III-3:
Collection and Concentration of Urine to Produce a Mineral Fertilizer

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Abstract

This study focuses on the development of a method which makes it possible to remove a maximum amount of water from urine whilst keeping nutrient losses as low as possible. With this goal in mind, three different urine drying systems, so-called as batch, circulation and continuous systems, were designed and assessed in Can Tho University. Their operations are based upon the principle of solar distillation. The objective of the research is to find their efficiency of producing a final product with a high nutrient content, which can easily be transported, and which is accepted by farmers and consumers.

The results show that the batch system is a “low-tech” treatment unit made of concrete and characterised by a high treatment efficiency.

Keywords: urine, yellow water, evaporation, concentration, nitrogen, phosphorous

Introduction

Vietnam, with its agriculture-based economy, is a country which has known a strong development in recent years. As a result of this economic growth and a rising food demand, the fertilizer demand has increased strongly. Chemical fertilizers are being used as a favourable source of nutrients; however, the farmers have to pay money for these and may face pollution problems when applying excessive dosages to the soil. Increasing fertilizer prices and decreasing resources are strong incentives to investigate into alternatives for mineral fertilizers. In the south of Vietnam, the recycling of nutrients from human urine could be an innovative method for recovering valuable nutrients and reusing these as a plant fertilizer. Nutrient recovery could be achieved by making use of the solar energy for removing the liquid fraction from stored human urine with the aim of generating a solid end product as a concept in Figure 1.

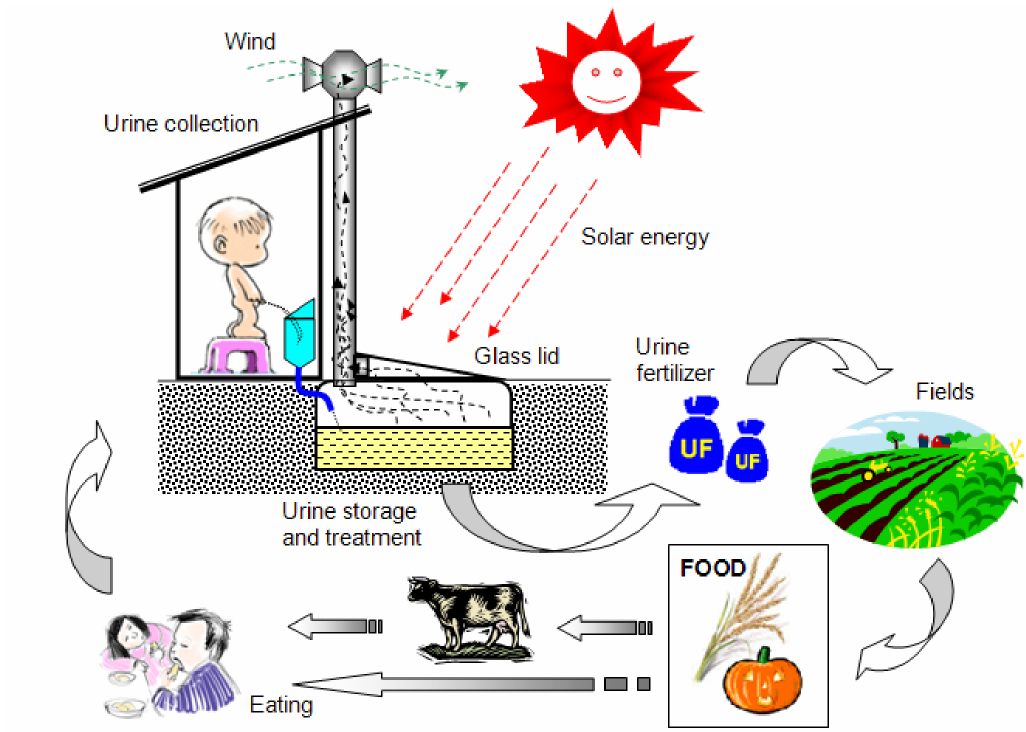


Figure 1: Human urine used as a mineral fertilizer source (Tuan et al., 2005)

Indeed, the Mekong Delta area is characterised by a tropical climate with high numbers of sunlight hours each year. Temperatures are relatively constant and high throughout both the sunny and the rainy seasons, with an average value of around 27°C (Tuan, 2006). Furthermore, the nutrients in urine are in soluble form. The major element in urine is nitrogen (N), which can be found in the form of urea (80%) and ammonia (7%). Phosphorous (P) is present in the form of inorganic phosphates (>95%), and potassium is mainly found as free ions (Vinnerås and Jönsson, 2004). The concentration of heavy metals on the other hand is very low. In summary, the nutrient content of urine is high and these soluble nutrients are available for many plant types as they can easily be absorbed.

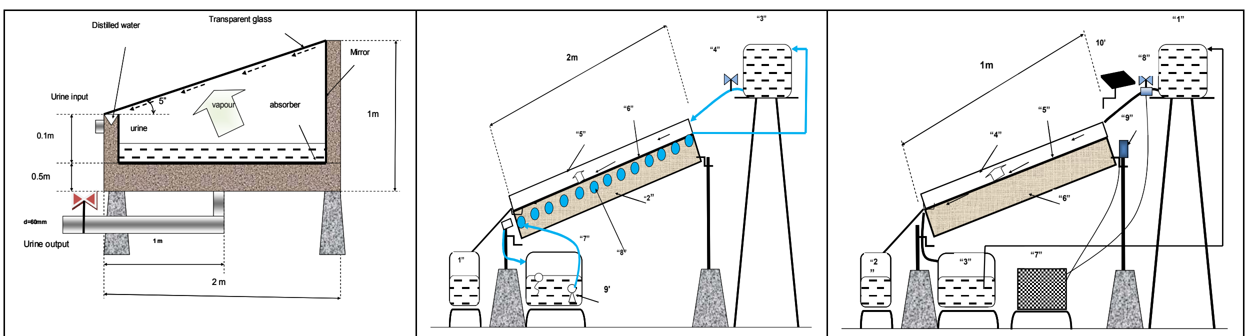
Material and methods

Urine Collection and Treatment

Diluted urine was collected from a storage tank located behind the dormitory "B23" on the grounds of Can Tho University (CTU). This dormitory, which accommodates 100 male students in 10 rooms, has been equipped with 10 separation toilets and 10 waterless urinals. Both diluted and non-diluted "Yellow Water" streams are discharged into the storage tank mentioned above. For the trials in Hoa An, non-diluted urine was collected directly in plastic containers from male students living in a neighbouring dormitory.

Three different treatment units, all built with material readily available in Vietnam, were implemented: the so-called batch, circulation and continuous systems (see Figure 2). The batch system is a "low-tech" alternative which consists of a urine holding tank made of concrete, a glass cover and separate inlets and outlets for the urine and the distilled water respectively. The urine remains in the reactor until all liquid has evaporated.

The continuous system and the circulation system are both made of metal and require an energy source to operate a recirculation pump. In both cases, the urine flows over a dark fibre material (area for crystallisation to take place) located below a glass cover. The urine is circulated in a closed loop until the absence of liquid causes the submersible pump to switch off. In addition, when being pumped back to the inlet of the circulation system, the urine has to pass through a series of pipes located below the dark cover, which causes an additional temperature increase.



Batch system	Circulation system	Continuous system

Figure 2: The different treatment systems employed for urine treatment

Experimental Set-Up and Sample Analysis

A first series of experiments focusing on treatment efficiency and optimisation of all three systems was carried out at CTU using diluted urine. 10 litres of diluted urine (urine/water ratio of 1:6) were transferred into all three units. The change of nutrients within the various systems was monitored for one week; sampling of urine and evaporated water took place on a daily basis. The collected samples were acidified with sulphuric acid to stabilise the urine and to conserve nitrogen. The required amount of acid was determined by titration of the urine.

In order to minimise nitrogen losses in the form of NH_3 with the evaporating water, experiments were performed into decreasing the pH of urine down to 4 (prevalence of NH_4^+ ions). Two acids (sulphuric and phosphoric acid) were used to achieve such low pH values, with special focus on the hypothesis that phosphoric acid could further increase the nutrient content of the final product. As an alternative to the addition of acid solution, acid soil was tested for its efficiency to lower the pH of urine and its capacity to absorb nutrients.

A further assessment of the performance of the batch system with undiluted urine was performed at Hoa An Research Station. 50 Litres of undiluted urine were placed into the concrete holding tank and left in the reactor for 1 month of treatment. During the first week, known volumes of urine and distilled water were collected on a daily basis, thereafter sampling intervals were increased.

All samples were analysed at CTU for their concentration of phosphorus (Hach-Lange test cuvettes, photometer) and nitrogen (Quantofix method), and the pH and the electricial conductivity (EC) were recorded. *Escherichia coli* (E.coli) and total coliforms were counted at CTU before and after the treatment. Temperature data was recorded at 15 minute intervals inside and outside the three systems by using Tynitag data loggers.

Results and discussion

Temperature

The various treatment units were characterised by a distinctive behaviour in terms of temperature evolution. As expected, the temperature within the reactors was, during the daytime, much higher than the ambient temperature (differences of up to 40°C).

The temperature data recorded inside the circulation and the continuous systems reached peaks of up to 80°C; these indicate that temperatures increased and decreased rapidly in the morning and evening respectively. It took only 3 hours (from 11 a.m. to 13 p.m.) for temperatures to increase from 40°C to 80°C for example. The maxima could be maintained for about 4 hours every day. At night time on the other hand, the temperature inside the reactors was lower than the ambient temperature. This indicates that both systems can absorb the heat very well, but that they cannot store the solar energy for longer time periods. This could be explained either by poor insulation or by the fact that both treatment units are made of metal. Metal can absorb - but also release heat very quickly. As soon as the system is not exposed to solar radiation anymore, temperatures within the system decrease rapidly. The batch system is made of concrete and therefore characterised by a different temperature evolution than the metal reactors. It took much longer for temperatures to increase and decrease inside this unit. The afternoon peaks, which were reached after 3 to 4 hours, were lower with an average value of around 60°C.

Microbiology

The bacteriological data collected from the three urine drying systems showed that almost all pathogens were killed after three days of operation. This decrease of pathogens can be explained by the high temperatures and the extreme pH values which were achieved within the various systems during treatment. Most microorganisms do not survive such adverse conditions.

Nutrient Recovery

With an initial starting volume of 50 L of undiluted urine, it was possible to recover between 300 and 400 g of solid material after 30 days of treatment in the batch system. The collected raw urine had N and P concentrations of 5000 mg.L^{-1} and 315 mg L^{-1} respectively, thus representing a nutrient load of 250 g of nitrogen and 16 g of phosphorus. Evaporation of the liquid fraction was effective with volumes of distilled water increasing from about 1.7 L on day 1 to 2.5 L on day 14, then decreasing again until virtually all liquid had evaporated on day 30. More than 90% of the liquid fraction could be removed after 16 days of treatment. Chemical analysis revealed that nutrient losses via the evaporating water were negligible in the case of phosphorus. For nitrogen on the other hand, about 30% had been lost with the evaporating water droplets. This can be explained by the high pH values (pH 9.5) and the high temperatures (20-60°C), which both cause nitrogen to be present in the form of volatile ammonia gas.

The evaporation rate of the continuous and the circulation systems was about 1.1 L.m^{-2}.day^{-}1 (experiments performed with diluted urine). The increase of nutrients in both systems also showed similar trends. After 1 week of treatment, the nitrogen concentration of the urine had increased from 980 mg L^{-1} L to 1800 mg L^{-1}. On the other hand, the phosphorous concentration measured in the concentrated urine samples had decreased from 590 to 570 mg L^{-1}. These losses can be explained by the fact that – as expected - phosphorus crystals had settled down on the black fibre material. Unfortunately, it was not possible to find a method allowing easy recovery of the crystals from the black fabric. An alternative or a field of application for a piece of textile saturated with nutrients would have to be elaborated. In addition to this, both units were prone to corrosion as they were made of metal, and blockages of the circulation pipes became increasingly frequent during treatment because of precipitate formation.

Taking all these factors into account, the "low-tech" batch system appeared to be the treatment option most adapted to the local conditions. The relative nutrient contents of the dried urine product were 7% of nitrogen, 16% of phosphorus and 2% of potassium. The remaining 75% were probably made up of other minerals such as Na, Cl, Ca, Mg etc.

Nitrogen losses during the drying process could be prevented by adding sulphuric acid to the urine. At low pH, the nitrogen remained in the system during operation instead of leaving the system with the evaporating water. An additional experiment involving the addition of phosphoric acid instead of sulphuric acid to adjust the pH demonstrated that the phosphorus concentrations in the processed urine increased even further. Chemical analysis showed an increase from 0.5 g P/L to 6 g P/L after 3 days of treatment only. Acidifying urine with phosphoric acid to a pH of 4 seemed to be the most beneficial way to dry urine in the batch system. In addition to preventing nutrient losses, acidification can prevent bad odour and inhibit microbial activity. Table 1 summaries the disinfection ability of three urine drying systems.

Further experiments revealed that acid soil is not a good additive for trapping nitrogen due to the large volumes involved in reducing the pH of urine. In this case, 12 kg of soil were required to reduce the pH of 10 L of urine from pH 7 to pH 4.

Table 1: The disinfection ability of three urine drying systems

System	Circulation	Continuous	Batch
Max. inside temperature (^oC)	80	78	60
Max. temperature retention time (hours)	3 (10:00 - 13:00)	4.5 (10:00 - 14:30)	4.5 (10:00 - 14:30)
Average different temperature (^oC) (Inside - Outside)	40	30	20
Disinfection ability evaluation	Very good	Very good	Good
Nutrient recovery	Medium	High	Medium
Required energy	Yes	Yes	No
Corrosion	Yes	Yes	No
Longivity	Low	Low	High
Price	Expensive	Expensive	Cheap
Suitable system for urine drying	Not reasionable	Not reasonable	Reasonable

Conclusions and Outlook

Recycling nutrients from human urine has many advantages: rather than diverting municipal wastewater directly into canals and rivers as it is common practice in the south of Vietnam, valuable nutrients can be recovered by transforming the so-called "Yellow Water" into a stable and safe product. In this way, nutrients contained in human urine can be used as a fertilizer in agriculture instead of causing environmental pollution such as eutrophication of lakes and rivers. Also, farmers could spend less money when replacing mineral fertilizers with urine-based nutrients.

This concept was put into practice by drying human urine with 3 different treatment systems, of which the operational procedures are based on the principle of solar distillation (i.e. evaporation of the liquid fraction by making use of solar energy).

The batch system is a "low-tech" treatment unit made of concrete and characterised by a high treatment efficiency. Its operation is more reliable than that of similar reactors made of metal and using pumps and pipes for urine circulation (power failures, blockages etc.). When starting with an input of 50 L of undiluted urine, about 90% of the water could be removed after 16 days of treatment. At the end of 1 month, between 300 and 400 g of dry solids could be recovered. These contained up to 100% of the initial P load, and about 70% of the initial N load. Nitrogen was partially lost in the form of volatile ammonia because of the high pH values and temperatures prevailing within the system. In the future, ammonia losses can be minimised by acidifying the collected urine prior to treatment. When using phosphoric acid, the P concentration of the final product can be increased even further.

Literature

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List of Abbreviations	
CTU	CanTho University
E.coli.	Escherichia coli
EC	Electrical Conductivity
N	Nitrogen
P	Phosphorous