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Human urine as fertilizer: Feasibility study of use in corn and lettuce cultivation in a university campus in Brazil.

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Abstract: Greenhouse experiments were conducted to evaluate the response of corn and lettuce to different levels of human urine, and to evaluate the effects on soil. Plants treated with the urine showed measurable improvements when compared to the control group. Recommended dosages for better development of these species is included in the conclusion. The main experiment results obtained in both the corn and lettuce cultivation was that the groups that received regular rates of urine developed significantly better. Corn showed a higher number of leaves, height, leaf area, shoot dry weight, root weight and number of ears measured against the control group. Lettuce showed higher values of root length, number of leaves and shoot fresh weight also compared to the control group treated only with tap water. It is recommended for corn cultivation the urine dosage of 125 mL of neat urine per pot once a week applied during 2 months. For lettuce, the dosages of groups B (400 mL of diluted urine, 3:1 water: urine) and C (one application of 51 mL of neat urine per pot) are recommended. In both experiments, the electrical conductivity of soil with the highest urine dose increased and pH decreased.

Keywords: *Ecosanitation. Fertilizer. Reuse. Urine. Waterless sanitary systems.*

Introduction

Many water-related diseases affect health of human population. According to World Health Organization, diarrhea is the main cause of infant mortality in developing countries, totalizing more than 4 billion of cases per year (WHO, 2011). Some measures are important to reduce occurrence of these diseases, as: access to safe drinking water; improved sanitation; and good personal and domestic hygiene.

Although sanitation is a human right, there are 2.4 billion inhabitants who don't have access to any type of improved sanitation facility. In Brazil according to Sanitation National Research, in 2008, of all 5564 Brazilian municipalities, just 3069 had sewage collection system. As the water supply, 5531 municipalities had the service in 2008. The Brazilian regions with main lack of water and inadequate sanitation are North and Midwest (IBGE, 2008).

Currently the existing sanitation solutions cause many impacts to environment, because they assume yet that environment has the infinite capacity to absorb pollution and waste. Some consequences are: contamination of water sources and soil pollution.

Other sanitation approaches that aim human excreta reuse as fertilizer can contribute to improve water security and to reduce food insecurity, particularly in poor communities without sanitation services.

One serious problem is a tendency to scarcity of natural resources used for commercial fertilizers production. It is estimated that the stocks of natural phosphorus reserves will be depleted between next 60 and 130 years (Cordell, 2009). This scarcity can aggravate food insecurity condition. Data from 2009 states there are 1.02 billion undernourished people in the world (FAO, 2010). In many countries this condition is aggravated by low soil fertility, high natural loss of soil nutrients and low access to chemical fertilizers (ECOSAN CLUB, 2010).

In that background of lack of basic sanitation, food insecurity and sanitation technologies that impacts significantly environment, there is a approach known as Ecological Sanitation that assumes among other actions: the reuse of human urine and faeces as fertilizer in agriculture, and the use of dry toilets (or with water reuse).

That system has many advantages compared with conventional systems, such as: to prevent disease transmission; to increase the access to sanitation (with low costs); to protect environment and conserve natural resources; to operate with simple maintenance (Winblad *et al*., 2004).

The nutrient content in human urine depends on the diet. Urine contains significant quantities of nitrogen, phosphorus and potassium. Many authors suggest one person produces in urine about 2.5 to 4.3 kg of nitrogen; 0.4 a 1.0 kg of phosphorus and 0.9 to 1.0 kg of potassium per year (Guyton, 1992; Jonsson *et al*., 2004; Vinneras & Jonsson, 2002).

In many countries there are experiences testing application of urine as fertilizer in cultivation of several species, like: fruit trees, lettuce, corn, onion, tomato, spinach, leeks and ornamental plants (Morgan, 2007; Otterpohl, Malisie & Prihandrijanti, 2007; Matsui, 1997).

The use of urine in agriculture has many advantages: to increase soil nutrient content; water retention capacity; and to increase plant resistance to pests, insects and parasites (ECOSAN CLUB, 2010).

From a health perspective urine has less risk than faeces. World Health Organization recommends technical measures to minimize health risks in excreta reuse: collected urine should be used after a storage period that varies between 1 and 6 months. This storage period is important to decrease risk of pathogen transmission and depends on fertilized species. This is recommended for large-scale systems because when urine is collected from many users and the product is sold/transferred to a third party, the microbial risks increase. A less strict storage (1-2 weeks) can be applied for urinals where the faecal cross-contamination is excluded (WHO, 2006). Concentration of any pharmaceutical residues can compose urine but do not reach concentration which affect plant growth. The potential toxic effects to human food chain have not yet been studied (Winker *et al*, 2008).

After this overview, the acceptance of practice aims to reduce water and soil pollution and allow nutrient recycling can contribute emphatically to public health, environmental health

and human well-being. Based on this information, this study aimed to address the integrated and sustainable concept of sanitation, with reuse of human urine as fertilizer for plants and tried to evaluate the benefits and impacts of this technology in university campus of University of São Paulo.
The specific objectives were: to evaluate the use of human urine as fertilizer for corn (*Zea mays* L.) and lettuce (*Lactuca sativa* L.) in soil with different urine doses; to analyze the effects of urine fertilizer in soil and in plants, based in the comparison of fertilized and non-fertilized plants; to recommend appropriate urine dose that result in better development of that species.

Methods

The human urine was collected from one waterless urinal installed in a male bathroom of university *campus* of School of Arts, Sciences and Humanities, in São Paulo, Brazil. The piping of urinal was connected to a 10 litre tank. Urinal has a system with a sealant liquid (blocking fluid) which is biodegradable and constitutes an effective odour barrier. Below is a photo of urinal and urine collection tank.

Figure 1- Waterless urinal installed in a male toilet in the *campus*.

Publicizing to recruit users to urinal was through e-mail to groups of students and staff of *campus*. Poster also were placed next to the door of the bathroom and on the wall where the urinal is supported, for dissemination to users about its characteristics, and to provide information about its cleaning. Urine collected volume per week was about 8 litres of urine (1,600 $mL.day^{-1}$).
To analyze the effects of urine fertilizer in soil and in plants, trials with corn and lettuce planting were conducted in *campus* greenhouse. Groups were established and each one received a treatment with a different amount of urine. One of them didn't receive urine and was control (irrigated with tap water only). Table 1 describes each group/treatment.

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

Treatment/Species	Corn	Lettuce
A	125 mL of neat urine per pot, once a week, 8 applications.*	48 mL of neat urine per pot, distributed in 3 applications (15, 30 and 45 days after seeding).
B	54 mL of neat urine per pot, 35 days after seeding.	400 mL of diluted urine per pot (1:3 urine to water ratio), twice a week during first month; dilution 1:5 during the second month; and in third month dilution 1:5, once a week.*
C	Irrigated with only water.	51 mL of neat urine per pot, once application 48 days after seeding.**
D	—	Irrigated with only water.

* Based on Morgan (2007).
** Based on Guadarrama, Pichardo and Oliver (2002).

The pot capacity was 10 litre for corn treatments, 8 litre for treatments A, B and D and 5 litre for treatment C of lettuce. All groups were watered with the same water volume. Irrigation was done manually with a watering pot. For corn, water volume was 400 mL per pot three times per week. Two months after seeding this volume was reduced to 350 mL twice a week. For lettuce, water volume was 180 mL per pot for groups A, B and D, and 118 mL per pot for group C. In days when soil was moister because of rain, the water volume was reduced by half or wasn't applied (when soil was soaked). The urine application was followed by watering to avoid soil salinization and toxicity effects (Gensch, Miso, Itchon, 2011). Before being applicated the urine wasn't stored except for treatment B of corn, which urine was stored during 7 days.

According to the literature, urine should not be applied on leaves, roots or other parts of plants to avoid leaves burning. Thus urine was applied only to soil in dug holes next to the plant, 10 cm of distance from plant and about 10 cm depth (Gensch; Miso; Itchon, 2011).The soil used in planting was topsoil.
Urine application rate of treatment A of corn was based on experiment of Morgan (2005). The first urine application happened 9 days after seeding. Second application was one week after the first. And from third application frequency was the same that Morgan recommends. Urine application rate of treatment B of corn was based on plant

requirements of nitrogen (N) and on nitrogen content in urine. Dose was calculated at a rate corresponding to the desired N requirements of corn. We chose recommendations from Brazilian Agricultural Research Agency and Campinas Agronomic Institute for nitrogen fertilizing for corn (Coelho *et al*., 2006; IAC, 2005). We considered nitrogen average content in urine was 11 grams per 1.5 litre of urine. The calculation resulted in 54 mL of neat urine per pot. The pots were dispersed randomly in the greenhouse, to avoid influences of external factors, as: luminosity, exposure to wind and rain and others.

In corn experiment each pot received three seeds and in lettuce experiment each pot received six seeds to increase germination possibility. Each treatment was replicated ten times (ten pots).

Urine application rate of treatment A of lettuce was based on plant requirements of nitrogen (IAC, 2005). The calculation resulted in 48 mL of neat urine per pot, applied distributed in three times (Table 1) in different growth stages of plant.

Rate of treatment B was based on experiment of Morgan (Morgan, 2007) and it is described in Table 1. Urine application rate of treatment C was based on an experience performed in Mexico by Guadarrama, Pichardo and Oliver (2002). Considering nitrogen average content in urine and capacity of pot, the calculated dose for this group was 51 mL of neat urine per pot, applied 48 days after seeding.

The period of observation of species growth was 5 months and 17 days (corn) and 3 months and 8 days (lettuce). The seeding of corn occurred on May 18^{th} ,2011 and seeding of lettuce occurred on September 2^{nd} , 2011.

After cited period, some plant biological factors were measured to compare the different fertilizing treatments and control group and to analyze what dose is the recommended to cultivation. It was measured: root weight, leaf area and shoot dry weight (plant aerial parts) (for corn). For lettuce it was measured: root length and shoot fresh weight. Aerial parts of each plant were placed in envelop and were oven-dried in BOD incubators at temperature between 55-75ºC during 5 or 6 days. After, data were collected and were subjected to analysis of variance (ANOVA) using Minitab 15 statistical software.

Before and after cultivation period it also was made physicochemical analysis of soil such as: organic matter content, nitrogen content, phosphorus, potassium, calcium, magnesium, sulphur, Aluminum + Hydrogen, Sum of bases, Cation exchange capacity, base saturation, and micronutrients. These analyzes were performed by specialized laboratories. In addition pH and soil electrical conductivity were measured throughout all cultivation period. To measure pH and electrical conductivity of soil we collected samples of soil of each pot to compose sample representative of each treatment. The samples were diluted in established volume of deionized water. After this procedure we measured with a pH Meter and a conductivity meter.

Results and Discussion

Through statistical analysis (ANOVA) we concluded that the urine application significantly ($P < 0.05$) increased growth and leaf production compared with the control treatments. There was significant difference between treatments. Treatment A which received the highest urine concentration had a better growth and development, with higher number of leaves, height, leaf area, shoot dry weight, root weight and ear of corn number. This proved better development, which can indicates: best nutrient uptake, mainly nitrogen; lower hydric deficit and higher photosynthetic capacity (Severino *et al*., 2004; Marriel *et al.*, 2000).

Plants of treatment B had the second best results for biological characteristics measured and they were followed by treatment C which had worst results. After cultivation period, all pots of treatment A had plants with ear of corn, and two plants of group B had ear of corn, none of plants of group C had ear of corn and they reached lower number of leaves (3.3 leaves per plant) compared with treatments which received urine as fertilizer (8.3 leaves per plant-group A; 5.4 leaves per plant- group B).
Figure 2 illustrates the results of shoot dry weight for each treatment. And Figure 3 shows the results of statistical analysis of leaf area for corn.

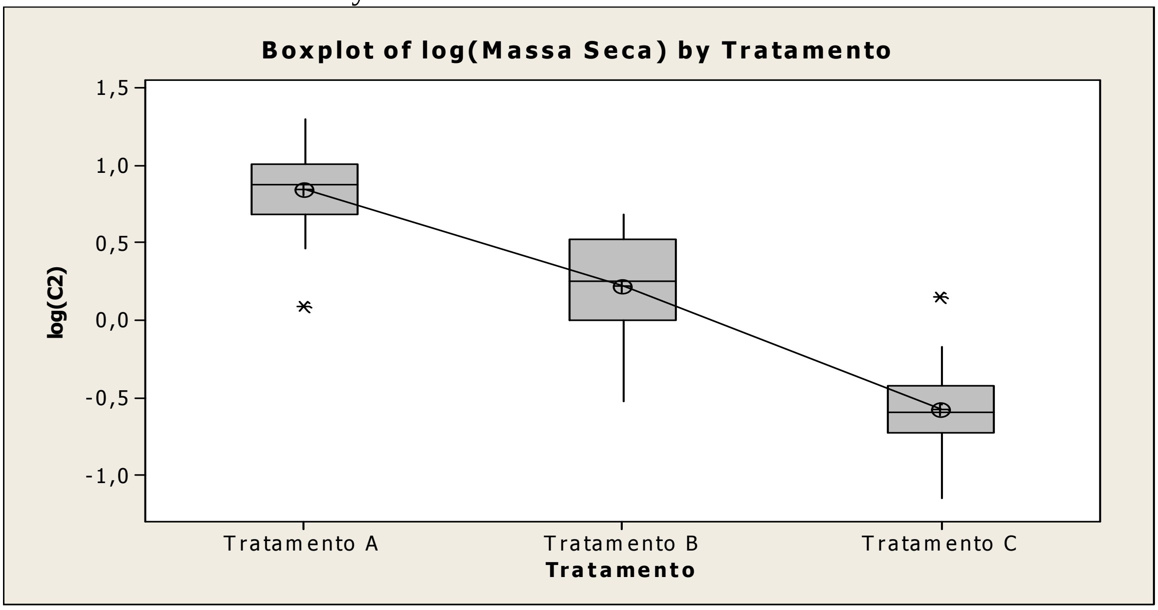

Figure 2– *Box-plot* of data distribution of shoot dry weight (´´Massa Seca``) of each treatment (´´Tratamento``).

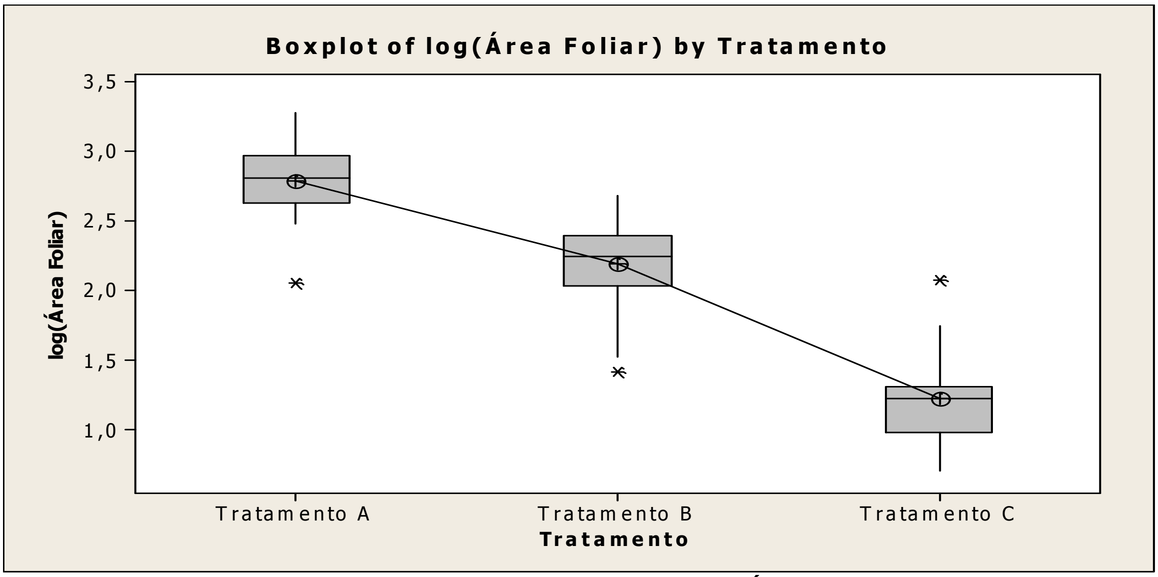

Figure 3 – *Box-plot* of data distribution of leaf area (´´Área Foliar``) of each treatment (´´Tratamento``).
We observed that plants of group A developed better than others, with the best values of biological characteristics, higher height, number of leaves and ear of corn number. Based on color of leaves we noted that plants belonging to group C presented symptoms of lack of phosphorus and nitrogen in their leaves, and leaves of group B presented symptoms of

lack of nitrogen. Plants of group A didn't have none symptoms and had dark green leaves (Ferreira *et al.*, 2001).
Results of Soil analysis indicated that physic-chemical characteristics didn't vary significantly among the groups. The only noticeable difference was in group A there was an increase in potassium content. Group B had higher number of characteristics with increase, comparing values before and after cultivation. Analysis of soil pH and electrical conductivity resulted in lower pH values to treatment A and values practically constant and with small increase to treatments B and C.

However the effect of urine decrease soil pH is used to being temporary because when nitrate is absorbed by plant roots, it releases two hydroxide ions which neutralizing protons action (Schonning, 2001). Results indicated that there was meaningful increase of electrical conductivity of soil in treatment A. Although it is interesting to note that electrical conductivity of group A greatly increased but decreased as time passed. Treatments B and C did not have significant changes of value.

After lettuce cultivation, it was revealed there was mortality in all treatments and the cause was attack of insects (*Doru luteipes* e *Lepdoptera: Gracilariidae*) which were observed in some leaves. Furthermore it was observed some pots of treatment B were with yellow precipitate in soil. Probably it might be because urine fertilization with highest dose. We also noted fungi were growing on the surface of soil of treatment A and B. At the end of cultivation, plants belonging to groups A and D had lower mortality followed by group C and B (with the highest mortality). Relative to number of leaves, plants of treatment B had the highest values. Statistical analysis showed for all biological parameters (root length and shoot fresh weight) the plants belonging to treatment B showed best results and the distribution of pattern statistics was the same, the highest values were in group B, followed by groups C, A and D.

Based on this study, it was showed the positive effect of human urine as fertilizer on lettuce production. Control group showed the lowest values in statistical analysis and the values of shoot fresh weight and root length were proportional to amount of applied urine. Higher values of shoot fresh weight may indicate best water-holding capacity and higher availability of nutrient in soil (Medeiros *et al.*, 2001). Higher values of root length may indicate best absorption of water and nutrient.

Figure 4: Plants of group B (urine fertilized lettuce).

Figure 5: Plants of group D (irrigated with only water).

Nitrogen content, boron, zinc, manganese, phosphorus, potassium and potential acidity were higher in soil of group B than in others. Calcium, magnesium, sum of bases, Cation exchange capacity and base saturation in exchange capacity at pH 7.0 were higher in soil of group A. And soil of group D was with the highest organic matter content.

Analysis of nitrogen content in samples have indicated values: 2.32 g of N/kg in soil of treatment A; 3.48 g/kg in soil of treatment B; 1.93 g/kg in soil C and 1.54 g/kg in soil D. Results of pH and electrical conductivity had pattern similar to corn results.

In addition, it was also calculated a payback period considering replacement of all flush urinals of *campus* with waterless urinals. Payback study showed that investment would be payed in 10 months. Simple payback period refers to the period of time required for the return on an investment to "repay" the sum of the original investment. In this case, the investment would be the buy of waterless urinals. The value of simple payback was 9 months and 7 days. Discounted payback period considers a rate of return and the time value of money, this value was: 10 months and 9 days. We considered that conventional urinals of *campus* had flush of 3 litre per use. If all units in campus were waterless urinals the economy in water bills would be substantial, about U$ 48,286.00 annually.

Conclusions

Based on this research we concluded:

Reuse of human urine as fertilizer is a possible practice that can be implanted easily as it has been happening in many countries recently.

Both corn and lettuce cultivation the treatments received urine dose have developed significantly better than the control group and had higher values in all of the biological parameters measured.

It is recommended for corn cultivation the dosages of groups A and B, but the latter with less significant results.

In lettuce cultivation group which received the highest urine dose had raise mortality what we can assume the cause was the higher electrical conductivity (salinity), or decrease of soil pH or toxicity by micronutrient.

We recommend for lettuce cultivation besides dose applied in group B the dose applied in group C which obtained higher values in measured parameters and had low mortality.

Lettuce soil that received urine doses had higher nutrient content compared with control group. The group that received highest urine dose obtained better values in most parameters analyzed.

In Brazil and many other countries there is lack of policies that stimulate and encourage reuse of human excreta as fertilizer and the new sanitation practices, in this way this study could also be used as a learning tool in university campus.

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