require a very large sample size like other statistical tests (e.g., multivariate, logistic regression, or factor analysis). In some cases where the expected cell counts did not meet minimum requirements, the Fisher's exact test was used mostly because of fewer responses in the "Don't know" category. However, significance ($p < 0.050$) was always verified by conducting the Pearson's chi-squared test for independence without the "Don't know" data responses. To address confounding between

DOI: 10.1021/acs.est.8b02431
Environ. Sci. Technol. 2018, 52, 11803−11812

demographic variables, each category was disaggregated to determine if there were still significant differences (e.g., if indigenous respondents are more favorable to resource recovery but pit latrine users are not, a chi-squared test was run between indigenous pit latrine owners and indigenous composting latrine owners). More detail and results on the statistical analysis in this study are provided in Section 3.3.2.

2.5. Limitations. While phases one and three included at least 200 respondents each, phase two was a more informal addition with a limited sample size of 18. Additionally, phases one and three were not matched in a way to make comparisons between observations of latrines and perceptions of resource recovery (e.g., analyzing if owners of improperly used composting latrines had differing perceptions). Respondents and communities were not selected randomly or meant to be representative of the country population. However, five communities were surveyed and respondents represented at least 25% and up to 75% of household heads in the community and included both composting and non-composting latrine owners to allow comparison between technology users in each community. Since the research was designed and conducted after composting latrine projects were implemented, a perceptions survey was not conducted prior to construction of composting latrines so households that chose to construct latrines may have been more favorable to resource recovery before construction.

3. RESULTS AND DISCUSSION

3.1. Composting Latrine Use. Of the completed composting latrines ($N = 201$) in 23 Indigenous communities, 78% were in use and 65% of the in use latrines were used properly. This is within the range (27−89%) reported for continued usage of pit latrines but higher than an average 58% usage calculated in a systematic review of 11 studies on pit latrine usage.[24] In Malawi 63% ($N = 64$) of composting latrines were functional in a peri-urban area and 77% ($N = 30$) were operational in a rural area after seven years.[27] In South Africa, 97% of respondents stated they used their composting toilets but only 20% were maintained properly and the users were highly dissatisfied with the technology.[26]

Of 102 composting latrines that were observed to be used properly in our study, 34 latrine users claim they mixed their compost at least once. Twenty-five of these 34 users said they had mixed the latrine contents within the past three months. Original training of composting latrine users by Peace Corps Volunteers recommended to mix latrine contents once to twice a week.[40] The 35% of latrines used improperly had higher observed moisture content, strong odors, and lack of visible desiccant in the compartment. Overall, 25% of the composting latrines were unfinished, 4.0% were broken, and 23% of users mentioned problems with the urine tubes ($N = 201$). Some latrines could no longer be used because of severe flooding, low quality construction materials, or poor placement/backfilling in marshy areas. Most respondents did not know which month they would change chambers or remove compost. In fact, 19% owners said they would change sides and remove compost when one side fills. Only communities with latrines constructed since August 2011 mentioned a one-year storage time because before recipients were instructed to use each side for only six months and later this was deemed insufficient for destruction of all pathogens.[40]

Some latrines (29%) in this study were missing small components that are important to implement successful resource recovery; for example, compartment access doors, urine tubes, or seats or did not have privacy structures to enclose the latrine seating area. In this location, small components are normally provided by project funding while the privacy structure is the responsibility of the latrine owner. Without privacy structures, people may have felt uncomfortable and rarely if ever used the latrine. Unfinished latrines may have reflected a lack of interest from the stakeholder though some cited economic barriers. This was also the case in South Africa where 80% of the composting toilets were maintained improperly and many respondents cited broken doors, toilet seats, and back vault covers.[26] However, those that maintained the latrine properly would purchase and replace these items when broken.[26] Thus, a better understanding of the attitudes and perceptions related to composting latrines and their operation and maintenance is valuable in assessing levels of interest and priorities (see Section 3.3 for further discussion). The sustainability of a sanitation project depends on several economic and social factors[41] that require stakeholder engagement.[42,43] Furthermore, new latrine owners often expressed the desire to see the resulting product before deciding whether or not they would use the compost on their crops. This desire reflects a need for pilot latrine projects so the level of interest and sustainability can be observed and significant amounts of time and money are not invested in semisuccessful composting latrine projects.

3.2. Likes and Dislikes of Composting Latrines. Composting latrines offer users advantages over other household sanitation options and sewer systems (e.g., local resource recovery and odor reduction) though how users perceive and rank the advantages and disadvantages of resource recovery sanitation technologies depend on a variety of factors (exposure to other sanitation technologies, culture, geographic characteristics, and/or population density). During the informal interviews in 18 different Indigenous communities with 18 respondents, the most frequently listed advantages of composting latrines were: provides compost ($N = 13$), no mosquitoes or flies ($N = 11$), no smell ($N = 8$), no contamination or leaking ($N = 7$), proximity to household ($N = 6$), development worker recommended ($N = 6$), privacy ($N = 5$), and can be built in areas that are prone to flooding or have high water tables ($N = 5$). Less frequent ($N < 5$) mentioned advantages were that you can stop using the stream, safety, avoids illness, and it can be offered to visitors.

Some of these advantages were similar to those listed by respondents in Malawi who cited the source of human fecal compost and no smell as advantages.[27] In comparison, composting latrine users in Uganda did not list compost as the primary advantage of the technology because of their geographic context; they preferred that it can be built above ground in rocky terrain (50% of 806 respondents).[25] Peri-urban composting latrine users in Malawi preferred the advantages of space saving and smell reduction while rural users preferred the compost production, smell reduction, and that composting latrines were less likely to collapse during the rainy season.[27] Although urban residents and those in occupations other than farming may not have as much of a use for the compost, compost latrines are easier and cheaper to empty than pit latrines that require expensive mechanical equipment that is difficult to maneuver in dense urban areas or settlements.[26] Overall, environmental sustainability and health reasons are not seen as primary advantages for resource recovery technology users. Similarly, in a systematic review of nine sanitation studies (mostly pit latrine and flush toilets), health and environment were not found as top

DOI: 10.1021/acs.est.8b02431
Environ. Sci. Technol. 2018, 52, 11803−11812

Table 2. Significance Results (p-Values)[b] from the Pearson's Chi-Squared Test for Independence[c] between Survey Statement Responses and Demographic Information from the Participants (N = 200)

Survey Statements	Ethnicity	Indigenous Communities[d]	Latino Communities[e]	Gender	Occupation	Age	Education	Latrine Type
1. HF[a] is a waste	**<0.001**	*0.629*	*0.191*	*0.208*	0.678	**0.007**	*0.833*	***<0.001***
2. Handling HF[a] is a great health risk	***0.001***	***<0.001***	*0.572*	*0.078*	***0.009***	0.491	*0.095*	***0.001***
3. HF[a] should not be handled	***<0.001***	***0.030***	*1.000*	*0.325*	**0.002**	**0.035**	*0.693*	***0.010***
4. HF[a] has no benefit	**0.001**	***0.015***	*0.780*	***0.001***	**0.013**	0.197	*0.100*	***0.001***
5. It is ok to touch feces	**0.024**	***0.024***	*0.605*	*0.058*	***0.025***	0.855	***0.003***	*0.435*
6. It is ok to touch treated feces	**<0.001**	*0.062*	*1.000*	*0.288*	0.686	0.365	*0.099*	**0.035**
7. HF[a] are a resource for the soil	**0.038**	***0.006***	*0.793*	*0.240*	0.269	0.187	*0.066*	**0.006**
8. HF[a] from a composting latrine can be used as fertilizer	**<0.001**	*0.424*	*0.870*	*0.557*	0.110	**0.018**	*0.009*	**0.022**
9. I will use HF[a] on my crops if composted	***0.009***	***0.017***	*0.843*	*0.106*	***0.008***	0.284	*0.159*	***0.001***
10. Taste of vegetables composted with HF[a] will change	0.930	*0.387*	0.313	*0.116*	0.982	0.685	0.067	0.262
11. Smell of vegetables composted with HF[a] will change	**0.035**	*0.145*	0.190	*0.159*	0.338	0.520	**0.033**	**<0.000**
12. Crops can be killed when fertilized with composed HF[a]	**<0.001**	*0.055*	0.518	*0.888*	0.107	0.132	*0.670*	*0.057*
13. Crops fertilized with HF[a] are good for consumption	**<0.001**	***0.044***	*1.000*	*0.501*	0.257	**0.039**	***0.008***	***0.004***
14. I will never consume crops fertilized with HF[a]	***<0.001***	0.840	*0.071*	*0.049*	*0.049*	**<0.000**	***0.001***	***0.037***
15. Animal manure can be used as fertilizer	***0.034***	*0.099*	*1.000*	*0.854*	*0.066*	0.104	*0.570*	*0.429*
16. Ever used animal manure as fertilizer	*0.320*	*0.478*	0.815	0.835	0.055	0.862	*0.393*	*0.547*

[a]HF= Human Feces. [b]Values in bold indicate significance at the 95% confidence interval ($p < 0.050$). [c]Where the expected cell counts did not meet minimum requirements, the Fisher's Exact Test and values are indicated in italics. [d]Differences between the survey responses in the Indigenous communities of: Filo Verde, Norteño, and San San Puente. [e]Differences between the survey responses in the Latino communities of: Quebrada Honda and Altos de Cristo.

drivers of adoption.[44] Thus, other advantages particularly economic and social should be further emphasized in future promotion of sanitation technologies that promote resource recovery.

While many of the advantages of the composting latrine in our study were cited in comparison to the pit latrine that does not produce compost and can generate mosquitoes, flies, and odors; the dislikes of composting latrines were often in comparison to pour-flush septic tank systems that are viewed as more modern. On-site resource recovery technologies require more user interaction and input which makes them more socially complex, potentially leading to incorrect operation and maintenance that may compromise safe and successful resource recovery. The major dislikes of composting latrines were: cannot use water for washing (N = 8), getting desiccant (sawdust or ash) (N = 5), daily maintenance (N = 4), not kid friendly (N = 3), cannot use compost for organic cacao (N = 3), difficult to change behavior (N = 3), requires education (N = 2), compost is disgusting (N = 2), and leaky urine tubes (N = 2). Less frequent ($N < 2$) responses were cost of toilet paper, river cleans better, and no need for compost. The Indigenous communities primarily used water for anal cleansing, so having to switch to dry materials was a major behavior change and expense for them. There is need to further redesign and retrofit composting latrines in these areas to allow for anal wash which is already being attempted in Panama. In contrast, the Latino communities surveyed in the next phase primarily use dry materials for anal cleansing so this is not as much of a concern. Furthermore, the urine tubes are the most prone to failure and a redesign of these should also be investigated. Foreign particles, such as dry materials added like sawdust and ash, and chemical precipitates, such as struvite can block the pipe.[45,46] Urine tube clogging was also mentioned as a disadvantage for composting latrine users in Malawi.[27] The use of larger diameter pipes and curved, or less sharp, conduits may avoid this obstacle to use.[46]

In regards to the disadvantage cited of "not kid friendly," another important consideration for resource recovery from compost latrines is their use by children. With a greater maintenance, proper use of composting latrines are more difficult for young children (e.g., adding desiccant, may urinate in the dry pit or defecate in the urine diversion area).[27] Other studies have found that mothers discourage the use of the composting toilet as children may use them incorrectly[27] or they are afraid their children may hurt themselves or fall in the pit.[26] Children then practice open defecation which is known to contaminate the local environment and have negative health implications. Thus, design of composting latrines and training as with any sanitation option should emphasize the proper use by children.

There are other potential factors of composting latrine technologies that may contribute to people's dislikes of the technology as well as impede full resource recovery, health and environmental benefits. Pits must be sized correctly for the family size and for geographically appropriate pathogen destruction (e.g., taking into account temperature of the area). Also, compost chambers can became very moist and even produce maggots when pits are not sealed or maintained well to prevent water infiltration (rain entering through leaky roof, users adding wash water and/or urine to the pits, and not adding sufficient desiccant after use).[27]

3.3. Perceptions of Feces and Use for Resource Recovery. *3.3.1. Community Demographics and Sample Sizes.* In phase 3, 200 surveys on perceptions of excrement and use of feces for resource recovery were administered (123 in indigenous communities, 77 in Latino communities). Demographic and sample size information on these five communities

DOI: 10.1021/acs.est.8b02431
Environ. Sci. Technol. 2018, 52, 11803−11812

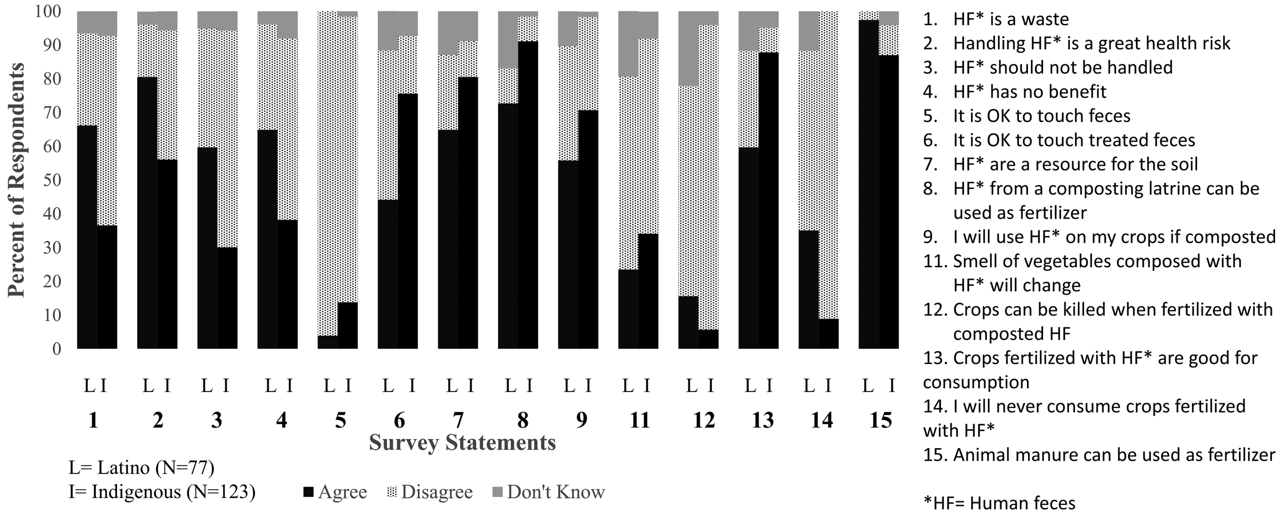

Figure 1. Significantly different ($p < 0.050$) responses to survey statements between Indigenous and Latino communities.

are summarized in Table 1. Overall, there was a similar range and average age and gender of respondents in all five communities though many more respondents were female in Altos de Cristo (85%). Three communities had respondents with relatively similar education levels with some form of schooling ($M = 82\%$) but Filo Verde respondents were relatively less formally educated (39%) and Altos de Cristo respondents had high levels of education (98%). The percentage of respondents who were farmers for their primary occupation varied per community but was usually over one-third. Although only 4.0% of respondents were farmers in San San Puente, 52% worked in agriculture on banana plantations. The Indigenous communities were located in regions with lower Human Development Indices (0.449 and 0.668) than the Latino communities (0.769) that suggests lower income. At least 15% of respondents in each community owned compost latrines.

3.3.2. Statistical Analysis of Feces and Resource Recovery Perceptions. The significance (p-values) results from the Pearson's Chi-Squared Test for Independence between the different demographic categories in Table 1 and survey statement responses related to the perceptions of excrement and resource recovery are included in Table 2. For these data sets, the null hypothesis was that the demographic factor and the response to the perception statements were not associated. However, if the p-value is less than 0.050, the null hypothesis is rejected indicating that there is a potential association between the demographic variable and the survey statement response. Knowing which demographic characteristics of people are most and least favorable to resource recovery can aid in maximizing composting latrine adoption by both targeting areas that have more favorable perceptions and designing education interventions to overcome negative perceptions. Moreover, determining if use of composting latrine technologies is associated with a user's perceptions of excreta more favorable to resource recovery is important to evaluate the success, training, future use, and dissemination of the technology. From Table 2, the variables most associated with the different statement responses which will be explained further in the following sections are first ethnicity (14 out of 16 statements) followed by latrine type (11 statements), then between the three different indigenous communities (7), occupation (5), education (4), age (3), and gender (1).

3.3.2.1. Ethnicity. For a closer look at the percentage of responses to the survey statements that differed significantly ($p < 0.050$) between Indigenous and Latino communities from Table 2, see Figure 1. Indigenous communities responded to statements in line with positive perceptions of resource recovery. For example, 66% of Latino respondents agreed that human feces is a waste that should only be disposed of while only 37% of Indigenous respondents agreed (statement 1). When asked if human feces is a resource for the soil (statement 7), 81% of Indigenous respondents agreed and only 65% of Latino respondents. More Indigenous respondents agreed (88%) that crops composted with human feces are good for consumption (statement 13) than Latino respondents (60%).

While on average, responses were similar within each ethnic group; there were some significant differences between the Indigenous communities but not the Latino communities. In general, Filo Verde had responses more favorable to resource recovery than the other two Indigenous communities (Norteño and San San Puente). For instance, in response to statement 4 in Table 2 that human feces has no benefit to humans, 67% of Filo Verde respondents disagreed and only 50% and 44% of Norteño and San San Puente disagreed, respectively. However, this is still much higher than the Latino communities with 32% and 30% disagreement. Filo Verde is distinguishable from the other communities with a higher percentage of farmers (81%) and lower educated population (39%). Although Filo Verde and Norteño were in a region with a lower Human Development Index (HDI) (0.499) than San San Puente (0.668), there were not significant differences in responses between Norteño and San San Puente. Nevertheless, Latino communities were located in a higher HDI region (0.769) than the Indigenous communities which may also be associated with perceptions in addition to ethnicity. Latino households also tended to have smaller household sizes ($M = 4$) than Indigenous households ($M = 8$).

The ethnic differences in resource recovery perceptions found in this research are supported by research in sanitation options for Muslim communities in Pakistan that noted the importance of incorporating cultural values including religious and spiritual values in intervention design and implementation.[30] Muslims use water for cleansing, ablutions before prayer, and also use anal wash instead of dry materials after defecation believing that this is cleaner. In Uganda, Muslims were 10 times less likely to adopt

DOI: 10.1021/acs.est.8b02431
Environ. Sci. Technol. 2018, 52, 11803−11812

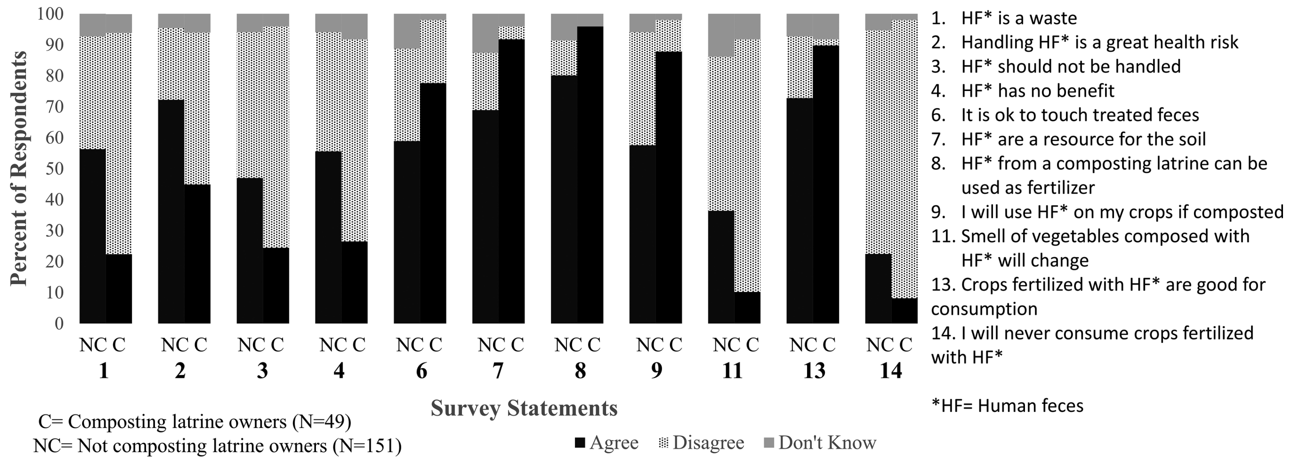

Figure 2. Significantly different ($p < 0.050$) responses to survey statements between compost latrine and noncomposting latrine users.

compost toilets than people of other religions such as Catholics.[25] In this study, although respondents were primarily Catholic or Christian and there were no Muslim respondents, the Indigenous respondents often used anal wash like Muslims which also made adoption of dry composting latrines that were not equipped with anal wash functionality difficult.

3.3.2.2. Sanitation Type. For the significantly different ($p < 0.050$) responses between composting latrine users and non-composting latrine users from Table 2, see Figure 2. For example, more non-composting latrine users agree (56%) that human feces has no benefit (statement 4), while only 27% of composting latrine users agree. A large percentage of composting latrine users (88%) agree that they will use human feces on their crops if composted (statement 9) compared to 58% of non-composting latrine users. More composting latrine users agree (90%) that crops fertilized with human feces are good for consumption (statement 13) compared to 73% of non-composting latrine users. Even though more Indigenous respondents answer in line to statements favorable to resource recovery than Latino respondents, these significant differences remain between non-composting and composting latrine users within the two ethnic groups.

3.3.2.3. Occupation. Following ethnicity and sanitation type, there were significant differences in responses when separated by occupation; notably, farmers and non-farmers. Indigenous and Latino farmers tended to respond to statements in a way that supports resource recovery. For example, 56% of non-farmers agreed that human feces has no benefit to humans (statement 4) and only 41% of farmers agreed. Also, 76% of farmers agreed they will use human feces on their crops if composted (statement 9), while 56% of non-farmers agreed. This is slightly higher than a study of Indian farmers that found that 59% were receptive to reuse of urine and 46% responded positively to the use of human feces as fertilizer.[47] Nevertheless, most non-farmers (90%) and farmers (95%) in our study agreed that animal manure can be used as fertilizer more so than human feces. In India, 52% of farmers agreed that cow and human urine were different.[47] Given the more positive perceptions of resource recovery by farmers overall compared to non-farmers, composting latrines may be a more attractive option to farming communities compared to other sanitation methods (i.e., the pit latrine). Furthermore, the largest growth in urban populations is expected in smaller cities located close to agricultural zones that need and can more readily utilize recovered resources from wastewater.[48]

3.3.2.4. Age. Interestingly, those in the middle age group (21−50 years old) tended to respond more favorably to some statements for resource recovery than the younger (≤20) and older (over 50) groups. For example, only 44% of respondents aged 21−50 agreed that human feces is a waste only for disposal while 63% of those 20 years old and younger and 71% of those over 50 years old agreed. Additionally 37% of 21−50 year olds agreed that human feces should not be handled in any way and 57% of those less than 20 years old and 58% of those over 50 agreed. Older groups also responded more affirmatively (87% for 21−50 and 81% for over 50) that human feces is a resource for the soil than the younger age group (67% agreement for those ≤20). The older age group may not be as accepting of resource recovery because they are accustomed to either open defecation or pit latrines that do not reuse the waste. For example, older generations in South Africa were more accustomed to the Ventilated-Improved Pit (VIP) latrine and preferred it to the composting latrine.[26]

3.3.2.5. Education. Respondents without formal education tended to respond to some statements more favorable to resource recovery than community members with formal education (primary, secondary, and university). When asked if crops fertilized with human feces are good for consumption, 91% of respondents without education agreed and only 73% of those with education agreed. A higher percentage of respondents without education agreed (98%) that human feces from a composting latrine can be used as fertilizer, while 80% of those with education agreed. More educated respondents agreed (24%) that they would never consume crops fertilized with human feces compared to 2.3% of non-educated respondents. Education was also related to ethnicity ($p < 0.001$) in this study where a higher percentage of Latino respondents were educated (94%) compared to Indigenous respondents (68%) so cultural differences may have been associated with their responses as well as education or vice versa. However, within the Indigenous ethnic group 45% of those with education agreed that human feces has no benefit and 23% of those without education agreed ($p = 0.024$). There were no significant differences between statement responses of educated and non-educated Latino respondents, possibly related to the small sample size.

In contrast, in Uganda, respondents who were more educated (secondary and tertiary education) were 2−5 times more likely to adopt composting latrines.[25] The Ugandan study reasoned that education may help overcome negative societal beliefs of

DOI: 10.1021/acs.est.8b02431
Environ. Sci. Technol. 2018, 52, 11803−11812

excreta reuse.[25] However, the composting toilets in Uganda were mostly unsubsidized and those with higher education may also have had higher incomes to afford the new facilities. Furthermore, if there are not existing, negative societal beliefs about resource recovery from waste then hygiene education without discussing resource recovery potential may deter people from reusing human waste.

3.3.2.6. Gender. The only statistically significant difference in responses between males and females overall was that more females (55%) agreed that human feces has no benefit to humans than men (37%). Women have closer interaction with feces and illness from caring for children and cleaning latrines which may cause them to have a more negative perception of human feces. Additionally, all families with male and female household leaders expressed similar divisions of labor where the female performs daily cleaning of the latrine and males remove the composted excrement. However, this is not always the case in other areas or cultures. For example, in South Africa many women were responsible for both cleaning and emptying the latrine.[26] Compost latrine trainings should ensure that the technology does not cause an unequal labor burden on women.[30]

3.3.2.7. The Association between Resource Recovery and User's Perceptions. Although we recommend that a full perceptions community survey be performed before implementing a sanitation technology, particularly for composting latrines, this research also demonstrates that training and use of resource recovery technologies is potentially associated with users' perceptions of human feces and resource recovery. Overall, composting latrine users responded significantly differently from non-composting latrine users and had more positive responses to statements favorable to resource recovery (e.g., human feces are a resource for the soil and they will use composted feces on crops and consume them). This held true even within the Indigenous and Latino ethnic group respondents. However, overall, Indigenous communities surveyed had more agreement to responses favorable to composting latrines demonstrating that culture and potentially lower income are crucial determinants of resource recovery perceptions.

Moreover, results from pit latrine and septic tank users demonstrated more negative perceptions of resource recovery than both composting latrine users and open defecators. For example 83% of other sanitation users (pit latrines and septic systems) agreed that handling human feces is a great health risk compared to 46% of open defecators and 40% of composting latrine owners ($p < 0.001$). Also, 68% of other sanitation users agreed it is "ok to touch treated human feces," whereas 86% of composting latrine owners and 76% of open defecators agreed ($p = 0.008$). Therefore, use or lack of use of a certain technology is potentially associated with a user's perception of resource recovery from waste more than other demographic characteristics such as age, gender, and education. As seen in Table 2, demographics other than ethnicity did not show as many statistically significant differences in statement responses. Overall, we need to think more holistically about how to integrate the resource recovery paradigm for a combination of on-site technologies especially water flushed systems as these may be more appropriate and desired by certain households.

3.3.2.8. "Modernity" and Resource Recovery Use and Perceptions. Although use of composting latrine technology is potentially associated with a more positive user perception of resource recovery, it is important to take into account the perception of "modernity" concerning a user's comparison of different sanitation technologies (traditional and improved pit latrines and pour-flush sewer or septic systems). It was apparent from field observations and interviews in this study that Latino respondents aspired to flush systems, as they viewed these as more modern. Composting latrines/toilets are more advanced and complex than other sanitation technologies, requiring more biogeochemical reactions for resource recovery and pathogen destruction, but has not necessarily been perceived that way due to their promotion in lower income and rural communities. Based on qualitative data collected, Latino respondents seemed less receptive to composting latrines due to sheer status. They viewed latrines, of all kinds, as gross and unsanitary. Many Latino respondents thought composting latrines were a poor people's toilet and any chance they had to upgrade to a flush toilet, they would.

In other studies respondents also aspired to an "upgraded" sanitation technology.[26,27] South African respondents aspired to flush toilets.[26] Some rural respondents in Malawi viewed composting latrines as more advanced because chambers were constructed with cement compared to traditional pit latrines made from local materials. However, other respondents in peri-urban areas Malawi whose pit latrines were made out of concrete did not see composting latrines as an improvement.[27] Cordova and Knuth (2005)[49] noted that rural communities will tend to follow the lead of urban sanitation users. Once composting toilets gain ground in urban settings, the rural arena will be more willing to accept composting toilets as well. Thus, promotion of composting latrines solely in rural, farming areas may not necessarily be correct or successful even though there may be an easier application and direct need for the composted excreta.

Although composting latrine users may be receptive to resource recovery, they may still aspire to what they perceive as a more modern or convenient sanitation option. In some developed countries, people have installed indoor composting toilets in their homes, vacation homes, and environmentally certified buildings that appear similar to flush toilets which could be a potential upgrade in developing countries.[28] Composting toilet use in wealthier communities should be promoted more to influence "modernity" perceptions. However, there is a need to innovate the components of on-site resource recovery technologies (such as the urine diversion tubes, doors, and toilet seats that often break) in a way that increases their durability without exorbitant cost for poorer users.

Lastly, composting latrine projects need long-term monitoring, maintenance, technical assistance, education, and marketing for sustained use to reap the important environmental, health, and economic benefits from resource recovery. For example, in South Africa, new tenants moved into a property with a composting toilet after the education campaign had finished and they were not aware of how to properly use it.[26] Most composting latrine projects, like many development projects, are short-term and funded by non-government organizations; leaving users with broken and malfunctioning systems that they do not have adequate knowledge or resources to repair.[27,37] Composting latrine projects in this study were limited given that communities may only receive a certain number of Peace Corps Volunteers and there is not consistent funding for compost latrine projects and continued training. Thus, 29% of latrines had missing pieces and 35% were not used properly ($N = 201$). Establishing collection services of the composted excrement and maintenance of the latrine including cash incentives, especially in urban areas, may increase adoption and sustained use of household composting toilet technologies.[28,50,51] Too often

DOI: 10.1021/acs.est.8b02431
Environ. Sci. Technol. 2018, 52, 11803−11812

development efforts are focused on the user-interface (toilet/latrine) and not the entire sanitation value chain including collection, treatment, and disposal of waste and recovery of resources.[50] As the world moves forward to provide safe and adequate water and sanitation for all in a resource limited world, ecological sanitation such as composting latrines are a promising technology that can achieve multiple SDGs. However, when implementing such sanitation, it is important to consider cultural and demographic characteristics that are associated with adoption of the technology and resource recovery perceptions of the users when designing and implementing ecological sanitation projects. This research demonstrated the potential association between different factors and resource recovery perceptions. The methods and results of this study should be used as a basis to design other studies to more rigorously quantify, analyze, and understand the factors associated with resource recovery perceptions by including both a pre and post survey on user perceptions of resource recovery for respondents who install resource recovery technologies as well as a control group over a large sample size.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.8b02431.

A map of the study communities (Figure S1) and list of interviews, observation, and survey questions (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: jm41@usf.edu; Phone: (813) 974-9896; Fax: (813) 974-2957.

ORCID

Colleen C. Naughton: 0000-0002-3923-7465
James R. Mihelcic: 0000-0002-1736-9264

Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under grant numbers 1243510 and 0965743.

■ REFERENCES

(1) WHO/UNICEF *Joint Monitoring Program (JMP) Website*; https://www.wssinfo.org/.
(2) Diarrheal Disease; http://www.who.int/mediacentre/factsheets/fs330/en/.
(3) *A Snapshot of the World's Water Quality: Towards a Global Assessment*; United Nations Environment Programme: Nairobi, Kenya, 2016; https://uneplive.unep.org/media/docs/assessments/unep_wwqa_report_web.pdf.
(4) *United Nations Sustainable Development Goals* Website; http://www.un.org/sustainabledevelopment/sustainable-development-goals/
(5) Asano, T.; Levin, A. D. Wastewater reclamation, recycling and reuse: Past, present, and future. *Water Sci. Technol.* **1996**, *33* (10−11), 1−14.
(6) McCarty, P. L.; Bae, J.; Kim, J. Domestic wastewater treatment as a net energy producer- Can this be achieved? *Environ. Sci. Technol.* **2011**, *45* (17), 7100−7106.
(7) Ren, Z. J.; Umble, A. K. Water treatment: Recover wastewater resources locally. *Nature* **2016**, *529*, 25.
(8) *State of the Art Compendium Report on Resource Recovery from Water*; The International Water Association: London, U.K., 2015; http://www.iwa-network.org/publications/state-of-the-art-compendium-report-on-resource-recovery-from-water/.
(9) *The United Nations World Water Development Report 2017: Wastewater: The Untapped Resource*; United Nations World Water Assessment Program; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2017; http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/.
(10) Guest, J. S.; Skerlos, S. J.; Barnard, J. L.; Beck, M. B.; Daigger, G. T.; Hilger, H.; Jackson, S. J.; Karvazy, K.; Kelly, L.; Macpherson, L.; Mihelcic, J. R.; Pramanik, A.; Raskin, L.; Van Loosdrecht, M. C.; Yeh, D.; Love, N. G. A new planning and design paradigm to achieve sustainable resource recovery from wastewater. *Environ. Sci. Technol.* **2009**, *43* (16), 6126−6130.
(11) McConville, J. R.; Künzle, R.; Messmer, U.; Udert, K. M.; Larsen, T. A. Decision support for redesigning wastewater treatment technologies. *Environ. Sci. Technol.* **2014**, *48* (20), 12238−12246.
(12) Ries, M.; Trotz, M.; Vairavamoorthy, K. 'Fit-for-Purpose' sustainability index: a simplified approach for U.S. water utility sustainability assessment. *Water Practice & Technology.* **2016**, *11* (1), 35−47.
(13) Mihelcic, J. R.; Ren, Z. J.; Cornejo, P. K.; Fisher, A.; Simon, A. J.; Snyder, S. W.; Zhang, Q.; Rosso, D.; Huggins, T. M.; Cooper, W.; Moeller, J.; Rose, B.; Schottel, B. L.; Turgeon, J. Accelerating innovation that enhances resource recovery in the wastewater sector: Advancing a national testbed network. *Environ. Sci. Technol.* **2017**, *51* (4), 7749−7758.
(14) Coats, E. R.; Wilson, P. I. Toward nucleating the concept of the Water Resource Recovery Facility (WRRF): Perspective from the principal actors. *Environ. Sci. Technol.* **2017**, *51*, 4158−4164.
(15) Bair, R. A.; Ozcan, O. O.; Calabrian, J. L.; Dick, G. H.; Yeh, D. H. Feasibility of anaerobic membrane bioreactor (AnMBR) for onsite sanitation and resource recovery (nutrients, energy, and water) in urban slums. *Water Sci. Technol.* **2016**, *72* (9), 1543−1551.
(16) *Faecal Sludge Management: Systems Approach for Implementation and Operation*; Strande, L., Ronteltap, M., Brdjanovic, D., Eds.; IWA publishing: London, U.K., 2014; https://www.eawag.ch/en/department/sandec/publikationen/faecal-sludge-management-fsm-book/.
(17) Lansing, S.; Bowen, H.; Gregoire, K.; Klavon, K.; Moss, A.; Eaton, A.; Lai, Y.-J.; Iwata, K. Methane production for sanitation improvement in Haiti. *Biomass Bioenergy* **2016**, *91*, 288−295.
(18) Morgan, P. R. *Toilets That Make Compost: Low-Cost, Sanitary Toilets That Produce Valuable Compost for Crops in an African Context*; Stockholm Environment Institute: Stockholm, Sweden, 2007; http://www.ecosanres.org/pdf_files/ToiletsThatMakeCompost.pdf.
(19) Fry, L. M.; Mihelcic, J. R.; Watkins, D. W. Water and nonwater-related challenges of achieving global sanitation coverage. *Environ. Sci. Technol.* **2008**, *42* (4), 4298−4304.
(20) Mihelcic, J. R.; Fry, L. M.; Myre, E. A.; Phillips, L. D.; Barkdoll, B. D. *Field Guide to Environmental Engineering for Development Workers: Water, Sanitation, And Indoor Air*; American Society of Civil Engineers: Reston, VA, 2009.
(21) Strenström, T. A.; Seidu, R.; Ekane, N.; Zurbrügg, C. *Microbial Exposure and Health Assessments in Sanitation Technologies and Systems*, EcoSanRes Series; Stockholm Environment Institute: Stockholm, Sweden, 2011−1; http://www.ecosanres.org/pdf_files/Microbial_Exposure_&_Health_Assessments_in_Sanitation_Technologies_&_Systems.pdf.
(22) Jenkins, M. W.; Cairncross, S. Modelling latrine diffusion in Benin: towards a community typology of demand for improved

sanitation in developing countries. *J. Water Health* **2010**, *8* (1), 166−183.
(23) Dreilbelbis, R.; Jenkins, M.; Chase, R. P.; Torondel, B.; Routray, P.; Boisson, S.; Clasen, T.; Freeman, M. Development of a multidimensional scale to assess attitudinal determinants of sanitation uptake and use. *Environ. Sci. Technol.* **2015**, *49*, 13613−13621.
(24) Garn, J. V.; Sclar, G. D.; Freeman, M. C.; Penakalapati, G.; Alexander, K. T.; Brooks, P.; Rehfuess, E. A.; Boisson, S.; Medlicott, K. O.; Clasen, T. F. The impact of sanitation interventions on latrine coverage and latrine use: A systematic review and meta-analysis. *Int. J. Hyg. Environ. Health* **2017**, *220* (2B), 329−340.
(25) Tumwebaze, I. K.; Orach, C. G.; Nakayaga, J. K.; Karamagi, C.; Luethi, C.; Niwagaba, C. Ecological sanitation coverage and factors affecting its uptake in Kabale municipality, Western Uganda. *Int. J. Environ. Health Res.* **2011**, *21* (4), 294−305.
(26) Mkhize, N.; Taylor, M.; Udert, K. M.; Gounden, T. G.; Buckley, C. A. Urine diversion dry toilets in eThekwini Municipality, South Africa: acceptance, use and maintenance through users' eyes. *J. Water, Sanit. Hyg. Dev.* **2017**, *7* (1), 111−120.
(27) Kumwenda, S.; Msefula, C.; Kadewa, W.; Ngwira, B.; Morse, T.; Ensink, J. H. J. Knowledge, attitudes and practices on use of Fossa Alternas and double vault urine diverting dry (DVUDD) latrines in Malawi. *J. Water, Sanit. Hyg. Dev.* **2016**, *6* (4), 555−568.
(28) Cordova, A.; Knuth, B. A. User satisfaction in large-scale, urban dry sanitation programs in Mexico. *Urban Water J.* **2005**, *2* (4), 227−243.
(29) Lienert, J.; Larsen, T. A. High acceptance of urine source separation in seven European countries: a review. *Environ. Sci. Technol.* **2010**, *44* (2), 556−566.
(30) Nawab, B.; Nyborg, I. L. P.; Esser, K. B.; Jenssen, P. D. Cultural preferences in designing ecological sanitation system in North West Frontier Province, Pakistan. *Journal of Environmental Psychology* **2006**, *26*, 236−246.
(31) Naughton, C. C.; Sissoko, H. T.; Mihelcic, J. R. Assessing factors that lead to usage of appropriate technology handwashing stations in Mali, West Africa. *J. Water, Sanit. Hyg. Dev.* **2015**, *5* (2), 279−288.
(32) *Progress on Sanitation and Drinking-Water 2013 Update*; WHO/UNICEF Joint Monitoring Programme; United Nations: New York, 2013; http://www.wssinfo.org/fileadmin/user_upload/resources/JMPreport2013.pdf.
(33) *Panamá en Cifras: años 2006−2010*; Instituto Nacional de Estadística y Censo: Panama City, Panama, 2011; http://www.contraloria.gob.pa/inec/archivos/P3521DATOS_GENERALES.pdf.
(34) *Iniciativa Latinoamericana y Caribeña para el Desarrollo Sostenible: Indicadores de Seguimiento − Panamá 2010 Indicadores*; Autoridad Nacional del Ambiente/ Controlaría General de la República/ Instituto Nacional de Estadística y Censo/ Programa de las Naciones Unidas Para el Medio Ambiente: Panama City, Panama, 2010; http://www.pnuma.org/deat1/pdf/ILAC%20vFINAL%202010.pdf.
(35) Food and Agriculture Organization of the United Nations Panama Country Profile; http://www.fao.org/countryprofiles/index/en/?iso3=PAN.
(36) Mihelcic, J. R.; Phillips, L. C.; Watkins, D. W. Integrating a global perspective into education and research: engineering international sustainable development. *Environ. Eng. Sci.* **2006**, *23* (3), 426−438.
(37) Wilbur, P. A. *An Evaluation of the Use of Composting Latrines and the Perceptions of Excrement in Ngäbe Communities in Panama*; MSEnvE Thesis, University of South Florida: Tampa, FL, 2014; https://scholarcommons.usf.edu/etd/5331/.
(38) *Informe Nacional de Desarollo Humano: Panama 2014*; United Nations Development Programme: Panama City, Panama, 2014. http://media.gestorsutil.com/PNUD_web/651/centro_informacion_documentos/docs/0675529001392164175.pdf.
(39) Mariwah, S.; Drangert, J. O. Community perceptions of human excreta as fertilizer in peri-urban agriculture in Ghana. *Waste Manage. Res.* **2011**, *29* (8), 815−822.
(40) Mehl, J.; Kaiser, J.; Hurtado, D.; Gibson, D.; Izurieta, R.; Mihelcic, J. Pathogen destruction and solids decomposition in composting latrines: study of fundamental mechanisms and user operation in rural Panama. *J. Water Health* **2011**, *9* (1), 187−199.
(41) Mara, D.; Lane, J.; Scott, B.; Trouba, D. Sanitation and Health. *PLoS Med.* **2010**, *7* (11), e1000363.
(42) Chambers, R.; Kar, K. *Handbook on community-led total sanitation*. Plan UK: London, U.K., 2008; http://www.communityledtotalsanitation.org/sites/communityledtotalsanitation.org/files/cltshandbook.pdf.
(43) Rheinländer, T.; Samuelsen, H.; Dalsgaard, A.; Konradsen, F. Hygiene and sanitation among ethnic minorities in Northern Vietnam: does government promotion match community priorities? *Social Science & Medicine* **2010**, *71* (5), 994−1001.
(44) Seymour, Z.; Hughes, J. Sanitation in developing countries: a systematic review of user preferences and motivations.. *J. Water, Sanit. Hyg. Dev.***2014**, *4* (4), 681−690. DOI: DOI: 10.2166/washdev.2014.127.
(45) Kvarnström, E.; Emilsson, K.; Stintzing, A. R.; Johansson, M.; Jönsson, H.; Petersens, E.; Schönning, C.; Christensen, J.; Hellström, D.; Qvarnström, L.; Ridderstolpe, P.; Drangert, J. O. *Urine Diversion: One Step towards Sustainable Sanitation*; Stockholm Environment Institute: Stockholm, Sweden, 2006−1; http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf.
(46) Katukiza, A. Y.; Ronteltap, M.; Niwagaba, C. B.; Foppen, J. W. A.; Kansiime, F.; Lens, P. N. L. Sustainable sanitation technology options for urban slums. *Biotechnol. Adv.* **2012**, *30*, 964−978.
(47) Simha, P.; Lalander, C.; Vinneras, B.; Ganesapillai, M. Farmer attitudes and perceptions to the re-use of fertilizer products from resource-oriented sanitation systems- The case of Vellore, South India. *Sci. Total Environ.* **2017**, *581−582*, 835−896.
(48) Verbyla, M. E.; Oakley, S. M.; Mihelcic, J. R. Wastewater infrastructure for small cities in an urbanizing world: Integrating protection of human health and the environment with resource recovery and food security. *Environ. Sci. Technol.* **2013**, *47*, 3598−3605.
(49) Cordova, A.; Knuth, B. A. Barriers and strategies for dry sanitation in large-scale and urban settings. *Urban Water J.* **2005**, *2* (4), 245−262.
(50) Tilley, E.; Strande, L.; Lüthi, C.; Mosler, H.-J.; Udert, K. M.; Gebauer, H.; Hering, J. G. Looking beyond technology: An integrated approach to water, sanitation and hygiene in low income countries. *Environ. Sci. Technol.* **2014**, *48*, 9965−9970.
(51) Tilley, E.; Günther, I. The Impact of Conditional Cash Transfer on Toilet Use in EThekwini, South Africa. *Sustain.* **2016**, *8* (10), 1070.

DOI: 10.1021/acs.est.8b02431
Environ. Sci. Technol. 2018, 52, 11803−11812