Linking Sanitation to Agriculture: Recycling Nutrients from Human Excreta in Food Production

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Abstract

Poor sanitation services and water scarcity have become a global issue and not only a problem relevant to arid zones. In addition, hunger and malnutrition, poverty and limited energy access that constrain the achievement of human wellbeing and economic growth are worldwide problems, including Brazil. Large conventional municipal wastewater treatment plants are often expensive to establish and difficult to operate. As a result many cities and villages in developing countries are unable to set up such facilities and operate them. Decentralized wastewater treatment systems have proved to be successful in many communities, particularly in peri-urban settlements in Asia and Africa. This approach is based on the principles of decentralization of responsability, simplification of technology and the focus is on recycling the waste and nutrients.

Palavras-chave: *human urine, ecological sanitation, unfertilized soil, urban agriculture, permaculture.*

1. Introduction

Appropriate sanitation is crucial for human health, dignity, poverty alleviation and sustainable development but several challenges such as inadequate access to sanitation facilities and to safe drinking water must be addressed. Diarrhea is the third major cause of death in children under five years[1,2]. In urban areas, less than 50% of Brazilian houses are connected by network sewers. In rural households, rudimentary septic tanks are the main solution, causing soil and groundwater contamination, increasing risks of drinking water from wells.

Mostly of developing regions in world still lack wastewater collection and treatment, and this situation create a huge opportunity to plan, design and implement innovation in the water sector in order to approach the sewage management in a matter to maximize the treatment as a source of valuable products instead of a waste. Brazil has the highest rate of urbanization in Latin America, with 84.4% of its inhabitants living in cities. In some areas, including rural settlements and some of the fast-growing peri-urban areas around major cities, there are serious problems providing basic services such as solid waste management, water supply and sewage management.

Considering that conventional sewage collection and treatment is not a solution for all situations, it is worthwhile to explore additional sanitation solutions based on the recovery of nutrients from human excreta to increase the soil fertility and to reduce sewage discharge to water ecosystem. This conception includes onsite segregation of different wastewater fractions such as graywater from showers, lavatory basins, laundry and kitchen sinks; yellow water from urine; and black water from feces. Each fraction can be collected, stored and treated separately, instead of mixture with drinking water as the conventional sanitation system do. Safely treated feces and urine can thus be used as fertilizer and soil enrichment material in agriculture, and graywater can be reused for many purposes. In addition it can contribute to enhance the access to sanitation and food security in poor communities.

The urine treatment includes storage, adding acid to inhibit the urea decomposition, stabilizing solutions and precipitating struvite and recovering nutrients. To eliminate the pathogens in feces, the dehydratation with lime, calcium oxide or wood ash or biological processes such as termophilic composting, vermicomposting and Terra Preta are alternatives.

Human urine has been reported as a high-quality and low-cost fertilizer. Experimentally, researchers in many countries have shown that human urine can improve and stimulate plant growth of several species of ornamental flowers, fruit trees and vegetables. Published data shows that the average nutrient contents per liter in human urine are around 7.4 g of total nitrogen, 407 mg of total phosphorus and 1.7 mg of potassium.

Heinonen-Tanski *et al.* reported cucumbers fertilized with pure urine did not present any enteric microorganism. Besides the benefits of nutrient recovery from urine in crop production, more scientific investigation is needed to address the accurate application rates and the effects of urine as fertilizer on specific crops and on soil chemistry.

This study aimed to evaluate the responses of corn and lettuce to different levels of urine fertilization, the effects on soil and to recommend appropriate urine dosage that leads to the optimal development of these species.

Finally the study can contribute as a technical basis for policymakers and reuse practices providing information to support excreta use in peri-urban agriculture, linking the sanitation and agricultural sectors in order to re-orient the linear fluxes to a more cycling systems.

2. Methods

We used plastic pots from 5 to 10 L capacity; graduated watering, reservoirs for urine collection; *Lactuca sativa* L. and *Zea mays* L. seeds; waterless urinal; organic topsoil material.

The study was conducted in the campus of the University of Sao Paulo, Brazil (23°29'0"S, 46°30'8"W). Annual average temperature was 19ºC and rainfall was approximately 1,680 mm.

- Human urine collection

To collect the human urine, one waterless urinal was installed in a male´s toilet of the university campus. The piping was connected to a storage tank, placed under the urinal and daily 1.6L were collected.

- Plants Trial and experimental procedures

To analyze the effects of human urine on soil and plants, the experiments were conducted in plant nursery. We established two treatments for corn and three treatments for lettuce, receiving different urine dosages. We also established one control treatment for each species (non-fertilized and irrigated with tap water). The application rates are described in Table 1.

Table 1: Urine application rate for the corn and lettuce crops.

Treatment/Species	Corn	Lettuce
A	200,000 L/ha of neat urine, distributed in 8 applications once a week.*	12,000 L/ha of neat urine distributed in 3 applications (15, 30 and 45 days after seeding).
B	10,800 L/ha of neat urine, 35 days after seeding.	1,500,000 L/ha of diluted urine, distributed twice per week at a dilution of 3:1 (water: urine) during the first month, a dilution of 5:1 during the second month, and a dilution of 5:1 once per week in the third month.*
C	No urine (control).	20,000 L/ha of neat urine, one application 48 days after seeding.**
D	—	No urine (control).

* Based on Morgan. ** Based on Guadarrama *et al*.

For lettuce each pot used in treatments A, B and control was filled with 5.5 kg of topsoil, and the pots used in treatment C was filled with 3 kg. Six seeds were planted per pot. For the corn experiments was used 7 kg of topsoil and three seeds per pot.

All treatments were watered with the same volume of tap water, including the water volume in the dilution. Irrigation was performed manually. On days when the soil was moist due excessive rain, the water volume was reduced by half or was not applied. The pots were dispersed randomly inside the plant nursery to avoid influences of luminosity and rain. In both experiments, each treatment and control was replicated ten times.

Before application, the urine was not stored for a specific period, except in treatment B of corn, stored for 7 days. The urine application was followed by watering to avoid soil salinization and toxic effects, directly to soil in holes as described by Gensh *et al*.

For the Treament A of corn, urine application started after seedlings emerged. The urine application rate for corn in treatment B was calculated based on the plants nitrogen requirement[14,15] and N content in urine (7.4 g/L).

The urine application rate for treatment A of lettuce was also based on the requirements for nitrogen[15]. Other rates are presented in Table 1.

The study lasted 167 and 98 days for corn and lettuce respectively.

- Plant data collection and statistical analysis

After the monitoring period, we compared the biological parameters of the different fertilization treatments and the control to determine the best dosage for each species. We measured the root weight and leaf area in addition to the shoot dry weight (for corn) and the root length and shoot fresh weight (for lettuce).

After the growth period, shoots of each plant were oven-dried at temperatures of 55 to 75°C for 5 to 6 days until they reached a constant weight. Leaf area was measured with a leaf area meter (Portable LI-3000-C). All collected data had a normal distribution and were subjected to Analysis of Variance (ANOVA) using Minitab 16 statistical software.

- Soil sampling, analysis and analytical procedures

Samples of composite soil were taken at 0–15 cm depth in each pot. Before and after the cultivation period, we analyzed the physicochemical soil properties, including the organic matter content, phosphorus, potassium, calcium, magnesium, sulfur, aluminum+hydrogen (potential acidity) and others. For the lettuce experiment, in addition it was measured micronutrients content, total nitrogen, nitrate and ammonium. The analyses were run in specialized laboratory.

3. Results and Discussion

In both corn and lettuce experiments, urine application significantly (p-value<0.05) increased growth and leaf production relative to the control treatments.

3.1. Effects of urine as fertilizer on corn growth

Ten days after planting, seeds germinated in all pots. The intervals between vegetative phases were influenced by winter season. Three months after planting, some plants in all treatments were attacked by insects. And in the same period, only two pots of corn in treatment A had fully emerged tassels. On October 4th, five pots of treatment A had plants with fully emerged tassels; five pots of treatment B, one of treatment A and three of control had stigmatas and two pots of treatment A had an ear of corn. The mean number of leaves was 8.29 in treatment A, 5.57 for treatment B and 3.28 for control. At the end of the experiment, there were stigmata in one pot in treatment C, in six pots in treatment B and in five in treatment A. There were tassels in eight pots in treatment A, and ears of corn in six pots in treatment A and two pots in treatment B.

Based on the leaves color intensity, the corn plants belonging to control showed symptoms that, according to Ferreira *et al*., might be attributed to phosphorus and nitrogen deficiency, while the leaves of treatment B presented symptoms of nitrogen deficiency. There were no symptoms in the plants of treatment A, and those plants presented dark green leaves.

After the cultivation period, all pots in treatment A had plants with at least one ear of corn, two plants in treatment B had ears, and no plants in control had ears. Plants in control also had fewer leaves (3.3 leaves per plant) and were significantly shorter compared with the treatments that received urine as fertilizer (8.3 and 5.4 leaves per plant in treatments A and B respectively). None of the plants in the treatments A, B and C reached physiological maturity. However, all plants belonging to treatment A were in the reproductive stage, most of the plants of treatment B were in this stage, and only two plants of control were in this stage.

The corn experiment showed that plants in treatment A had better growth with more leaves and ears. The leaf area, shoot dry weight and root weight increased significantly ($P<0.05$) with the urine application compared with the Control. This increase could be attributed to higher nutrient uptake by roots, lower hydric deficit and higher photosynthetic capacity.

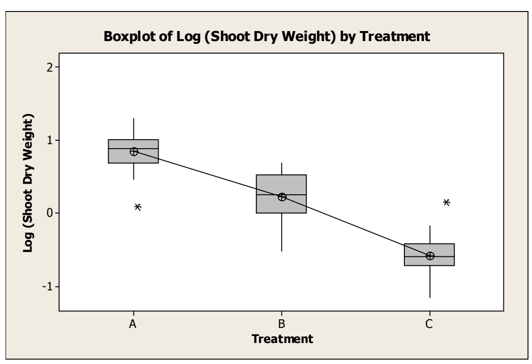

Figure 1– Boxplot of shoot dry weight for each treatment.

The boundaries of each box indicate the first and third quartiles of the sample data, and the solid line within the box marks is the median. The point inside the box is the mean. The whisker bars extend to the values known as the adjacent values. These values in the data are the furthest away from the median on either side of the box. The asterisks are the outliers.

Mnkeni *et al.* evaluated the different dosages of urine (0, 50, 100, 200 and 400 kg of N/ha). The highest values of fresh and dried biomass of stems and leaves occurred in plants that received the two highest doses of urine. Plants that received these rates showed higher N, P and K accumulation in corn stems and leaves. In our study, treatment B received 80 kg N/ha and treatment A received 183 kg N/ha. These treatments had higher shoot dry biomass, leaf area and root fresh biomass, confirming the positive effect of urine as fertilizer. In a study by Morgan, more plants, heavier cobs and higher kernel weights were in soil that received 200,000 L/ha of urine compared to untreated or with commercial fertilizer soils. Plants in our treatment A (200,000 L/ha) showed higher number of ears. Akpan-Idiok *et al.* tested urine in okra production and compared it with chemical fertilizer. The application of 15,000 L/ha and 20,000 L/ha produced plants significantly taller than plants treated with NPK 15:15:15 fertilizer.

3.2. Effects of urine as fertilizer on lettuce growth

Ten days after planting, seeds emerged from the soil in all pots, except one from treatment B. During the lettuce cultivation, there was mortality in all treatments, mainly from insect attacks (*Doru luteipes* and *Lepdoptera*).

One month after planting, pots in treatments A and B showed a yellow precipitate in the soil, that could be struvite precipitate. Furthermore, fungi were found on soil upper layer in treatments A and B. The plants in treatment B had the higher number of leaves, but also the higher mortality (Figure 2).

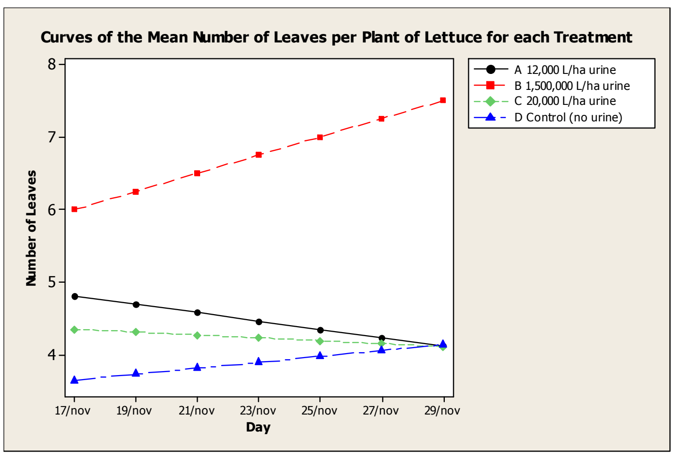

Figure 2 - Curves of the mean number of leaves per plant for each treatment. The point represents the mean of number of leaves of all plants in each treatment on that day.

At the end of the experiment, plants in treatment B presented greater values for all biological parameters measured. The root length and shoot fresh weight increased significantly ($P < 0.05$) with the increase in application rate. Other parameters followed the same pattern: the highest values in treatment B, followed by treatments C, A, and D. Higher values of shoot fresh weight and root length may indicate superior water-holding capacity, higher availability of nutrients in the soil and superior absorption of water and nutrients. The shoot fresh weight and root length values were proportional to the amount of applied urine. Based on these results, the best growth of lettuce occurred on soils fertilized with dosages of treatments B and C. However, this greater urine dosages does not necessarily improve plant growth because each species has different nutrient requirement.

Guadarrama *et al.* conducted a study with lettuce comparing four treatments. After fertilization, leaf area and fresh weight showed better results when pure urine treatment was applied to soil. This treatment had 248 cm² of leaf area, 87.4 cm of coverage and 1,233 g of fresh weight of lettuce and was followed by compost treatment, urine-compost treatment and control. In treatment C for lettuce, dosage was the same as that tested by Guadarrama *et al.* and as mentioned above, these plants showed the second higher root length and shoot fresh weight values.

3.3. Effects of urine fertilization on soil physicochemical properties

In both corn and lettuce cultivation, in the treatments that received more urine, soil presented lower pH and higher electrical conductivity. The other treatments and controls had constant values throughout the monitoring period. It is important to monitor these soil properties during and after fertilization to avoid soil salinity and acidity. These results agreed with the trend of soil salinity increased with urine fertilization, reported by Mnkeni *et al*., Kassa *et al*, Gensh *et al*. The decrease in pH results could be influenced by the ammonium nitrification process in soil. As urea is degraded, one hydroxide ion is released. Two protons are released in nitrification, and another hydroxide ion is released during plant uptake, so the proton action is neutral in soil. The pH of soil fertilized with the highest dose decreased initially, but it increased slowly as time passed. It is worth to note that for both species, the electrical conductivity effect in the treatments with the highest dosages was also temporary, which may be attributed to the phenomenon related above.

3.3.1. The effects on soil during corn cultivation

The physicochemical soil analysis before fertilization revealed high contents of phosphorus, magnesium and potassium for all treatments, according to Malavolta. After the fertilization, soil analyses indicated that the physicochemical characteristics did not vary significantly among the treatments. The only noticeable difference was an increase in potassium content in treatment A. treatment B had increases in organic matter content, phosphorus, sum of bases, calcium, magnesium, potential acidity, cation exchange capacity and base saturation after cultivation. There was no exchangeable aluminum or aluminum saturation detected, which indicates that urine fertilization did not cause increase in soil acidity.

Comparing the physicochemical properties before and after cultivation, phosphorus concentration decreased in all treatments and was high (from 61 to 120 mg/dm³) in the soil in treatment B and sufficient (between 31 and 60 mg/dm³) in the other soils. In all soils samples, the calcium content was very high (higher than 40 mmol/dm³), and the magnesium content was classified as high (higher than 8 mmol/dm³) in all treatments. Potassium content was very high in treatment B (higher than 6 mmol/dm³), sufficient in treatments A and C (3.1-6 mmol/dm³), and low in the control soil. Soil of treatment B had medium acidity values, while the other treatments had low acidity.

According to the soil analyses after fertilization, nitrogen, boron, zinc, manganese, copper, phosphorus, potassium and potential acidity were higher in the soil in treatment B than in others.

Because phytotoxic potential of micronutrients is higher than macronutrients potential, the high mortality of plants in treatment B could be a result of it. The nitrogen content values were directly proportional to the urine rate. The exception was the treatment A with higher nitrogen content than C, though the latter received higher urine dosage. Control soil showed the lowest values for most of the analyzed parameters.

According to Garcia *et al*., nitrogen is the primary nutrient that promotes increased productivity and average weight in lettuce since it is mostly composed of leaves. Plants from treatment B had the highest shoot fresh weight and higher total nitrogen content in soil, which may indicate greater nitrogen uptake. The pH analysis showed that neat urine and stored urine had the same pH value of 9.5. Stored urine had higher chloride content (10,300 mg/L) than fresh urine (8,230 mg/L).

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4. Conclusions

O The use of human urine as fertilizer increased the shoot fresh weight, root weight, number of leaves and leaf area. In lettuce cultivation, the soils that received higher urine doses had higher nutrient contents compared with the control.

Nowadays there is an increased understanding of the importance of working toward better sustainability in our wastewater treatment systems in order to better capture the water and nutrient resource potential contained in wastewater as a highly desirable goal. The use of human urine as fertilizer is a viable alternative that could be implemented without major difficulties, as has been demonstrated in our study. The waterless urinal technology proved to be economically viable, operationally easy with good level of user acceptance in the context of a university campus The scientific basis studies has shown its viability and the next step is to marketing this approach in order to support decision makers to fund projects in peri-urban agriculture in developing countries.

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