Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 114 No. 2 (2013) 89–100

urn:nbn:de:hebis:34-2013081343323 ISSN: 1612-9830 – journal online: www.jarts.info

Short-term effects of human urine fertiliser and wood ash on soil pH and electrical conductivity

Dora Neina*, Gabriel Nii Noi Dowuona

Department of Soil Science, School of Agriculture, University of Ghana, Legon, Accra

Abstract

The fertiliser value of human urine has been examined on several crops, yet little is known about its effects on key soil properties of agronomic significance. This study investigated temporal soil salinization potential of human urine fertiliser (HUF). It further looked at combined effects of human urine and wood ash (WA) on soil pH, urine-NH_3 volatilisation, soil electrical conductivity (EC), and basic cation contents of two Acrisols (Adenta and Toje series) from the coastal savannah zone of Ghana. The experiment was a factorial design conducted in the laboratory for 12 weeks. The results indicated an increase in soil pH by 1.2 units for Adenta series and 1 unit for Toje series after one week of HUF application followed by a decline by about 2 pH units for both soil types after twelve weeks. This was attributed to nitrification of ammonium to nitrate leading to acidification. The EC otherwise increased with HUF application creating slightly saline conditions in Toje series and non-saline conditions in Adenta series. When WA was applied with HUF, both soil pH and EC increased. In contrast, the HUF alone slightly salinized Toje series, but both soils remained non-saline when WA and HUF were applied together. The application of WA resulted in two-fold increase in Ca, Mg, K, and Na content compared to HUF alone. Hence, WA is a promising amendment of acid soils and could reduce the effect of soluble salts in human urine fertilizer, which is likely to cause soil salinity.

Keywords: Ammonia volatilisation, basic cations, charcoal, firewood, plant nutrients, soil salinization, tropical soils

1 Introduction

Human urine has been used for diverse purposes from ancient times till date. Recently it has gained popularity because it contains high concentrations of major plant nutrients including nitrogen (N), phosphorus (P) and potassium (K). The urine-N content reported in literature ranges from 700 mg/L to over 900 mg/L, 500–650 mg/L for P and while K is about 500–800 mg/L (Heinonen-Tanski & van Wijk-Sijbesma, 2005; Kirchmann & Pettersson, 1995). However, the composition and nutrient content of human urine are strongly dependent on the nutritional quality of food consumed, to a less extent on its human source and living conditions, location, (Vinnerås & Jönsson, 2002; Höglund, 2001; Drangert, 2000), health conditions (Alters & Alters, 1996), ambient temperature, liquid intake (Jönsson *et al.*, 2004), and nature of physical activity (Johnson, 2008). Many crops have been fertilised with human urine yielding impressive results which show that its fertiliser value is comparable to inorganic fertilizers (Pradhan *et al.*, 2010, 2009, 2007; Sridevi *et al.*, 2009; Mnkeni *et al.*, 2008; Heinonen-Tanski *et al.*, 2007; Guzha *et al.*, 2005). Other studies have focused on the health risks of human urine with regards to pathogens, pharmaceutical residues and trace elements (Winker *et al.*, 2009, 2008; Vinnerås *et al.*, 2003; Höglund *et al.*, 2002; Schönning *et al.*, 2002). These studies have so

* Corresponding author
Department of Soil Science, School of Agriculture,
P.O. Box LG 245, University of Ghana, Legon, Accra
Email: dneina@gmail.com
Phone: +49 152 10219883

far shown that human urine as a fertiliser, has almost no trace elements, and is safe for use after proper storage. However, the effect of human urine fertiliser (HUF) on soil properties both in short and long terms has received less attention. HUF has diverse ionic composition (e.g. Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-, CO_3^{2-}). Besides, the major source of soluble salts is NaCl. Thus, the use of HUF could cause soil salinization. Electrical conductivity (EC), a measure of soil salinity, is caused by the presence of excess chlorides (Cl^-) and sulphates (SO_4^{2-}) of Na^+, K^+, and NH_4^+ ions or Mg^{2+} and Ca^{2+} ions (Kolek & Kozinka, 1992). Soil salinity is categorised into four classes according to crop tolerance: (1) non-saline soils (EC $< 2\,\mathrm{dS\,m^{-1}}$) have negligible effects on crop production, (2) slightly saline soils (EC 2–4 $\mathrm{dS\,m^{-1}}$) affect the yield of very sensitive crops, (3) moderately saline soils (EC 4–8 $\mathrm{dS\,m^{-1}}$) restrict the growth and yield of many crops while (4) highly saline soils (EC 8–16 $\mathrm{dS\,m^{-1}}$) can only support the growth and yield of tolerant crops. Above an EC value of $16\,\mathrm{dS\,m^{-1}}$ only few and very tolerant crops can survive (Richards, 1954). To avoid further soil salinization, it is imperative to take a critical look at the effect of applying HUF on soil pH and EC in different soil types and at different spatial scales.

Until now, few studies on agronomic trials have showed the effect of HUF on soil pH and EC. For instance, Mnkeni *et al.* (2008) observed an increase in soil EC and a decrease in soil pH following HUF application on Cambisols (young soils). On the contrary, Ndzana & Otterpohl (2009) reported a decrease in EC (0.2 to $< 0.1\,\mathrm{dS\,m^{-1}}$) and an increase in soil pH (4 to 5) for Anthrosols (a mixture of soil and organic matter); whereas Pradhan *et al.* (2009) found increases in both soil pH and EC in Anthrosols when HUF was applied. Although the nitrification of urine-NH_4^+ could decrease soil pH, other edaphic factors, urine properties and plant characteristics could dictate the chemical dynamics in soils following HUF application.

In contrast to HUF, wood ash (WA) has abundance of Ca and K and significant amounts of Mg and P, but has a low N content (Pradhan *et al.*, 2009; Huotari *et al.*, 2008; van Ryssen & Ndlovu, 2004; Erich, 1991). Even though WA is reported to contain about 50 % calcium carbonate equivalent (CCE), the chemical strength of commercial liming materials and neutralises soil acidity (Park *et al.*, 2004; Demeyer *et al.*, 2001; Naylor & Schmidt, 1986), its nutrient content is also variable depending on the source and combustion process for its production. Meanwhile, in the tropics, crop production is affected by several factors including limiting growth conditions of the soils. According to Sanchez & Salinas (1981), low chemical soil fertility alone represents over 50 % of all soil constraints in this region. This phenomenon is partly because tropical soils are highly weathered and are associated with low cation exchange capacity (CEC), high acidity and low base saturation. In this case, the high element content in WA could be utilised to improve the fertility of these soils. It could supplement the nutrients in HUF to boost crop production, and improve the base status of the soils. Wood ash could also influence rhizosphere chemical dynamics and could possibly reduce the effects of Na salts from HUF application. Studies have shown that WA amended Ultisols produced high biomass in rye grass compared to lime treatments (Voundi Nkana *et al.*, 1998). In US, wood ash applied with N fertilizer augmented grain yield and biomass of barley by >50 % in a green house study), canola oil seed yield by 124 % on field trials on Eutrochrepts and Boralfs (Patterson *et al.*, 2004). In Spain, the number of kiwi fruits increased by 45 % on a Dystric Cambisol (Merino *et al.*, 2006). Wood ash also influenced P availability on a soil-compost mixture and on a Haplic Luvisol (Muse & Mitchel, 1995; Lopez *et al.*, 2009). Solid fuels like firewood and charcoal are the major energy sources in Ghana. According to Duku *et al.* (2011), these fuels constitute 64 % of total energy consumption in the country. Charcoal is most preferred and its use is rising (Duku *et al.*, 2011) probably because it is relatively more convenient than firewood and produces less smoke. The Ghana government strongly promotes the use of Liquefied Petroleum Gas (LPG), but shortages and cost remain great constraints for its use by the populace. Hence, WA from kitchens forms a reasonable component of municipal solid waste which could be used as a fertiliser supplement to replenish soil nutrients for crop production.

On the other hand, the Valley View University (25 km from Accra) implemented an ecological plan in 2003 where human urine is easily separated through urine-diverting toilets. The urine is used to fertilise tropical fruit trees and cereals. Soil analyses from the plots (after harvest) showed that the HU fertilised plots had the lowest EC compared to control (Yemofio, 2011, unpublished). These findings, together with those in literature propelled this study, which was designed to study further into the dynamics of HUF in soils. Wood ash was incorporated into the project to examine both the individual and combined effects of WA and HUF on soil pH and EC. We hypothesised that soils respond differently to HUF and WA application. Consequently, (a) the effect of HUF on soil pH and EC will vary with soil type, (b) the combined application of WA with HUF will enhance the cation content and reduce the effect of Na salts on soils, (c) when WA is applied early, it could stabilize soil pH before HUF application to reduce any eventual NH_3 losses. Hence our objectives for this study were to: (1) investigate the effect of WA and HUF application on soil pH and electrical conductivity on two Ghanaian soils, (2) evaluate the effect of WA application on soil EC, pH and urine-NH_3 volatilization from the soils, and (3) assess the combined effect of WA and HUF application on exchangeable cation content of the soils. This paper presents the outcome of the study which showed that HUF increased EC and decrease soil pH after twelve weeks of application.

2 Materials and methods

2.1 Site description and soil sampling

To analyse the impact of HUF and WA on soil properties, Toje and Adenta soil series at the University of Ghana farm located at 05°39'03" N 00°11'13" W in the coastal savannah zone of Ghana were used. The soils are Ferric Acrisols (IUSS Working Group WRB, 2006). The annual rainfall of the area is about 800 mm per annum while the average minimum temperature range is 21–23°C and the average maximum is 30–35°C. Toje series is located at the upper middle slope of the Legon hill and is used for arable crop production, while Adenta series is at the foot slope and is used for vegetable production by the Crop Science Department. However, at the time of sampling in March 2011 the sites were on fallow. In March 2011, five soil cores were taken at 20 cm depth within a 10×10 m frame and composited. Soil samples were air-dried and passed through 2 mm sieve to obtain fine earth fraction, which was used for the experimental studies and laboratory analyses of selected soil properties.

2.2 HUF and WA collection

The author's urine was used for the study. Medication was avoided during the period of urine collection to exclude pharmaceuticals. Fresh urine was also not added from the start of storage. The HUF was stored in a tight container at an average temperature of 30°C for 3 months before use. Wood ash was collected from some local food vendors in the Accra Metropolitan Assembly. The major sources of firewood used by the vendors are mostly wood waste from wood and building construction and timber processing industries as well charcoal. The WA was stored for 2 months and sifted with a 2 mm sieve before use. The water content of the ash was 0.5 %.

2.3 Sample analyses

The soil samples were analysed using the Kjeldahl method for total N, the Walkley and Black method for organic carbon OC (Walkley & Black, 1934), NH_4OAc to extract exchangeable cations. The soil pH in water and in KCl (only for non-incubated soils) and EC were measured in 1:2 soil-solution ratio using H1 9017 Microprocessor pH Meter (Hannah Instruments, UK) and Jenway PCM3 Conductivity Meter, respectively. We determined both water soluble and acid soluble elements in WA for comparison since most WA analyses use pure acids or extraction solutions such as Mehlich 3 extract (Mehlich, 1984). The basic cations (Mg, Ca, K and Na) in WA were determined by extraction with water and 3N H_2SO_4 acid in 1:5 ash-solution ratio. Calcium and Mg were analysed using Atomic Absorption Spectrometer (Perkin Elmer AAnalyst 800, Germany) while K and Na were analysed by flame photometry (Jenway PFP7, UK). The N components in HUF were analysed with Kjeldahl method with Devarda's alloy (Liao, 1981). HUF was diluted with water and with concentrated H_2SO_4 acid in 1:1 ratio followed by analysis for Ca, Mg, K, and Na in the same way as WA (Table 1 and Table 2).

2.4 Experimental design

There were two experiments in 2×4 factorial design. An extrapolation was made from some assumptions and used as the basis for the HUF and WA applications rates which include: (a) most farmers and field agricultural officers (in the tropics) who are involved in agricultural technology transfer to farmers have limited access to laboratory services for the determination of nutrient contents in HUF and WA, (b) NH_3 volatilization occurs during the handling and application of HUF, (c) N content in HUF is variable, (d) HUF application rates recommended by Jönsson *et al.* (2004) and Kvarnstrom *et al.* (2006) are based on crop type and on local fertilizer recommendations, and (e) application rates used for HUF and WA in literature range from 50–1400 kg N ha^{-1} and 3–20 t ha^{-1} respectively. It was also necessary to use HUF volume that could give quantifiable results from the NH_3 volatilization experiments. The soils were incubated in the laboratory for twelve weeks at an average temperature of 30°C. Soils were watered every other day as would have been done in the presence of plants. The first experiment was to study the effect of HUF on soil pH and EC while the second experiment was an acid trap (4 % boric acid) to capture NH_3 gas for subsequent titration with 0.005 M H_2SO_4. In both experiments HUF was applied once to the soil.

Table 1: *Selected characteristics of soils and wood ash used for the study.*

Soil type	*pH* $_{H_2O}$ (1:2)	*EC* ($dS\,m^{-1}$)	*BD* ($g\,cm^{-3}$)	*Total-N*	*OC* (%)
Adenta series	5.71	0.06	1.40	0.43	0.40
Toje series	5.62	0.12	1.43	0.45	0.79

Wood ash	*pH* $_{H_2O}$	*EC* ($dS\,m^{-1}$)	*Ca* ($g\,kg^{-1}$)	*Mg* ($g\,kg^{-1}$)	*Na* ($g\,kg^{-1}$)	*K* ($g\,kg^{-1}$)
Water	13.81	59.35	35.85	3.60	23.00	41.00
Acid	–	–	80.65	46.40	80.00	95.50

Ash-water/acid (1:5), soil-water (1:2),
EC: Electrical conductivity, BD: Bulk density, OC: Organic carbon, "–": not measured

Table 2: *The composition of human urine fertilizer (HUF) used for the study.*

HUF	*pH*	*EC* ($dS\,m^{-1}$)	*OC* (%)	*Nitrogen* ($g\,L^{-1}$)			*Basic cations* ($g\,L^{-1}$)			
				NO_3-N	*NH_4^+-N*	*TN*	*Ca*	*Mg*	*Na*	*K*
Conc. Urine	9.01	25.87	3.78	–	–	–	–	–	–	–
Water	–	–	–	0.51	0.51	3.93	0.018	2.7×10^{-3}	4.0	0.6
Acid	–	–	–	–	–	–	0.018	0.02	2.0	1.0

[1] EC and pH were measured in concentrated human urine, OC: organic carbon, "–"= not measured

2.4.1 *Experiment 1: Effects of HUF on soil pH and EC*

This experiment consisted of two soil types as specified in section 2.1 with four treatments and three replicates each. Two hundred grams of soil were placed in polythene bags. The treatments used were: control (0 mL), 10 mL, 15 mL, and 20 mL HUF in three replicates. These translate into 0, 182, 273, and 364 kg N HUF ha^{-1} for Toje series and 0, 186, 279, and 372 kg HUF N ha^{-1} for Adenta series. The required volume of HUF was diluted with deionised water in a 1:1 ratio. It was then mixed with the soil and watered to 18 %–20 % moisture content. The samples were monitored and watered every other day. A week later, the soils were homogenised and scooped with a 25 mL cup into 50 mL beakers for measurement of soil pH alone. After 12 weeks of HUF application, soil pH and EC were measured.

2.4.2 *Experiment 2: Effects of WA and HUF on soil pH, EC and NH_3 volatilisation*

This experiment was designed to examine the volatilisation of ammonia after the application of HUF. It is similar to the experiment of section 2.4.1 except that WA was applied one and two weeks before HUF. The four treatments used were: control (0 mL HUF), 20 mL HUF + WA applied two weeks before HUF (WA2wk), and 20 mL HUF + WA applied one week before HUF (WA1wk). Six hundred grams of soil each were placed in transparent 1.48 L containers made of plastic. The HUF and 2.495 g WA were applied to the soil. The application rates for WA were 11.9 t ha^{-1} and 11.6 t ha^{-1} for Toje and Adenta series, respectively. Fifty-millilitre beakers containing 20 mL 4 % boric acid with indicator (0.66 g methylene blue and 0.13 g methyl red dissolved in 96 % alcohol) were placed in each container by hanging with a string above the soil surface. The containers were tightly closed to trap NH_3 gas by preventing it from loss to the surround atmosphere. To avoid interruption in the incubation, a second set of soil samples was placed plastic bags to monitor soil pH and EC after WA and HUF application. Each plastic bag had 150 g of soil. Equivalent rates of HUF and WA were applied to the soils. The soil pH and EC were measured one and twelve weeks later.

2.5 Data processing

The data were tested for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests in SPSS 16.0. Homogeneity of variances was checked with Levene's test of equality of error variances. Two-way ANOVA was performed using General Linear Models. Where the homogeneity of variance was violated even after data transformation, Dunetts T3 in SPSS was used to compare the means. This was particularly the case for EC of WA and HUF treatments at twelve weeks. Differences between the means were compared by Tukey posthoc tests.

3 Results

3.1 Nutrients in HUF and WA

The chemical analyses showed that both HUF and WA had alkaline pH. The total N content of HUF was 3.93 g/L. The element content in HUF was much less than in WA (Table 1 and Table 2). The order was $Na > N > K > Ca = Mg$ while that of WA was $K > Ca > Na > Mg$ both in acid and in water extracts. There was more K and Ca in water and more K, Ca, and Na in acid.

3.2 The effects of HUF on soil pH and EC

A two-way ANOVA was conducted to examine the effect of soil and HUF treatment on soil pH and EC. There was a significant interaction between the effects of soil type and HUF treatment levels on soil pH after one week of HUF application ($F\ (3, 16) = 3.405$, $p = 0.043$) (Table 3). The main effect showed that HUF significantly influenced soil pH ($p = 0.0001$), but there were no effects of soil type ($p = 0.248$). The soil pH increased significantly ($p < 0.0005$) with the volume of HUF applied one week after application. The highest soil pH was obtained from the highest HUF application whereby pH increased by 1.2 units for the Adenta series and by 1 unit for the Toje series compared to un-incubated soil pH of 5.7.

After twelve weeks of HUF application, the soil pH dropped to around 4 ($p = 0.432$). Moreover, there was no significant interaction between HUF and soil type (Table 3). However, there were significant effects of soil type on soil pH ($p = 0.005$) where the average soil pH of Adenta series was about 4.5 while that of Toje series was about 4.6. Tukey posthoc tests showed no significant differences between HUF treatments ($p > 0.05$). An unusual observation in the experiment was the change in both soil pH and EC for the control treatments. Soil pH prior to incubation was $pH \geq 5.6$ while EC was $\leq 0.1\ dS\ m^{-1}$ (Table 1). When the soils were incubated, soil pH had dropped below 5 and EC increased above $0.2\ dS\ m^{-1}$.

The EC of the soil was only measured at the end of twelve weeks of incubation and it increased with HUF application rates. There was no significant interaction of soil type and HUF treatment ($p = 0.132$). The soil type had no significant influence ($p = 0.962$) on EC whereas HUF treatment had significant effects ($p < 0.0005$). Tukey test showed significant differences ($p < 0.05$) between the HUF treatments (Table 3). At the highest HUF rate, EC reached $1.8\ dS\ m^{-1}$ and $2.0\ dS\ m^{-1}$ for Adenta and for Toje series, respectively.

3.3 Effects of WA and HUF on EC, soil pH and NH_3 volatilisation

This experiment was monitored for urine-NH_3 volatilization three hours after HUF was applied. There was no sign of NH_3 loss (no colour change of acid trap). The monitoring continued the next day, two days later, and then a week thereafter without sign of NH_3 loss. Therefore the soil pH at that time was measured (Table 4) and the soils were discarded.

Following one week of HUF application there were no significant interaction of soil type and treatment (HUF and WA, $p = 0.516$) on soil pH, and no significant effect of soil type ($p = 0.086$). Conversely, significant effects of treatments on soil pH were observed ($p < 0$ 0001). The soil pH rose above 7 (Table 4). The highest pH was obtained from WA applied a week before HUF; 7.9 for Adenta series and 8.1 for Toje series at 20 mL HUF. Tukey posthoc tests showed significant differences ($p < 0.0005$) between all treatments except between the WA treatments ($p = 0.199$) which had a pronounced effect on soil pH by raising it to values above 7 (Table 4). Twelve weeks later, there was still no significant interaction of soil type and treatment (HUF and WA, $p = 0.058$). However, a significant effect ($p = 0.0001$) of treatment was observed. The average soil pH was decreased to about 7 for WA treatments. Tukey test also showed significant differences between treatments in both soil types (Table 4).

The soil EC showed significant interactions ($p = 0.010$) between soil type and treatments, significant effects of treatments on EC ($p < 0.0001$), but not of soil type ($p = 0.674$) after one week. The highest EC was $2.2\ dS\ m^{-1}$ for Adenta series and $1.6\ dS\ m^{-1}$ for Toje series (Table 4). Twelve weeks later, no significant interaction was observed between soil type and treatments, but there were significant

Table 3: *Effects of human urine fertiliser soil pH and electrical conductivity (EC) after one and twelve weeks of HUF treatment (mL).*

HUF treatment (mL)	*Mean soil pH*		*EC* (dS m^{-1})
	Week 1	Week 12	Week 12
Adenta series			
0	3.9 ± 0.06 ^{d}	4.4 ± 0.02 ^{a}	0.4 ± 0.04 ^{d}
10	5.5 ± 0.29 ^{c}	4.1 ± 0.12 ^{a}	1.4 ± 0.06 ^{c}
15	6.4 ± 0.10 ^{b}	4.2 ± 0.29 ^{a}	1.7 ± 0.20 ^{b}
20	6.9 ± 0.18 ^{a}	4.5 ± 0.23 ^{a}	1.8 ± 0.12 ^{a}
Toje series			
0	4.1 ± 0.11 ^{d}	4.6 ± 0.01 ^{a}	0.8 ± 0.04 ^{d}
10	5.4 ± 0.11 ^{c}	4.5 ± 0.33 ^{a}	1.1 ± 0.06 ^{c}
15	6.4 ± 0.03 ^{b}	4.7 ± 0.33 ^{a}	1.6 ± 0.20 ^{b}
20	6.6 ± 0.09 ^{a}	4.5 ± 0.12 ^{a}	2.0 ± 0.12 ^{a}
F(3, 16)	3.405	1.413	2.165
P	0.043	0.275	0.132

Mean values (n=3 ± SD), F and P values were obtained from two-way ANOVA.
Means followed by the same letter do not differ significantly from each other (Tukey $_{0.05}$).

Table 4: *Effects of wood ash and human urine fertiliser on soil pH and EC.*

HUF treatment (mL)	*Mean soil pH*		*EC* (dS m^{-1})	
	Week 1	Week 12	Week 1	Week 12
Adenta series				
Control	5.2 ± 0.04 ^{d}	4.4 ± 0.12 ^{a}	0.2 ± 0.00 ^{a}	0.3 ± 0.04 ^{d}
HUF	6.2 ± 0.28 ^{c}	4.3 ± 0.13 ^{a}	0.7 ± 0.10 ^{b}	1.1 ± 0.05 ^{c}
WA1wk	7.9 ± 0.11 ^{a}	7.2 ± 0.14 ^{a}	1.8 ± 0.20 ^{c}	2.0 ± 0.08 ^{a}
WA2wk	7.7 ± 0.07 ^{b}	7.2 ± 0.23 ^{a}	2.2 ± 0.20 ^{d}	1.8 ± 0.23 ^{b}
Toje series				
Control	5.3 ± 0.19 ^{d}	4.7 ± 0.13 ^{b}	0.2 ± 0.01 ^{d}	0.4 ± 0.03 ^{c}
HUF	6.2 ± 0.14 ^{c}	4.5 ± 0.12 ^{b}	0.6 ± 0.10 ^{c}	1.2 ± 0.24 ^{b}
WA1wk	8.1 ± 0.05 ^{a}	7.1 ± 0.01 ^{a}	1.2 ± 0.15 ^{b}	1.8 ± 0.03 ^{a}
WA2wk	7.9 ± 0.27 ^{b}	7.3 ± 0.05 ^{a}	1.6 ± 0.25 ^{a}	1.8 ± 0.27 ^{a}
F (3, 16)	0.792	3.071	5.325	0.835
P	0.516	0.058	0.010	0.494

Mean values (n=3 ± SD) with standard deviation. F and P obtained from ANOVA. Means followed by the same letter do not differ significantly from one another (Tukey $_{0.05}$).
WA2wk: WA applied two weeks before HUF application, WA1wk: WA applied one week before HUF application, 20 mL HUF applied.

effects ($p < 0.0001$) of treatments. The Dunetts T3 test showed significant differences ($p < 0.0001$) between all treatments except the WA treatments ($p = 0.822$) which resulted in EC of >1.5 dS m^{-1} for both soils. There was an interesting trend in EC the of Adenta series, resulting in a decrease from 2.2 dS m^{-1} at week one to 1.8 dS m^{-1} at week twelve. For the Toje series, the EC remained at 1.8 dS m^{-1} for both WA treatments.

3.4 *Effect of WA and HUF application on exchangeable cation content*

There were significant interactions between soil types and treatments ($p < 0.0001$). When HUF was solely applied to the soils, the cation content increased in both soils compared to the controls (Table 5). Furthermore, the application of wood ash had doubled the cation content for both soils.

4 Discussion

The pH of the stored HUF was alkaline. This is in agreement with what Akpan-Idiok *et al.* (2012) and Sakthivel *et al.* (2012) found. Hydrolysis of urine-urea to NH_4^+ during storage accounts for the alkalinity of stored HUF (Kirchmann & Pettersson, 1995). The element content of WA was higher than that found in HUF as reported by Germer *et al.* (2011) and Akpan-Idiok *et al.* (2012). In both cases, the element content was variable and largely dependent on the source. The Mg and K contents in acid-urine solution (Table 2) were higher than those of water-urine solution. This is attributed to acid dissolution and release of the elements into solution from struvite ($(NH_4)Mg[PO_4] \cdot 6H_20$), a precipitated phosphate compound in stored urine following urea hydrolysis (Ikematsu *et al.*, 2007; Ronteltap *et al.*, 2007). Similarly, the acid extractable elements in WA were also higher than water extractable elements due to the presence of minerals which are not readily water-soluble. According to Demeyer *et al.* (2001), Ca, Mg and K are the most acid-soluble elements in WA. Mineralogical analysis of WA showed the presence of $CaCO_3$, fairchildite ($K_2Ca(CO_3)_2$), CaO, MgO, quartz, periclase, bassanite, siderite and dolomite (Sakthivel *et al.*, 2012; van Ryssen & Ndlovu, 2004; Misra *et al.*, 1993). A review by Demeyer *et al.* (2001) also indicated the presence of Riebeckite ($(NaCa)_2(FeMn)_3Fe_2(SiAl)_8$), portlandite ($Ca(OH)_2$, calcium silicate ($Ca_2SiO_4$), hydrotalcite ($Mg_6Al_2CO_3(OH)_{16} \cdot 4H_2O$) serandite ($Na(MnCa)_2Si_3O_8(OH)$). With this composition of WA, strong extraction solutions were required to obtain significant results. In this study, Ca and K were dominant in WA followed by Na and Mg. This in accordance with what Park *et al.* (2004) and van Ryssen & Ndlovu (2004) found in their studies on WA. However K was higher than Ca, Mg and Na. This is contradictory to other studies which reported high Ca content. It suggests the possible influence of combustion temperature (Misra *et al.*, 1993), which might have produced more potash as shown in the high WA pH (Babayemi *et al.*, 2011; Onyegbado *et al.*, 2002; Kuye & Okorie, 1990; Nwoko, 1980). More so further studies will be required to elucidate factors that account for the dominance of Ca and K in WA.

According to our experiment of urine alone, soil pH increased with increasing HUF application rate. After one week of application the pH was above 6 for both soil types. This increase can be attributed to the initial deposition effect of urine-NH_4^+ (Monaghan & Barraclough, 1992). By the twelfth week (end of experiment), the pH had dropped to 4.5 for the highest HUF volume applied. The decrease is attributed to nitrification of urine-NH_4^+ which is associated with soil acidification. On the contrary, HUF application increased soil pH (Ndzana & Otterpohl, 2009; Pradhan *et al.*, 2009). Soil acidity is influenced by a balance of processes that produce and consume H^+. In tropical soils, cation precipitation as in the case of Al^{3+} and water, and also deprotonation of pH-dependent charges affect soil acidity (Tisdale *et al.*,

Table 5: *Enrichment of basic cations (means ± SD, cmol$_c$ kg^{-1} soil) in the soils after wood ash and human urine fertiliser application.*

Soil type	*Control*	*HUF **	*WA1wk*	*WA2wk*
Adenta series	4.6 ± 0.21 ^{d}	5.4 ± 0.52 ^{c}	11.9 ± 0.22 ^{a}	11.7 ± 0.00 ^{b}
Toje series	5.3 ± 0.31 ^{d}	5.8 ± 0.32 ^{c}	12.9 ± 0.24 ^{b}	14.3 ± 0.09 ^{a}

* 20 mL of HUF applied in all treatments.
Different letters within soil indicate significant differences of treatments (Tukey$_{0.05}$)

2002). In the presence of plants, differences in nutrient uptake, as well as the rhizosphere could cause variations in soil pH even in the same soil. This is because the rhizosphere is known to modify pH by releasing H^+ or OH^- ions into the surrounding environment to maintain electroneutrality (Tisdale *et al.*, 2002), soil pH decreases when plants receive NH_4^+. Besides, the excess base to nitrogen ratio (EB/N) is also said to influence acidity formed by nitrification. For instance, plants with EB/N ratio <1 decrease acidity formed by nitrification and vice versa. Hence plants of the grass family with EB/N ratio of 0.43 and 0.47 only acidify 43 and 47 % N uptake respectively (Tisdale *et al.*, 2002).

The EC also increased with increasing HUF application rate. The highest EC was observed in 20 mL HUF volume for both soil types (Table 3). This is in agreement with the results of Mnkeni *et al.* (2008). Pradhan *et al.* (2009) also had similar results in soil grown with tomatoes. Mnkeni *et al.* (2008) observed that the increase in EC varied with plant type and application rate. For instance, they found that with HUF application rates of 160 mL HUF/5 kg soil (400 kg N ha^{-1}) and 270 mL HUF/5 kg soil (800 kg N ha^{-1}), the EC had already reached the threshold level for saline soils (>4 dS m^{-1}), and EC in soils grown with beetroot and carrot were 4.90 and 13.40 dS m^{-1}, respectively. For our study, there were no interaction effects of soil type on EC after twelve weeks of HUF application. However, in practical terms, 20 mL of HUF created slightly saline conditions in Toje series which can affect the growth and yield of very sensitive crops. With an EC value of less than 2.00 dS m^{-1} Adenta series remains non-saline and will thus have negligible effects on crop production (Richards, 1954). On the contrary, Ndzana & Otterpohl (2009) found that EC decreased with increasing HUF application rate in a carbon-rich soil medium. With the observation of other authors, it can be concluded that different crops grown on the same soil type will yield variable changes in EC and soil pH following HUF application. From the agronomic trials it was observed that, with the grass family there were less effects of HUF applications on soil EC compared to the non-grass plant species. Maize roots for instance, secret exudates with high concentrations of amino acids and carbohydrates (Kolek & Kozinka, 1992). It is therefore possible that the organic carbon content in soil also affects EC and soil pH. Apart from crop and soil effects, HUF composition which is variable, could also account for the variations in EC changes following its application to soil. The crop type, soil type and HUF composition should therefore be taken into consideration in HUF application.

The observed decrease in soil pH and increase in EC of control treatments could be attributed to watering of soil, a simulation of watering of plants. This created relatively continuous moisture conditions during the entire period of incubation as compared to air-dried soils which had been shaken in water for only half an hour prior to pH measurement.

The NH_3 volatilization experiment showed no NH_3 loss from the soils applied with HUF after WA treatment. It is not clear what accounted for that since NH_3 volatilization is controlled by soil pH, other soil properties and external environmental factors like temperature (Rawluk *et al.*, 2001; Hargrove, 1988; Kissel & Cabrera, 1988). According to Rawluk *et al.* (2001) and Koelliker & Kissel (1988), NH_4^+ is susceptible to volatilization losses if present in sufficient concentration near the soil surface, and the extent of loss actually depends on weather conditions (Hargrove, 1988). In this study, the HUF was applied by incorporating it into the soil. Therefore the NH_3 was distributed through the soil preventing high concentrations near the soil surface. Soil moisture content has been found to be the most significant factor controlling NH_3 volatilization. Liu *et al.* (2007) found about 2–3 times NH_3 losses in three N sources at 20 % field capacity (FC) compared to 80 % FC. This implies less NH_3 loss at high soil moisture content possible due to restrictions in exchange of gases. Even though the temperature of incubation was favourable for volatilisation, the soil moisture content (18 % for Adenta series and 20 % for Toje series) might have restricted the movement of NH_4^+/NH_3 in the soil.

In the HUF and WA experiment, HUF alone decreased soil pH by more than two units after twelve weeks. For WA treatments, there was only a drop of about half pH unit. This maintained the soil pH at around 7. Depending on the target pH, the $CaCO_3$ equivalent of WA can be calculated to obtain the rate of application. In this study, the target pH was not considered because it was incorporated into the HUF programme to observe pH and EC response. The effect of WA as a liming material was most significant as shown in soil pH increases to >7. Patterson *et al.* (2004) noted that WA can be a good option to improve crop productivity of acid soils to reduce Al, H+ and Mn toxicity, because it reacts with soil faster than agricultural lime (Demeyer *et al.*, 2001; Muse & Mitchel, 1995; Clapham & Zibliske, 1992). The reaction capacity stems from its particle size, and the neutralizing power of oxides, hydroxides and carbonates of K and Na which are readily soluble (Demeyer *et al.*, 2001; Vance, 1996; Ulery *et al.*, 1993).

When WA was incorporated into HUF application, the WA treatments gave rise to the highest EC in both soil types. The temporal reaction effect between WA and soil might have also accounted for slightly higher EC of WA1wk than WA2wk. There was a retrogressive change in EC from the first to the twelfth week for the WA treatments.

The cation content of soils can be enriched through WA application treatments. In this study cations increased by up to 158 % for Adenta and up to 173 % for Toje through WA application compared to 16 % and 11 % for Adenta and Toje, respectively for HUF alone. Similar results have been obtained from Arvidsson & Lundkvist (2003) and Kahl *et al.* (1996) who used WA application rates of 3 t WA ha^{-1} and 6, 13 and 20 t CCE ha^{-1} respectively. Adekayode & Olojugba (2010) also found significantly higher amounts of Ca and Mg in arable soil treated with WA. The significant quantities of Ca, Mg, Na and K in WA could offset the effects of soluble salts in HUF and reduce soil EC. This was observed in the EC of WA2wk compared to EC of WA1wk.

5 Conclusion

The results of the study indicate that soil pH and EC increased with HUF application. While pH dropped due to nitrification of urine-NH_4^+, EC did not. Wood ash raised the soil pH to neutral, but at that pH there was no evidence of urine-ammonia loss from the soil. The EC also increased with WA application but was however not as high as with HUF alone. This could possibly be due to some chemodynamic effects of WA. The cation content of the soils surged by two-fold when WA was applied. For the application of WA, the calcium carbonate equivalent (CCE) should be taken into account before use in HUF programmes for it to reduce soil acidity, increase the basic cation content of soils and reduce the EC of the soil as well. Further research is required on several soils, WA and HUF types in the presence of different crop type to ascertain these findings in the long term, especially in field conditions.

Acknowledgements

We owe the following people an appreciation for their assistance in soil sampling and laboratory analyses: Mr. J. A. Nartenor, Mr. Daniel Tsatsu, Mr. Martin Kojo Aggrey, Mr. Vincent Adusei-Okrah and Mr. Edmund Anum.

References

Adekayode, F. O. & Olojugba, M. R. (2010). The utilization of wood ash as manure to reduce the use of mineral fertilizer for improved performance of maize (*Zea mays L.*) as measured in the chlorophyll content and grain yield. *Journal of Soil Science and Environmental Management*, 1 (3), 40–45.

Akpan-Idiok, A. U., Udo, I. A. & Braide, E. I. (2012). The use of human urine as an organic fertilizer in the production of okra (*Abelmoschus esculentus*) in south eastern Nigeria. *Resources, Conservation and Recycling*, 62, 14–20.

Alters, S. & Alters, B. (1996). *Biology: understanding life. First Edition*. John Wiley & Sons Inc., Hoboken, New Jersey, US.

Arvidsson, H. & Lundkvist, H. (2003). Effects of crushed wood ash on soil chemistry in young Norway spruce stands. *Forest Ecology Management*, 176, 121–132.

Babayemi, J. O., Adewuyi, G. O. & Obi-Egbedi, N. O. (2011). Evaluation of options in wood waste management: burning and consequent alkali production. *Journal of Sustainable Development and Environmental Protection*, 1 (2), 98–109.

Clapham, W. M. & Zibliske, L. M. (1992). Wood ash as a liming amendment. *Communications in Soil Science and Plant Analysis*, 23, 1209–1227.

Demeyer, A., Voundi Nkana, J. C. & Verloo, M. G. (2001). Characteristics of wood ash and influence on soils properties and nutrient uptake: an overview. *Bioresource Technology*, 77, 287–295.

Drangert, J.-O. (2000). Reuse - the ultimate sink? Urine-diverting toilets to protect groundwater quality and fertilize urban agriculture. In I. Chorus, G. Ringelband, G. Schlag, & O. Schmoll (Eds.), *Water, Sanitation and Health. Proceedings of the International Conference, Bad Elster, Germany, 24-28 November, 1998* (pp. 275–280). IWA Publishing, London, UK.

Duku, M. H., Gu, S. & Hagan, E. B. (2011). A comprehensive review of biomass resources and biofuels potential in Ghana. *Renewable and Sustainable Energy Reviews*, 15 (1), 404–415.

Erich, M. S. (1991). Agronomic effectiveness of wood ash as a source of phosphorus and potassium. *Journal of Environmental Quality*, 20, 576–581.

Germer, J., Addai, S. & Sauerborn, J. (2011). Response of grain sorghum to fertilisation with human urine. *Field Crops Research*, 122, 234–241.

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

Hargrove, W. L. (1988). Soil, environmental, and management factors influencing ammonia volatilization under field conditions. In B. R. Bock, & D. E. Kissel (Eds.), *Ammonia volatilization from urea fertilizers* (pp. 17–36). National Fertilizer Development Centre, Muscle Shoals, AL.

Heinonen-Tanski, H., Sjöblom, A., Fabritius, H. & Karinen, P. (2007). Pure human urine is a good fertiliser for cucumbers. *Bioresource Technology*, 98, 214–217.

Heinonen-Tanski, H. & van Wijk-Sijbesma, C. (2005). Human excreta for plant procution. *Bioresource Technology*, 96 (4), 403–411.

Höglund, C. (2001). *Evaluation of microbial health risks associated with the reuse of source-separated human urine*. Ph.D. thesis Royal Institute of Technology (KTH) and Swedish Institute for Infectious Disease Control (SMI).

Höglund, C., Ashbolt, N., Stenström, T. A. & Svensson, L. (2002). Viral persistence in source-separated human urine. *Advances in Environmental Research*, 6, 265–275.

Huotari, N., Tillman-Sutela, E., Pasanen, J. & Kubin, E. (2008). Ash-fertilization improves germination and early establishment of birch (*Betula pubescens* Ehrh.) seedlings on a cut-away peatland. *Forest Ecology Management*, 255, 2870–2875.

Ikematsu, M., Kaneda, K., Iseki, M. & Yasuda, M. (2007). Electrochemical treatment of human urine for its storage and reuse as flush water. *Science of the Total Environment*, 382, 159–164.

IUSS Working Group WRB (2006). World reference base for soil resources 2006. World Soil Resources Reports No. 103. FAO, Rome. ISBN 92-5-105511-4.

Johnson, M. D. (2008). *Human biology: concepts and current issues. 4th edition*. Pearson Prentice International Edition of Benjamin Cummings.

Jönsson, H., Stinzing, A. R., Vinnerås, B. & Salomon, E. (2004). Guidelines on the use of urine and faeces in crop production. EcoSanRes Publication Series Report 2004-2. Stockholm Environment Institute, Sweden. pp 1-35.

Kahl, J. S., Fernandez, I. J., Rustad, L. E. & Perkenham, J. (1996). Soil processes and chemical transport: threshold application rates of wood ash to an acidic forest soil. *Journal of environmental Quality*, 25, 220–227.

Kirchmann, H. & Pettersson, S. (1995). Human urine: chemical composition and fertilizer use efficiency. *Fertilizer Research*, 40, 149–154.

Kissel, D. E. & Cabrera, M. L. (1988). Factors affecting urea hydrolysis. In B. R. Bock, & D. E. Kissel (Eds.), *Ammonia volatilization from urea fertilizers* (pp. 53–66). National Fertilizer Development Centre, Muscle Shoals, AL.

Koelliker, J. K. & Kissel, D. E. (1988). Chemical equilibria affecting ammonia volatilization. In *Ammonia volatilization from urea fertilizers* (pp. 37–52). National Fertilizer Development Centre, Muscle Shoals, AL.

Kolek, J. & Kozinka, V. (1992). *Physiology of the plant root system. Development in Plant and Soil Sciences 46*. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Kuye, A. O. & Okorie, C. (1990). Factors affecting the lixiviation of palm bunch ash as a source of alkali for soap production. *Ife Journal of Technology*, 3 (2), 33–37.

Kvarnstrom, E., Emilsson, K., Stintzing, A. R., Johansson, M., Jönsson, H., Petersens, E., Schönning, C., Christensen, J., Hellström, D., Qvarnström, L., Ridderstolpe, P. & Drangert, J.-O. (2006). EcoSanRes Publications series, Report 2006-1. Urine diversion: one step towards sustainable sanitation. The EcoSanRes Programme and the Stockholm Environment Institute. ISBN 91 975238 9 5. pp 1-64.

Liao, C. F. H. (1981). Devarda's alloy method for total nitrogen determination. *Soil Science Society of America Journal*, 45 (5), 852–855.

Liu, G., Li, Y. & Alva, A. K. (2007). High water regime can reduce ammonia volatilization from soils under potato production. Publications from USDA-ARS / UNL Faculty. Paper 512. URL `http://digitalcommons.unl.edu/usdaarsfacpub/512`.

Lopez, R., Padilla, E., Bachmann, S. & Eichler-Loebermann, B. (2009). Effects of biomass ashes on plant nutrition in tropical and temperate regions. *Journal of Agriculture and Rural Development in the*

Tropics and Subtropics, 110 (1), 51–60.

Mehlich, A. (1984). Mehlich No. 3 extractant: a modification of Mehlich No. 2 extractant. *Communications in Soil Science & Plant Analysis*, 15, 1409–1416.

Merino, A., Otero, V., Omil, B., Lastra, B., Piñeiro, V. & Gallego, P. P. (2006). Application of wood ash compared with fertigation for improving the nutritional status and fruit production of kiwi vines. *Journal of Plant Nutrition and Soil Science*, 169, 127–133.

Misra, M. K., Ragland, K. W. & Baker, A. J. (1993). Wood ash composition as a function of furnace temperature. *Biomass and Bioenergy*, 4 (2), 103–116.

Mnkeni, P. N. S., Kutu, F. R., Muchaonyerwa, P. & Austin, L. M. (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 Research*, 26, 132–139.

Monaghan, R. M. & Barraclough, D. (1992). Some chemical and physical factors affecting the rate and dynamics of nitrification in urine-affected soil. *Plant and Soil*, 143, 11–18.

Muse, J. K. & Mitchel, C. C. (1995). Paper mill boiler ash and lime by-products as soil liming materials. *Agronomy Journal*, 87, 432–438.

Naylor, L. M. & Schmidt, E. (1986). Agricultural use of wood ash as a fertilizer and liming material. *Tappi Journals*, 69, 199–206.

Ndzana, J. E. & Otterpohl, R. (2009). Urine reuse as fertilizer for bamboo plantations. In K. Ashley, D. Mavinic, & F. Koch (Eds.), *International Conference on Nutrient Recovery from Wastewater Streams*. IWA Publishing, London, UK.

Nwoko, V. O. (1980). Chemical processing development. In *Proceedings of the 10th Annual Conference of the Nigerian Society of Chemical Engineers* (pp. 40–53).

Onyegbado, C. O., Iyagba, E. T. & Offor, O. J. (2002). Solid soap production using plantain peels ash as source of alkali. *Journal of Applied Sciences and Environmental Management*, 6 (1), 73–77.

Park, B. B., Yanai, R. D., Sahm, J. M., Ballard, B. D. & Abrahamson, L. P. (2004). Wood ash affects on soil solution and nutrient budgets in a willow bioenergy plantation. *Water, Air, and Soil Pollution*, 159, 209–224.

Patterson, S. J., Acharya, S. N., Thomas, J. E., Bertschi, A. B. & Rothwell, R. L. (2004). Barley biomass and grain yield and canola seed yield response to land application of wood ash. *Agronomy Journal*, 96, 971–977.

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 Agricultural 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 Agricultural Food Chemistry*, 58 (3), 2034–2039.

Pradhan, S. K., Nerg, A.-M., Sjöblom, A., Holopainen, J. K. & Heinonen-Tanski, H. (2007). Use of human urine fertilizer in cultivation of cabbage (*Brassica oleracea*): impacts on chemical, microbial and flavour quality. *Journal of Agricultural Food Chemistry*, 55, 8657–8662.

Rawluk, C. D. L., Grant, C. A. & Racz, G. J. (2001). Ammonia volatilization from soils fertilized with urea and varying rates of urease inhibitor NBPT. *Canadian Journal of Soil Science*, 81, 239–246.

van Reeuwijk, L. P. (Ed.) (2002). *Procedures for soil analysis. Technical Paper 9. Sixth edition*. International Soil Reference and Information Centre (ISRIC), Wageningen, The Netherlands. ISBN: 90-6672-044-1.

Richards, L. A. (Ed.) (1954). *Diagnosis and improvement of saline and alkali soils. Agriculture Handbook 60*. United States Salinity Laboratory Staff, United States Department of Agriculture, Washington D. C. Pp 1-159.

Ronteltap, M., Maurer, M. & Gujer, W. (2007). Struvite precipitation thermodynamics in source-separated urine. *Water Research*, 41, 977–984.

van Ryssen, J. B. J. & Ndlovu, H. (2004). Ash from fireplaces at homesteads in rural regions of South Africa as potential source of minerals to goats. *South African Journal of Animal Science*, 34 (1), 111–113.

Sakthivel, S. R., Tilley, E. & Udert, K. M. (2012). Wood ash as a magnesium source for phosphorus recovery from source-separated urine. *Science of the Total Environment*, 419, 68–75.

Sanchez, P. A. & Salinas, J. G. (1981). Low input technology for managing Oxisols and Ultisols in tropical America. *Advances in Agronomy*, 34, 279–406.

Schönning, C., Leeming, R. & Stenström, T. A. (2002). Faecal contamination of source-separated human urine based on the content of faecal sterols. *Water Research*, 36, 1965–1972.

Sridevi, G., Srinivasamurthy, C. A., Bhaskar, S. & Viswanath, S. (2009). Evaluation of source separated human urine (ALW) as a source of nutrients for banana cultivation and impact on quality parameter. *Journal of Agricultural and Biological Science*, 4 (5), 44–48.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. & Havlin, J. L. (2002). *Soil fertility and fertilizers, 5th Edition*. Prentice Hall of India, New Delhi.

Ulery, A. R., Graham, R. C. & Amrhein, C. (1993). Wood ash composition and soil pH following intense burning. *Soil Science*, 156, 358–364.

Vance, E. D. (1996). Land application of wood-fired and combination boiler ashes: an overview. *Journal of Environmental Quality*, 25, 937–944.

Vinnerås, B., Holmqvist, A., Bagge, E., Albihn, A. & Jönsson, H. (2003). The potential for disinfection of separated faecal matter by urea and by peracetic acid for hygienic nutrient recycling. *Bioresource Technology*, 89 (2), 155–161.

Vinnerås, B. & Jönsson, H. (2002). The performance and potential of faecal separation and urine-diversion to recycle plant nutrients in household wastewater. *Bioresource Technology*, 84 (3), 275–282.

Voundi Nkana, J. C., Demeyer, A. & Verloo, M. G. (1998). Chemical effects of wood ash on plant growth in tropical acid soils. *Bioresource Technology*, 63 (3), 251–260.

Walkley, A. & Black, I. A. (1934). An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science*, 63, 251–263.

Winker, M., Gulyas, H., Otterpohl, R., Clemens, J. & Reich, M. (2008). Fertilization of rye grass with carbamazepine, ibuprofen, and 17α-ethinylestradiol spiked urine: a greenhouse experiment. 3rd SWITCH Scientific Meeting, 30 November–4 December 2008, Belo Horizonte, Brazil.

Winker, M., Vinnerås, B., Muskolus, A., Arnold, U. & Clemens, J. (2009). Fertilizer products from new sanitation systems: their potential values and risks. *Bioresource Technology*, 100 (18), 4090–4096.