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Review

Lactic acid fermentation of human excreta for agricultural application

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A B S T R A C T

Studies show that source separated human excreta have a fertilizing potential with benefits to plant growth and crop yield similar or exceeding that of mineral fertilizers. The main challenges in fertilizing with excreta are pathogens, and an increased risk of eutrophication of water bodies in case of runoff. This review shows that lactic acid fermentation of excreta reduces the amount of pathogens, minimizes the nutrient loss and inhibits the production of malodorous compounds, thus increasing its agricultural value. Pathogens (e.g., *Enterobacteriacea*, *Staphylococcus* and *Clostridium*) can be reduced by 7 log CFUg^{-1} during 7–10 days of fermentation. However, more resistant pathogens (e.g. *Ascaris*) are not always efficiently removed. Direct application of lacto-fermented faeces to agriculture may be constrained by incomplete decomposition, high concentrations of organic acids or insufficient hygienization. Post-treatment by adding biochar, vermi-composting, or thermophilic composting stabilizes and sanitizes the material. Pot and field experiments on soil conditioners obtained via lactic acid fermentation and post treatment steps (composting or biochar addition) demonstrated increased crop yield and growth, as well as improved soil quality, in comparison to unfertilized controls.

Contents

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1. Introduction

Global population growth, intense urbanization, economic development, and climate change increase competition for water, energy and land. While the need to produce more food to feed for a growing population is well known, the worldwide degradation of soil and water is increasingly worrisome (Hoff, 2011). Energy can be obtained from renewable resources, but water and soil have no substitutes. Therefore, it is imperative to prevent their further degradation and restore their quality.

Soil is currently lost 10–40 times faster than it is regenerated (Bai et al., 2008; Pimentel, 2006). For this reason, farmers must spend more on energy, without a corresponding increase in crop yield, thus negatively affecting the livelihood of poor populations, especially in the developing countries of Africa, Asia and Latin America, whose economies depend on agriculture. Erosion and desertification are increasing throughout the world, which declines agricultural production in India, Pakistan, Nepal, Iran, Jordan, Lebanon and Israel (Pfeiffer, 2006).

In Africa, three quarters of farmland is affected by soil degradation due to erosion and nutrient depletion (Mihelcic et al., 2011). The loss of nutrients and organic matter is also a concern in Europe, where approximately 45% of soils have reached a low or very low organic matter content of 0–2% (Rusco et al., 2001). This depletion is particularly intense in the Mediterranean region, Southern and Eastern Europe, as well as for some countries in Western Europe (Jones et al., 2012; Virto et al., 2014).

Freshwater resources around the globe also face degradation and scarcity. For a number of countries in Africa and the Middle East, water is becoming physically scarce, while for others (e.g. Latin America) it is economically scarce (Rijsberman, 2006). Sanitation is a major consumer and polluter of water resources (Gleick, 2003). Large volumes of drinking water are used to transport excreta, generating enormous amounts of wastewater which cannot be fully cleaned with existing conventional technology. This results in significant amounts of nutrients and organic matter being discharged into surface waters, especially since 90% of the wastewater is released without treatment. Reusing excreta in agriculture returns nutrients to the soil and reduces the pollution of freshwater resources and, thus, the energy costs required for its treatment. Approximately one third of nitrogen, phosphorus and potassium fertilizer equivalents required by the farmers at the global level can be recovered from sanitation waste (Werner et al., 2003). Phosphorus reuse from sanitation is of particular interest, considering the projected increase in the price of phosphorous fertilizers. Mineral reserves are getting depleted, the geopolitical distribution is uneven, and the energy costs for mining, processing and extraction are increasing (Cordell and White, 2011).

Prehistoric human societies have created long-lasting rich fertile soils by integrating their excrement, biochar and other substances into the ground (Lehmann et al., 2003). This occurred in the Amazon (terra preta or Amazonian dark earths; Glaser and Birk, 2012), Northern Europe (Wiedner et al., 2015), Australia (Downie et al., 2011), and West Africa (Frausin et al., 2014). This ancient practice of forming so-called terra preta soils highlights the potential for application of excreta and biochar for improving the soil fertility. In addition, with increased appreciation of the damage caused to the environment and human health by the use of agrochemicals, there is more demand for organic production (Chojnacka, 2015). In this regard, lactic acid fermentation receives increased attention for its potential to substitute petroleum-derived chemicals with biodegradable bio-based products, thus reducing greenhouse gas emissions and increasing the security of raw material supply (Daful et al., 2016; Ghaffar et al., 2014). The use of organic wastes for industrial production of organic acids (e.g. lactic acid) is becoming increasingly interesting due to low material costs (Couto, 2008). Among these, biodegradable polylactic acid has become of interest as it can replace synthetic plastics (Gavrilescu and Chisti, 2005).

The anaerobic process of lactic acid fermentation (LAF) of manures and human excreata has recently received renewed attention as it is a key process in the resource-oriented approach, named “terra preta sanitation system” (Otterpohl and Buzie, 2013; Schuetze and Santiago-Fandiño, 2014), which treats excreta by two combined processes: lactic acid fermentation (LAF), followed by composting (usually worm composting). Biochar is also applied to reduce nutrient losses and obtain stable organic soil conditioners (Bettendorf et al., 2014; Glaser and Birk, 2012; Yemaneh et al., 2014). Lactic acid fermentation contributes to controlling foul odour (Yemaneh et al., 2014) and suppresses the growth of pathogenic bacteria (Scheinemann et al., 2015). It is also shortens the required stabilization time during the subsequent vermicomposting stage (with earthworms), where further pathogen reduction, fragmentation and aeration occur in the faeces (Otterpohl and Buzie, 2013).

This review evaluates the efficiency of the anaerobic process LAF, followed by vermi-composting and thermophilic composting in treating human excreta to improve their agricultural value. The role of biochar for avoiding nutrient loss and contributing to the formation of humus is highlighted and the potential fertilizing effects of excreta treated via LAF combined with composting and biochar addition are overviewed.

2. Nutrient and resource challenges in sanitation

Conventional water-based sanitation aims to increase hygiene, but it is not applicable in all the societies of the world. Clean drinking water is used to transport excrement and is then treated via energy-intensive processes, but is never 100% clean again (Fig. 1, I). This is inappropriate, especially in regions with scarcity of freshwater or energy resources, which are growing due to droughts caused by global climate change (Hanjra and Qureshi, 2010).

Freshwater pollution increases the costs of potable water treatment, but the wastewater that contaminates it contains numerous valuable resources, such as nutrients and organic matter from the food people eat (Fig. 1: II), in addition to constituents of concern, including pathogens, pharmaceuticals, hormones and pesticides (III). Wastewater is centrally collected and transported to the treatment facilities (IV), where the pollutants are only partly removed (Muga and Mihelcic, 2008), in addition to getting mixed with industrial wastewater and stormwater (V) (Tchobanoglous et al., 2003). Even with advanced treatment, such as microfiltration and reverse osmosis (Watkinson et al., 2007), micropollutants (e.g., pesticides, phenol compounds, heavy metals,