Urine reuse as fertilizer for bamboo plantations

Jean Emmanuel Ndzana and Ralf Otterpohl

Institute of Wastewater Management and Water Protection, Hamburg University of Technology, Eißendorfer Strasse 42, D-21073, Hamburg, Germany (ndzana.emmanuel@tuhh.de)

Abstract It has never been reported on fertilization of bamboo plantations with urine derived from the Source Control Sanitation, the so called Ecological Sanitation (Ecosan), although urine has demonstrated its potential as a valuable resource for the agriculture. Basically urine is a pathogen-free mixture. In terms of nutrient elements nitrogen (N), phosphorus (P) and potassium (K) in wastewater streams, urine alone represents 87% (N), 50% (P) and 54% (K), making it the major component nutrient-rich of wastewater. Urine is in use for fertilizing a variety of crops ranging from vegetables to fruit trees. Usually application of urine on the soil only happens on a discontinuous basis; that means a couple of applications per year. This study is a pioneer one investigating the reuse of urine on bamboo plantations as fertilizer on a year-round basis. The optimum nutrient loading rate based on nitrogen feeding is researched. The nutrient uptake of the bamboo species used Phyllostachys *viridiglaucescens* (P. *viridiglaucescens*) is analysed. The effect of continuous feeding with urine on the biomass production is discussed. The experiments are conducted on a lab-scale plant under measured and controlled parameters. The year-round reuse of urine can be a method of choice for urine reuse where the storage of urine is not feasible.

INTRODUCTION

The fundamental idea of innovative and integrated water concepts is based on the principle of separating different flows of domestic wastewater according to their characteristics (Otterpohl *et al.*, 2002). This constitutes the basis of the Ecological Sanitation (Ecosan) where waste streams greywater, urine and faeces are collected and treated separately for the benefit of the agriculture. Urine is the major component nutrient-rich of municipal wastewater. In terms of nitrogen (N), phosphorus (P) and Potassium (K) human urine contains about 87% N, 50% P and 54% K. A complete picture of domestic wastewater constituents is given in Table 1. Urine has been and is currently used in agriculture as fertilizer for a diverse range of fruits and vegetables in many regions of the World. It is used in countries such as Mexico, Germany, USA, Sweden, and Denmark (Pearson *et al.*, 2007). In Zimbabwe a series of successful experiments were carried out on

Edited by Ken Ashley, Don Mavinic and Fred Koch. ISBN: 9781843392323. Published by IWA Publishing, London, UK.

tomato, covo, spinach and lettuce (Calvert *et al.*, 2004). In Sweden there is some experience with agricultural use of urine (Kärrrman *et al.*, 1999). However it has never been reported on bamboo plantations fertilization with urine derived from the Ecosan. Furthermore, the application of urine for fruit trees and vegetables occurs only on a discontinuous rhythm as urine is applied just a couple of times in the year at the beginning of the growing season (Calvert *et al.*, 2004).

Table 1. Typical characteristics of household wastewater components.

Volume 1/(P*year) Yearly loads kg/(P*year)	Greywater 25.000 - 100.000	Flush water savings 6.000 - 25.000 Urine ~500	Faces ~50 (option : add biowaste)
N ~ 4-5	~3%	~87%	~10%
P ~ 0.75	~10%	~50%	~40%
K ~ 1.8	~34%	~54%	~12%
DCO ~ 30	~41%	~12%	~47%
S, Ca, Mg and trace elements	Treatment ↓ Recycling / Water cycle	Treatment ↓ Fertilizers	Biogas-station Composting ↓ Soil conditioners

Geigy, Wiss. Tabellrn, Basel 1981, Vol. 1, Larsen and Gujer 1996, Fitschen and Hahn 1998

Bamboo as the fastest growing line vegetable species (Villegas, 1990) appears to be a very good candidate for urine application recipient. Bamboo reaches its full length within 2 to 4 months growth (Liese, 1985). The rest of the life of the plant, its culms – bamboo stems made of nodes and internodes – will harden through accumulation of nutrients in the culm tissue for them to come to maturity.

The rhizome system constitutes the structural foundation of the plant, in which nutrients are stored and through which they are transported (Liese, 1985). At the difference of the culm, the rhizome exhibits year-round non-stop growth. From this fact, a continuous feeding of bamboo plant with nutrients appears feasible.

At the Institute of Wastewater Management and Water Protection of the Hamburg University of Technology a pioneer research coupling bamboo plant and Ecosan has started. Figure 1 is an overview of the whole research concept. As entire part of it, this study aims to determine the effects and impacts of continuous direct reuse of urine derived from the Ecosan on bamboo plantations in terms of nutrients uptake, nutrient loading rate and biomass production.

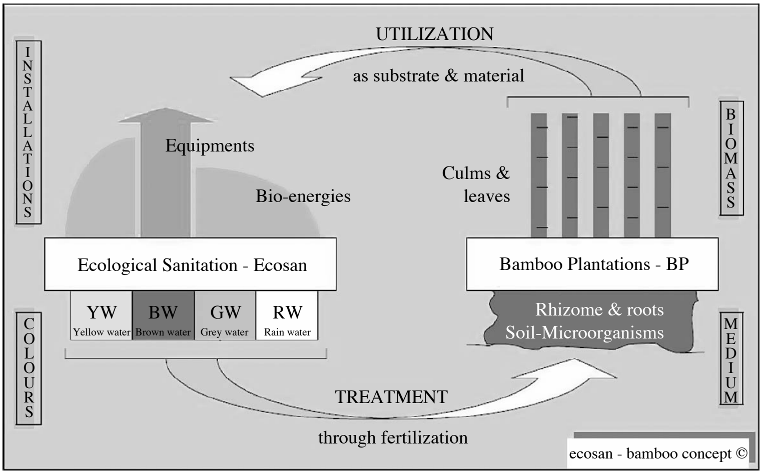

Figure 1. The Research concept Ecosan-Bamboo from which the current study derives.

MATERIALS AND METHODS

The experimental set up

Nine reactors were placed at the interior court of the Institute of Wastewater Management of the Hamburg University of Technology-TUHH. Each reactor is a huge PVC container of 160 l in which bamboo plant is planted.

The 53 cm height of the reactor allows efficient growth of bamboo; Li *et al.* (1998), An *et al.* (1995) and Widmer (1998) found that the effective root zones for several bamboo species is comprised between 0 and 30 cm of top soil. Thus efficient growth of bamboo is performed within the first 30 cm. Openings were made at the bottom part of each reactor to allow effluent collection that percolates only from the top part of the reactor; effluent collectors are sized and placed so that rainwater could not be collected. A schematic set-up of the experimental site is provided on Figure 2. Mature bamboo plants were transplanted from a living stand of the Botanic Garden of Hamburg. Culms height is comprised between 3.00 and 8.00 m. The bamboo species tested is

Phyllostachys (P) *viridiglaucescens,* a winter-hard plant that withstands temperatures up to −22°C. Bamboo roots balls were placed in the PVC container and filled with a self-made composition of soil. The soil in the container is of 2 layers; a drainage layer of 5 cm gravel at the bottom part and the rest upper part is soil. The soil composition is a mixture of flower earth (85%), sand (10%) and crushed tree barks (5%).

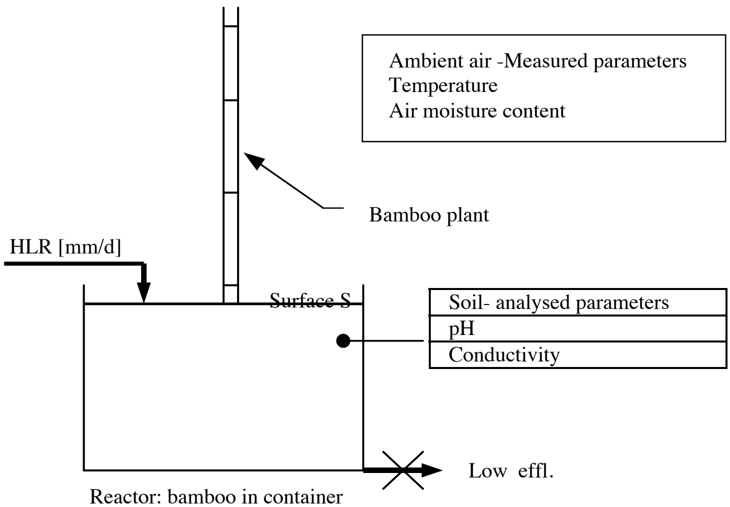

Figure 2. Schematic set-up of the experimental site.

The analytical method

Author's self-collected urine was used in this study to ensure no pathogen contamination and avoid possible side effects from pharmaceuticals (no tablets were taking during the whole study). Urine was mixed with tap water (substrate); the substrate was fed 3 times a week at the top of the reactor. The other 4 days of the week were fed with tap water when necessary to do not let the reactors to dry. The reactors were named S1 to S9 and fed with low hydraulic loading rate so that less effluent occurs, as the optimum nutrient uptake is one of the key issues researched in this study. As Midmore and Kleinhenz (2001) suggested a nutrient uptake of 350 kg N/ha/year, this value was taken as basis for the fertilization rate defined on Table 2. The argument of Toky and Ramakrishnan (1981) and Mailly *et al.* (1997) about less leaching of nutrients in bamboo stand sustains the defined rates.

Table 2. Fertilization rate of the 9 reactors.

Reactor	S1, S2, S3	S4, S5	S6, S7	S8, S9
Fertilization rate [kg N/ha/a]	400	800	1200	1400

Measured parameters and performed analyses

The air temperature and moisture content were measured by using a data-logger which records data each 30 minutes (results are not shown). Analyses were performed on the substrate and the soil. The bamboo biomass produced was analysed in terms of number of shoots, culms diameter and shoots growth pattern. For the analyses the German standard methods (DIN) for soil and substrate were applied. In the substrate, the Total Organic Carbon (TOC) and Total Nitrogen (TN) were analysed with a TOC/TN analyser. NH_4-N was measured by using a reflectometer. Dr. Lange cuvette tests were used to measure the Total Phosphorus (TP) and ortho-phosphate (ortho $P\text{-}PO_4$). The pH and electrical conductivity (EC) were measured by using electrodes incorporating temperature measurement (Microprocessor pH Meter pH 196 for pH and Conduktometer LF 191 for EC). For the soil, the German Norm *[VDLUFA, Methodenbuch Band I (1991)]* was used to analyse the pH and the electrical conductivity (EC). For the pH, the soil samples were collected at the first 10 cm of top soil. They were dried at ambient air, passed through a sieve of 1 mm and a solution of 0.01 molar $CaCl_2$ was added in a ratio of 1:10 before the measure is taken after 1 hour. The EC analysis followed the same procedure but with addition of deionised water and a waiting time of 2 hours.

RESULTS AND DISCUSSION

The results of this study are concerned with the biomass production, the TOC removal and nutrient uptake of bamboo in terms of N and P.

The biomass production

The first shoots emerged from S6 2 months later (May 2.) after potting. This shooting started within the normal shooting period of bamboo in Europe (the beginning of the Spring, when the soil starts to warm a bit and sunshine increases). By shooting at the year of planting, bamboo in the reactors shows very rapid rooting. Shooting was observed until the end of October. This also corresponds to the normal end of shooting season. The rate of production (average number of culm produced per reactor) was 5.77. This value is similar to the one in natural stands (Liese, 1985) (up to 10 shoots). The maximal shoot diameter (Ø) was exhibited by S3:2.5 cm. Table 3 summarized the biomass produced by the 9 reactors. Thus the continuous fertilization with urine did change neither the shooting season nor the rate of production. Except for reactor S3 and S7, all reactors showed some emerged shoots with a curved growth pattern at their basis. These are shoots that were primarily to establish as rhizome. Because of containment in container, they were converted into culms. The establishment of a bamboo stand starts with the development of a stable solid rhizome system.

Table 3. Biomass production of the 9 reactors.

Reactor	S1	S2	S3	S4	S5	S6	S7	S8	S9
Nber of shoots	7	8	1	9	4	7	2	9	5
Curved culms	2	1	0	3	2	3	0	3	1
Production	5.77								

TOC removal through urine application – soil pH and conductivity (salts concentration)

The mean value of TOC in raw urine is 2807 mg/l, the min value being 1080 mg/l and the max value being 6960 mg/l. The hydraulic retention time being 50 days, within which only 21 days are fed with the mixture tap water and urine, an average of 943 (for S1, S2, S3), 1886 (for S4, S5), 2829 (for S6, S7) and 3301 mg/l TOC (for S8, S9) was fed into the reactors, respectively to the fertilization rates 400, 800, 1200 and 1400 kg N/ha/year. Figure 3 gives TOC in the influent and effluent regarding the reactors and their corresponding fertilization rates. The TOC removal efficiency varied from 74.6, 87.1, 90.8 and 91.1 respectively for fertilization rate of 400, 800, 1200 and 1400 kg N/ha/a.

Independently to the fertilization rates the TOC concentration in the effluent of reactors remains almost at the same level varying between 239 and 295 mg/l.

The pH in the influent for each reactor remains almost at levels of which in the raw urine around 8.00 (detailed results are not shown). A slight increase of pH-value was encountered with the increase of nitrogen concentration: 8.44, 8.57, 8.61 and 8.62 respectively for 400, 800 1200 and 1400 kg N/ha/year.

Reactors presented effluent only when severe rain felled. S8 did not leak at all; no effluent was collected from this reactor.

Table 4 presents the results of soil pH and EC analyses. From these, the soil pH value at the start of the study was 3.91, with an EC value 201 µS/cm.

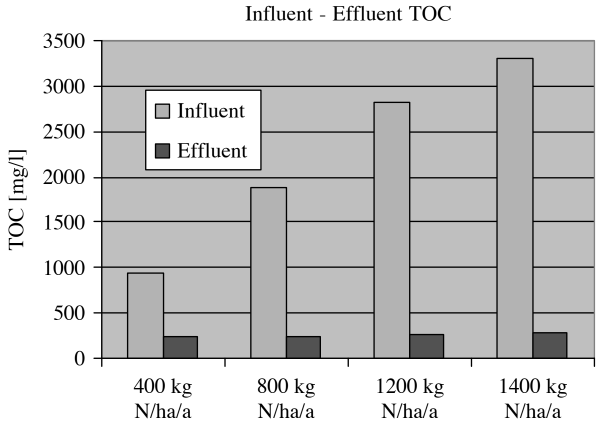

Figure 3. TOC removals according to the fertilization rates.

Table 4. Soil pH and electrical conductivity.

	Date	S1	S2	S3	S4	S5	S6	S7	S8	S9
pH [-]	04.08.08	4.12	4.36	4.23	4.13	4.33	4.47	4.18	4.18	4.15
	29.10.08	4.99	4.86	4.40	4.39	4.56	4.59	4.33	4.41	4.22
EC [μS/cm]	04.08.08	230	81	247	281	98	115	85	115	97
	29.10.08	66	68	84	71	63	96	77	88	78

In the course of the study, it slightly increases in all reactors to achieve 4.99 (value in S1). This is favourable to bamboo plants which prefer light acidic soils with pH between 5.5 and 6.5.

The decrease of EC in the soil consequently results to the decrease of salt content in the soil; this was not expectable since addition of urine on soil is usually known to increase it as Pearson *et al.* (2007) concluded their study based on some vegetables. The decrease of salts concentration in the top soil complies with the statement of Kleinhenz and Midmore (2001) that the top soil of bamboo stands is typically well aerated and natural mineralization of nutrients is usually quicker there than in deeper layers. Plant-available ions are effectively and almost immediately absorbed by the dense root system of bamboo plants in this horizon. This may explain the well-known statement that bamboo accumulate and sequester nutrients in its top layer.

Nutrient loading rate and nutrient uptake N and P

The average TN in raw urine is 5060 mg/l with a max value of 7390 mg/l and 2860 mg/l as min value. Taking into consideration the hydraulic retention time of 50 days, within which only 21 days were fed with substrate (the rest being tap water for watering the plants), and regarding the fertilization rates, the reactors were fed with 1700, 3400, 5100, 5951 mg/l TN. Similarly to TN, with consideration of the average of 424 TP in raw urine (the min value and max value of TP being 204 and 1050 mg/l respectively), the fed rates of TP were 142, 285, 427 and 499 mg/l TP for reactors fed with 400, 800, 1200 and 1400 kg N/ha/a respectively.

The effluent value both for TN and TP are so low that they are not noticeable on Figure 4 (TN and TP uptake by the system "soil-bamboo").

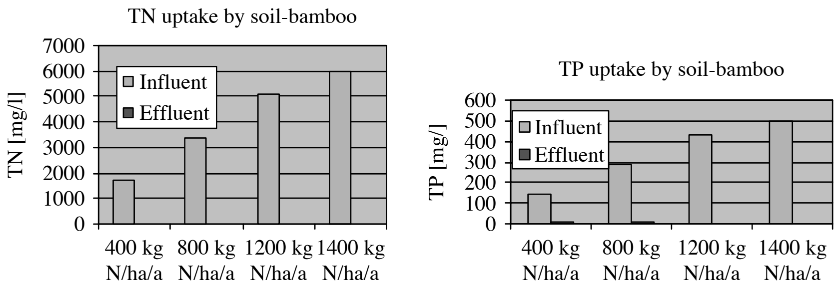

Figure 4. TN and TP uptake by the system "soil-bamboo".

The maximum levels of TN and TP in the effluent were found by reactor S6 and S1 and were 15.4 for TN and 7.97 mg/l for TP respectively. Almost 100% of nitrogen was taken up by the system "soil-bamboo" with an average of 99.8%. The same consideration is valid for phosphorus with a mean uptake of 97.9% by the system "soil-bamboo". $N\text{-}NH_4$ concentration in the effluent was considerably reduced. The maximum concentration is found by S6 and is 2.05 mg/l.

CONCLUSION

As a pioneer study investigating the fertilization of bamboo plantations with urine derived from the Ecosan, the results of this study show that human urine as a valuable nutrient can effectively be reused by stands of giant bamboos (in this case P. *viridiglaucescens*). From a wastewater point of view, bamboo plants constitute a remover of urine, while from an agricultural point of view; urine is reused as fertilizer for bamboo plantations. Thus the year-round application of urine through continuous feeding of bamboo plantations is feasible. Up to 1400 kg N/ha/year loading rate of the reactors, all bamboo plants remain healthy without any sign of disturbance in their growth. All of them operate well still. The biomass production did not change in comparison to natural stands of bamboo plantations, thus the continuous feeding of the reactors did affect neither the shooting season nor the rate of production. The continuous feeding of urine into the reactors at fertilization rate from 400 to 1400 kg N/ha/a resulted in to an efficient TOC removal; the efficiency increased from 74.6 to 91.1% regarding the considered fertilization rates although the concentrations of organic carbon is still high in the effluent. This study confirms the well known statement that bamboo plants absorb quite enormous quantity of nutrients at their top layer. In fact it was analysed that the EC of soil in its first 10 cm (top soil) decreased, while the expectations were turned to an increase as with most trials with vegetables and fruit trees. The pH of the soil slightly increased from 3.91 to 4.99 in the course of the study. The system soil-bamboo reacts very positively to continuous application of urine on land as the TN and TP are almost completely absorbed by it; about 100% for nitrogen and 97.9% for phosphorus.

REFERENCES

An, Q.-N., Wang, J.-P., Zhang, X.-M., Du, W.-Y., Wu, M.-H. and Hu, X.-Q. (1995). Study on fertilization in *Phyllostachys nidularia* forest. *J. Bamboo. Res.*, **14**, 73–80.

Calvert, P., Morgan, P., Rosemarin, A., Sawyer, R. and Xiao J. (2004). Ecological Sanitation, revised and enlarged edition. Stockholm Environment Institute, 2004.

Kärrrman, E., Jönsson, H., Gruberger, C., Dalemo, M. and Sonesson, U. (1999). Management of wastewater and organic waste – systems analysis. Paper presentation at *Managing the Wastewater Resource, 4th International Conference for Ecological engineering for Wastewater Treatment, Ås, Norway, June 7–11.*

Kleinhenz, V. and Midmore, D.J. (2001). Aspects of bamboo agronomy, Advances in Agronomy, Vol. 74, Academic Press, 2001.

Li, R., Werger, M.J.A., During, H.J. and Zhong, Z.-C. (1998). Carbon and nutrients dynamics in relation to growth rhythm in the giant bamboo *Phyllostachys pubescens*. *Plant Soil*, **201**, 113–123.

Liese, W. (1985). Bamboos – biology, silvics, properties, utilization. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Eschborn, Germany.

Mailly, D., Christanty, L. and Kimmins, J.P. (1997). Without bamboo, the Land dies: Nutrients cycling and biogeochemistry of a Javanese bamboo Talun-Kebun system, 1997.

Otterpohl, R., Braun, U. and Oldenburg, M. (2002). Innovative technologies for decentralised wastewater management in urban and peri-urban areas. *Keynote presentation at IWA Small2002, Istanbul, September 2002.*

Pearson, N.S., Mnkeni, Funso R. Kutu and Pardon, M. (2007). Evaluation of Human urine as source of nutrients for selected vegetables ad maize under tunnel house conditions in the Eastern Cape, South Africa – *Waste Management and Research*, 2008(**26**), 132–139.

Toky, O.P. and Ramakrishnan, P.S. (1981). Run-off and infiltration losses related to shifting agriculture (Jhum) in North-Estern India, 1981.

Villegas, M. (1990). Tropical Bamboo. Rozzoli New York, 1990.

Widmer, Y. (1998). Soil characteristics and *Chusquea* bamboos in the *Quercus* forests of the Cordillera de Talamanca, Costa Rica. *Bull. Geobot. Inst. Eth.*, **64**, 3–14.