Converting urine into liquid fertilizer

With an innovative recycling method, valuable nutrients recovered from urine can be sold as fertilizers. As well as conserving natural resources, this reduces water pollution and makes sanitation systems in developing countries economically more attractive. Three pilot plants are already in operation – one at Eawag in Dübendorf and two in the South African city of Durban. *By Bastian Etter and Kai M. Udert*

Peter Penicka

Fig. 1: At the Eawag pilot plant in Dübendorf, urine collected from staff toilets is processed into fertilizers.

In the depths of the Swiss winter, a chilli plant laden with bright orange peppers is thriving in an office at Eawag – thanks, not least, to a liquid fertilizer developed in collaboration with the institute's South African research partners. While the chilli crop is a welcome by-product, the VUNA project is primarily concerned with the recovery of nutrients from urine: as well as meaning "harvest" in the Zulu language, VUNA is an acronym standing for "Valorization of Urine Nutrients in Africa". The basic idea is that, rather than being flushed into sewers in wastewater, urine can be separately collected and processed into a reusable product [1].

Fertilizer production – an energy-intensive process

Conventional flush toilets require large amounts of (drinking) water and an elaborate sewer network for the disposal of wastewater. If it passes through a treatment plant, wastewater has to undergo extensive treatment. If it goes untreated, it can pollute rivers, lakes, seas or groundwater. Although urine only accounts for about 1 per cent of the wastewater entering our treatment plants, the nutrients it contains make up a large proportion of the contaminants (Fig. 2). For example, about 85 per cent of the nitrogen in wastewater comes from urine. Likewise, nitrogen conversion and removal processes account for much of the energy consumed at modern wastewater treatment plants (WWTPs).

The production of agricultural fertilizers is also energy- and resource-intensive. The Haber-Bosch process alone – used to extract nitrogen from the air – consumes more than 1 per cent of the total global energy output. Phosphorus is obtained from phosphate rock. As known reserves of these minerals are concentrated in a small number of countries, prices may fluctuate considerably in the future. There is thus a major interest in tapping alternative sources of nutrients.

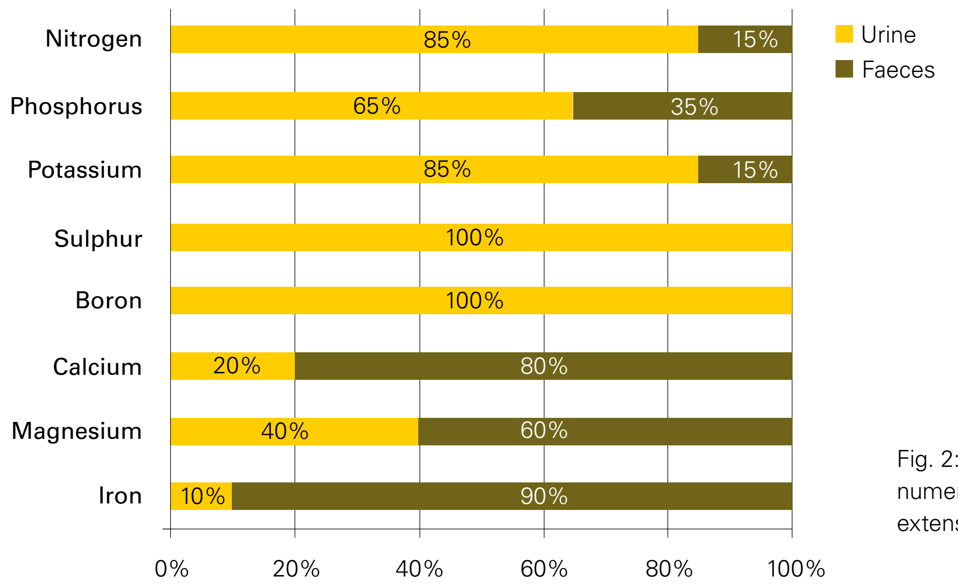


Fig. 2: Human urine contains numerous nutrients, requiring extensive treatment at WWTPs.

Water for drinking, not flushing

Separate collection of urine (source separation) can help to close the nutrient cycle. This is made possible by urine-diversion toilets (also called NoMix toilets), where urine collected in the front section of a divided bowl flows into an independent pipe. If these toilets function without a flush, water can be saved and there is no need for a sewer system. In "dry" diversion toilets, solid excreta can be directly composted or dehydrated.

The dry diversion toilet system has met with particular interest in South Africa. Here, under the Constitution, municipalities are required to provide appropriate sanitation services for residents who lack access to toilets – a policy adopted in the post-apartheid era. All over the country, campaigns were launched to provide toilets for thousands of households. At the same time, many households were also connected to water supply systems. As flush toilets would make excessive demands on Durban's scarce water resources, the city decided that piped water should be used primarily for drinking, cooking and personal hygiene – and installed dry urin diversion toilets. This also obviated the need for a major expansion of the city's sewer network and the installation of extra treatment capacity at WWTPs. The city's infrastructure is already under pressure as a result of migration from rural areas, with an estimated 200,000 people per year coming to live in Durban.

Installation of urine-diversion toilets in Durban

Since 2003, thanks to the municipality's initiative, around 90,000 households in peri-urban areas of Durban have been provided with dry (non-flush) urine-diversion toilets. As well as saving a lot of water [2], these new toilets separate urine and faeces for further use. As it was seeking possible ways of treating urine, the municipality in Durban contacted Eawag [3], where researchers have been investigating urine treatment processes for several years. In 2005, when the new Eawag headquarters (Forum Chriesbach) was built in Dübendorf, urine-diversion toilets were installed. Here, the urine collected is stored in tanks in the basement, while solid waste is flushed into sewers in the conventional manner (Fig. 3).

Ruedi Keller

Fig. 3: Diversion toilet and separate tanks for urine storage at Eawag headquarters (Forum Chriesbach).

The enquiry received from Durban gave rise to VUNA – a joint project involving Eawag, the Water and Sanitation unit of the eThekwini municipality, the University of KwaZulu-Natal and the Federal Institutes of Technology in Zurich and Lausanne. Funding for the project was secured from the Bill & Melinda Gates Foundation in 2010, and VUNA is now being completed (beginning of 2015). This project offered ideal conditions for applying Eawag's and its partners' research experience in urine separation and treatment to the implementation of toilet installa-

Maximilian Grau

Fig. 4: Members of Durban's water service staff on a urine collection round.

tions in Durban. In VUNA, the entire system of nutrient recovery – from urine collection to the finished fertilizer product – was studied for the first time. The municipality in Durban began to develop a collection service for urine from diversion toilets (Fig. 4; see box) [4].

Urine stabilized by bacteria

Methods for treating source-separated urine and recovering nutrients in a suitable form had already been developed by various research labs. But experience with nutrient recovery from urine outside the laboratory – let alone in large-scale field trials – was extremely limited. The goal of existing laboratory methods had been to recover specific nutrients from urine. The Durban project prompted us to seek uses beyond laboratory experiments, also for the urine collected at Eawag headquarters. Rather than extracting individual nutrients, we developed a new approach – separating the water in urine from the nutrients. What then remains is a concentrated nutrient solution.

The production of fertilizer involves two steps. First, half of the nitrogen present in urine in the form of ammonia is converted to nitrate with the aid of bacteria. This process, known as nitrification, is also used at WWTPs. In the second step, the liquid is evaporated in a distiller to produce a concentrated nutrient solution. Partial nitrification is sufficient to stabilize the nitrogen. Without this process, nitrogen would be released in the form of gaseous ammonia during urine storage and distillation. Stabilization also removes the pungent odour [5].

In the basement of Forum Chriesbach, this method is used to treat the urine collected from staff toilets. The nitrifying bacteria are kept in two transparent plastic columns (Fig. 1). Here, suspended plastic particles provide a substrate for bacterial colonization. Compressed air is used to supply oxygen to the bacteria and, at the same time, to ensure that the urine in the container is well mixed. Stabilized urine then flows into a distiller, where 97 per cent of the volume is removed and returned as distilled water to the toilet flushing system. The remaining 3 per cent contain all the nutrients: 30 litres of highly concentrated liquid fertilizer is thus obtained from 1000 litres of urine [6].

Initial tests successful

The effectiveness of the urine-based fertilizer has already been demonstrated in initial tests: compared with synthetic fertilizers, its performance was excellent [7]. (Fig. 5a). The product contains all the substances required for plant growth – not just the most important nutrients (nitrogen, phosphorus and potassium), but numerous trace elements, such as iron, zinc or boron, which also contribute to plant health (Fig. 5b). The fertilizer contains almost no heavy metals. Some pathogenic bacteria are inactivated during nitrification [8]. In addition, the VUNA product is pasteurized during distillation, and any viruses surviving the nitrification process are inactivated as a result.

One challenge, however, remains to be overcome – pharmaceutical residues. Depending on the origin of the urine and the intended use of the fertilizer, these substances may need to be eliminated via an additional treatment step. In the laboratory, pharmaceutical residues have already been successfully removed with the aid of activated carbon. This method will now also be tested in our pilot plant.

a)

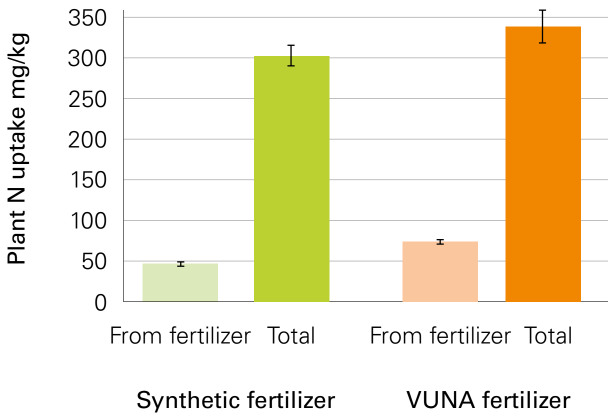
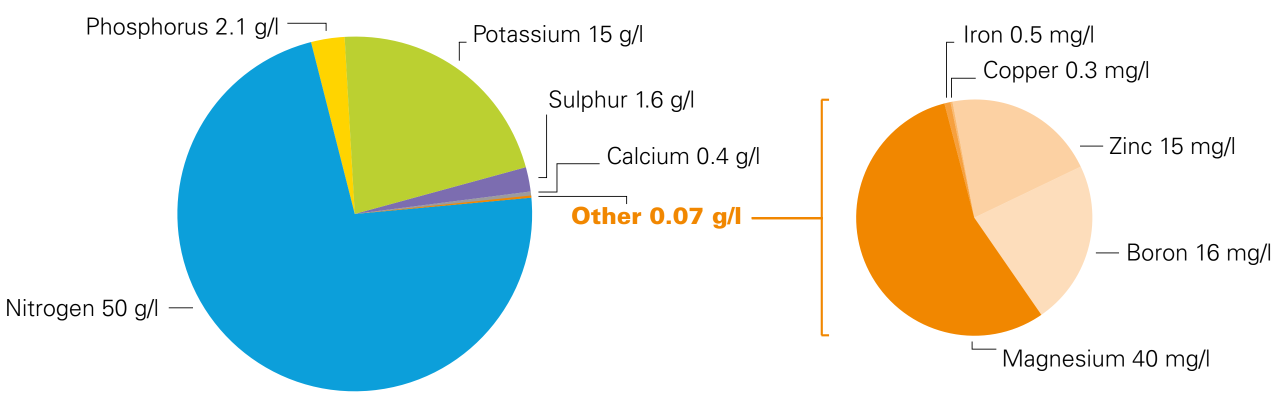


Fig. 5: a) In test plants, nitrogen uptake from the VUNA fertilizer is comparable to that from an artificial fertilizer. b) Composition of the fertilizer solution produced at Forum Chriesbach.

b)



Will fertilizer production soon be scaled up?

Based on the experiences at Eawag, two pilot plants for the production of urine-based fertilizer have now also been built in Durban (Fig. 6) – one at the Newlands-Mashu research site and the second at the headquarters of the municipal water utility. The Newlands-Mashu plant treats urine collected by the municipality on a trial basis from 700 households with urine-diversion toilets. The city is also planning to construct a larger plant so that even more households can be involved. Urine treatment on a larger scale is also under discussion in Switzerland. Eawag plans to begin serial production of plants in cooperation with industrial partners, and initial enquiries have already been received. First, however, the automatic control system needs to be improved so that the process operates as far as possible without human intervention.


Bastian Etter

Fig. 6: Pilot plant at the Durban water utility's customer care centre.

The VUNA project has demonstrated a highly promising way of converting urine into a valuable product. With an integrated sanitation system – comprising urine collection, treatment and fertilizer distribution – it is possible not only to conserve natural resources but also to open up new commercial opportunities and stimulate local entrepreneurship. This in turn provides incentives for the establishment of an affordable and effective disposal system, helping to improve urban sanitation.

However, urine source separation is appropriate not only for dry toilet systems like those in Durban. In areas with flush toilets, sewer networks and WWTPs, it offers the possibility to reduce the nutrient load on wastewater treatment plants.

Urine collection as a service, urine-based fertilizers as a business?

So far, urine from most of the urine-diversion toilets in Durban has been allowed to infiltrate into the ground. In a pilot study involving 700 households, the municipal authorities are investigating how urine can be efficiently collected. Based on the findings of this trial, the city intends to expand urine collection to cover all areas where urine-diversion toilets are installed. The idea is not only to provide a service for toilet owners, but also to make these facilities more attractive for users. Surveys in recent years indicated that, before the trial, most of the population had a preference for conventional (flush) toilets [9]. However, after the first toilets were included in the urine collection scheme, user numbers and satisfaction levels increased.

To demonstrate that this approach is applicable not only for the poorer peri-urban areas of Durban, the authorities have also installed diversion toilets and waterless urinals at the water utility's customer care centre. City-wide awareness-raising campaigns are explaining the advantages and disadvantages of the novel system and informing users about the measures required for toilet maintenance [10]. In the future, a fully developed business model should cover the entire production chain, from urine collection and treatment to fertilizer distribution. Locally produced fertilizers make the sanitation system economically attractive and offer an alternative to industrially manufactured synthetic products.

In Switzerland, the VUNA liquid fertilizer has just received provisional approval from the Federal Office for Agriculture. For a 3-year period – until the beginning of 2018 – the recycled nutrient product can be used as a fertilizer for flowers, lawns and ornamental plants and also for trial purposes in agricultural applications. Whether definitive approval is subsequently granted will depend on the results of further research. In particular, it must be demonstrated that no micropollutants of concern, such as antibiotics, enter the environment with this fertilizer.

Glynn Erasmus

>> Further information is available at: www.vuna.ch

Kai Udert
VUNA project manager, Process Engineering department
kai.udert@eawag.ch

Bastian Etter
VUNA project coordinator, Process Engineering department
bastian.etter@eawag.ch

[1] Etter B., Udert K. M., Gounden T. (2014): VUNA – Scaling up nutrient recovery from urine. Technology for development international conference, EPF Lausanne

[2] Gounden T., Pfaff B., Macleod N., Buckley C. (2006): Provision of free sustainable basic sanitation: the Durban experience. 32nd WEDC International Conference, Colombo, Sri Lanka

[3] Udert K. M., Buckley C. A., Etter B., Wächter M., McArdell C. S., Kohn T., Strande L., Zöllig H., Fumasoli A., Oberson A. (2015): Technologies for the treatment of source-separated urine in eThekwini. Accepted by Water SA

[4] Joseph H. R., Gebauer H., Friedrich E., Buckley C. A. (2014): Institutionalised collection for rural on-site sanitation. WISA Biennial Conference, Mbombela, South Africa

[5] Udert K. M., Wächter M. (2012): Complete nutrient recovery from source-separated urine by nitrification and distillation. Water Research 46 (2), 453–464

[6] Etter B., Hug A., Udert K. M. (2013): Total nutrient recovery from urine – operation of a pilot-scale nitrification reactor. WEF/IWA International Conference on Nutrient Removal and Recovery, Vancouver

[7] Bonvin C., Udert K. M., Etter B., Frossard E., Nanzer S., Tamburini F., Oberson A. (2015): Plant uptake of phosphorus and nitrogen recycled from synthetic source-separated urine. Accepted by Ambio

[8] Bischel H. N., Schertenleib A., Fumasoli A., Udert K. M., Kohn T. (2015): Inactivation kinetics and mechanisms of viral and bacterial pathogen surrogates during urine nitrification. Environmental Science: Water Research & Technology 1, 65–76

[9] Roma E., Philp K., Buckley C., Xulu S., Scott D. (2013): User perceptions of urine diversion dehydration toilets – Experiences from a cross-sectional study in eThekwini Municipality. Water SA 39 (2)

[10] Mkhize N., Coertzen M., Taylor M., Ramsay L., Udert K. M., Gouden T. G., Buckley C. A. (2014): Promoting sanitation and nutrient recovery through urine separation: The role of health and hygiene education and social acceptance factors. WISA Biennial Conference, Mbombela, South Africa