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Reuse of Human Excreta in Developing Countries: Agricultural Fertilization Optimization

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ABSTRACT: In developing nations, 1.2 billion people suffer from a lack of a basic sanitation system and fecal sludge management challenges, despite many efforts to combat this issue. Fecal sludge is a mixture of waste, including human excreta, soil, and water. Human excreta contains a significant amount of nutrients that can be used in agricultural fertilizers. The use of human excreta in agricultural fertilizers would reduce the need for artificial fertilizers and improve human excreta disposal through the use of composting and vermicomposting toilet systems. In developing nations where soil conditions are poor and fresh water is unavailable, the use of human excreta in fertilizer can ameliorate two problems: low food productivity and lack of sanitation service. Among the seventeen Sustainable Development Goals (SDGs) established by the United Nations (UN), ensuring a sanitation system for everyone addresses the Goal 6, securing food for everyone. Additionally, enhancing low food productivity addresses the second goal of the SDGs, improving low food productivity. Thus, more efficient use of human excreta can help achieve two SDGs at the same time.

Keywords: fecal sludge, human excreta, pathogen, biosolids, composting, vermicomposting

AUTHOR'S NOTE: This world has so many problems that I sometimes feel helpless. However, a change in sanitation systems might open the possibilities of achieving other global goals, including eradicating poverty, reducing health risks, and improving the environment. Because I grew up with sanitation systems such as toilets, I have taken them for granted without realizing the interconnection among sanitation systems, health risk, gender inequality, and poverty. While human excrement is regarded as a distasteful topic we try to ignore, it has the potential to enrich agricultural soils and lead to an increase in food supplies and a reduction of poverty. Establishing efficient sanitation systems would be key to utilizing the potential of human excrement. This article argues that enforcing sanitation systems in developing countries can contribute not only to improving health risk, but also breaking down the vicious cycle.

Introduction

Human waste management divides humanity into the fortunate "haves" and the unfortunate "have nots." Adults produce approximately 130g of feces and 1.4l of urine every day (Harada, Strande, & Fujii, 2015). Fecal sludge sanitation technology addresses sanitation issues by aggregating the human excreta and wastewater. While those in developed countries have the privilege of disposing their waste sanitarily and eliminating common fecal borne pathogens, about 1.2 billion people lack the access to basic sanitation, with the majority living in developing countries (Lalander, Hill, & Vinnerås, 2013). Improper fecal management results not only in water pollution but also the transmission of infectious diseases through person-to-person interaction, water, and food due to pathogens found in human excreta. The diseases transmitted through human excreta accounts for 4% of deaths in the world, and children are the most affected (Academies, 2007).

In response to this issue, the Sustainable Development Goal 6 of the Sustainable Development Goals (SDGs) established by the United Nations (UN) in 2015 focuses on establishing the availability and sustainable management of water and sanitary systems for every society by 2030 ("Making Every Drop Count," 2018). Although many efforts have been made to remedy this issue, illegal dumping of human excreta still persists, and there is still a lack of adequate and safe disposal of human excreta into the environment which prevents developing nations from attaining proper fecal sludge management (Goal 6 Sustainable Development Knowledge Platform, 2019).

In a number of areas, fecal sludge has been used for fertilizing food crops, since ensuring food security to sustain 9 billion people on Earth by 2050 is one of the major global challenges. In response to this issue, SDG 2 was established to work towards achieving food security and improved nutrition and promoting sustainable agriculture (Goal 2 Sustainable Development Knowledge Platform, 2019).

Although sometimes unhygienic and disease-spreading, human excreta in fecal sludge has great potential as an enriched agricultural fertilizer (Klingel et al., 2002). The reuse of human excreta involves several risks, however, and the treatment process for it to be used in fertilizers seems to be costly and require advanced technology. Nevertheless, the reuse of human excreta in an appropriate way promotes agricultural fertility and higher crop yields, as well as the improvement of local sanitation systems including fecal sludge management and toilet systems in developing nations.

Historical Use of Human Excreta as Fertilizer

Historically, human excreta were collected as "night soils." In Asian countries such as China and Japan, untreated human excreta were commonly used as a fertilizer for crop fields from the sixteenth century to the early twentieth century (Ferguson, 2014). The Asian farmers' success with excreta fertilizer garnered interest from Europe. In the second half of the nineteenth century, European farmers began to use human waste as an agricultural fertilizer. For example, many people from Finland and the Netherlands use dry toilet latrines, from which excreta is collected and regularly used as fertilizer for arable farming (Tanski & Wijk-Sijbesma, 2005). Despite recognizing the value of human waste as a night soil fertilizer, after the nineteenth century, European and North American farmers ultimately replaced the usage of excreta in favor of chemically synthesized fertilizers (Ferguson, 2014). The implementation of large-scale sewage systems was also introduced in Europe at that time, and the water-based systems have since been combined with all domestic waste and industrial effluent, and technology and the regulation of wastewater management have progressed to a high standard level in the developed nations. In Europe, for instance, the EU legislation about sewage sludge regulates the application of biosolids to land. In the case of source-separated human excreta, however, the regulation is unclear on the reuse of treatment products (Moya, Parker, & Sakrabani, 2019). In 2006, the World Health Organization (WHO) provided guidelines that focused on the safe use of excreta and greywater in agriculture to protect people from health risks (WHO, 2006). However, untreated human excreta reuse is still practiced in an inappropriate way in several regions, such as China, Southeast Asia, Africa, and Latin America, to enhance agricultural productivity regardless of the potential hygiene and health risks that human excreta can pose (Dring, 2015).

Why is Human Excreta Valuable?

Micronutrients are essential for plants and crops to grow, and human excreta contains almost all those which are necessary for such growth. Micronutrients consist of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca) and magnesium (Mg). While urine is rich in nitrogen, feces are rich in phosphorus, potassium and organic matter. The need for nitrogen is highest at times of vigorous growth, when leaf and seed proteins develop. Although air contains 79% nitrogen, plants cannot fix atmospheric nitrogen without specific nitrogen-fixing microorganisms (Tanski & Wijk-Sijbesma, 2005). As for their effects on crop growth, Moya, Parker, and Sakrabani (2019) found that, compared to artificial fertilizers, there was a 30% increase in yield using human excreta fertilizer on French beans in Nairobi. In addition, manufacturing fertilizers depends on phosphorus and requires fossil fuels, which are non-renewable resources predicted to be exhausted by 2033 (Dring, 2015). Thus, not only could human excreta fertilizers replace the unsustainable reliance on artificial fertilizers, but they would also be more effective for crop growth.

Animal manure is another commonly used fertilizer, and researchers have found that there is no significant nutrient difference between them (Penakalapati et al., 2017). However, the nutrient levels vary depending on whether livestock and animal manure nutrient value is accurately estimated (Leip et al., 2019). Also, since animal feces management is often careless, pathogen transmission associated with exposure to animal feces could, in some cases, be higher than exposure to human feces, which may result in health risk (Penakalapati et al., 2017). Furthermore, the contents of hazardous or contaminating substances such as heavy metals and pesticide residues are generally low in human excreta and urine compared to artificial fertilizers and farmyard manure (Jönsson, et al., 2004). Thus, human excreta will not harm human health more than animal manure. Rather, it can be used to create a nitrogen-enriched fertilizer.

Food Security and Sanitation Challenges in Developing Nations

The reuse of human excreta would solve two challenges in developing countries. One challenge is that food productivity is unable to meet the demand of the population; the other key challenge is outdated excreta sanitation systems.

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First, food security, which is not ensured in developing countries, could be increased by using rich nutrients derived from human excreta to promote food production. Food production requires resources such as water, energy, and fertilizers (Doukas et al., 2019). Nowadays, however, the issue of fertilizers becomes more critical as soil nutrient depletion is predicted to affect one-fourth of all agricultural land. This compromises low-income countries such as Sub-Saharan Africa (SSA) due to population growth, agricultural expansion, and inadequate use of fertilizer (Moya et al., 2019). In order for developing countries to secure food, ensuring that the nutrients remain in the soil for food production is vital.

Secondly, the sanitation system is inadequate in low-income areas. The lack of a disposal system often results in a discharge of fecal sludge, which is a threat to human health (Moya et al., 2019). Ingestion of water contaminated with feces results in a variety of diseases important via fecal-oral route of transmission. In 1998, 2.2 million deaths were estimated as being associated with diarrhea, which was more likely to result from fecal pollution of water. The majority of the victims were children in low-income countries (WHO, 2000). Therefore, the introduction of reusing human excreta as fertilizer would help not only to increase food production, but also to build safe sanitation systems through the treatment of fertilizers from human excreta.

Obstacles and Solutions Over Human Excreta

Transmission of Pathogen

Despite the benefit of lower contents of heavy metals and other contaminating substances in feces than in artificial fertilizers, human excreta can contain pathogens such as viruses, protozoa, and parasitic worm eggs (Tanski et al., 2019). These pathogens can cause serious diseases, such as cholera, typhoid, schistosomiasis, infectious hepatitis, and polio (Academia, 2007). In a recent Chinese study, COVID-19, a virus that spread from animals to humans and has infected millions of people around the world since the outbreak in China in December 2019, has been found to possibly be transmitted through human feces, in addition to other paths of transmission (Nouri-Vaskeh & Alizadeh, 2020). Furthermore, once these pathogens are brought into the environment, some of them are likely to remain infectious for the long-term, although the affected people are often asymptomatic.

If the sludge treatment is not sufficiently conducted, pathogenic organisms contained in the sludge are easily dispersed in the crop fields, where they can infect the farmers working there. Bacteria and worm eggs in the soil may also attach to the plants and infect consumers who eat raw crops or do not thoroughly wash the crops prior to ingestion (Klingel et al., 2002). Another example of exposing people to risk is the reuse of excreta by an infected person. The urine of infected persons can be a passage for some human parasitic germs such as certain helminth eggs or *schistosome miracidia*. Because of inadequate sludge treatment, the eggs can enter the soil through urine. This becomes particularly problematic for developing countries in the tropics, where the number of infected persons is high.

Nevertheless, with appropriate heat treatment, all harmful pathogens in human excreta can be reduced to produce fertilizers safe to use in agriculture. Increasing temperatures of 30°C-40°C can prevent the helminth eggs from surviving. In developing countries where temperature levels are high, the preserved urine will often be in the soil. Moreover, the resulting heat-dried soil can decrease relative humidity, which will further reduce the survival chances of the pathogenic agents (Tanski & Wijk-Sijbesma, 2005). Another way to eliminate harmful pathogens is to store the sludge for over six months. This allows natural pathogens to die off. Although natural drying is not an effective way to reduce moisture content to a level that is sufficiently low for complete pathogen destruction, the drying of sludge can enhance the pathogen destruction during storage. Thus, this method increases the security of the excrement sludge soil (Klingel et al., 2002).

In most developing countries, the high temperatures can eradicate harmful pathogens. This pathogen control increases the efficiency of food production. Thus, heating and drying human excrement effectively kills pathogens that could otherwise compromise its safety as an agricultural fertilizer. The increased nutrients in fertilization lead to higher crop yields.

Cost Management

Another obstacle is that extracting nutrients from human fecal sludge is technically complicated and requires expensive technology. This is because the sludge consists of a variety of materials such as flush water, heavy metals, toilet paper, domestically used water, industrially used water, and possibly even stormwater (Harder et al., 2019). In most urbanized areas, fecal sludge treatment facilities, including breeding insect larvae on feces, are employed to convert fecal sludge to biosolids. Biosolids are biochemically stable and hygienically safe solids known as the nutrient-rich organic materials that are agriculturally valuable (Klingel et al., 2002). In the UK, for instance, approximately 80% of biosolids are applied to soils following Safe Sludge Matrix guidelines, 75% of which are applied to agricultural land (Moya et al., 2019). Building highly mechanized systems for resource recovery from fecal sludge is too expensive in low-income countries. In most urbanized areas in developing countries, excreta are disposed of in facilities such as septic tanks, dry latrines, bucket latrines, or communal toilets, and they all accumulate fecal sludge (Klingel et al., 2002). In Accra, Ghana, for instance, the cost of emptying a latrine is ten times more expensive than an average household income; therefore, introducing fecal sludge treatment facilities to low-income countries becomes economically challenging (Diener et al., 2014). Sludge management is less likely to be advanced in developing countries due to financial restrictions and inadequate waste management in poor education institutions (Fagnani & Guimarães, 2017).

However, if urine and feces can be separated, both of these factions can be treated independently and utilized so that infectious diseases (pathogens) can be prevented. The process of composting is the best way of doing so without using expensive technology. A simple pit latrine or ventilated improved pit latrine can also be used to divert feces from urine and to make it fall directly into the pit container (Tanski & Wijk-Sijbesma, 2005). The use of vermicomposting is yet another treatment used to separate feces. Vermicomposting is a composting process that optimizes the movement of worms. Various species of worms facilitate microbial decomposition by maintaining aerobic conditions and changing the biochemical properties of the excrement. The optimal conditions for vermicomposting are placing feces at the moisture of 65–80% at 20–25°C, and achieving a 50–80% reduction in organic carbon after 96 days of treatment (Lalander et al., 2013). In developing countries where western processing technology can be cost prohibitive, these waterless and inexpensive systems can be used in both rural and urban communities. They help heighten nutrients in human excreta and decrease pathogen contamination. Additionally, these alternative toilet facilities create more sustainable sanitation systems.

Concerns Entrenched in Use of Human Excreta

Public Perception of Food Quality

Even though the use of human excreta has positive effects on soils, public perception of excreta is critical. One of the concerns could be the quality of crops and vegetables grown using human excreta as fertilizer compared to artificial chemical fertilizers. Since hegemonic standards currently do not allow the use of treated human sewage sludge on fields, many farmers showed their unwillingness to use the excreta (Moya et al., 2019). In addition, some farmers suspect composting could spread infections; they assume that consumers would avoid crops on which co-compost had been used for fear of infections. Studies have shown, however, that both local farmers and their customers preferred to use human excreta base fertilizer if it had a positive effect on their soil enrichment and was affordable (Danso et al., 2002; Diener et al., 2014). In Finland, an experiment that compares urine-based fertilizer to the same amount of commercial mineral fertilizer was conducted. As a result, almost the same yields of cucumber and the same quality of cucumbers were produced (Tanski & Wijk-Sijbesma, 2005).

Another study investigated the productivity of hydroponic tomato production. This study was designed with three nutrient conditions: decentralized wastewater treatment system (DEWATS) effluents, nitrified urine concentrate (NUC), and commercial hydroponic fertilizer mix (CHFM). Tomato plants treated with commercial fertilizer mix showed higher growth performance compared to those from human excreta derived materials. However, both DEWATS and NUC treated plants indicated specific positive effects: improving plant height, photosynthetic rate, fruit mass, harvest index, and nutrient uptake in DEWATS. In NUC, the result showed improved growth performances in terms of shoot dry matter, leaf area index, and chlorophyll content. Therefore, nutrient balances and the maximization in excreta could be adjusted and supplemented to enhance the production of tomatoes in the hydroponic system, which could meet the same nutrient quality level as commercial fertilizers (Magwaza et al., 2020).

In terms of health risk, the people who ate the food produced with urine-containing compost have not reported any health problems (Tanski & Wijk-Sijbesma, 2005).

Concern about Nutritional Value

As for the limitations on excreta as a fertilizer, the nutritional content of human waste largely depends on how nutritious the diet of those producing the waste is. The diet varies from person to person and country to country. Although nutritional content of diets varies, there are not significant differences overall in nutritional value of excreta from country to country. For example, Harder et al. (2019) found negligible differences in nutritional nitrogen (N) and phosphorus (P) levels in urine and excreta comparing results from both Sweden and China. There is a successful example of the composting of human

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waste in Haiti, which is known as a low-income country. In Haiti, in response to the earthquake that occurred in 2010, thermophilic composting was developed to safely treat human fecal waste and transform it into nutrient-rich compost. Through the compost treatment, they were able to eliminate pathogens and create a reusable nutrient-rich soil condition (Preneta et al., 2013). Therefore, regardless of whether it is in developed nations or developing nations, the nutrients contained in human excreta positively affect soil conditions.

Education and Communication to Raise Public Awareness

In order to reduce these concerns and to achieve better sludge management, raising public awareness about human excreta and hygienic facilities is significant. One of the ways of doing so is hygienic education. Hygienic education should be targeted not only on issues related to fecal sludge management but also on all aspects of hygiene and sanitation (Klingel et al., 2002). Hygienic education in a community involves several steps: communication with the local agencies, selection of hygiene behavior change, and analysis of influence of the behavior. Hygiene behaviors are difficult to change because the behavior strongly relates to daily activities such as the community's culture and tradition (World Health Organization [WHO], n.d.). Through hygiene education, individuals' behavior changes. Changes manifest when people empty the vault of their toilets and their septic tank more often or promote the prohibition of throwing waste into the toilets (Jönsson, et al., 2004; Klingel, et al., 2002). It is significant, therefore, to cooperate with the whole community and especially with school children because children are more susceptible to be exposed to the risks that improper waste management poses. It is also important to let them engage in all stages of hygiene education, including selecting hygiene behaviors, understanding the influences on such behaviors, choosing educational approaches, and implementation. The educational methods can not only raise both farmers' and customers' awareness regarding the importance of human excreta but also strengthen and empower individuals and communities to work and further understand for change (WHO, n.d.).

Challenges in Consent with a Wide Range of Regulations and Creating a Certification Scheme of Human Excreta Use

Currently, in Europe, the use of biosolids in farming is generally regulated by the sewage sludge instruction of the Global GAP, known as the standard for quality assurance of agricultural crops, and it does not allow the use of human sewage sludge on certified farms. However, several countries such as the UK, Sweden, Australia, and the US created specific certification schemes to reduce public prejudice and fear of contamination with various compounds from sewage sludge (Moya et al., 2019). As for the regulation of human excreta, neither use of human excreta nor use of composting excreta has clear national standards due to lack of knowledge of human excreta potential and risks regarding its application to agriculture (Malkki, n.d.). In low income countries, the export of agricultural products is profitable and important rather than the local market. In Kenya, for instance, horticultural exports to the EU account for its large economy. Therefore, EU laws for product quality, safety, and chemical residues could encourage Kenyan compliance with these regulations. This causes Kenyan farmers to be reluctant to employ human excreta base fertilizer. Therefore, a similar scheme could be applied for human excreta delivered fertilizer. Creating the certification or assurance scheme that provides the importance of recovering nutrients from human excreta would increase confidence in the quality and safety of the products and clarify the safe level of contaminants. This clear understanding of human excreta potential could result in creating a national standard of use of fertilizer from human excreta. Also, the founding in Ghana shows that certification of human excreta base fertilizer could encourage to pay for compost. Nevertheless, while the biosolids assurance scheme created in the UK seems to have had a positive effect on the acceptance of biosolids for agriculture, the use of biosolids for growing vegetables is still controversial. Furthermore, gaining the necessary certification remains difficult. Such a certification usually requires not only the adoption of specific farm practices and infrastructure but also a yearly renewal, which can have significant cost implications. The costs of applying and complying with Global GAP certification can account for 30% of the annual crop income for farmers in Kenya. Thus, creation of certification brings challenges and takes time to spread understanding within a community (Moya et al., 2019).

Conclusion

Even though human excreta potentially provides many nutrients to improve soil fertility rather than artificial fertilizer, the reuse of human excreta is difficult to adopt due to the pathogen risk, fecal sludge management, and public stigma regarding excreta in the fertilizer. In developing nations such as SSA, rich nutrient fertility is crucial for food productivity. Moreover, the sanitation system is not satisfactory due to lack of fecal sludge management and the

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devaluation of sanitation such as toilets. In order to deal with these obstacles, composting and vermicomposting toilets should be introduced. Regarding the concern of the food production quality, fertilizer from human excreta is proven to work the same as normal artificial fertilizers or even provide better crop yield due to the nutrient difference in human excreta. Moreover, the stigma regarding human excreta could be eliminated by educating people to gain support to propagate the significance of human excreta. If more people are aware of the potential that human excreta and improved waste management have, laws and policies of use of excreta, which are currently strict, can be improved. As a result, use of human excreta contributes to solving the issue of low soil fertility as well as the problem of fecal sludge management. Thus, sanitation, including the collection and treatment of human excreta, involves ensuring the well-being of individuals within a community.

Human excreta can save the world that suffers from both the crisis of inadequate food production and poor waste management.

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