沙漠研究 **24**-1, 85-88 (2014)
Journal of Arid Land Studies

Salts Monitoring and Management for Human Urine Fertilization and Treated Greywater Irrigation in Sub-Sahel Region

Nowaki HIJIKATA*[1), 2)], Takahisa FUJII[2)], Drissa SANGARE[1)], Mariam SOU[1)], Ken USHIJIMA[2)] and Naoyuki FUNAMIZU[2)]

Abstract: Human urine and greywater are available as liquid fertilizer and irrigation sources. However, salt in the materials might accumulate in soil, particularly in semi-arid regions, such as the sub-Sahel. Salt loading was monitored in pilot gardens where urine and greywater were reused. Sodium distribution was observed in a pot scale experiment to assess the potential of leaching and phytoremediation by sorghum during rainy season cultivation. The chemical properties and usage estimation of the urine and greywater inferred that applied Na and major cations in pilot-garden might be mainly derived from greywater. Salt monitoring in pilot-gardens showed that soil SAR in two sites decreased significantly and in others remained stable during the reuse cultivation. Sorghum culture under sufficient irrigation showed that leaching potentially contributed to Na removal compared to phytoremediation. Supplemental amendment of gypsum and ash as Ca agents did not affect the Na removal. Therefore, we concluded that Na might be potentially removed by leaching in rainy season, when urine and greywater were reused under semi-arid zone.

Key Words: Human urine, Leaching, Phytoremediation, Salts accumulation, Sorghum

1. Introduction

Human urine and greywater, which is domestic waste water except human excreta, have been recognized as potential resources for agriculture as nutrients and irrigation. This reuse, particularly, would be an attractive option for small scale farmers in sub-Sahel regions, who suffer from limited irrigation resources and poor access to chemical fertilizers. Separation of human feces from urine and greywater would reduce the organic load and pathogens (Lopez *et al.*, 2002). Thus, the separation simplifies each treatment which leads to reduced overall investment for sanitation (Winblad, 2004).

Although many have shown the advantage of urine fertilization for various crops and vegetables because of its nutrient elements (Kirchmann and Pettersson, 1995; Mnkeni *et al.*, 2008; Mullegger *et al.*, 2010), it has been also reported that urine fertilization caused competitive uptake of potassium (K) and sodium (Na) in plants (Pradhan *et al.*, 2010; Sene *et al.*, 2013) and excessive urine application inhibited plant growth due to increasing soil electrical conductivity (EC) (Mnkeni *et al.*, 2008). Furthermore, greywater also contains undesirable components such as Na, oil and surfactants (Wiel-Shafran *et al.*, 2006; Al-Hmaiedeh and Bino, 2010; Travis *et al.*, 2010). Long term irrigation with greywater leads to increased soil EC and sodium adsorption ratio (SAR) (Al-Hamaiedeh and Bino, 2010). This might cause low water permeability and compacted soil. Furthermore, oil and surfactant accumulation in soil potentially disturbs water permeability and capillarity (Wiel-Shafran *et al.*, 2006; Travis *et al.*, 2010). Although simple greywater treatment facilities have been developed that successfully remove organic matter, surfactants and pathogens (Al-Hamaiedeh and Bino, 2010; Ushijima *et al.*, 2013), the facilities allowed soluble minerals, such as Na^{+}, to pass though. Therefore, salt monitoring and management of fields is essential when the urine and greywater are reused especially in sub-humid and semi-arid zone, where applied minerals are easily accumulated in soil surface due to high evaporation.

In order to remove excess salts from soil, leaching with sufficient irrigation, amending with gypsum or phytoremediation have been proposed (Qadir *et al.*, 2005). Small scale farmers in sub-Sahel region lack sufficient water resources, appropriate irrigation systems and funds to purchase gypsum in the local market. Thus, we hypothesize rainfall may provide sufficient irrigation, sorghum may serve as a remediation plant and ash derived from cook stoves can facilitate Na removal. In the present study, we monitored salt accumulation in pilot-gardens of small scale farmers, who amend their vegetable gardens with their own urine and greywater, in rural Burkina Faso. Additionally, Na distribution was observed in a pot experiment to determine Na phytoremediation and leaching capacity.

* Corresponding Author: nowaki@eng.hokudai.ac.jp
01 BP 594, Ouagadougou 01, Burkina Faso
(Received, September 15th, 2013; Accepted, November 26th, 2013)
1) Department of Teaching and Research in Water Efficiency Management and Sanitation, International Institute for Water and Environmental Engineering (2iE), Burkina Faso
2) Department of Environmental Engineering, Graduate School of Engineering, Hokkaido University, Japan

2. Materials and Methods

2.1.1. Pilot-garden

Six pilot-gardens (KB1, KB2, KD1, KD2, BK1 and BK2) of 50 m^2, of small scale farmers in rural Burkina Faso, were located on their premises. Experiments were conducted from the end of June to the first of October 2012. Okra and eggplant were cultivated with the farmers own urine and greywater. The urine was separately collected, stocked for a few months, and applied 3 times during the growing season (at the rate of 0.5 L, 0.5 L and 0.3 L per one plant; totally 1.3 L/plant, 7.8 L/m^2). The greywater was treated by a slanted soil system (Ushijima *et al*., 2013). The applied amount was estimated by questionnaire survey of the family. Total minerals input of urine and greywater were estimated with the applied amount and its concentration described as below.

2.1.2. Chemical property of urine and greywater

Source-separated urine and treated greywater were sampled before and after cultivation. pH and EC value in the urine and greywater were measured by electrode. Chemical oxygen demand (COD), total nitrogen (N) and total phosphorus (P) were measured with Hach kit (DR6500, Hach); and potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and minor cations were determined ICP-AES (ICPE 9000, Shimazu) after filtration (0.45 µm pore, ADVANTEC). SAR was calculated with following equation:

$$\mathrm{SAR} = \frac{[\mathrm{Na}^{+}]}{\sqrt{([\mathrm{Ca}^{2+}]+[\mathrm{Mg}^{2+}])/2}}$$

2.1.3. Chemical property of pilot-garden soil

Pilot-garden soil was sampled in July and October. Soil pH (1:2.5) and EC (1:5) were measured after 3 hours shaking with pure water. In the case of SAR in soil, soil was saturated with pure water (1:10) and the soil suspension was centrifuged at 3000 rpm for 10 min and the supernatant filtered with 0.45 µm membrane filter (ADVANTEC). Na, K, Ca and Mg in the filtered samples were determined by ICP-AES.

2.1.4. Pot experiment

A pot experiment was conducted in a greenhouse with sorghum as a model of a phytoremediation plant. Assumed as pilot-garden soil which Na was accumulated, red ocher color soil (en-tout-cas; clay particles of crushed brick) and black soil was mixed at the ratio of 3:1. The calcium and magnesium ratio in the soil mixture was adjusted at 10:1 with magnesium sulfate, and the SAR value was adjusted to 6 with sodium hydrogen carbonate. The pH and EC of the soil mixture was 7.74 and 3.48, respectively. The soil (2 kg) was mixed with 37 g (dry base) of compost in a plastic pot (200 cm^2 surface, 159φ × 190 mm depth). Polyvinyl tubing was connected to a drain of the pot and leachate was collected. To determine the effect of Ca on Na-removal, 9.56 g of ash (corresponded 0.42 g-Ca) or 2.62 g of $CaSO_4$ (gypsum, 0.42 g-Ca) were applied. Five replications of each treatment were prepared. Germinated sorghum seeds (6) were transplanted in the pot, and thinned to two plants per pot after two weeks. Mimicking precipitation from July to August in Ouagadougou, Burkina Faso, the pots were irrigated with tap water and the amount was 75 ml/day for first two weeks and 150 ml/day afterwards. Eight weeks after planting, sorghum stem and leaf were harvested and oven dried at 60°C for 5 days to determine dry weight.

2.1.5. Sorghum and leaching water cation

Leachate from each pot was collected every two weeks and determined the weight. K, Ca, Mg and Na concentration in the leachate were determined by same method with greywater analysis described above. Total amount of leached cations was calculated as a sum from one pot during planting period (4 times sampling) and the each mass was calculated with the leachate weight and its concentration. Dried sorghum samples (0.25 g) were ground with mortar and pestle, digested by nitrate and hydrogen peroxide at 140°C, diluted and filtered. The sample cations concentration was determined by ICP-AES as described above. Cation content in the shoot was calculated with the concentration and the dry weight. To observe early Na stress symptom (Tuna *et al*., 2007), K/Na and Ca/Na ratio was calculated with the concentration in sorghum.

2.1.6. Statistical analysis

Statistical analysis was conducted with IBM SPSS statistic 21 software. Significant difference of pilot-garden soil before and after vegetation was evaluated with t-test (p<0.05). Significant difference of Ca treatments in pot experiment was evaluated with ANOVA and Tukey-HSD test (p<0.05).

3. Result and Discussion

3.1.1. Quality of urine and greywater in pilot-garden

Chemical properties of urine were shown in **Table 1**. N, P and K in source-separated storage urine of 6 pilot-families, were 3.6 ± 0.7 g/L, 0.7 ± 0.3 g/L and 0.6 ± 0.3 g/L, respectively. In the case of minor cations, only boron and iron was detected. Others found these chemical properties varied from 1.7-8.4 g-N/L, 0.3-0.8 g-P/L, 0.9-2 g-K/L and 2.3-9.0 g-Na/L (Kirchmann and Pettersson, 1995; Mnkeni *et al*., 2008; Pradhan *et al*., 2010; Mullegger *et al*., 2010). The present results were similar and most of values were inside of these ranges.

Differences among samples reflect family lifestyle, food culture or differences in rainfall contribution. Similar to the urine, chemical properties of greywater also varied particularly in EC, SAR, COD, total N and Na (**Table 2**). The ranges were also followed by a previous report (Al-Hamaiedeh and Bino, 2010). However, relatively high bacteria were observed. This might be caused by lack of on-site maintenance. Therefore, simplified maintenance should be further investigated.

Table 1. Chemical properties of urine.

	Min	Max	Mean	STDEV
pH	8.6	9.0	8.8	0.1
EC [dS/m]	20.7	37.1	28.1	7.1
SAR	8.5	36.2	15.2	10.6
Total N [g/L]	2.4	4.4	3.6	0.7
Total P [g/L]	0.4	1.2	0.7	0.3
Na [g/L]	0.8	2.3	1.3	0.7
K [g/L]	0.4	1.2	0.6	0.3
Ca [mg/L]	2.0	26.3	10.9	9.1
Mg [mg/L]	2.0	32.8	10.1	11.5
B [mg/L]	0.5	2.0	1.1	0.6
Fe [mg/L]	n.d.	1.3	0.3	1.7
Zn [mg/L]	n.d.	n.d.	-	-
Mn [mg/L]	n.d.	n.d.	-	-
Cu [mg/L]	n.d.	n.d.	-	-
E. coli [cfu/ml]	n.d.	n.d.	-	-
Total Coliform [cfu/ml]	n.d.	n.d.	-	-

Table 2. Chemical properties of treated greywater.

	Min	Max	Mean	STDEV
pH	7.1	8.4	7.8	0.4
EC [dS/m]	4.7×10^{-1}	1.5	8.5×10^{-1}	2.8×10^{-1}
SAR	0.7	3.0	1.8	0.7
COD [mg/L]	42	195	79.4	46.3
Total N [g/L]	1.0×10^{-2}	7.7×10^{-2}	3.3×10^{-2}	1.9×10^{-2}
Total P [g/L]	1.3×10^{-4}	7.6×10^{-3}	2.1×10^{-3}	2.2×10^{-3}
Na [g/L]	2.3×10^{-2}	1.1×10^{-1}	6.1×10^{-2}	2.4×10^{-2}
K [g/L]	2.2×10^{-2}	4.5×10^{-2}	3.3×10^{-2}	1.0×10^{-2}
Ca [mg/L]	28.4	42.6	35.7	6.9
Mg [mg/L]	3.7	22.2	12.4	5.8
E. coli [cfu/ml]	4.0×10	2.2×10^{4}	3.0×10^{3}	6.3×10^{3}
Total Coliform [cfu/ml]	8.0×10^{2}	3.3×10^{5}	5.1×10^{4}	9.3×10^{4}

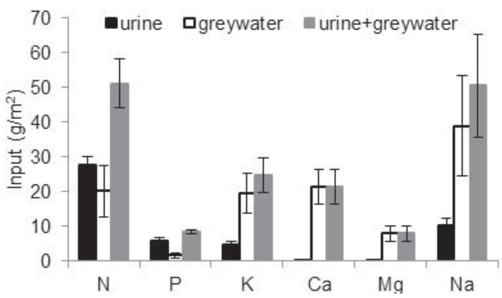

Fig. 1. Estimated total mineral input from urine and greywater.

3.1.2. Estimation of total mineral input into pilot-garden (Fig. 1)

From the survey with pilot-family, the total input of irrigation was estimated at 2.6-9.0 (mean 5.7 ± 2.7) L/m^2/day. The impact of greywater on the major cations input was higher than urine and large amount of Na was derived from greywater. Even the combined application of urine and greywater, total phosphorus was insufficient for okra and eggplant. Sene *et al.* (2012) showed low phosphorus content of plant in urine reuse. Therefore, it was suggested that additional materials such as wood ash (Pradhan *et al.*, 2009, 2010) or human feces (Guzha *et al.*, 2005) would be beneficial for vegetable production.

3.1.3. Salt monitoring in soil of pilot-garden

Soil EC in KD2 and BK1 site increased significantly from before cultivation to after cultivation (**Fig. 2**). EC at other sites did not change significantly. High urine application elevates soil EC (Mnkeni *et al.*, 2008; Sene *et al.*, 2013), but

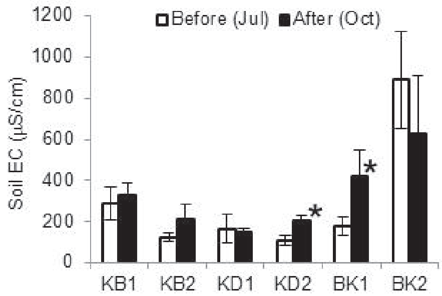

Fig. 2. Change of soil EC in pilot-gardens before and after vegetation.

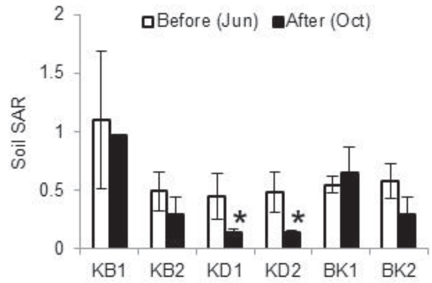

Fig. 3. Change of soil SAR in pilot-gardens before and after vegetation.

smaller urine applications did not alter soil EC more than chemical fertilizer (Pradhan *et al.*, 2009, 2010). Furthermore, greywater irrigation also increases soil EC (Weil-Shafran *et al.*, 2006; Al-Hamaiedeh and Bino, 2010). Therefore, the combination application of urine and greywater has the potential to increase soil EC value even during the rainy season.

Soil SAR in pilot-garden responded differently than soil EC with two sites (KD1 and KD2) observing a decrease in SAR over the course of the experiment (**Fig. 3**). All other locations did not observe a change in SAR. Soil SAR has been shown to increase with large amount of urine (Sene *et al.*, 2013) and long-term greywater irrigation (Al-Hamaiedeh and Bino, 2010) with less irrigation and rainfall than this experiment.

3.1.4. Distribution of Na and salt management

In the pot experiment, sorghum shoot dry weight of control, ash and $CaSO_4$ was 1.0, 1.0 and 0.8 g after 60 days, respectively (**Fig. 4**). The $CaSO_4$ treatment was significantly lower than the others. Shoot K content was lower with the +$CaSO_4$ treatment the control or +Ash. Ca, Mg and Na shoot content were not affected by treatment (**Table 3**). K/Na and Ca/Na ratios are not different among amendment treatments. Leaching amount of Ca, Mg and Na were not different among amendment treatments (**Table 4**). However, leached Ca, Mg and Na were higher than plant uptake. In the case of Na leaching, particularly, the amount was more than thousand times higher than plant uptake. This indicates the capacity of Na leaching under sufficient irrigation was much larger than phytoremediation or the effect of Ca amendment on Na removal. Similar results have been reported by Qadir *et al.* (2003) who showed larger contribution of Na leaching

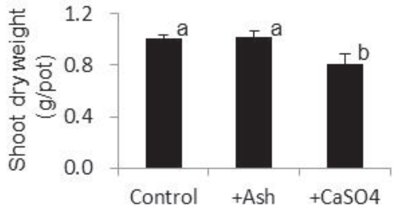

Fig. 4. Shoot dry weight of sorghum with sufficient irrigation.

Table 3. Cation shoot content 60 days after treatment.

	Control	+Ash	$+CaSO_4$
K [mg/pot]	5.0±0.5a	5.0±0.4a	3.7±0.1b
Ca [mg/pot]	4.5±1.6	4.3±0.1	3.2±0.6
Mg [mg/pot]	2.6±0.3	2.7±0.2	2.3±0.3
Na [mg/pot]	0.29±0.14	0.17±0.03	0.14±0.08
K/Na	19.7±11.4	27.3±3.3	33.0±15.2
Ca/Na	19.0±14.6	23.4±4.1	29.6±15.6

Table 4. Total amount of leached cations.

	Control	+Ash	$+CaSO_4$
Ca [mg/pot]	40.0±15	41.9±21.4	77.7±9.8
Mg [mg/pot]	25.1±10.9	32.9±13.1	40.8±5.0
Na [g/pot]	7.6±1.2	6.4±0.9	5.9±0.5

compared to Na phytoremediation.

The present experiment was conducted under the following conditions; (i) artificial soil mixture which chemical parameter were adjusted with reagent powder, (ii) plastic pot which had only 20 cm depth. Compared to the experimental condition, the real pilot-garden was different in that; (i') natural soil constructs complicated precipitation and the soil might be lower permeability (ii') leached water would rise up by capillary force after irrigation and rainfall or water could flush nutrients through the soil profile or lost through run-off. Therefore, more detail monitoring in pilot-garden or fields and more specific and larger scale experiment could be required to manage salt accumulation with urine and greywater reuse.

4. Conclusion

The present study aimed to monitor salt accumulation in pilot-gardens where human urine and treated greywater were reused and to observe a capacity of Na-leaching and Na-phytoremediation. Soil SAR may be of lesser concern when using urine and greywater during periods of rainfall, but sodium related problems may be a larger concern when these alternative water sources would be in higher demand during periods of low rainfall. Therefore, additional techniques for Na removal should be further investigated.

Acknowledgement

This study was supported by SATREPS (JICA/JST).

References

Al-Hamaiedeh H., Bino M. (2010): Effect of treated grey water reuse in irrigation on soil and plants. *Desalination*, **256**: 115-119.

Guzha E., Nhapi I., Rockstrom J. (2005): An assessment of the effect of human feces and urine on maize production and water productivity. *Physics and Chemistry of the Earth*, **30**: 840-845.

Kirchmann H., Pettersson S. (1995): Human urine -Chemical composition and fertilizer use efficiency. *Fert. Res.*, **40**: 149-154.

Lopez Z.M.A., Funamizu N., Takakuwa T. (2002): Onsite wastewater differential treatment system: modelling approach. *Water Science Technology*, **46**: 317-324.

Mnkeni P.N.S., Kutu F.R., Muchaonyerwa P. (2008): Evaluation of human urine as a source of nutrients for selected vegetables and maize under tunnel house conditions in the Eastern Cape, South Africa. *Waste Management and Res.*, **26**: 132-139.

Mullegger E., Angergraber G.L., Lechner M. (2010): *Sustainable sanitation practice, use of urine*, *EcoSan club 3*.

Pradhan S.K., Holopainen J.K., Heinonen-Tanski H. (2009): Stored Human urine Supplemented with wood ash as fertilizer in tomato (*Solanum lycopersicum*) cultivation and its impacts on fruit Yield and quality. *Journal of Agriculture and Food Chemistry*, **57**: 7612-7617.

Pradhan S.K., Holopainen J.K., Weisell J., Heinonen-Tanski H. (2010): Human urine and wood ash as plant nutrients for red beet (*Beta vulgaris*) cultivation: impacts on yield quality. *Journal of Agriculture and Food Chemistry*, **58**: 2034-2039.

Qadir M., Steffens D., Yan F., Schubert S. (2003): Sodium removal from a calcareous saline-sodic soil through leaching and plant uptake during phytoremediation. *Land Degrad. Develop.*, **14**: 301-307.

Qadir M., Noble A.D., Oster J.D., Schubert S., Ghafoor A. (2005): Driving forces for sodium removal during phytoremediation of calcareous sodic and saline-sodic soils: a review. *Soil Use and Manage.*, **21**: 173-180.

Sene M., Hijikata N., Ushijima K., Funamizu N. (2012): Adequate Human urine application pattern for agriculture. *Int. Res. J. Agric. Sci. Soil Sci.*, **2** (1): 038-045.

Sene M., Hijikata N., Ushijima K., Funamizu N. (2013): Effects of extra human urine volume application in plant and soil. *Int. Res. J. Agric. Sci. Soil Sci.*, **3**(6): 182-191.

Travis M.J., Weil-Shafran A., Weisbrod N., Adar E., Gross A. (2010): Greywater reuse for irrigation: effect on soil properties. *Science of Total Environment*, **408**: 2501-2508.

Tuna L.A., Kaya C., Ashraf M., Altunlu H., Yokas I., Yagmur B. (2007): The effects of calcium sulphate on growth, membrane stability and nutrient uptake of tomato plants grown under salts stress. *Environ. Exp. Bot.*, **59**: 173-178.

Ushijima K., Ito K., Ito R., Funamizu N. (2013): Greywater treatment by slanted soil system. *Ecological Engineering*, **50**: 62-68.

Wiel-Shafran A., Ronen Z., Weisbrod N., Adar E., Gross A. (2006): Potential change in soil properties following irrigation with surfactant rich greywater. *Ecological Engineering*, **26**: 348-354.

Winblad U., Hebert M. S., Calvert P., Morgan P., Rosemarin A., Sawyer R., Xiao J. (2004): *Ecological Sanitation revised and enlarged edition*. Stockholm Environment Institute, Stockholm.