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Dry toilets offer a sustainable solution for communal waste management and regional economies by enabling nutrient recycling

E. M. Jung [1], V. S. Rotter [2], C. Kirsten [3], J. Mühlenberg [4], A. Krause [5]

[1,2] *Chair of Circular Economy and Recycling Technology (CERT), Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany*
[3,4] *Deutsches Biomasseforschungszentrum gemeinnützige GmbH (DBFZ), Torgauer Str. 116, 04347 Leipzig, Germany*
[5] *Leibniz Institute of Vegetable and Ornamental Crops (IGZ), Theodor-Echtermeyer-Weg 1, 14979 Großbeeren, Germany*

Human excreta offer great nutrient potential but must be treated for hygienic reasons before they can be reused as fertilizer. The project zirkulierBAR examines recycling fertilizers from thermophilic composting for nutrients as well as contaminants (heavy metals, pharamaceuticals, pathogens). From a nutrient perspective, recycled fertilizer offers all the advantages of an organic-mineral fertilizer. Interim results also show that heavy metal and pharmaceutical contamination is neglibibly low. Concerning hygiene parameters, almost no limit value violations with current regulations were detected, except for *C. perfringens*. Further standardization and legal recognition are required to apply the process and the recovered recycling fertilizer on a broad scale.

Keywords: composting, nutrients, human excreta, sanitation, fertilizer

1. INTRODUCTION

Sustainable nutrient management is a crucial area of focus for both research and politics. Many current nutrient practices have a harmful environmental effect and the need to ensure future access to fertilizers increasingly imposes itself. System analyses have repeatedly identified one significant, but often overlooked, resource for nutrient cycling: sanitary residues (Krause et al., 2021a). Specifically, separately collected human excreta from dry toilets are considered a valuable resource for the integrated recovery of phosphorus, nitrogen, and other nutrients in a regional circular economy from farm to fork to farm. By improving nutrient management and cycling, one can reduce nutrient and water consumption, decrease greenhouse gas emissions, and enhance crop production (Kraus et al., 2019). Minimization of pathogens for safe handling must not be disregarded but has already been successfully demonstrated in other studies (Häfner et al., 2023). In Barnim, Germany, the zirkulierBAR project is creating a circular living lab for producing hygienically safe and quality-assured recycling fertilizers, including compost from solid materials and liquid fertilizer from urine. Practitioners are developing technical elements to integrate dry toilets and the subsequent valorization of collected contents into municipal waste management. Researchers are studying the agricultural, resource, and socio-economic requirements for scaling up this approach. Additionally, the project is evaluating social and political acceptance for producing recycling fertilizers from dry toilet contents and their subsequent application in agriculture.

2. METHODS & MATERIALS

Researchers from DBFZ and TUB carry out material analyses and validate analytical methods since 2021 in order to monitor the composting process as well as product quality. The first campaign (assessing five compost heaps of ca. 50 m³ each) took place from July 2021 until December 2022 at the pilot facility of Finizio GmbH and Kreiswerke Barnim in Eberswalde, Germany. The applied composting process comprises of two steps: (1) heat treatment through microbial activity in an insulated and aerated container, for at least seven days at 70 °C, and (2) thermophilic composting process in open heaps for eight to ten weeks. Dry toilet contents consist of fecal matter as well as toilet paper and straw chaff wetted by perkulating urine. They account for around half of the setup and originate from dry toilets located at various events and public places in Berlin and Brandenburg. Other feedstocks for the compost setup consist of straw and green cuttings, clay soil as well as vegetable charcoal in varying compositions.

Once started, the compost is machine turned in increasing intervals and regularly irrigated while stored under a breathable fabric. Temperature and carbon dioxide content of the substrate are measured until the substrate fulfills all physical, optical and olfactoric criteria of a ripe compost. Representative sampling of the input and output substrates takes place according to the official procedure guideline LAGA PN 98 (LAGA, 2004). Therefore, 12 evenly distributed samples among the heap of one kg each are collected, united on a tarpaulin, and subsequently reduced. Methodologically, the product standard DIN SPEC 91421:2020 is applied, which was developed for quality assurance to fill existing regulatory gaps for the production and use of recycled fertilizers from dry toilets. Next to general physical properties of the material, analyzed parameters include contents of nutrients, heavy metals, organic pollutants as well as hygiene parameters and pharmaceutical contaminants to assess and assure the quality and suitability of the recycled products as fertilizers (DIN SPEC 91421, 2020). The standard is reviewed with regard to its implementation in practice and continuously developed in order to adjust the methodology and set limit values in relation to real conditions.

In addition to the utilization of dry contents, a treatment of perculated and pure urine is carried out in a separate stream processing plant. Using an activated sludge tank for nitrification followed by an activated carbon filtration for the elimination of water-soluble pharmaceutical residues and distillation unit for dewatering and sanitization, nitrogen-rich fertilizer is produced. An adjusted sampling and analysing strategy for liquid substrates is currently in the making.

3. RESULTS

Findings of this work package can support a material flow analysis of the system studied in Barnim region. They further enable an assessment of the nutrient recovery potential of the innovation and its substitution potential for artificial fertilzers. The applied composting method and materials form a solid fertilizer that provides the soil with sufficient, and plant-available macro- and micronutrients (e.g. on average 1.65 % DM total nitrogen, 1.77 % DM total phosphate, 1.44 % DM total potassium oxide). According to our results, heating and thermophilic composting enables the removal of all relevant pollutants and pharmaceutical contaminants as well as most pathogens. *Enterococci, escherichia coli* and *salmonella* are not present or only detectable in negligible traces in the fertilizer product. However, two of five sampling campaigns show increased values concerning the anaerobic, spore-forming pathogenic bacterium *Clostridium perfringens* (<10 and 1,500 CFU/g FM, exceeding the limit value of 0 CFU/g FM

from DIN SPEC 91421:2020). With regard to somatic coliphages, no statement can yet be made on the hygenisation performance, as there is no accredited laboratory for the analysis of this parameter available in Central Europe so far.

4. DISCUSSION

Even if the utilization of dry toilet contents is carried out based on years of experience, there is still potential for optimization - especially concerning the ratio of raw materials, extend of irrigation and general site conditions. One crucial factor is minimizing anaerobic zones in the process by enabling sufficient aeration which could be reached by a smoother and more inclined surface. Switching to a semi-automated, multilevel 'humus shelf' that is independent of precipitation instead of composting on concrete slabs should remedy this situation in the upcoming months. Sampling of the output substrates are well feasible, but due to the inhomogeneity of the input materials, suitable sampling equipment and procedures still need to be developed to guarantee representative sampling that also complies with occupational safety standards.

Contents of nutrients as well as foreign substances align with the German fertilizer ordinance (DüMV) as well as the ordinance on biowaste (BioAbfV) and show a product that could serve the demand for nutritious, soil improving fertilizers in the agricultural application (cf. Häfner at al., 2023). The finished compost serves as an organic-mineral fertilizer, whose nitrogen content could supposedly be increased even more by adding urine during the composting process or combining liquid and solid fertilizer later in the field. However, interactions of those substances and effects on harvest results would still need to be investigated.

Initial comparisons of the input and output substrates of the composting process show a significant reduction in the total bacterial count and relevant hygiene parameters. This transformation has also been observed by previous microbial analyses of *Salmonella* and *E. coli* from thermophilic composting of human feces (Werner et al., 2022; Krause et al., 2021b). Further research and conscious endowments of the raw substrate with contaminants would enable further information on the efficiency of the zirkulierBAR process. Spores of *C. perfringens* can be resistant to higher temperature, which means that recolonization in anaerobic zones could occur even with diligent process control. Exceeding the limit value for *C. perfringens* of 0 CFU/g FM appears to be very reasonable, considering the bacteria is ever-present in nature and can be found as a normal component of decaying vegetation, insects and soil itself and not exclusively in the intestinal tract of humans (Kiu and Hall, 2018). Therefore, the research team questions its suitability as an indicator for decontamination in upcoming revisions of the DIN SPEC 91421.

Especially considering the recycling fertilizer as a substitute for sewage sludge and animal manure, results of the quality analysis promote further use in agricultural practice. The expansion of the legal definition of 'biowaste' to include human urine and feces as well as the inclusion of human excreta in the Fertilizer Ordinance would be neccessary political steps to make this circular solution a reality.

5. CONCLUSIONS

According to interim findings, collecting human excreta separately allows for targeted treatment of concentrated waste streams. It enables the removal of most pathogens, pollutants, and contaminants, while ensuring safe nutrient recycling and preventing their dispersion into soil and groundwater. Moreover, the research indicates that the risk of pathogens and pharmaceuticals entering the food system through fecal compost is minimal. Human excreta offer great potential to compensate for nutrient deficiencies, yet current legal hurdles must be adapted to enable commercial handling and use as recycling fertilizers.

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