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Nutrient Recycling Using Human Urine: Potential for Low Input Farming

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Abstract: Recycling human urine for farming was assessed in a peri-urban Kyanja parish, Kampala district, and in a rural Migyera parish, Nakasongola district, to demonstrate its potential and develop local use guidelines. Test crops were maize, *Nakati* (*Solanum aethiopicum*), kale, spinach, cabbage, tomatoes, egg plants. Urine-water mixtures (0, 10%, 20%, 30% urine) were applied weekly or bi-weekly. At Kyanja, 30% urine weekly gave the highest maize yields. Within 2 months, 10% urine weekly increased *Nakati* yield from 5,444 to 24,667 kg ha^{-1}. 20% Urine weekly increased kale yield (7,556 to 16,111 kg ha^{-1}) and spinach (4,222 to 19,022 kg ha^{-1}). At Migyera, 10% urine weekly increased cabbage yield (4,975 to 16,113 kg ha^{-1}) but 30% urine weekly decreased cabbage head-weight by 36%. Weekly applied urine produced heavier cabbage heads than bi-weekly (548 g vs. 427 g, $P < 0.05$). Leaf N was higher for weekly than bi-weekly applied urine (3.3% vs. 3.0%), implying more protein in the former than the latter. From this study, the following guidelines are proposed: Kyanja area, maize: apply 30% urine weekly for 8-weeks; *Nakati*: apply 10% urine weekly for 8-weeks; Kale and spinach: apply 20% urine weekly; For Migyera area, cabbage and spinach: apply 10% urine weekly. Apply urine 15 cm around each plant starting 2-weeks after transplanting. So kale and spinach prolong urine application for continued harvesting.

Key words: Human urine, ecological sanitation, closing the loop, organic fertilizers, urban agriculture.

1. Introduction

Increasing population growth and high rate of urbanization especially in developing countries have resulted in intense pressure being exerted on land to improve food production. It is estimated that to sustain the high population an appreciable increase in food production must be realized in the 21st century requiring a 3-fold increase in fertilizer use. This is in contrast with the decreasing level of nutrient reserves worldwide, especially P and K. Alternative fertilizer sources are urgently required to meet nutrient deficits, one of which is to reuse nutrients in human excreta. Furthermore, about 2.4 billion persons, mostly in developing countries, lack adequate sanitation [1]. Majority of farmers in rural and urban areas also experience shortage of water and nutrients in agriculture. By providing affordable sanitation emphasizing recycling of by-products for agriculture, ecological sanitation can potentially contribute to food security.

Ecological sanitation (EcoSan) is based on the principal that urine, faeces and waste water are resources in the ecological loop. It uses dry toilets to separate urine from faeces and through recycling the two may be used to support crop production. Important features in EcoSan are separation at source, destruction of pathogens and recycling of urine, faeces and grey water, thereby closing the loop. Nutrients and organic matter (OM) in human excreta can be recycled to benefit soil organisms and plant life and to

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produce human food. Consumed plant nutrients leave the human body through excreta. In adults, almost all nutrients in the food eaten are excreted. It is estimated that 2.2, 0.3 and 1.0 kg of N, P and K, respectively per person per year are excreted in urine in Uganda [2]. Reuse of urine in farming would facilitate recovery of these nutrients.

Inspite of being a good source of nutrients, human excreta also contain pathogens which if not carefully handled, can affect health. Excreta recycling calls for safe handling and management guidelines, to exploit its crop nutritional value safely. According to Hoglund [3], urine from a single household is safe for all types of crops if the crop is for household's own consumption, and one month is allowed between fertilizing and consumption. Urine used on cereals presents negligible risk of transmission of infection. Schonning and Stenstrom [4] advised that the amount of urine used should be based on the N recommended when fertilizing with urea-based fertilizers. Where no recommendations are available, a rule of thumb is to apply urine collected from 1 person during 1 day to 1 m^2 of land per growing season. According to Hoglund [3], urine can be assumed to have pH of 8.8 and N content of at least 1 g L^{-1}. Where no data is available, urine N content of 3 to 7 g L^{-1} can be used [5]. For urine collected from different households, the risk of infection decreases during 6 months storage [6]. Urine should be applied close to the ground to avoid aerosol formation and incorporated into soil. Urine can be applied diluted or without dilution. Dilution varies from 1 part water: 1 part urine to 10:1, but 3:1 is the most common [7]. In areas with heavy rainfall, repeated application of urine during the growing season rather than single doze may be an insurance against leaching.

Examples worldwide (India, South Africa, Botswana, Australia, Sweden, Mexico, among others) show high potential for EcoSan and nutrients reuse. In China, over 90% of garbage and human excreta are recycled as night soils [8]. Simons and Clement [9] observed that the N effect of urine on barley corresponded to 90% or higher than that of an equal amount of mineral fertiliser. Urine-fertilised Swiss chard yielded 4 times higher than the unfertilized in Ethiopia [10]. In Zimbabwe, lettuce, spinarch and tomatoes grown on 3:1 water/urine mixture applied 3 times per week yielded 2 to 7 times higher than unfertilized [11].

In Lusaka and Dar es salaam cities, urban agriculture contributes immensely to food consumption and livelihoods [12] and will no doubt continue to expand in cities like Kampala, hence, increased realization of the need to use urine in farming. While information exists from elsewhere on urine reuse, differences in diets lead to differences in nutrient (NPK) content of excreta. Thus, guidelines developed elsewhere need to be adapted to local conditions in different agro-ecological zones, to take into consideration the differences in diets, handling, storage-application conditions, and local crops to be grown. Further, many farmers would need advice on urine dilution rates and application frequently prior to field use. Rarely do they bother about local fertilizer recommendations, let alone nutrient content in urine. For leafy vegetables, studies recommend 65 to 75 kg N/ha for Soroti area, Eastern Uganda (sandy soils, lower fertility than in central Uganda) (National Horticulture Programme, personal communication). No fertilizer recommendations were found for vegetables in central Uganda, hence a further focus of the study. Preliminary investigations on maize, kale, spinach and *Nakati* (*Solanum aethiopicum*) have developed guidelines for use of human urine under Uganda local conditions in the lake Victoria crescent of Uganda (high clay soils with low to moderate fertility, high rainfall) conditions [13]. However, these guidelines need to be adapted to other parts of the country.

The objectives were to raise awareness of farmers, technical staff, local leaders and other stakeholders in Kampala (urban community) and Nakasongola (rural community) on the value and potential of using human urine in farming and to develop safe reuse and application guidelines for urine in farming.

2. Materials and Methods

2.1 Description of the Study Sites

The study was conducted at two sites. The first site is located in Kyanja parish which is a suburb of Kampala city in Nakawa division, Kampala district, central Uganda. This area is located in the lake Victoria Crescent zone and lies at 1250 m a.s.l. and receives 1390 mm of rainfall annually, bi-modally distributed between 2 seasons. The first season runs from March to June, the second season one August to November. The mean annual temperature is 21.4 °C. Soils are high clay with low to moderate natural fertility, high rainfall [14].

The second study site was located at Migyera Uweso Training Institute (MUTI), in Nakasongola district, central Uganda. This area lies in the Pastoral rangelands otherwise known as the "cattle corridor" and is characterised by low rainfall (915 to 1021 mm) with two rainy seasons, the main season is from March to May with peak in April and secondary season in September to December with a modest peak in November. The main dry season is from June to August, the second is January to February. Evaporation exceeds rainfall by a factor of about six during the dry months in June to August. During the main rainy months, April and May rainfall equals evaporation. Temperature ranges from 12.5-30 °C. Altitude ranges from 129-1,524 m Above Sea Level (ASL). Soils are sandy, with moderate to poor fertility, lower rainfall amounts and poorer distribution than the lake Victoria crescent. The area is dominated by rural smallholder farmers, communal grazing and agro-pastoral practices [15].

2.2 Establishment of Field Experiments

In Kyanja parish 20 farmers were selected to participate in the study. They were first sensitized on proper handling and the benefits of recycling human urine in farming. Farmers selected the test crops as maize (*Zea Mays* L. and *Nakati*) (*Solanum aethiopicum*, a popular local vegetable) in first season, and Kale (*Brassica oleracea* L.) and Spinach (*Spinacia Oleracea* L.) in the second. Farmers prepared the land and demarcated four, 1.4 m by 6 m plots for establishing the demonstration plots. Two plots were planted to maize and two to *Nakati* during the first season, then kale and spinach during the second season of 2005. Farmers collected urine from their individual households and stored it for at least two weeks in closed plastic jerricans prior to field application. During the first season, urine was diluted with water in ratios of 1 (urine):9 (water), 2 (urine):8 (water) and 3 (urine):7 (water), representing 10%, 20% and 30% urine respectively. 20 L of each urine-water mixture was prepared and applied once a week and once every two weeks (20 L of mixture per treated bed and 20 L water for the control). In the second season, urine was mixed with water in the ratios: 10%, 20%, 30% and 40% urine and applied weekly or bi-weekly. Treatments were allocated to farmers' plots taking into account the soil nutrient status, basing on the soil test and urine analysis results. The experiment was a completely randomized (CR) design comprising a factorial arrangement of urine concentration and application frequency, farmers (20) representing the replicates.

At MUTI, in Nakasongola district, nursery beds were established for five vegetables (Table 1). About one month after planting (June 2009) the seedlings were transplanted onto experimental plots of 4 m × 2 m. Because it was off-season at the time of transplanting, the vegetables were watered once every two days. At two weeks after transplanting urine-water mixtures were applied on to the vegetables in the ratios of 0:10, 1:9, 2:8 and 3:7 representing 0, 10%, 20% and 30% urine, respectively. Each urine-water mixture was applied either once every week or once every two weeks. The treatments

Table 1 Summary of the crops planted at Migyera Uweso training institute (MUTI).

Crop	Variety	Spacing	Transplanting date
Spinach (*Spinacia oleracea* L.)	Fordhook giant	30 cm × 30 cm	17/06/09
Cabbage (*Brassica olerecea capital* L.)	CopenHagen market	45 cm × 45 cm	17/06/09
Kale (*Brassica oleracea* L., *Sukuma wiki, Swahili*)	Georgia	45 cm × 45 cm	18/06/09
Tomato (*Solanum lycopersicum* L.)	Rio Grande	45 cm × 45 cm	18/06/09
Eggplants (*Solanum Melongena* L.)		45 cm × 45 cm	18/06/09

were replicated four times for each of the five vegetables, giving a total of 160 plots. The experimental design was a complete randomised block (CRB), with urine concentration and application frequency as the treatments, in a factorial arrangement, replicated four times. At time of application, each plot received 20 L of the diluted mixture. The urine-water mixtures were applied using a 10 L watering can. The urine-water mixtures were applied for 10 weeks. The crops were watered with Dithane M45 to control pests and diseases.

2.3 Soil and Urine Sampling Analyses

Soil (500 g) was sampled from 0 to 30 cm of each bed before planting, to make a representative composite. Air-dried soil samples were analysed using standard procedures as follows: Soil pH was measured on a mixture of soil and water in a ratio of 1:2.5 soil to water by volume [16]. Organic matter (OM) by the Walkley and Black [17] wet oxidation procedure, modified for colorimetric determination of OM using sucrose. Total N by the micro Kjeldahl [18] wet ashing procedure. Available P, extractable K, Ca and Mg by the ammonium lactate (pH 3.8) procedure [19]. Soil particle size was by the hydrometer method [16].

At Kyanja the participating households collected urine and kept it tightly closed in 20 L containers. After the container was full and urine was stored, tightly closed for at least 2 weeks before field application. At two weeks of storage a 300 mL urine sample was collected from the container. At MUTI, urine was collected from students in a dormitory overnight using buckets provided to each. This urine was kept in large plastic tanks that were kept tightly closed. A filled tank was kept closed for at least two weeks before field application of urine. At two weeks of storage two 300 mL urine samples were collected from the tank. Nutrient content in urine was determined on the wet ash digest following the micro-Kjeldahl [18] wet oxidation procedure. The N and P were determined colorimetrically, and K on a Flame Photometer.

2.4 Field Data Collection

Data were collected on yield characteristics of test crops. For maize, data included number and size of cobs per plot; For *Nakati*, number of plants and weight of leaf vegetable at each piece meal harvest; for kale and spinach, number of plants, weight and number of leaves harvested; for cabbage, tomatoes and eggplants, number and weight of fruits at each harvest. The number and weight of vegetable leaves or fruits harvested each time was recorded and summed up at the end.

2.5 Statistical Analysis

Using Genstat (3.2) data were analysed as a CR design for the Kyanja site and CRB for MUTI site to determine the effect of urine treatments (concentration, frequency of application). Statistically significant differences among means were determined at 5% level. Two means were declared as significantly different when the difference between them was greater than twice the standard error of difference (sed) value.

3. Results and Discussion

3.1 Soil Characteristics

Table 2 presents the soil characteristics from Kyanja farmers. Mean soil pH and organic matter

Table 2 Chemical characteristics of soils used in the study.

	pH	OM	N	P	Ca	Mg	K
				(mg kg^{-1})		($cmol_c$ kg^{-1})	
Kyanja soil[#]	6.95	3.70	0.12	51.9	6.7	nd[££]	1.5
MUTI soil[##]	6.70	3.72	0.18	78.4	7.3	2.6	6.0
Critical values[£]	5.2	3.00	0.20	na	na	na	na

[#]Number of observations = 20;
[##]Number of observations = 160;
[£]Below the critical value, soil is deficient or poor [19];
[££]nd = not determined; na = not applicable.

(OM) were above the critical values; only 7 out of 20 samples had OM below the critical value. The mean total N was 0.12% with values below the critical value in 19 out of 20 farmers' fields. This shows that soil N was deficient and would therefore limit crop growth. Soil P varied widely, with 8 out of 20 farmers' fields having values below the critical value of 5.0 mg kg^{-1}. Soil from MUTI was slightly acid with moderate organic matter and low in N (Table 2). The N, P and K contents were higher in Migyera soil than that at Kyanja which could be attributed to intense livestock grazing in the former than the latter.

3.2 Urine Characteristics

Urine mean pH for both sites was within the reported range [20] (Table 3). Urine N and P contents for both sites were much lower than that reported, reflecting a lower protein and P intake in local diets [7]. Nevertheless, considering the low soil N levels, addition of urine could supply the much-needed N, enhancing crop growth. Potassium was also lower than the literature value, more so for the MUTI site. These differences in urine nutrient content stress the need to develop local management guidelines for urine, to take into consideration the differences in local diets.

3.3 Effect of Urine Application on Maize Fresh Yield and Income: Kyanja Experimental Site

Being peri-urban, farmers preferred to harvest the maize fresh. The number of cobs from each bed was counted and from the market price of an average cob size from each bed, expected income from each bed was computed. Plots receiving 10% urine weekly produced slightly more and bigger cobs fetching a higher price than the control (Table 4). This translated into higher gross income from the treated plots than control. Applying 20% urine significantly increased the number and size of cobs over the control, resulting in a higher gross income over the control. Applying 30% urine weekly resulted in even greater number of cobs (and therefore income) over the control, 10% and 20% urine treatments. Thus, at the same frequency (weekly), higher urine concentrations resulted in increasing number and size of cobs, translating into higher income.

3.4 Effect of Urine Application on Different Yield Parameters of Nakati: Kyanja Experimental Site

The *Nakati* yields reported are the ones obtained within two months monitoring. Overall yields were higher since *Nakati* can be harvested up to four months if soil moisture is not limited. Overall, *Nakati* field stand was better on urine-treated beds than the control. For many farmers, urine-treated *Nakati* beds were harvested earlier, more frequently, and yielded higher than the control, although they were planted on the same day. Fig. 1 presents *Nakati* weight harvested over time for different urine treatments. The first harvested leaves were from 20% urine weekly followed by 10% urine weekly, harvested at 58 and 61 days after planting (DAP) respectively. The 30% urine bi-weekly was first harvested at 66 DAP while those from 30% and 20% bi-weekly were realized 74 and 103 DAP, respectively. The 10% urine weekly generated

Table 3 Characteristics of urine used in the study.

Sample	pH	N	P	K	Ca	Mg
				(g L^{-1})		
Kyanja urine#	9.1	2.26	0.06	1.63	na	na
MUTI urine##	8.6	2.33	0.02	0.75	0.01	0.005
Reported values£	8.8	8.0	0.8	1.8		

Number of observations = 20 households. A typical household consists of 5 people;

##2 The MUTI urine was collected from students' dormitories hence represents over 500 students;

£ SEPA [20].

Table 4 Effect of urine application on maize fresh yield and income.

Urine concentration	Application frequency	Number of cobs	Average market price per cob (US $)	Gross income (US $/ha)
Control		36	0.0250	1009.4
10% urine	Once a week	43	0.0375	1791.7
20% urine	Once a week	58	0.0500	3222.2
30% urine	Once a week	72	0.0500	4000.0
SED		6.1	0.0050	531.7

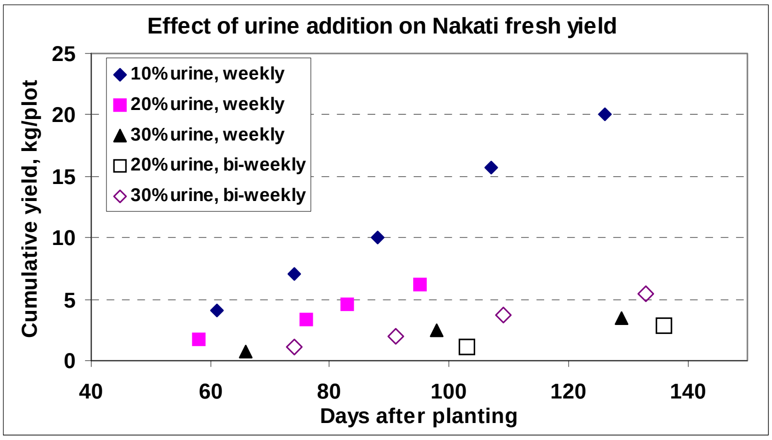

Fig. 1 Cumulative *Nakati* biomass following different urine treatments.

more biomass and maintained it throughout the monitoring period. The 20% and 30% weekly, and 20% and 30% bi-weekly maintained a linear but lower leaf biomass compared to 10% urine weekly.

There was a significant interaction between urine concentration and frequency of application in *Nakati* yields ($P < 0.05$). Weekly application of 10% or 20% urine significantly increased *Nakati* yield over untreated plots (Table 5). The 20% urine treatment gave higher fresh yield than 10% (26.2 kg vs. 22.2 kg) ($P < 0.05$). Average *Nakati* yield per plant was significantly higher for urine-treated plots than control ($P < 0.05$). The yield per plant is important economically since *Nakati* is sold in bundles in the local market a bundle costing for US$0.25 weighs 550 g. From the results in Table 3, one would need to harvest a fewer number of the urine-treated plants than the control to obtain the required weight. Yield per plant was similar for plots receiving 10% or 20% urine weekly and for plots receiving 20% or 30% urine bi-weekly. At 20% urine, yield per plant was higher for bi-weekly than weekly urine, suggesting increased lateral branching at bi-weekly compared to 20% urine weekly. The FAO [21] recommends a daily consumption of 700 g of leafy vegetables for a family of six (father, mother and four children aged 2, 5, 12 and 14). The number of *Nakati* plants to be harvested to produce 700 g of fresh vegetable was smaller on all

Table 5 Effect of urine application on *Nakati* fresh yield plus associated economic gains.

% urine	Application frequency	Fresh yield (kg ha^{-1})	Yield plant (g/plant)	No. of plants to yield 700 g	#Gross income (US$/ha)	##Total N applied (kg N ha^{-1})	Yield (kg) /kg N applied	£Nitrogen 'cost' (US$ ha^{-1})	Returns (US $ per 1 US $ spent on N)
0		5,444	14.7	49.8	2,497.2	0	--	--	--
10	Once a week	24,667	23.8	29.4	11,219.4	24	927	20.87	537.47
20	Once a week	29,111	23.1	30.3	13,247.2	82	356	71.00	186.57
20	Bi-weekly	3,111	35	20	1,413.9	42	75	36.40	38.84
30	Bi-weekly	6,000	34.6	20.2	2,736.7	31	196	26.60	102.89
SED		3,778	3.2	5.8	1,460.0	23	15	12.67	115.21

#Based on the prevailing market price: A 550g bundle of fresh *Nakati* leaves cost US $ 0.275.
##Total N (kg N ha^{-1}) applied over 2 months was calculated as shown in equation 3.
£Based on the market price for urea (50 kg bag urea cost US $ 20 in 2007).

urine treated plots than control ones, more so on 20 or 30% urine bi-weekly treated plots. Thus, urine use in farming can contribute to food security, better nutrition and income, thus improved people's livelihoods.

3.5 Economic Assessment of Urine Re-use for Nakati Production: Kyanja Experimental Site

The monetary value of *Nakati* obtained from farmers' plots was computed basing on prices in the nearby *Kalerwe* market, where most of Kyanja farmers sell their produce. Weekly application of 10% and 20% urine yielded higher than the control resulting in corresponding financial gains compared to control (Table 5). Income from 10% and 20% urine weekly treated beds was respectively 4 and 5 times higher than that of the control. Bi-weekly application of 20% or 30% had no significant effect on gross income from *Nakati* over the control. Applying 20% or 30% urine bi-weekly gave lower *Nakati* yields (hence lower income) than did 10% urine concentration applied weekly. Consistent with Jonsson [7], these results stress the need for frequent application of soluble fertilizer materials to minimize nitrogen leaching.

The total N (kg N/ha) applied over a 2 months period was computed basing on urine N content from each farmer, the dilution factor and application frequency, as follows:

$$N_{(kg/ha)} = (N_{urine} \times V \times n \times 10,000)/(D.F \times A \times 1,000)$$

where, N_{urine} = N concentration in urine, g L^{-1};

V = volume of urine-water mixture applied per plot (20 L);

n = number of times the urine-water mixture was applied over a 2 months period;

D.F = Dilution Factor (e.g., 0.5 L diluted to 5 L gives a D.F of 10);

A = Area of demonstration plot (1.4 m by 6 m).

From Table 5, 10% urine weekly corresponds to 24 kg N ha^{-1} and 20% weekly, to 82 kg N ha^{-1}. The un-proportional increase in N applied was due to differences in urine N content from the participating households. The monetary value of N from urine was computed based on urea market price. Basing on expected income from *Nakati* sales, expected return to "investment" if the N in urine were to be purchased was computed. Clearly, 20% urine weekly corresponds to the highest N applied while 10% urine weekly was the lowest (Table 3). Applying 10% urine weekly resulted in the highest *Nakati* yields per kg of urine N applied, thus representing the highest N recovery, hence a more profitable management practice. The N recovery was lower for 20% weekly than 10% suggesting possible N leaching. Bi-weekly application of 20% or 30% urine gave lower *Nakati* yield per unit of urine N applied, and correspondingly lower returns to "investment" compared to weekly and more so, 10% urine weekly. Since urine is generally free and available, recycling of urine would save huge sums of money otherwise be spent on N purchase.

3.6 Relationship between Nakati Yield and Soil Parameters: Kyanja Experimental Site

A detailed look at *Nakati* yields from participating farmers showed that sites with deficient to low N (0.0 to 0.15 %) and medium P (20 to 65 mg kg^{-1}) gave the highest response to urine. These sites had soil pH 6.7 to 7.2 and low OM levels, suggesting a fairly good soil medium for plant growth, except for low N. Added urine supplied the limiting N, thus increasing crop yields. On the other hand, soils with high P (> 150 mg kg^{-1}) and medium to high N (> 0.16% to 0.31 %) gave no response to urine. Apparently, these farmers had used cow dung, chicken droppings in their backyard gardens (also reflected in high OM levels). Despite high soil P and fairly good N levels, however, *Nakati* yields observed on these farmers' fields were lower compared to other farmers, suggesting other limiting factors (possibly micronutrient (s)) [22]. This possibility is supported by high soil pH (7.8 to 8.4). However, soil micronutrients were not analyzed.

3.7 Effect of Urine Application on Kale Leaf Yield Parameters: Kyanja Experimental Site

Table 6 presents the effect of urine application on the total Kale fresh yield as observed within two months of monitoring. Data is a summation of the observed yield for different piece-meal harvests. Applying 10% urine weekly had no significant effect on Kale fresh yield. Applying 20% or 40% urine weekly more than doubled Kale yields (although not significantly for 30% urine bi-weekly). Bi-weekly application of 20%, 30% or 40% urine actually depressed Kale yield (P < 0.05). This may be due to moisture limitations. The average leaf weight was computed by dividing total weight of kale by the total number of leaves harvested. Weekly urine treatment increased average leaf weight up to 20% urine, beyond which it decreased. The number of Kale leaves harvested to produce FAO daily recommended 700 g of fresh leaf vegetable was smaller on urine-treated plots than the control, more so on plots receiving 20% urine applied weekly (P < 0.05) (Table 6). This is due to increased biomass per leaf following urine addition. Terry et al. [23] reported increased Kale leaf biomass due to N fertilization. Results of this study show 20% urine weekly as the optimum rate for kale.

3.8 Economic Assessment of Urine Use for Kale Production: Kyanja Experimental Site

The gross income from kale sale was derived as described for *Nakati*. On average, a bundle of Kale leaves sold for US$0.025 weighed 600 g and contained 62 leaves. Based on this, applying 10% urine weekly had no significant effect on the gross income (Table 6). Applying 20% and 40% urine weekly resulted in higher vegetable yield (hence income) (P < 0.05). Gross income from 20% and 40% urine weekly were not significantly different. Kale yield per kg of N applied was the highest at 20% and was not significantly different from that at 10% urine

Table 6 Effect of urine application on the Kale fresh yield and associated economic gains.

% urine	Application frequency	Fresh yield (kg ha^{-1})	Average leaf wt (g/leaf)	No. of leaves to yield 700 g	Gross income (US$/ha)	Total N applied (kg N ha^{-1})	Yield (kg) per kg of N applied	Nitrogen "cost" (US$/ha)	Returns (US $ per 1 US$) "spent" on N
0		7,556	16.9	42.9	3,128.9				
10	Weekly	7,889	19.8	35.4	3,262.2	27.2	287.9	24.06	135.9
20	Weekly	16,111	23.6	29.6	6,710.6	55.8	288.6	49.38	135.9
40	Weekly	17,444	20.4	34.4	7,286.1	260.3	67.2	230.22	31.6
20	Bi-weekly	2,111	20.8	33.6	867.2	33.2	62.6	29.41	29.5
30	Bi-weekly	3,000	20.2	34.6	1,244.4	29.6	100.8	26.21	47.5
40	Bi-weekly	3,333	20	35.1	1,395.0	99.9	33.5	88.38	15.8
SED		2,111	1.1	2.7	871.7	45.2	58.4	39.99	27.5

weekly. Applying 40% urine weekly resulted in statistically similar biomass per kg N as that for 20%, 30% or 40% bi-weekly. These results suggest that 10% and 20% urine weekly were the most efficient treatments at recovering the applied N and transforming it into leaf biomass compared to other treatments. If the urine-derived N were to be purchased from the market, the cost would be the highest for 40% urine weekly and the lowest for 10% urine, weekly. The returns from such an investment would be the highest for 10% and 20% urine weekly, and the lowest for 40% urine, bi-weekly. These findings suggest that 10% and 20% urine applied weekly are viable management options for urine on Kale compared to other treatments investigated in this study.

Considering that fresh yield doubles on increasing urine rate from 10% to 20% weekly (with a corresponding significant increase in leaf weight), the authors propose 20% urine weekly as the most viable for kale growing in the study area (central Uganda with clay soils). This corresponds to 56 kg N ha^{-1}. For leafy vegetables, studies recommend 65 to 75 kg N ha^{-1} for Soroti area, Eastern Uganda (sandy soils, lower fertility than in central Uganda) (National Horticulture Programme, personal communication).

3.9 Effect of Urine Application on Spinach Yield Parameters: Kyanja Experimental Site

Weekly application of 10%, 20% and 30% urine increased spinach fresh yield from 4,222 to 4,656, 19,022 and 19,978 kg ha^{-1} respectively (Table 7). These responses were significant except at 10% urine. Bi-weekly application of 30% or 40% urine had no significant effect on spinach yield compared to the control. Biemond [24] reported increased biomass accumulation with increasing N application on Spinach. Splitting N application had smaller effect on biomass accumulation. The average leaf weight was determined as described for Kale. There was a significant increase in leaf weight following weekly urine addition up to 20% urine, beyond which it declined ($P < 0.05$) (Table 5). Biemond [24] observed that the size of mature spinach leaves increased with increasing N levels up to a certain level. The number of spinach leaves harvested to produce the FAO daily recommended 700 g of fresh leafy vegetables was overall smaller on urine-treated plots than the control, more so on plots receiving 20% urine applied weekly (Table 7). Thus, urine application can directly contribute to food security, better nutrition and improved people's livelihoods.

3.10 Economic Assessment of Urine Use for Spinach Production, Kyanja Experiment Site

Income from spinach sale was derived as described for *Nakati*. On average, a bundle of spinach leaves sold for US$0.25 weighed 450 g and contained 18 leaves. Based on this 10% urine weekly had no significant effect on gross income over the control (Table 7). Applying 20% urine weekly increased income over both the control and 10% urine ($P < 0.05$). Increasing urine concentration further to 30% did not increase income over 20%. Spinach yield per kg N applied was highest at 20% urine weekly and least at 40% bi-weekly. Thus 20% urine weekly was the most efficient management option in transforming applied N into biomass. If the urine-derived N were to be purchased from the market, the cost would be the highest for 30% urine weekly and the lowest for 10% urine weekly (Table 7). Returns from such an investment would be the highest for 20% urine weekly and the lowest for 40% urine bi-weekly. For leafy vegetables, studies recommend 65 to 75 kg N ha^{-1} for Soroti area, Eastern Uganda (sandy soils, lower fertility than in central Uganda) (National Horticulture Programme, personal communication). Results of this study suggest 76 kg N ha^{-1} corresponding to 20% urine weekly.

3.11 Effect of Urine Application on Vegetable Yield and Income: MUTI Experimental Site

There was a significant crop % urine frequency

Table 7 Effect of urine application on Spinach fresh yield and associated economic benefits.

% urine	Application frequency	Fresh yield (kg ha^{-1})	Average leaf wt. (g/leaf)	No. of leaves to yield 700 g	Gross income (US$/ha)	Total N applied (kg N/ha)	Yield (kg) per kg of N applied	Nitrogen cost (US $/ha)	Returns (US $ per 1 US $) spent on N
0		4,222	10.8	107.3	2,328				
10	Once a week	4,656	21.8	32.1	2,588	27.2	171.2	23.7	196.9
20	Once a week	19,022	34.5	20.3	10,568	75.7	251.2	65.8	289.0
30	Once a week	19,978	24.2	29	11,101	260.3	76.8	226.3	88.3
30	Bi-weekly	1,511	2.5	280	839	29.6	51	25.7	58.7
40	Bi-weekly	1,300	2.5	278	722	99.9	13	86.9	15.0
SED		2,444	3.8	40.2	1,371	47.8	48.5	41.6	59.4

interaction on total weight of leaves/fruits (and expected income). Application of 10% urine weekly significantly increased total cabbage head yield from 6,694 kg ha^{-1} to 16,112 kg ha^{-1} ($P < 0.05$) (Table 8). Expected income from cabbage also increased from US$3,344 to 8,057 per ha. Urine concentrations higher than 10% decreased cabbage yield (although not significantly). On the other hand, applying urine once every two weeks did not significantly affect cabbage yields. These results point to the fact that urine is a soluble nitrogen fertiliser whose benefits (e.g., increased cabbage yields) are better observed where it is applied more frequently (e.g., weekly) than once in 2 weeks. Semuli [25] reported increased cabbage yield following split N application, with 100 kg N ha^{-1} giving the highest head mass yield. Results for kale were inconsistent; there was a significant decrease in total yield on application of 10% urine weekly while with bi-weekly application yields were decreased at 30% urine ($P < 0.05$). Toose and Usher [26] reported reduced kale dry matter yields at high N rates. For other vegetables (spinach, eggplants and tomatoes), urine application had no significant effect on total yield and expected income ($P > 0.05$).

The average fruit or leaf size was computed by dividing the total weight of fruits or leaves by the total number of fruits or leaves harvested. Average leaf/fruit weight was affected by a significant crop frequency interaction. In general, urine application up to 20% had no significant effect on average leaf/fruit weight for all vegetables (Table 8). Increasing urine concentration to 30% urine decreased average cabbage head weight by 36% below the control (325.5 g vs. 506.2 g, $P < 0.05$). Similar trends were obtained for average income per fruit/leaf. Average cabbage head size was significantly bigger on treatments receiving urine weekly than where it was applied bi-weekly (548 g vs. 427 g per head, $P < 0.05$). For other vegetables no significant differences in leaf or fruit weight were observed between weekly vs. bi-weekly urine treatments.

3.12 Effect of Urine Application on Tissue Nutrient Composition of Vegetables: MUTI Study Site

Spinach leaves: leaf N was below the sufficiency range in the control plots (0% urine) (Table 9). This is consistent with the low soil N levels at this MUTI experimental site (Table 2). Leaf N levels increased sharply on addition of 10% urine weekly. Increasing urine concentration to 20% or 30% (weekly), however, did not increase tissue N content, which might suggest other limiting factors. Applying urine once every two weeks resulted in a gradual increase in tissue N content up to 20% when the sufficiency range was reached; further increase in urine concentration resulted in no increment in leaf N content. Increase in spinach N content following nitrogen fertilisation has been widely reported (Smatonova et al. [27]; Lefsrud et al. [28]). Data for P show an increase in tissue P content with addition of 10% urine weekly beyond which it remained constant. For urine applied every two weeks, tissue P remained essentially unaffected by

Table 8 Effect of urine application on vegetable yield and associated income: MUTI site.

Crop & market price	% urine	Weekly		Every 2 wks		Average wt. (g) per leaf/fruit	Average income per leaf/fruit
		kg ha^{-1}	US$ ha^{-1}	kg ha^{-1}	US$ ha^{-1}		
Cabbage	0	6,694	3,344	6,694	3,344	506.2	506.2
	10	16,112	8,057	2,987	1,492	571.5	571.5
Price: US$0.50 kg^{-1}	20	9,537	4,766	4,475	2,239	547.0	547
	30	8,975	4,484	4,675	2,339	325.5	325.5
Kale	0	16,169	12,127	16,169	12,127	26.7	40
	10	7,400	5,547	20,650	15,484	22.8	34.1
Price: US$0.75 kg^{-1}	20	8,325	6,239	17,925	8,967	27.6	41.4
	30	18,412	13,805	5,100	3,829	21.8	32.6
Spinach	0	4,562	3,420	4,562	3,420	11.1	16.7
	10	10,275	7,703	9,575	7,184	20.5	30.8
Price: US$0.75 kg^{-1}	20	6,462	4,842	2,937	2,203	19.4	29.1
	30	9,900	7,425	7,750	5,812	32.3	48.4
Eggplants	0	3,744	937	3,744	937	191	95.5
	10	5,812	1,453	1,650	411	188.9	94.4
Price: US$0.25 kg^{-1}	20	212	531	2,712	677	134.1	67
	30	2,025	505	1,887	472	110.4	55.2
Tomato	0	5,219	1,827	5,219	1,827	52.1	36.5
	10	3,925	1,374	7,850	2,746	58.5	40.9
Price: US$0.35 kg^{-1}	20	7,612	2,665	4,000	1,400	60.6	42.4
	30	8,262	2,891	4,800	1,682	51.2	35.8
sed		3,959	2,696	3,959	2,696	43.3	40.3

Table 9 Effect of urine application on spinach leaf nutrient composition, MUTI site.

% urine	Frequency	Plant tissue nutrient composition in spinach				
		N	P	K	Ca	Mg
		(%)				
0	Control	2.3516	0.3461	4.3674	0.8365	1.1299
10	Once a week	3.2752	0.4529	4.2841	0.8294	1.0767
20	Once a week	2.5967	0.4129	4.1980	0.7689	0.9819
30	Once a week	2.4887	0.3881	4.6188	0.7509	1.0205
10	Every 2 weeks	2.7547	0.3095	4.5318	0.6571	1.0767
20	Every 2 weeks	3.1220	0.3290	5.0484	1.1512	1.1858
30	Every 2 weeks	2.8387	0.3995	4.6976	0.6852	0.9806
Sufficiency ranges [29]		3.0-4.0	0.3-0.5	2.5-3.5	0.6-1.0	1.0-1.6

urine application. Tissue P levels were within the sufficiency range, which is consistent with the high P levels and a nearly neutral soil in this MUTI area (Table 2). The leaf K, Ca and Mg levels were above sufficient levels, indicating that they were not limiting.

Fig. 2 presents data on the N content of spinach mature leaves at harvest. The relationship between leaf N and % urine is quadratic for both weekly applied urine and one where it was applied once every week. The nitrogen sufficiency range for most recently mature leaf at harvest is given as 3%-4% [29]. Based on this, for weekly urine application this range was attained at a urine concentration of 10% to 15% while for urine applied every two weeks, leaf N range within the sufficiency range was attained at 20% urine. This finding suggests two possible management options for urine: either applying 10% urine once a week, or 20% urine every two weeks. However, this

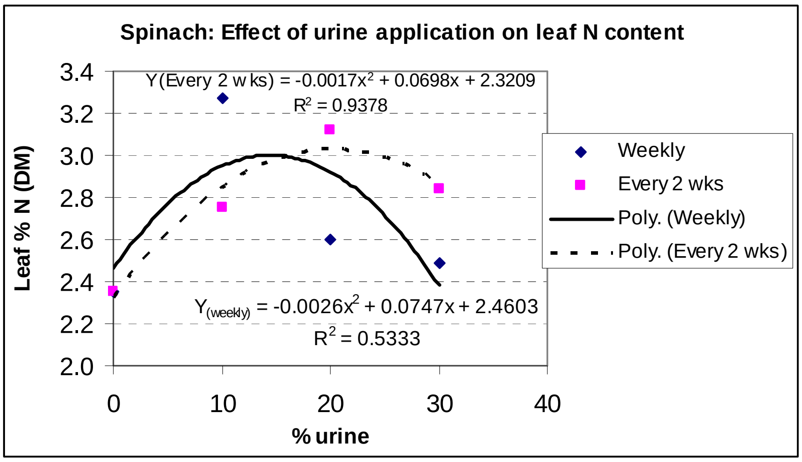

Fig. 2 Relationship between spinach leaf N content and urine concentration applied.

conclusion is only preliminary due to the rather large scatter observed in the data, especially for weekly applied urine, as reflected in the low R^2 value.

Fig. 3 is a further illustration of the relationship between spinach leaf N content and the observed average leaf weight. The relationship is quadratic for both weekly and bi-weekly applied urine. Leaf weight is an important parameter because it has economic implications. Spinach is usually sold in bundles in many Uganda markets. Obviously, one would need fewer of the well grown harvestable leaves to make a bundle of say US$0.25 compared to if the leaves were smaller in size. Fig. 3 shows that although both curves peak off at an average leaf weight of about 23 g, the N content would be about 3.3% for weekly applied urine compared to 3.1% for urine applied once every two weeks. This finding suggests that weekly application is not only more economical but also gives a better quality food product (higher N content, therefore more protein) than one where urine is applied once every two weeks.

Eggplant fruits: mean values for N, P, K, Ca and Mg for all treatments including the control, were higher than those reported in the literature (Table 10). The lowest values for N, P, K, Ca and Mg were observed at the control plots (0% urine) and these were not significantly affected by addition of 10% urine weekly or once in 2 weeks. Plots that received 20% or 30% urine weekly or once every 2 weeks had higher amounts of N, P, K, Ca and Mg compared to the 0 or 10% urine. This result suggests that urine addition promotes N, P, K Ca, Mg uptake by eggplants. Urine application had no significant effect on the nutrient (N, P, K, Ca, Mg) composition of mature kale leaves, tomato and cabbage fruits (data not presented).

4. Conclusions

Application of urine in Kyanja parish, Kampala district increased maize fresh yield, number and size of cobs. Higher urine concentrations (30% urine) favored better maize growth. Urine application increased *Nakati* yields, with 10% urine weekly being most economically feasible. Urine application increased kale and spinach yield, with 20% urine weekly being the best management practice. For all crops, weekly application was more effective than bi-weekly. Response to urine was most pronounced on soils of low N and P. Application of 10% urine weekly at Migyera in Nakasongola district, increased cabbage yield significantly from 4,975 to 16,113 kg ha^{-1} (P < 0.05), with corresponding economic gains. Weekly urine application at concentrations higher than 10% decreased cabbage yield (although not significantly). Cabbage heads were heavier on treatments receiving urine weekly than bi-weekly (548 g vs. 427 g, P < 0.05). Optimum spinach leaf N content

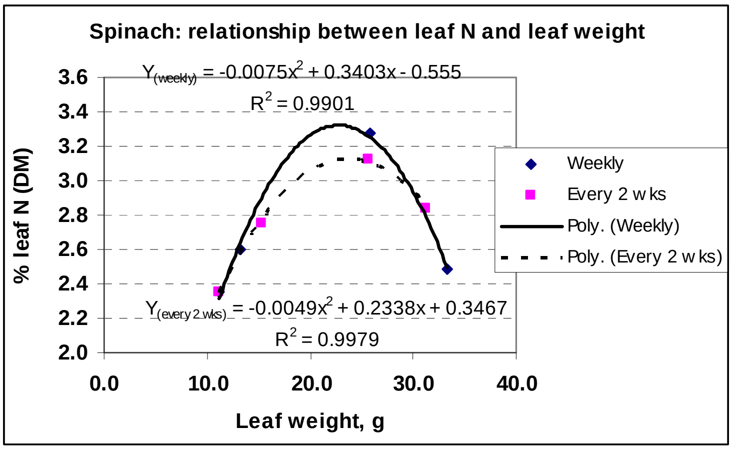

Fig. 3 Relationship between spinach leaf N content and average leaf weight.

Table 10 Effect of urine application on the nutrient composition of eggplant fruit.

% urine	Frequency	N	P	K	Ca	Mg
				(%)		
0	Control	2.388	0.339	3.432	0.229	0.295
10	Once a week	2.334	0.335	3.511	0.219	0.309
20	Once a week	3.809	0.490	4.653	0.357	0.449
30	Once a week	3.659	0.557	5.969	0.582	0.563
10	Once every two weeks	2.217	0.316	3.208	0.138	0.268
20	Once every two weeks	3.405	0.469	4.760	0.277	0.498
30	Once every two weeks	2.807	0.353	3.798	0.257	0.336
Literature values [30]		2.100	0.310	3.000	0.120	0.230

was attained at 10% urine applied weekly and 20% urine applied once every two weeks. At optimum spinach leaf weight (23 g) the leaf N content was higher for weekly than bi-weekly applied urine (3.3% vs 3.0%), giving the former as a more proteinous food material than the latter. Results for kale, tomatoes and egg plants were not conclusive.

Use of urine in farming is agronomically feasible and economically viable. Being readily available, urine re-use should be promoted especially among small holder farmers who may not be able to purchase external inputs to improve soil fertility. Further to the guidelines developed elsewhere, findings from this study suggest the following local guidelines: for Kyanja area in central Uganda, apply 30% urine (3:7 urine to water) weekly on maize for eight weeks starting at two weeks after emergence. For *Nakati (Solanum aethiopicum* L.**)**, apply 10% urine (1:9 urine to water) weekly for 8 weeks (corresponding to 24 kg N ha^{-1}). For Kale (*Brassica oleracea* L.), apply 20% urine (2:8 urine to water) weekly for 8 weeks (corresponding to 56 kg N ha^{-1}). For Spinach (*Spinacia Oleracea* L.), apply 20% urine (2:8 urine to water) weekly for 8 weeks (corresponding to 76 kg^{-1}). For Cabbage and spinach in Migyera area in Nakasongola district, apply 10% urine (1 urine to 9 water) weekly for at least eight weeks. Urine application should start at two weeks after transplanting. The urine-water mixture should be applied about 15 cm around each plant to minimise possible scorching of leaves.

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