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Heavy metal uptake of corn irrigated with human urine

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Abstract

The ground, infiltration of liquid effluent into the soil can continuously occur. Poor sanitation systems permit the spread of heavy metals in urine to water bodies especially the groundwater. This study investigated the accumulation of heavy metals in shoots of corn plants irrigated with urine. A pot experiment with corn was conducted under greenhouse conditions. Urine was diluted to 3:1 ratio (water and urine respectively) and was compared to control (water only). Using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), heavy metals such as Boron, Barium, Cobalt, Copper, Iron, Manganese, Nickel, Silicon, Strontium and Zinc were detected in shoots of all plants with contents ranging from 0.22 to 2,487.44 milligram (mg) per kilogram (kg). The higher amounts detected in urine irrigated plants than the control proved the presence of the metals in the urine. Reuse of urine will definitely benefit farmers while at the same time reduce the risk of heavy metal contamination in groundwater.

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Introduction

PLis one of the most common disposal systems for human excreta in low-income countries and used by an estimated 1.77 billion people (Graham & Polizzotto, 2013). It is basically characterized as a hole in the ground that collects urine and faeces, without any concrete flooring. Either no water is added into the pit after each defecation or 1 - 3 liters per flush with pour-flush PL (Tilley *et al.*, 2014). Typically a pit is only 3 - 5 meters deep and 1meterin width (Tilley *et al.*, 2014; WORLD BANK GROUP). Each person produces 500 liters of urine per year (Otterpohl, 2000) and considering the number of users in every PL, the volume of urine added per year is tremendously large for the capacity of a PL. Because of this, infiltration of liquid effluent in the soil can continuously occur and this scenario is a very serious environmental and health concern (as illustrated in Fig. 1). Microbial and chemical contamination in groundwater associated with PL has been widely studied (Graham & Polizzotto, 2013). Such septic system can contaminate groundwater with dissolved solids, Nitrate, anoxic constituents (Manganese, Iron and hydrogen sulfide), organic compounds and microorganisms (McQuillan, 2004). Contents of Nitrogen in human excreta is high and consumption of high Nitrate concentrations in drinking water is known to cause methemoglobinemia, and associations with cancer in humans have been observed (Graham & Polizzotto, 2013).

Urine normally mixes with flushing-water and faeces which altogether comprise the domestic wastewater (Otterpohl, 2000). In developing countries like the Philippines, wastewater treatment plants are not common. Only about 3% of urban population in the Philippines are served with some form of sewerage facility and the rest rely on septic tanks or none at all (Roncesvalles, 2008). The Sanitation Code of the country clearly set the guidelines for the standard septic tank (Mogol, 2008) however, the majority install sub-standard structures to avoid high cost. Just like PL, sub-standard designs allow the infiltration of domestic wastewater in soil which is extremely posing a very high risk of groundwater contamination.

Field experiments have scientifically proved urine's efficiency as comparable to chemical fertilizers in increasing crop yields (Muskolus, 2008; Höglund, 2001). Chemical analysis of urine revealed heavy metal contents (Cornelis *et al.*, 1995; Fujimori *et al.*, 1996; Zeiner *et al.*, 2004). However, studies dealing with plant tissue analysis after urine fertilization are still very limited. This study investigated the accumulation of heavy metals in shoots of corn plants irrigated with urine.

Materials and methods

A pot experiment with corn was conducted under greenhouse conditions at the Institute of Wastewater Management and Water Protection, Hamburg University of Technology, Germany. Each plant was grown in a 5-liter plastic pot. The growing medium was a mixture of 73% woodchips, 18% soil and 9% sand. Undiluted urine was collected from a male diverting-toilet of a train station in a city located in Hamburg. Urine was diluted to 3:1 ratio (water and urine respectively). Control and the urine treatment were replicated 5 times in which control plants only received water. Irrigation schedule was the same for all pots including volume. Volume was increased gradually overtime. Light was provided for 12 hours per day. Twenty-six (26) days after sowing (DAS), plant height was measured from the base of the plant shoot up to the base of the last node. After measuring plant height, the plants were cut at the base of the shoot, placed individually in paper bags and dried in the oven. After drying, each plant shoot was milled and analyzed for heavy metal contents using ICP-OES at the Institute of Plant Nutrition, Leibniz University of Hannover, Germany.

Results and discussion

Plant growth and development

The use of woodchips was a demonstration of a soil with poor structure and organic matter composition and as wells as low retention capacity for water and nutrient. Control plants had grown up to an average of 20.76 centimeters (cm) only and did not develop further.

Table 1. Average plant height (cm) and dry weight (gram) at 26 DAS.

Parameters	Control	Urine
Plant height	20.76	56.80
Dry weight	0.67	35.08

The plants were thin and stunted while their shoot color completely changed to purple. It is a clear indication of the absence of plant nutrients in the growing medium. On the other hand, corn plants irrigated with urine showed normal growth and development. Plant biomass reached up to an average of 35.08 grams 26 DAS while control plants only had 0.67 grams in dry weight (Table 1). With high biomass yield in the urine treatments, reuse of urine can be recommended in crop production especially in areas with degraded and unproductive soils. Although not measured in the experiment, Nitrogen is normally the main nutrient in urine that is responsible for plant biomass production according to several studies (Morgan & SEI, 2004; Höglund, 2001).

Table 2. Average heavy metal contents (mg/kg) in shoots of the control and urine irrigated plants at 26 DAS.

Heavy metals	Control	Urine
Barium	20.26	52.33
Boron	21.01	30.04
Cobalt	0.87	0.95
Copper	6.11	8.64
Iron	15.51	41.95
Manganese	73.86	136.166
Nickel	2.58	3.68
Silicon	276.45	434.15
Strontium	0.22	4.67
Zinc	31.61	56.59

Heavy metal uptake

Heavy metals were detected in shoots of all plants (Table 2). Results of the control plants basically indicated the presence of the elements in the growing medium.

But the higher amounts detected in the urine irrigated plants than the control signified the presence of the metals in the urine (Table 2). The experiment had shown that the uptake and accumulation of heavy metals in plant shoots could proceed regardless of soil quality.

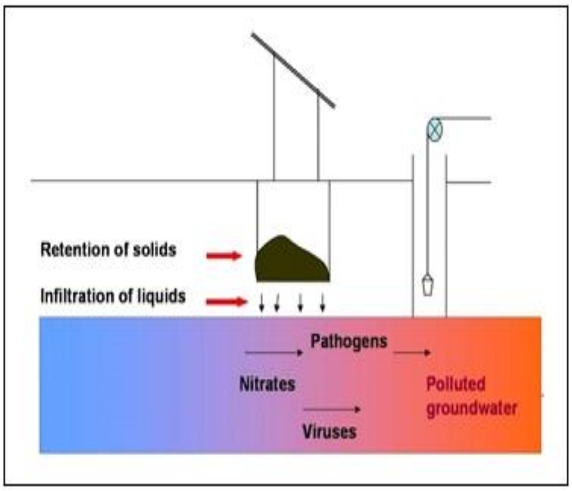

Fig. 1. Schematic presentation of a PL showing liquid infiltration into groundwater (source: Deutsche Gesellschaft für Technische Zusammenarbeit - GTZ, 2005).

The poor growth and development of the control plants did not hinder the absorption of heavy metals. Differences particularly in Barium, Boron, Iron, Silicon, Zinc and Manganese contents detected in plant shoots between the control and the urine treatment (Table 2) can be used as basis in stating that urine can be potentially hazardous to groundwater. Iron, Copper and Zinc are heavy metals in drinking water linked most often to human poisoning (Mohod & Dhote, 2013).

Phytoremediation that uses the remarkable ability of plants to concentrate elements and compounds from the environment and to metabolize various molecules in their tissues appears very promising for the removal of pollutants from the environment (Nouri *et al.*, 2009).

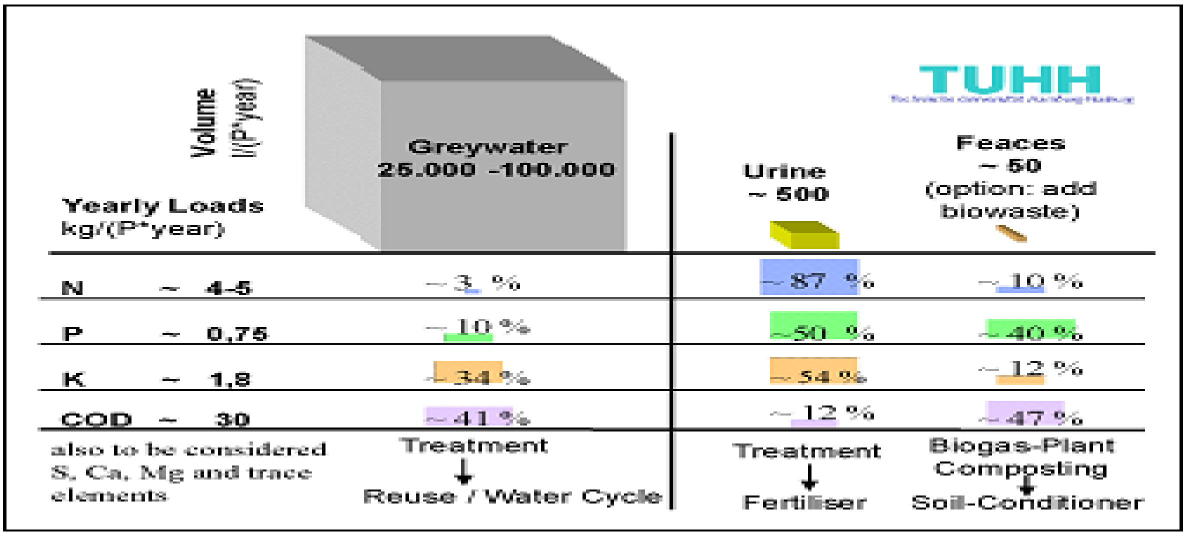

Fig. 2. Composition of domestic wastewater (Otterpohl, 2000).

Related studies

These findings are similar to the results of a study cited by the European Commission in 2013. Potatoes and onion shoots and leaves contained Nickel and Chromium after irrigation using contaminated water (European Commission - Science for Environmental Policy, 2013). Accumulation of heavy metals in above-ground tissue of *Brassica juncea* was related more closely to Copper, Lead and Zinc EDTA-extractable concentrations in soils (Cu, 2015). Sweet potato grown in a mixture of municipal sewage sludge and yard waste media was found to have greater total concentrations of Lead, Nickel and Chromium in its plant parts than the control (Antonious *et al.*, 2011).

Fig. 3. Facilities of the TPS system with reuse of urine in vegetable crops (Factura *et al.*, 2014).

Crops cultivated around dumpsites had high metal concentrations (mg/kg) of Cobalt (0.33) and Iron (0.32) in roselle leaves; Copper (0.71) and As (0.37) in groundnut; Copper (0.48) and Arsenic (0.28) in maize grains; Arsenic (0.36) and Cobalt (0.32) in spinach leaves; and Copper (0.36) and Cobalt (0.32) in okro (Opaluwa *et al.*, 2012). These are just few of the literatures that provide evidences showing that any heavy metal present in the growing media or irrigation source can accumulate in plant parts once absorbed by the roots. While all the above-metioned elements are considered heavy metals, Copper, Zinc, Manganese, Iron, Nickel and Molybdenum are actually essential micronutrients for plants (Page & Feller, 2015).

Holistic sanitation technologies

Sanitation technologies have been developed to provide methods and techniques for the separate collection, treatment and reuse of human excreta (urine and faeces) (Otterpohl *et al.*, 2002). Ecological sanitation (ecosan) is a cylce - a sustainable, closed-loop system, which closes the gap between sanitation and agriculture by recycling the nutrients contained in human excreta in crop production (Langergraber & Muellegger, 2004).

A community urine diversion dehydration toilet (UDDT) as shown in Fig. 4 has been widely implemented by various organizations especially in tropical countries of Asia and Africa (EcoSan Club, 2010; Gensch *et al.,* 2010). Urine and faeces are separately collected and treated. Urine is stored in closed plastic container for at least 1 month before reuse.

Fig. 4. UDDT of the Periurban Vegetable Project in Manresa Farm, Xavier University-Ateneo de Cagayan, Cagayan de Oro City, Philippines.

The pH of fresh urine is normally between 4.8 and 7.5 but after collection it is around 9 and hygienizes (Höglund, 2001).

The World Health Organization (2006) published treatment guidelines that renders safe reuse of excreta in agriculture. Terra Preta Sanitation (TPS) is a technology that converts faeces using vermicomposting into hygienic organic matter that can be used to improve soil condition (Factura *et al.*, 2010). TPS with UDDT (Fig. 3) was successfully implemented in Xavier Ecoville, a resettlement community with 500 survivor families who were affected by typhoon Washi that devastated Cagayan de Oro City, Philippines in 2011 (Factura *et al.*, 2014).

Conclusion

Heavy metals contributed by urine in domestic wastewater can be efficiently captured using phytoremediation technology.

Reuse of urine will definitely benefit farmers by reducing dependence from chemical fertilizers and at the same time reduce the risk of heavy metal contamination in water bodies especially in areas where household sanitation systems are absent or poorly established.

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