Working Paper:

Utilisation of Urine in Agriculture

Andrea Munoz, Máryeluz Rueda, Ruth Schaldach, Joachim Behrendt

'SDG6, the water and sanitation Goal, is in need of a major push. The time is right, thus I encourage you all to join together to develop concerted global action to deliver on the targets of [that Goal].'
United Nations General Assembly President Peter Thomson, 2017

Abstract

Urine contains four important nutrients for plant growth: nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) and its use as fertiliser can not only recover these nutrients, but also reduce the use of chemical fertilisers and freshwater, as well as minimise the wastewater and excreta contamination of surface and open waters. However, if not managed properly, the risk of pathogen transmission, soil salinisation and pharmaceutical contamination, as well as the strong and offensive odour, can cause significant health problems and discomfort. Other challenges that have to be addressed in the process of urine utilisation in agriculture are separation techniques, storage time, urine amount to be applied, odour prevention and transport. The possibilities and difficulties of this technique will be addressed in this paper. The utilisation of urine in agriculture can help to achieve the Sustainable Development Goal (SDG) 6: 'ensure availability and sustainable management of water and sanitation for all' of the 2030 Agenda.

Keywords: urine fertilisation, ecological sanitation, nutrient recovery, struvite precipitation

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Introduction

Degradation of fresh water, improper sanitation systems and disposal of wastewater increase water stress. Sanitation systems have a big impact on the environment in regard to discharges to water bodies, air emission, soil degradation and use and reuse of natural resources. Therefore, new approaches in sanitation and irrigation should be pursued, aiming towards public health, water savings and water pollution prevention. The use of excreta and urine in agriculture can help to achieve these aims and recycle the nutrients from human excreta. However, if not used properly, there can be many complications in their usage, such as pathogen and pharmaceutical contamination, social acceptance, and other (WHO 2006).

In 2010, United Nations (UN) declared access to clean water and sanitation an essential human right. Prior to this, already in 2000, the 7th of the 8 Millennium Development Goals (MDGs) was to 'Ensure Environmental Sustainability' and one of the sub-targets was 'to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation'. This goal was partially met in 2015. The proportion of people with access to safe drinking water has increased between 1990 and 2015 from 76 % to 91 %. This means that 2.6 billion people gained access to improved water sources. However, the access to basic sanitation is, with an improvement between 1990 and 2015 of 14 % (from 54 % to 68 %), still below the MDG target. Although 2.1 billion people have already gained access to basic sanitation, 2.4 billion people still live without an improved sanitation system and 946 million people still practice open defecation (United Nations 2015). The 2030 Agenda for Sustainable Development, an expansion of the MDGs, contains 17 Sustainable Development Goals (SDGs) with SDG 6 aiming to ensure 'availability and sustainable management of water and sanitation for all'. Regarding sanitation in specific, the goal is to achieve 'an equitable sanitation and hygiene for all and end open defecation' by 2030 (UN-Water 2016).

Urine contains four important nutrients for plant growth: nitrogen (N), phosphorus (P), potassium (K) and sulphur (S). Phosphorous, for example, is a limited resource and is mainly used as a fertiliser for plant productivity. Nevertheless, if high amounts of phosphorous reach surface waters, they can cause eutrophication of the water bodies. Moreover, phosphor elimination, as well as phosphor recovery, require advanced wastewater treatment processes. Hence, the direct recycling of phosphorous from human urine could support crop production as well as the reduction of treatment steps needed to remove phosphorus from wastewater (WHO 2006).

In addition, the use of urine minimises different negative impacts on the environment, such as the amount of wastewater reaching surface water and groundwater, as well as the amount of freshwater use. Urine utilisation also reduces the use of chemical fertilisers, which can have a negative impact on the environment and human health. This in turn reduces the expenditures on waste management and chemical fertilisers (Haq & Cambridge 2012; WHO 2006). However, according to the WHO guidelines (2006), there are different steps that have to be followed to guarantee user health protection. Other challenges that have to be addressed within urine utilisation in agriculture are separation techniques, storage time, amount of urine to be applied, odour prevention and transport.

This paper will review the available research on urine utilisation for agriculture purposes, its benefits and risks, as well as its treatment and application methods. The focus will be on small scale use, meaning small households and private use, aiming to acknowledge the benefits of nutrients recovery contained in urine and support basic ecological sanitation systems.

Urine as a valuable resource

Since nutrients in urine originate from arable land and its crops through the intake of food, closing the nutrient loop and giving them back to the arable land is a rather logical process. Urine contains the majority of nutrients excreted by the body and has been studied for crop fertilisation in many countries, such as Germany (Clemens et al. 2008), Sweden (Andersson 2014), India (Andersson 2014), Ethiopia (Kassa, Meinzinger & Zewdie 2010) and the Philippines (Soria Akut 2014), among others. The utilisation of urine as a crop nutrient source has recently been receiving greater attention among researchers. Unfortunately, it is still highly underestimated in present agricultural and horticultural practices (Karak & Bhattacharyya 2011).

Nutrients in urine and its potential as fertiliser

Plants have different growth limiting factors, such as light, water, soil structure and nutrients. Their needed nutrients can generally be divided into macronutrients and micronutrients. Macronutrients are taken up in higher amounts compared to micronutrients. These are nitrogen (N), phosphorous (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg). The most important one is nitrogen and is taken up as ions of nitrate (NO_3^-) or ammonium (NH_4^+). In urine, nitrogen is available between 75 - 90 % as urea and ammonium. The enzyme urease converts urea to ammonium, which is directly available for the plants. Phosphorous is taken up by plants as orthophosphate ions (HPO_4^{2-}, H_2PO_4), which are available between 95 - 100% in urine and can be taken up directly by the plants. The presence of potassium and sulphur in urine is in form of ions (potassium and sulphur ions), which are also directly plant available. Thus, the nutrients provided by urine can be directly taken up for plant growth and have a similar composition to chemical fertilisers (Jönsson et al. 2004; Uchida 2000).

Once a human body is fully-grown, the consumed nutrients do not stay in the body (for the growth of muscles, bones and nerves) but leave the body with the excreta almost in the same amount as consumed. Because of this, the amount of nutrients in urine (N, P, K and S) can be calculated from the nutrient intake. On average, one person produces between 0.8 and 1.5 L of urine per day, which equals around 550 L of urine per person and year. The proportion of the total nitrogen, phosphorous and potassium in urine, as opposed to the concentration in faeces, are for an average person in Sweden nearly 88 %, 67 % and 73 % respectively. However, the nutrient concentration, as well as the amount of urine produced, depend on many factors, such as diet, climate, gender, water intake, physical activity and body size. For example, countries like Haiti, India and Uganda have much lower nutrient concentrations (nearly half of those of Sweden) (Eawag, Gensch & Spuhler 2014; Jönsson et al. 2004).

Health aspects

Human kidneys filter blood and produce from it two quarters of the body's urine. The produced urine is mostly sterile and has a high hygiene quality compared to faeces. The risk of urine contamination is mainly a result of cross contamination by the pathogens contained in faeces. For the most part, this can be overcome by the use of urine diverting systems. However, another source of pathogens can be an infection on the urinary passage (Clemens et al. 2008; WHO 2006).

Studies made by researchers at Hamburg University of Technology (TUHH), have revealed the existence of risks associated with pharmaceutical restudies, in particular water-soluble substances, which are excreted via urine. Many of those do not exhibit good biodegradability and can accumulate in plants, entering the human food chain. Additionally, it is important to consider that pharmaceuticals present in urine, derived from small collectives with several persons under medication, can be transferred to groundwater when urine is used as a fertiliser (Behrendt et al. 2009; Gajurel et al. 2007). Even so, research carried out so far shows that concentrations of pharmaceutical residues in urine do not represent such concentration levels, which affects plant growth. This is due to the much lower load of hormones and antibiotics in human urine compared to the load in animal manure, which is already used for agricultural purposes (Winker et al. 2010). Other potentially harmful substances contained in urine are heavy metals. However, the concentrations are also lower compared to chemical fertilisers and farmyard manure (Clemens et al. 2008).

Although the risks for human health and environmental contamination are low, efficient pathogen removal treatments should be foreseen before applying urine as a fertiliser to guarantee use without negative consequences (Tettenborn 2012).

Conditioning of urine for agriculture purposes

The management of urine begins with the separation of human excreta, or rather urine separation from faeces. Afterwards, the urine can be treated depending on the location of the collection site and the application target, for example, collection at home for private use should undergo different treatment than collection at public locations for a wider and public use. Additionally, guidelines for the application rate of urine as a fertiliser should also be followed (Tettenborn 2012).

Urine separation

Alternative wastewater systems are applied for a range of purposes, such as the control of wastewater load at wastewater treatment plants, the reduction of micropollutants and contamination of surface and groundwater, the reduction of freshwater use and the reuse of nutrients contained in excreta directly at the source (Behrendt et al. 2009; Tettenborn 2012).

Focusing on sanitation systems without water, different urine diverting dry toilets (UDDT) have been developed with the main purpose of separating human urine from faeces at the source and thus enabling better recycling of nutrients from human urine and the composting of human faeces. An UDDT has two outlets and two collection systems; one for urine and one for faeces. The urine is stored for an appropriated period aiming hygiene treatment and finally used as a crop fertiliser (Rieck, Münch & Hoffmann 2012). Nevertheless, UDDT have some adaptions challenges, since their acceptance can be difficult and improper use can lead to clogging (Eawag, Wafler & Spuhler 2010).

Another possibility to collect urine are urinals and although they are the most common for men, some models have also been developed for women. Urinals for men can be either vertical wall-mounted units, or squat slabs. Urinals for women have raised foot-steps and a sloped channel or catchment area to lead the urine to the collection system (Tilley et al. 2014). Other alternatives for women are intravaginal urinals designed to be worn for long time periods and portable women's urinal devices for use in an upright position (Möllring 2003). Moreover, the technology used for urine separation depends on the physical context and the user demand and has to be adapted according to the situation.

Hygiene treatments for the safe use of urine in agriculture

There are different options to eliminate pathogens. The designated urine use, as well as the source of collection, determine the prior treatment requirements. Two of the possible treatments are going to be explained further in this paper: urine storage and struvite precipitation. Urine storage as hygiene treatment is mostly sufficient on a small scale (household level), if the recommendations of the WHO guidelines are followed (Clemens et al. 2008; Eawag, Gensch & Spuhler 2010; Udert et al. 2015; WHO 2006). Moreover, some scientist see the agricultural use of urine primarily as a favourable option for rural areas (Behrendt et al. 2002; Soria Akut 2014). In urban areas, where there the population density is high, the storage and transport of separately collected urine can be difficult. Thus, it is necessary to employ concentration techniques, such as struvite precipitation, that permit not only treatment, but also volume reduction (Behrendt et al. 2002).

Urine storage

Concentrated urine increases the pH and the ammonia content, improving the die-off rate of pathogens and preventing the breeding of mosquitos. According to the WHO guidelines for safe use of excreta in agriculture, the optimal storage period recommended is 1 month, when a family's urine is used to fertilise individual plots for own consumption (WHO 2006). However, when urine is collected from many households or facilities and then mixed, high pH, temperature and concentration, as well as long storage periods are recommended, in order to eliminate pathogens and viable viruses. The optimal storage period recommended is 6 months at 20°C or higher. (Karak & Bhattacharyya 2011; Richert et al. 2007; WHO 2006).

At excretion, the pH of urine is normally around 6.0 but can vary between 4.5 and 8.2. In the collection vessel, the pH of urine increases to 9.0-9.3 and has a high ammonium concentration. This leads to a risk of losing nitrogen in form of ammonia if the vessel is ventilated. Thus, the vessel should not have any ventilation but be pressure equalised, which also helps to eliminate malodours (Jönsson et al. 2004). The removal of hormones and pharmaceuticals cannot be overcome though urine storage.

An advantage of this technique is its simplicity and low-cost implementation and maintenance. It can be implemented almost everywhere with a specific place for the storage tanks (Miso & Spuhler 2014).

Struvite Precipitation

A simple and fast concentration technique is struvite precipitation, which is mostly used for the recovery of phosphorous. Struvite precipitation happens naturally, when magnesium ions react with phosphate and ammonium ions contained in urine. They precipitate and form struvite ($MgNH_4PO_4$) and apatite ($Ca_{10}(PO4)_6)(OH)_2$). This product is found in form of sludge at the bottom of the collection vessel and can be used directly with the urine or separated and then filtered and dried to create an odourless powder. However, the chemical reaction happens only as long as there are soluble magnesium ions in urine and the amount of magnesium in urine is low. For an overall use of the phosphate ions, the reaction can be stimulated by adding magnesium to the stored urine (Jönsson et al. 2004; Miso & Spuhler 2014; Udert et al. 2015).

In struvite is the concentration of phosphorous twice as high as in liquid urine and can be used for crops with a high phosphorus demand. Nevertheless, 97 % of the nitrogen and nearly all of the potassium stays in liquid urine (Behrendt et al. 2002). Thus, if only struvite is to be used as fertiliser, it is recommended to also use a combination of other fertilisers. In addition, struvite can have a negative impact on soil (high pH) and nutrient uptake of plants, when the application rate is overdosed (Behrendt et al. 2002; Miso & Spuhler 2014).

Other, much more extensive methods also exist, such as nitrification together with distillation and electrolysis. Although a combination of nitrification and distillation recovers all nutrients through the nitrification process and concentrates the solution through distillation, it is also more complex than struvite precipitation. The electrolysis process could be used in very small on-site reactors and then be integrated into toilets, due to its high degradation rates and simple operation. However, the electrolysis process degrades ammonia, so there is no major recovery of nutrients. The system should be used there, where there is no need for nutrients recovery but a high need for on-site treatment. For example, in urban areas with a special need for hygiene treatment of excreta (Udert et al. 2015).

Proper application rate of urine

The application rate of urine depends not only on its nutrient content, but also on the main goal of urine utilisation. Urine is, for the most part, an N-fertiliser, due to the high content and quality of nitrogen. If a detailed application rate is pursued, the measurements of nutrient concentrations in urine and in soil, as well as the needed nutrient concentration for specific crop growth must be carried out. However, it has been estimated that the urine production of one person (550 L/year) is sufficient to fertilise 300 - 400 m^2 of arable land per year with a nitrogen level of about 3 - 7 g N/L urine. These means 1.5 L of urine should be applied to one square meter of land, corresponding to an application rate of 40- 110 kg N/ha (Jönsson et al. 2004).

If the main goal is to replace the phosphorous, the urine application rate should be about 6 kg P/ha, which corresponds to 0.9 L of urine per square meter and a phosphorous level of 0.7 g P/L urine. At this rate, the urine utilisation as a phosphorus fertiliser could achieve a fertilisation area of 600 m^2 (Jönsson et al. 2004).

Urine can be applied to crops without dilution, or be diluted with water on a level between 1:1 (1 part water to 1 part urine) and 10:1. However, the dilution of urine increases the volume to be spread, the equipment needed and the labour. In addition, urine is used as a fertiliser and not as an irrigation method. Hence, urine and water can be applied parallel to each other according on the nutrient and water requirements of the crops. Fertilisation with urine should be concluded after 2/3 or 3/4 of the time between sowing and harvesting to assure the hygiene of the crops, especially if consumed raw (Jönsson et al. 2004; Karak & Bhattacharyya 2011; Tilley et al. 2014; WHO 2006; eds Winblad & Simpson-Hébert 2004).

Furthermore, urine has a better effect on soils with a high content of humus, due to the beneficial soil bacteria in these kinds of soils that support the conversion of urine nitrogen into plant available nitrogen. If the soil is poor on humus, the best way to maximise the urine potential is to combine it with humus formed through processed faeces. Then the urine can be applied as usual for fertilising purposes (eds Winblad & Simpson-Hébert 2004).

Case studies

Urine utilisation in agriculture has been used for many years on a small-scale. In some developing countries, such as Ethiopia, Ghana, Rwanda and India, among others there have been many projects which introduce ecological sanitation and the use of urine (but also faeces) in agriculture. Some of the experiences will be summarised here:

A project conducted in 2010 in Arba Minch (Ethiopia) related to the resource-oriented sanitation concepts for peri-urban areas in Africa (ROSA) used urine to fertilise two maize crop trials sites. For one of the trials, the response of the maize plant to urine was with a seven-times-increased yield compared to unfertilised soil. However, soil salinity also increased, which represents an issue in areas where irrigation water is scarce. In addition, experiences showed difficulties with collection, transport, treatment and reuse of urine, due to a lack of awareness of the advantages (Kassa, Meinzinger & Zewdie 2010).

Another pilot project was carried out in Nalanda District, Bihar State, India. This project focused on ecological sanitation systems for the use of human urine in crop production. The test showed that urine was at least as efficient as NPK fertilisers. One of the main factors in changing farmers' ingrained attitudes about urine handling, was the annual savings of nearly US$ 72 per family using urine instead of commercial fertiliser. According to Andersson (2014), to overcome the social, political and strategical barriers, there has to be an open communication (including workshops and incentives) with the key stakeholders, such as government representatives, local farmers, media and district representatives, as well as agricultural researchers and universities.

Additionally, there have been also many projects in Europe, especially in Germany, Sweden, Switzerland and Austria, promoting the use of urine as an alternative to mineral fertiliser (Boh 2013).

Conclusion

Urine is already proved as a fertiliser. Its use depends on the particular social, economic and environmental characteristics of the location of the crops and the application target. The idea is to try to adapt each system to the local context and to know the needs of the people before choosing a solution, to avoid it becoming a problem. The use of urine is not yet a conventional technology and as in every technology, there are advantages and disadvantages.

If urine is not managed properly, the risk of pathogen transmission, as well as the risk of soil salinisation and the strong and offensive odour of urine, can cause significant health problems and discomfort. Another disadvantage is complicated transport, due to the high volume and weight of urine, especially if a big scale urine use is pursued. Thus, it is important to teach people under which conditions urine can be used for agricultural purposes and which guidelines and steps are to be followed, so that there are no negative impacts (Eawag, Gensch & Spuhler 2014).

The advantages of using urine as a fertiliser are many, such as the recovery of nutrients, the reduction of chemical fertilisers and freshwater-use, as well as the minimisation of wastewater and excreta contamination of surface and open waters. The use of urine contributes to self-sufficiency and food-security. It is an easy and low-cost technique with also monetary benefits by the user and can be used by anyone. The hygiene quality of urine is normally very high compared to faeces and the risk of pathogen transmission is low (Eawag, Gensch & Spuhler 2014).

Finally, urine as a liquid fertiliser should be used in urban areas on small scale to avoid the difficulties of transport and assure through storage only a pathogen-free urine and hygiene utilisation as fertiliser. However, the use of urine on a big scale can be foreseen in rural areas worldwide, with the additional advantage in developing countries of contributing to public health, water savings and water pollution prevention. This would help to achieve the MDGs target ‘to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation’.

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