

Human urine as a source of nutrients for maize and its impacts on soil quality at Arba Minch, Ethiopia

Kinfe Kassa, Yesuf Ali and Wubishet Zewdie

ABSTRACT

A pot experiment was conducted at Arba Minch, Ethiopia to study the effects of urine on soil properties and yield of maize in natural settings. The pot treatments consisted of 500, 800, 1,000 and 1,200 ml of neat human urine collected from a UDDT (Urine Diversion Dry Toilet) added at different portions and control. The results showed that the response of the maize for most of the variables was very well expressed or significantly different at the application rate of 500 ml of urine; however, there was no significant difference between the 500 ml and the rest of the application. A significant increase in height, diameter, and length of leaf of maize was found in the urine treated soils. An improvement in soil phosphate chemical properties was noticed with increasing addition of urine; however, there was no significant increase in the ammonium nitrogen content and pH. The salinity of treated soil significantly increased at the bottom of the pot when compared with the control. In order to limit the increase in salinity of the soil and to get optimum maize growth in natural conditions, 500 ml urine addition per maize is recommended. The findings encourage the use of urine as fertilizer and a possible sink for UDDT waste.

Key words | conductivity, human urine, semi-arid, soil salinity, urine diversion dry toilet

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INTRODUCTION

In the Sub-Saharan Africa region, agriculture is dominated by small holder farmers that continuously struggle to maintain the productivity of their land (Anderson 2015). The government of Ethiopia strongly promotes the use of artificial fertilizer by the farmers with the provision of credit services, indicated by the fertilizer usage increment from 5.7 kg/ha in 2003 to 25.97 kg/ha in 2014 (World Bank 2014). Although the farmers' production increased, they were unable to pay back their loans on time and eventually some reduced the fertilizer application rate. In order to replace the expensive industrial fertilizer, the use of urine

as an alternative input for agriculture is a cheap option and encourages waste recycling.

Urine is the major product of ecological sanitation toilets such as urine diversion dry toilets (UDDTs) and its utilization as an agricultural input is a current challenge in developing countries. The use of urine in agriculture has become a new phenomenon in some countries in recent years but it is not understood and not accepted in developing countries. Urine contains plant nutrients that may supplement or replace commercial fertilizers for crop production (Jönsson *et al.* 2004).

The beneficial effects of applying urine in agriculture have been proven by numerous researchers. The chemical composition of urine is in ionic form and its plant availability compares with chemical fertilizer (Kirchman & Pettersson 1995; Johansson *et al.* 2001). Urine is best utilized if the nitrogen concentration is known, as it is variable from different

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doi: 10.2166/wrd.2018.060

sources, and if the plant nitrogen demand and soil nature is known (Winblad & Simpson-Hébert 2004). In addition, treated urine and gray water can normally be used without crop restricting, due to the low degree of fecal contamination (World Health Organization (WHO) 2006).

The urine application may lead to the accumulation of a number of potentially harmful components such as pharmaceuticals and salt content in crops and soils. The presence of salts, heavy metals, persistent organic compounds, hormones and nutrients in the applied urine can result in soil and water contamination and accumulation in food supplies (WHO 2006). The major concern for soil is salinization of the soil when urine is applied. Salinity effects are of concern in arid and semi-arid regions, where accumulated salts are not flushed regularly from the soil profile by rainfall (Mateo-Sagasta & Burke 2010). Soil salinization is affected by insufficient drainage, the type of soil and climate. Depending on the type of soils and drainage conditions, salinity problems in soil occur with dissolved concentrations of more than 500 mg/l, and are severe for dissolved concentrations of more than 2,000 mg/l and a sodium adsorption ratio of more than 3–9 (Ayles & Westcot 1985).

Proper management of urine application for agriculture is essential to maximize its benefit and minimize its adverse effects. The management should consider different aspects such as the volume of urine added, the content of the urine, crop type, nutrient requirements and the soil's chemical and physical properties. In order to avoid the negative effects of urine as agricultural fertilizers, it is also important to improve agricultural practices, establish criteria to operate water supply wells, and to routinely monitor the ground water required (Foster *et al.* 2004).

The objectives of the experiment were to investigate the effect of application of different volumes of neat human urine on the growth of maize and its effect on soil in tropical semi-arid conditions. The study provides data on ecological sanitation, which is generally scarce.

MATERIALS AND METHODS

Description of the study area

Experiments were carried out at Arba Minch, in southern Ethiopia, at an elevation of 1,390 m.a.s. According to the

national meteorology agency of the southern zone, the town receives mean annual rainfall of at least 887.5 mm for the 15-year period from 1990 to 2005, characterized by bi-modal distribution. The mean minimum and mean maximum temperatures are 17°C and 30°C, respectively.

Experimental set-up

Twenty pots, each filled with an equal amount of soil from a farm, were prepared and maize seeds were planted in each. One control and four treatments, each with four replicates, were prepared. Except for the control, each pot was treated with urine from a UDDT portion-wise at the growing stages of the maize. Watering was done for all at the same time and the pots were kept in the open throughout the experiment. The volume of urine and the total nitrogen equivalent are presented in Table 1.

Analysis of plant biomass

Leaf size and length, and height and circumference of each maize shoot, were measured at the end of the experiment. The biomass of each whole maize was air-dried and weighed.

Analysis of soil quality

After removing the maize plant for analysis, soil conductivity, pH, phosphate, ammonia nitrogen and Kjeldahl nitrogen were analyzed as follows (Dewis & Freitas 1970).

Ten grams of air-dried soil and 50 ml of water were shaken for 30 minutes and allowed to settle for 2 hours. Conductivity was measured with a JENWAY 4510 conductivity meter and pH was measured with a standardized JENWAY-3520 digital pH meter.

Two and a half grams of oven dried soil, 25 ml of water, 5 g of salt catalyst and 17.5 ml of concentrated sulfuric acid

Table 1 | Urine application rate in each pot and the calculated nitrogen in grams

Urine added per each pot (ml)	0	500	800	1,000	1,200
Nitrogen calculated from the added urine (gram)	0	3	4.8	6	7.2

mixture was transferred into a 250 ml Kjeldahl flask for digestion. The digestate was made alkaline with strong sodium hydroxide, distilled in boric acid indicator solution and finally titrated with standard sulfuric acid. Ammonia nitrogen was analyzed after mixing 0.5 g of air-dried soil with water, and the pH was adjusted with sodium hydroxide. The solution was distilled into indicator boric acid solution and titrated with standard sulfuric acid.

The available phosphate was extracted with 1 N sodium bicarbonate from 2.5 g of air-dried soil in an Erlenmeyer flask. The mixture was filtered and the phosphate measured at 690 nm after molybdenum blue color development according to the American Public Health Association (APHA 2005).

The collected data were subjected to an analysis of variance. Contrast was employed to test the significance of treatment effects on the plant biomass and soil quality using SPSS version 20.

RESULTS AND DISCUSSION

Effect of urine application on crop

The maize parameters measured were dry biomass weight, height, circumference, number of leaves, width, length and color of leaves and presence of disease on the plant. The analysis of variance showed a significant urine treatment effect for the dry biomass, height, circumference, and length of leaves variables measured, compared to the control for the maize (Table 2). The experiment demonstrated the effect of converting the nutrient held in urine into vegetative growth of valuable plants. It also describes the availability and sufficiency of the plant nutrients in urine.

From Table 2 and analysis of variance, it is found that dry biomass, height, length of leaf, and leaf number of 500 ml and 800, 1,000 and 1,200 ml urine treated maize was not significantly different. The fact that there were no significant differences between the treated variables implies that 500 ml of urine is the optimum for growth of maize (Figure 1). Extra addition of urine does not add any positive effects for the plant. This is especially important for those who do not have the option to extract essential nutrients from urine, where 500 ml of urine can be applied per maize portion-wise during its growing stages. However, the circumference of the 500 ml treated maize was significantly different from the other treatments.

A non-significant treatment effect for the number of leaves was observed in the experiment. Besides, there was no special disease observed either on the control or the treated maize during the experiment. However, the color of the control was yellow, and the 500 ml urine treated and the rest of the treatments showed green leaves. The yellow leaf color is due to a deficiency of nutrients, mainly nitrogen (Chen *et al.* 2014). This indicated that the added urine supplements the nutrient required for the maize. The rate of application based on the 500 ml neat urine is about nine litres per square metre.

Effect of urine on soil properties

The analysis of variance showed that there was no significant treatment effect for ammonium nitrogen on the soil. This may be because the added nitrogen in the form of urea from urine changed to ammonia and was taken by the plant and some evaporated at the given condition. Sene *et al.* (2013) have shown that the concentration of

Table 2 | Maize measured variables ($n = 4$; average \pm standard deviation)

Treatments (ml)	Maize Dry biomass (g)	Maize stem		Maize leaf		
		Height (cm)	Maximum circumference (cm)	Number	Width (cm)	Length (cm)
Control	43.8 \pm 5.6	87.0 \pm 8.04	4.9 \pm 0.9	13.0 \pm 2.2	5.3 \pm 0.4	48.3 \pm 4.9
500	85.8 \pm 13.2	136.9 \pm 9.1	7.2 \pm 0.6	15.0 \pm 1.6	7.1 \pm 0.8	73.9 \pm 8.6
800	116.7 \pm 21.3	146.0 \pm 10.4	8.4 \pm 0.6	16.5 \pm 1.3	7.5 \pm 0.6	77.0 \pm 10.1
1,000	113.5 \pm 28.4	147.8 \pm 10.7	8.7 \pm 0.6	15.9 \pm 1.0	7.8 \pm 1.7	81.8 \pm 5.0
1,200	126.5 \pm 13.8	153.3 \pm 13.6	8.6 \pm 0.3	15.5 \pm 0.6	7.9 \pm 0.8	83.0 \pm 10.4

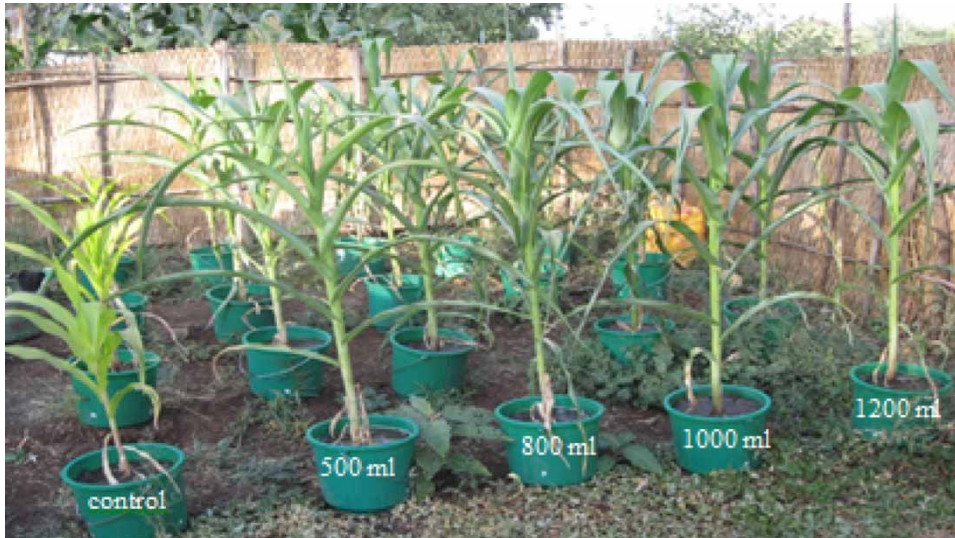


Figure 1 | Pot experiment on maize with four neat urine treatments and a control, each with four replications.

nitrogen in plant shoots increases significantly with the increase of urine. The Kjeldahl concentration of the soil was increased with treated soil as shown in [Table 3](#).

The phosphate concentration of the treated top part of the soil was significantly different from the control and increased with the added urine volume. However, the bottom sampled treated soil showed almost no change compared to the control. Phosphate ion does not migrate until adsorption and precipitation sites saturate in the top soil ([Wang *et al.* 2015](#)).

Effect of urine application on salinity and pH

The treatment effect of the pH of the soil was not significant sampled from either the bottom or the top of the pot. The non-significant treatment of pH could be explained by the

fact that pH needs a longer time to impact on the soil buffer capacity. Any change in pH of soil by irrigation water will take place slowly because the soil buffer resists the change ([Tak *et al.* 2012](#)).

The conductivity of the soil is higher at the bottom of the pot, indicating that the salt percolates with rain and applied water. When comparing bottom soil conductivity values with each other, conductivity of control and 500 ml treated soil is not significantly different. However, the conductivity of the bottom soil of the 800, 1,000 and 1,200 ml treatments was significantly increased compared to the 500 ml treatment. Conductivity increase can be a possible danger for groundwater. Although the conductivity of human urine varies depending on the source and at what conduction it is collected, in the experiment the conductivity of the urine was 25 millisiemens per cm. Therefore, conductivity of the soil increased with quantity of urine added, as shown in [Table 4](#). Watering the plant or rain leaches the salt available on the surface to the bottom ([Ayres & Westcot 1985](#)). Repeated addition of urine will result in an accumulation of salt at the bottom, as shown in [Figure 2](#).

According to [Chapman \(1992\)](#), increasing salinity from the effect of irrigated agriculture is one of the most widespread forms of groundwater pollution. The author also claimed over-irrigation without adequate drainage can cause rises in groundwater level, which result in soil and groundwater salinization from direct phreatic evapotranspiration. When this is translated to the use of urine in a

Table 3 | Soil properties analyzed after urine treatment

Treatments (ml)	Ammonia-N (mg/kg soil)	Kjeldahl-N (mg/kg soil)	Phosphate- P (mg/kg soil)	
			Top	Bottom
Control	257.6 ± 4.6	1232.0	35.5 ± 2.1	49.4 ± 14.9
500	250.6 ± 16.1	1288.0	51.2 ± 9.5	40.7 ± 12.9
800	303.8 ± 66.9	1400.0	45.5 ± 4.3	44.1 ± 7.1
1,000	284.2 ± 46.1	1405.6	60.9 ± 3.1	41.0 ± 13.7
1,200	268.8 ± 37.7	1495.2	60.8 ± 17.7	34.6 ± 6.9

Table 4 | Soil physical and chemical properties with different urine volume treatment (top and bottom means analysis was done either on surface or bottom of the soil collected from the pots; $n = 4$ in each treatment)

Treatments (ml)	pH		Conductivity ($\mu\text{S}/\text{cm}$)	
	Top	Bottom	Top	Bottom
Control	6.8 ± 0.2	6.8 ± 0.1	159.8 ± 15.0	90.8 ± 6.4
500	7.0 ± 0.2	6.8 ± 0.1	180.0 ± 9.4	156.3 ± 19.4
800	7.0 ± 0.1	6.9 ± 0.1	171.5 ± 9.6	265.3 ± 79.6
1,000	6.8 ± 0.1	6.9 ± 0.1	169.5 ± 5.7	310.5 ± 22.8
1,200	6.9 ± 0.1	6.9 ± 0.2	180.5 ± 15.4	473.0 ± 58.9

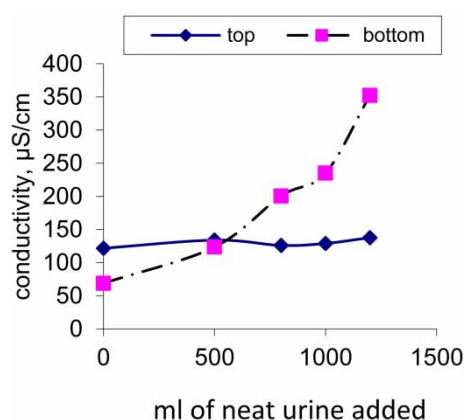


Figure 2 | Conductivity of soil sampled at the bottom and top of the pot measured at the end of the experiment. Conductivity increased towards the bottom by rain leaching and regular watering.

subsistence farm, where provision of adequate drainage facility is unaffordable, the groundwater and the soil may be exposed to salinization, ultimately leading to the loss of land. However, neat urine can be utilized in plantations with provision of a proper drainage facility. Maybe the economic cost analysis of the use of neat urine with drainage facility installation, and the use of nutrient extracted urine, can be compared. However, even if drainage measures are implemented the disposal of saline water and irrigation return flows have a serious impact on surface water quality in many places (Meybeck et al. 1989).

If the use of human urine by a farmer is mandatory as an alternative to fertilizer and as a means of reusing and disposing of the UDDT product, the amount of urine used should be limited to 500 ml per plant to avoid the cumulative salt accumulation on the soil with repeated use. But it should be known that irrigation and rain, as in regular farming and in

the pot experiment, can leach salts to the groundwater. This transfers the problem from the top soil to the groundwater (Chapman 1992). For arid and semi-arid regions like Arba Minch, extraction of the nutrient is preferable to using neat urine. In Ethiopia, when land is not producing sufficient yield for a farmer because of salinization, the whole family look to deforestation for new farmland or firewood and charcoal production to feed them themselves.

CONCLUSIONS

The experimental results conducted at Arba Minch, Ethiopia in natural settings showed urine application as fertilizer increased the production of maize but adversely increased the salt content of the bottom soil significantly as it leached with applied water and rain. Therefore, the optimum dose of urine (500 ml) per maize should be applied in order not to lose arable land, which is a concern in arid and semi-arid regions, or the useful nutrient should be extracted and waste reuse from UDDTs encouraged.

ACKNOWLEDGEMENTS

The ROSA project (Resource-Oriented Sanitation concepts for peri-urban areas in Africa; Contract No. 037025-GOCE; duration: 1.10.2006–31.03.2010), a Specific Target REsearch Project (STREP) was funded within the EU 6th Framework Programme, Sub-priority 'Global Change and Ecosystems'. The ROSA team is grateful for the support.

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First received 3 October 2017; accepted in revised form 8 January 2018. Available online 12 February 2018