Farmer's Perception in the Central Amazon on the Agricultural use of Human Urine

Percepción de agricultores en la Amazonia Central sobre el uso agrícola de orina humana

Percepção de agricultores na Amazônia Central sobre o uso agrícola de urina humana

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Abstract

Urine Diverting Dry Toilets (UDDT) provide a technological alternative for the challenging environments found in Amazonia, and have the advantage of not consuming water. To verify their viability, however, it is necessary to understand users' behavior in relation to the use of toilets' byproducts. The objective of the present study was to evaluate farmers' perceptions of the use of human urine as a fertilizer for agricultural crops in Central Amazon. We interviewed 73 smallholder farmers from a rural village in Tefé County and in the municipal farmers' market of Tefé. It was verified that 12% of farmers have knowledge of the use of human urine in agriculture, and that more than a third consider it possible to use urine in their gardens and fields. However, more than half did not consider the possibility of using urine, manifesting concerns about crop development and doubts regarding the efficacy of its use as a fertilizer. The informants believed that crops watered with urine would be adequate for human consumption. It is possible to conclude that human urine has the potential to be used in agriculture in the study region and we understand that dry toilets should not be taken as the only alternative for sanitation in Amazon.

Keywords: UDDT; ecological sanitation; floodplain.

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Resumen

El Sanitario Seco con Separación de Orina (ssso) es una tecnología alternativa para los desafíos ambientales en la Amazonia, teniendo la ventaja de no utilizar agua en sus procesos. Para verificar su viabilidad, sin embargo, es necesario comprender el comportamiento de los usuarios con relación al uso de los subproductos de los sanitarios. El objetivo del presente estudio fue evaluar la percepción de los agricultores sobre el uso de orina humana como fertilizante para cultivos agrícolas en la Amazonía Central. Se entrevistaron setenta y tres agricultores familiares de una villa rural de Tefé y del mercado municipal de agricultores de Tefé. Se verificó que el 12% de los agricultores tienen conocimiento del uso de orina humana en la agricultura y que más de un tercio consideran posible usar orina en sus jardines y cultivos. Sin embargo, más de la mitad no consideró la posibilidad del uso de orina, manifestando preocupaciones sobre el desarrollo de las culturas y dudas en cuanto a la eficacia de su uso como fertilizante. Pero los informantes creen que los cultivos irrigados con orina son adecuados para el consumo humano. Se concluye que la orina humana tiene potencial para ser utilizada en la agricultura en la región de estudio y entendemos que los sanitarios secos no deben ser tomados como la única alternativa para saneamiento en la Amazonia.

Palabras clave: ssso; saneamiento ecológico; várzea (llanura de inundación).

Resumo

Sanitário Seco com Separação de Urina (sssu) é uma tecnologia alternativa para os desafios ambientais na Amazônia, possuindo a vantagem de não utilizar água em seus processos. Para verificar sua viabilidade, no entanto, é necessário compreender o comportamento dos usuários em relação ao uso dos subprodutos dos sanitários. O objetivo do presente estudo foi avaliar a percepção dos agricultores sobre o uso de urina humana como fertilizante para culturas agrícolas na Amazônia Central. Foram entrevistados 73 agricultores familiares de uma vila rural de Tefé e no mercado municipal de agricultores de Tefé. Verificou-se que 12% dos agricultores têm conhecimento do uso de urina humana na agricultura e que mais de um terço consideram possível usar urina em seus jardins e cultivos. No entanto, mais da metade não considerou a possibilidade de uso de urina, manifestando preocupações sobre o desenvolvimento das culturas e dúvidas quanto a eficácia de seu uso como fertilizante. Mas os informantes acreditam que as culturas irrigadas com urina são adequadas para o consumo humano. Conclui-se que a urina humana tem potencial para ser utilizada na agricultura na região de estudo e entendemos que os sanitários secos não devem ser tomados como a única alternativa para saneamento na Amazônia.

Palavras-chave: UDDT; saneamento ecológico; várzea.

Introduction

Across the globe, more than 2.5 billion people do not have access to adequate sanitation facilities (Unesco 2017). In the Northern region of Brazil, the scenario is much the same; here, a mere 8.4% of rural houses are linked to sewage networks, or have their own septic tanks (ibge 2011), leaving 3.9 million people without access to proper sanitation.

Urine Diverting Dry Toilets (UDDT) are considered a promising technology to meet the demand for sanitation services based on the following this positive characteristics: (a) that water is not needed to treat waste and (b) that feces are separated from urine at the source, and (c) this urine byproduct can be used as fertilizer in agricultural production systems (Deegener, Samwel & Gabizon 2006).

Besides that, the UDDT is a new perspective to sanitation. It allows the *productive sanitation* approach, defined as the use of human excreta in agricultural production that contribute to food security trough the recovery of resources at the source, reduction of consumption and pollution of water sources, and supporting the conservation of soil fertility (Gensch et al. 2012). A study conducted by Simha, Zabaniotou & Ganesapillai (2017) showed that human urine can produce ~4.5 Kg urea per person per year; this fact, and others presented by these authors, is an example of the potential of human urine for the contribution for the bio-based economy.

The use of human urine as a fertilizer is a widespread practice because of its chemical composition. According to a literature review (Karak & Bhattacharyya 2011), each year, one individual produces 2.5 to 4.3 kilos of nitrogen, 0.7 to 1.0 kilo of phosphorus, and 0.9 to 1.0 kilo of potassium, all of which are elements used as fertilizers in agriculture. These properties define its potential as a fertilizer, which has been proven by numerous experiments with different crops, for example: cabbage and beets cultivated in Finland (Pradhan et al. 2007; 2010); corn, tomatoes, carrots, and beets in South Africa (Mnkeni et al. 2008) ; bananas in India (Sridevi et al. 2009); carrots and cabbage in Ethiopia (Seid & Chimdessa 2014); tomatoes in Zambia (Kawanga 2015); chickpeas in India (Ganesapillai et al. 2016) among other examples.

Despite this potential, the successful use of UDDT and its sub-products (urine and feces) as fertilizers, is directly related to building awareness about the technology and its potential among those involved (Wendland, Deegener & Jorritsma 2011). In addition, social and cultural factors are directly related to the acceptance of sanitation technologies (Nawab et al. 2006).

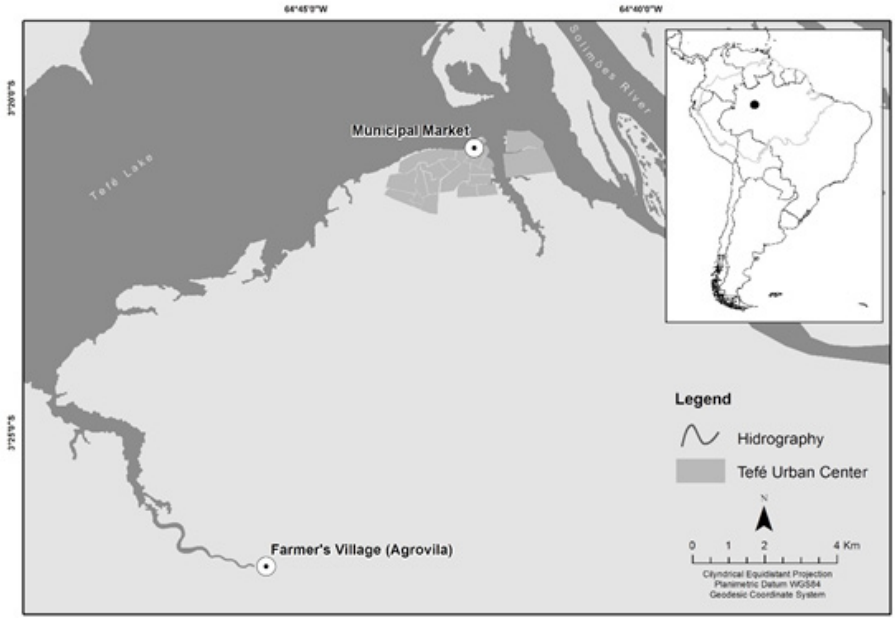
Studies regarding users' and farmers' perceptions have been conducted in different regions of the world, and results vary according to the local culture and previous experience with urine as a fertilizer (Okem et al. 2013; Lienert et al. 2003). In a recent research carried out in Southern India with the application of face-to-face interviews, the authors stated that "the survey responses indicated that besides socio–demographic factors, other factors such as 'trust' might have to be taken into consideration when planning and implementing nutrient recycling programmes" (Simha et al. 2017).

Data on perceptions of the use of human waste in food production can help determine the acceptance of sanitation technologies among different social groups. Results can also be used as a basis for the creation of rules and legislation that encourage the utilization of human urine as a fertilizer (Manyanhaire & Mutangadura-Mangeya 2009).

Considering that in rural areas of the Brazilian Amazon, access to adequate sanitation is insufficient, and that the UDDT is a promising technology for this environment, this study investigated Amazonian farmers' perception

regarding the use of human urine as a fertilizer. In our case, it is necessary to understand the point of view of users before promoting the use of UDDT and its byproducts in the agriculture.

Figure 1. Location of farmer interview sites



Source: Geographic Information System - Mamirauá Institute.

Methodology

This study was conducted in the county of Tefé in the Brazilian Amazon, in a rural settlement or village ("Agrovila") and in the municipal agricultural market in the city of Tefé, Amazonas state (figure 1), March and April 2016. These places were selected for aggregate a large number of the farmers from the city.

We interviewed 73 smallholder farmers individually that were willing to participate in the research, independent of gender. The farmers were selected randomly and the interviews occurred opportunistically at the farmer's home and in the place where they work at the market. Each interview lasted an average of 15 minutes and was conducted by one researcher. The only criteria to choose the respondents was that they should be the family leader and indeed a farmer. Based on our experience, we understand that generally the family leader is the person that takes decision about the agricultural production, independently on gender.

It was used semi-structured questionnaires. Some questions were adapted from the literature (Lamichhane & Babcock 2013; Manyanhaire & Mutangadura-Mangeya 2009) and the rest were created based on the local situation. The main questions were about: social characteristics (schooling, age, sanitation access…); agriculture (use of pesticides, cultures types, field area, bio-fertilizers); and questions about human urine (knowledge, use availability, ways for the collect human urine, and others).

We interviewed at least 70% of the household farmers of the village. At the municipal market we calculate 50% of all farmers that sell their products daily and live in the rural area of Tefé, outside "Agrovila".

The questions aimed to gather the following data: socioeconomic profile, conditions of access to water and sanitation, information on chemical and organic fertilizers, crop characteristics, and participants' perceptions on the use of human urine in agriculture with a view to determine if the use of UDDT and its byproducts are a viable option to promote in this area.

The costs of UDDT was not informed to the interviewed to avoid any influence on the responses. Our purpose was intrinsically related to farmers' perceptions about urine use for agriculture, regardless of costs.

We analyzed the data applying descriptive statistics using Excel (measures of central tendency and measures of variability). To verify the influence of social characteristics on the willingness to use urine we conducted an Analysis of Variance.

This research was approved by the Ethics Committee of the Mamirauá Institute for Sustainable Development.

Results and discussion

Socio-economic and health characteristics

Socio-economic attributes of research subjects can be observed in table 1. Seventy percent (n = 51) of all participants reported earning less than US$ 200 per month from agricultural work, and 64% of participants declared that they do not have any other type of work. Of those who work with additional activities (36%), most (61%) reported to also engage in fishing for additional income or subsistence. The farmers rear animals only for subsistence.

Most of their houses (84%) have basic piped water (doubtful quality); while 11% get their drinking water from rivers or streams. According to the answers 11% of household informants do not have toilets. In these cases, people use their neighbors' or relatives' facilities, or go to a so-called *pau-da-gata* (cat walk) composed of a single log, where users defecate in the squatting position (Gomes et al. 2015), generally near a water body without a subsequent cleaning.

Table 1. Profile of participants

		Village	%	Market	%	Total
Gender	Female	33	45	10	14	59
	Male	22	30	8	11	41
Age	19-38	24	33	8	11	44
	39-58	19	26	7	10	36
	59-78	12	16	3	4	20
People per Household	1-4	29	40	8	11	51
	5-8	22	30	8	11	41
	9-12	4	5	1	1	7
	13-16		0	1	1	1
Piped Water	No	1	1	11	15	16
	Yes	54	74	7	10	84
Toilet	No	6	8	2	3	11
	Yes	49	67	16	22	89
Other activities besides agriculture	No	40	55	7	10	64
	Yes	15	21	11	15	36

Source: Elaborated by the authors.

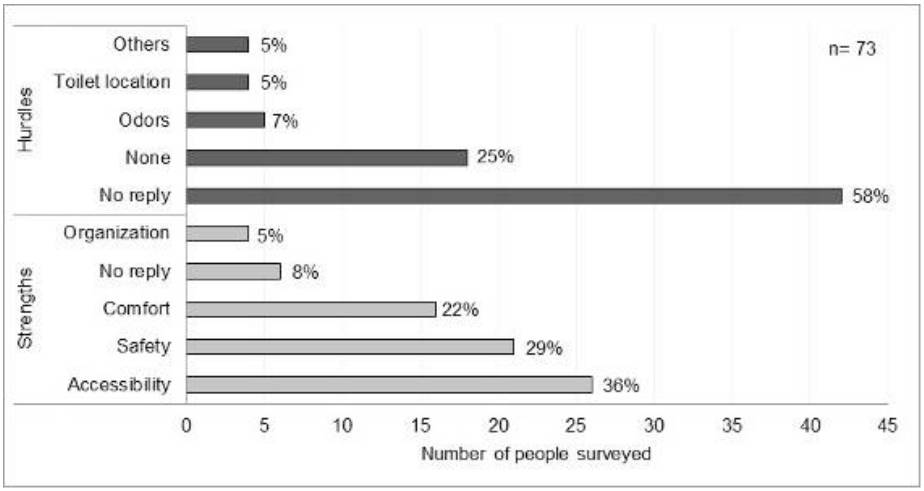
Of the 65 houses that have toilets, 63% use a simple septic tank and 37% use a waterless pit latrine. Even the latter technology is considered improved sanitation, they are not well constructed and managed, and indeed leads to the contamination of soils and water bodies. Besides the market be a public space, there is not public toilets or access to water for the workers or population in general.

Sixty five percent of interviewed farmers identified accessibility, comfort and safety (87% combined) as the main factors motivating the installation of toilets in their homes (figure 2). On the other hand, obstacles to toilet installation included: toilet location (5%); foul odor (7%); other miscellaneous problems (5%), including concerns regarding the flooding (considering the seasonal rains in Amazonia), proliferation of diseases and lack of a toilet well maintained.

It is important to emphasize that only 25% of the participants stated that they perceived not a single barrier to having a toilet. At the same time 58% of the interviewed farmers did not reply about the hurdles. They were not comfortable to talk about the hurdles. Probably they had this behavior to avoid an undesired atmosphere with the researchers. This behavior is typical from the local people from Amazon. But this behavior is ambiguous: or the farmers really do not perceive a hurdle on the toilets considering the benefits, or they perceive it and prefer not to talk about it. We believe in the first hypothesis. The difficulty to talk about human excreta can be an important factor in this case. Simha et al. (2017) have mentioned *faecophobia;* this

term means a personal or cultural response to the fact that human faeces are malodorous and potentially dangerous (Winblad and Simpson-Hébert 2004). More studies are necessary to know the existence of *faecophobia* in Agrovila Farmers.

Figure 2. Strengths and barriers to the use of toilets in household



Source: Elaborated by the authors

A crucial aspect related to sanitation is the number of diseases linked to poor sanitary conditions. Pathogenic agents existent in human faeces, such as viruses, bacteria, protozoa and helminths, compromise human health (Mara et al. 2010). Our survey confirmed that health is not always perceived as an important factor promoting improved sanitation (health was not even mentioned). As was the case in our study, other publications demonstrate that health was not highlighted as a positive factor motivating the adoption of sanitation technologies. Health is indeed second to characteristics of wellbeing, convenience, and organization of collective space, among other factors (Roma et al. 2013; O'Connell 2014).

Agriculture and the use of fertilizers and human urine

The main economic activity of participants is agriculture (64%), where bitter manioc (*Manihot esculenta*) and sweet manioc are cultivated by almost three quarters of interviewed farmers (table 2). The area under agricultural production varies from 1.0 to 3.1 hectares, in 86% of the cases. It was also verified that 71% of the interviewed farmers do not use pesticides.

Table 2. Characteristics of agricultural activities

		Number of participants	%
Farm plot (hectares)	0.1-3.0	63	86
	3.1-6.0	6	8
	6.1-9.1	2	3
	No reply	2	3
Main crop	Bitter and Sweet Manioc	52	71
	Fruits	7	10
	Vegetables and Greens	14	19
Uses pesticides	No	52	71
	Yes	21	29
Uses industrial fertilizers	No	53	73
	Yes	20	27
Fertilizer	NPK	12	60
	Urea	4	20
	Other	2	10
	No reply	2	10

Source: Elaborated by the authors.

Only 27% (n = 20) of the interviewed farmers buy fertilizers locally and, of those, 60% (n = 12) cultivate vegetables and greens. Sixty-five percent of the interviewed farmers use between 1 to 10 kilograms of industrial fertilizers, the most common being NPK (nitrogen, phosphorus and potassium). The frequency of acquisition is 1 to 3 times per year, in 63% of the cases; spending varies between US$ 1.00 and US$ 101.00. Money spent on fertilizers, in general, represents only 5% of interviewed farmers' income.

In relation to the use of organic waste (compost materials), results indicate that 70% of participants use this material to feed livestock; four percent bury or use it in their gardens.

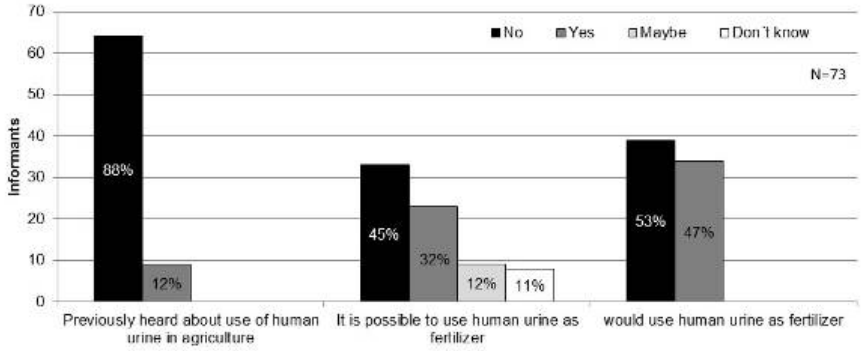
Use of organic fertilizers

It was found that 12% of interviewed farmers knew about this practice. A third of the participants believe that it is possible to use human urine in their crops (figure 3). A study in Hawaii found satisfying results when asking if human waste could be used as fertilizer, where 92% of the participants answered affirmatively—despite the fact that no historical evidence of the use of human urine as a fertilizer exists for Hawaii (where the study took place) (Lamichhane & Babcock 2013). In Brazil, we identified some studies conducted on corn (Araújo et al. 2015), lettuce (Chrispim & Nolasco 2012) and millet (Santos Júnior et al. 2015) with promising results and good applicability potential, but none were conducted in Amazonas state.

Of the 45% that do not consider the possibility of using urine as fertilizer, 70% (n = 16) did not know how to justify their answer, saying only that it was not adequate. Some factors are directly linked to the rejection of using urine, such as religion, culture and soil fertility (Adewole et al. 2013; Drangert & Bahadar 2011). In our case, our hypothesis is that these factors had an important role in shaping farmers' perceptions, even if subconsciously.

In a study conducted in Switzerland, 42% of farmers said they would purchase a "urine-based fertilizer"; 43% were in favor of altering regulations for the approval of this kind of fertilizer, and more than half of them had a positive view of the use of human urine as a fertilizer (Lienert et al. 2003). These authors' opinion was that the demand for nutrients by Switzerland's producers could, to a certain degree, be supplied by human urine.

Figure 3. Participants' perception of the use of human urine



Source: Elaborated by the authors.

One interesting result from the Switzerland study is that 47% (n = 34) of farmers report that they would use human urine as a fertilizer even if the origin of the urine was unknown (Lienert et al. 2003). Origin is an important factor that needs to be considered. In a study conducted in South Africa, more than 50% of participants stated that they would use human urine as fertilizer if it was from family members (Okem et al. 2013). In our case study, this aspect did not determine acceptance because we did not observe a cultural pattern related to urine use. Participants did not consider the origin of urine an important factor in determining its re-use. In other words, whether the source was from close relatives or not, did not influence participants' decisions to re-use this byproduct. Thus, our results show that concern regarding origin is not culturally relevant in our case and probably for all farmers from the city; in fact, perception varies according to cultural norms (Drangert 1998).

Of the farmers willing to use urine-based fertilizer, participants justified their willingness to use urine in the following terms: (a) they would like to try this method; (b) they have a positive expectation regarding crop development; (c) they believe it could be used as an insecticide.

Interviewed farmers who would not use urine (53%) primarily expressed concerns regarding crop development (29%), as well as doubts related to the efficacy of urine as a fertilizer. In a study the authors found that only 9.7% of their participants believed that urine would help crop development (Okem et al. 2013). Other recent study identified the same questions associated with the crop production (Simha et al. 2017). This kind of data reflects farmer concerns for crop growth and the possible negative impacts of urine on production.

As our data shows, the non-acceptance of human urine use as a fertilizer is understandable behavior, mostly explained by participants' lack of knowledge about this subject. In a similar study in South Africa, results were identical; farmers believe that urine may be harmful to crops, but at the same time, most of them do not have a clear opinion regarding the subject (Duncker, Matsebe & Moilwa 2007). This pattern repeats in a study conducted in Nigeria, where most participants did not have previous knowledge of the possibility of using urine as a fertilizer; nonetheless many considered it a good agricultural innovation (Cofie, Olubenga & Amoah 2010).

The results of Analysis of Variance (Anova) indicate that social attributes (education, gender and age) of the subjects do not influence their willingness to use human urine as a fertilizer. It is possible to interpret these results as positive since social attributes seem not to relate to farmers' perceptions about the use of urine.

Almost half of the farmers interviewed stated that they would be willing to invest in technologies to collect and store urine for later use. On the other hand, most participants did not know how much this type of investment might cost. Of the 32% that provided this information, the values ranged from US$ 1 to US$ 90. More than half of the participants (59%) believe that crops irrigated with human urine are acceptable for human consumption and 80% (n = 60) would like to receive more information about its use in agriculture. These results demonstrate farmers' interest in the subject. We agree with Okem et al (Okem et al. 2013) who called for more studies on this subject in which end-users are involved so as to increase knowledge on the potential use of urine as a fertilizer. People need to feel safe and confident when presented with a new idea or technology, so that doubts do not form barriers in obtaining good results—in this case, satisfactory results regarding the use of urine in agriculture.

Conclusion

It is evident from this study that users' perceptions should be taken into account before any intervention is made in these rural communities. It is very important to understand the users' point of view regarding sanitation technologies before any promotion action for adoption it, once the users are the responsible for its success. Furthermore, it is necessary to consider the costs to implement this technology e share this information with the community using adequate methodologies. We recommend further studies on this issue.

This research showed that the use of human urine is feasible practice in this region of Amazonia considering the perceptions aspects, and thus the UDDT can be promoted by local governments and sanitation practitioners.

Taking into account that most of rural Amazonia features poor sanitary conditions, and that almost half of the end-users present themselves as open to the idea of using human urine from dry toilets, we conclude that such technology has the potential for application in the region. Of course dry toilets should not be seen as the only alternative for sanitation in Amazonia, but rather exist as a viable option to improve the population's access to sustainable sanitation services.

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References

ADEWOLE, A.T., OYEKALE, A.S., OLUWA, A. & COFIE, O. (2013). Farmers' Perception on the Use of Urine for Growing Vegetables in Ibadan. *Journal of Human Ecology*, 41(1): 19-23.

ARAÚJO, N.C., DE AMORIM COURA, M., DE OLIVEIRA, R., MEIRA, C.M. & OLIVEIRA, S.J. (2015). Cultivo hidropônico de milho fertirrigado com urina humana como fonte alternativa de nutrientes. *Irriga*, 20(4): 718-729. http://revistas.fca.unesp.br/index.php/irriga/article/view/1751/1350

CHRISPIM, M. & NOLASCO, M. (2012). Human urine as fertilizer: Feasibility study of use in corn and lettuce cultivation in a university campus in Brazil. Study presented at 4th International Dry Toilet Conference. Tampere, Finland. August 22-25.

COFIE, O., OLUBENGA, A. & AMOAH, P. (2010). Introducing urine as an alternative fertiliser source for urban agriculture: Case studies from Nigeria and Ghana. *Urban Agriculture Magazine*, 23(2): 49-50.

DEEGENER, S., SAMWEL, M. & GABIZON, S. (2006). *Urine diverting toilets. Principles, operation and construction.* Utrecht: WECF.

DRANGERT, J. & BAHADAR, N. (2011). A cultural-spatial analysis of excreting, recirculation of human excreta and health. The case of North West Frontier Province, Pakistan. *Health Place,* 17(1): 57-66. https://doi.org/10.1016/j.healthplace.2010.08.012

DRANGERT, J.O. (1998). Fighting the urine blindness to provide more sanitation options. *Water SA*, 24(2): 157-164.

DUNCKER, L., MATSEBE, G.N. & MOILWA, N. (2007). *The social/cultural acceptability of using human excreta (faeces and urine) for food production in rural settlements in South Africa.* Republic of South Africa: Water Research Commission.

GANESAPILLAI, M., SIMHA, P., BEKNALKAR, S.S. & SEKHAR, D.M. (2016). Low-grade rock phosphate enriched human urine as novel fertilizer for sustaining and improving agricultural productivity of Cicerarietinum. *Sustainable Production and Consumption,* 6: 62-66. https://doi.org/10.1016/j.spc.2016.01.005

GENSCH, R., DAGERSKOG, L., VAN VEENHUIZEN, R., WINKER, M. & DRECHSEL, P. (2012). Productive sanitation and the link to food security. Factsheet of Working Group 5. Sustainable Sanitation Alliance (SuSanA).

GOMES, M.C., MOURA, E.A., PEDRO, J.P., BEZERRA, M.M. & BRITO, O. (2015). Sustainability of a sanitation program in flooded areas of the Brazilian Amazon. *Journal of Water Sanitation and Hygiene for Development,* 5(2): 261-270. https://doi.org/10.2166/washdev.2015.123

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. (2011). *Censo demográfico 2010: Características da população e dos domicílios, resultados do universo.* Rio de Janeiro: IBGE.

KARAK, T. & BHATTACHARYYA, P. (2011). Human urine as a source of alternative natural fertilizer in agriculture: A flight of fancy or an achievable reality?. *Resources, Conservation and Recycling,* 55(4): 400-408. https://doi.org/10.1016/j.resconrec.2010.12.008

KAWANGA, O.C. (2015). Urine drip fertigation of tomatoes: a solution to chemical fertilizer. Study presented at 5th International Dry Toilet Conference. Tampere, Finland. August 19-22.

LAMICHHANE, K. & BABCOCK, R. (2013). Survey of attitudes and perceptions of urine-diverting toilets and human waste recycling in Hawaii. *Science of The Total Environment*, 443: 749-756. https://doi.org/10.1016/j.scitotenv.2012.11.039

LIENERT, J., HALLER, M., BERNER, A., STAUFFACHER, M. & LARSEN, T. (2003). How farmers in Switzerland perceive fertilizers from recycled anthropogenic nutrients (urine). *Water Science and Technology*, 48(1), http://www.ircwash.org/sites/default/files/Lienert-2003-How.pdf

Manyanhaire, I.O. & Mutangadura-Mangeya, S. (2009). Perceptions on ecological sanitation in Zimbabwe: the case of Masiyararwa communal area in Zvimba District of Mashonaland West Province. *Journal of Sustainable Development in Africa,* 11(1). Pennsylvania: Clarion University of Pennsylvania.

Mara, D., Lane, J., Scott, B. & Trouba, D. (2010). Sanitation and health. *PLoS Med* 7(11): e1000363. https://doi.org/10.1371/journal.pbio.1002422

Mnkeni, P.N.S., Kutu, F.R., Muchaonyerwa, P. & Austin, L.M . (2008). Evaluation of human urine as a source of nutrients for selected vegetables and maize under tunnel house conditions in the Eastern Cape, South Africa. *Waste management and research*, 26(2).http://journals.sagepub.com/doi/abs/10.1177/0734242X07079179. https://doi.org/10.1177/0734242X07079179

Nawab, B., Nyborg, I.L., Esser, K.B. & Jenssen, P.D. (2006). Cultural preferences in designing ecological sanitation systems in North West Frontier Province, Pakistan. *Journal of Environmental Psychology*, 26(3): 236-246. https://doi.org/10.1016/j.jenvp.2006.07.005

O'Connell, K. (2014). *What influences open defecation and latrine ownership in rural households? Findings from a global review.* Washington: Water and Sanitation Program.http://www.wsp.org/sites/wsp.org/files/publications/WSP-What-Influences-Open-Defecation-Global-Sanitation-Review.pdf

Okem, A.E., Xulu, S., Tilley, E., Buckley, C. & Roma, E. (2013). Assessing perceptions and willingness to use urine in agriculture: A case study from rural areas of eThekwini Municipality, South Africa. *Journal of Water Sanitation and Hygiene for Development*, 3(4): 582-591. http://washdev.iwaponline.com/content/3/4/582. https://doi.org/10.2166/washdev.2013.036

Pradhan, S.K., Holopainen, J.K., Weisell, J. & Heinonen-Tanski, H. (2010). Human urine and wood ash as plant nutrients for red beet (*Beta vulgaris*) cultivation: impacts on yield quality. *Journal of agricultural and food chemistry*, 58(3): 2034-39. http://pubs.acs.org/doi/abs/10.1021/jf9029157. https://doi.org/10.1021/jf9029157

Pradhan, S.K., Nerg, A.M., Sjöblom, A., Holopainen, J.K. & Heinonen-Tanski, H. (2007). Use of human urine fertilizer in cultivation of cabbage (*Brassica oleracea*). Impacts on chemical, microbial, and flavor quality. *Journal of agricultural and food chemistry*, 55(21): 8657-63. http://pubs.acs.org/doi/abs/10.1021/jf0717891. https://doi.org/10.1021/jf0717891

Roma, E., Philp, K., Buckley, C., Xulu, S. & Scott, D. (2013). User perceptions of urine diversion dehydration toilets: Experiences from a cross-sectional study in eThekwini Municipality. *Water SA,* 39(2) http://www.scielo.org.za/scielo.php?script = sci_arttext&pid = S1816-79502013000200015. https://doi.org/10.4314/wsa.v39i2.15

SANTOS JÚNIOR, J. ET AL. (2015). Interação urina e efluente doméstico na produção do milheto cultivado em solos do semiárido paraibano. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 19(5). https://doi.org/10.1590/1807-1929/agriambi.v19n5p456-463

SEID, K.A. & CHIMDESSA, M. (2014). Use of human urine as fertilizer for cultivation of cabbage (*Brassica Oleracea L.*) and carrot (*Daucus Carota L.*). Doctoral dissertation. Master of Science in Applied Biology. Haramaya University. http://213.55.85.90/handle/123456789/1164

SIMHA, P., LALANDER, C., VINNERÅS, B. & GANESAPILLAI, M. (2017). Farmer attitudes and perceptions to the re-use of fertiliser products from resource-oriented sanitation systems. The case of Vellore, South India. *Science of the Total Environment,* 581: 885-896. https://doi.org/10.1016/j.scitotenv.2017.01.044

SIMHA, P., ZABANIOTOU, A. & GANESAPILLAI, M. (2017). Continuous urea-nitrogen recycling from human urine: a step towards creating a human excreta based bio-economy. *Journal of Cleaner Production*. [in press, corrected proof.] https://doi.org/10.1016/j.jclepro.2017.01.062

SRIDEVI, G., SRINIVASAMURTHY, C.A., BHASKAR, S. & VISWANATH, S. (2009). Evaluation of source separated human urine (alw) as a source of nutrients for banana cultivation and impact on quality parameter. *arpn Journal of Agricultural and Biological Science,* 4(5): 44-48. https://www.arpnjournals.com/jabs/research_papers/rp_2009/jabs_0909_153.pdf

UNESCO. *THE United Nations World Water Development Report 2017 – Wastewater: The Untapped Resource.* Perugia: United Nations World Water Assessment Programme.

WENDLAND, C., DEEGENER, S. & JORRITSMA, F. (2011). Experiences with urine diverting dry toilets (UDDTS) for households, schools and kindergarten in Eastern Europe, the Caucasus and Central Asia (eecca). *Sustainable Sanitation Practice*, 6: 16-48. http://www.wecf.eu/english/publications/2011/experiences-uddt.php

WINBLAD, U. & SIMPSON-HÉBERT, M. (2004). *Ecological Sanitation.* Stockholm: Environment Institute.