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Human urine as an efficient fertilizer product in agriculture

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Abstract. Flush toilet based water infrastructure, which handles blackwater and greywater together, causes a lot of environmental problems. Among these, the loss of valuable organic material and nutrient content of human excreta (faeces and urine) is not sufficiently emphasized yet. Utilization of human excreta for agricultural purposes is based on the separate collection of greywater and human excreta. As urine contains most of the nutrients of human excreta, researches focus mainly on urine's treatment and utilization for agricultural purposes. We reviewed the data in literature about the nutrient content of human excreta. In this paper we present the content of macro and microelements of human urine to show its potential value as a fertilizer. To confirm the necessity of urine's utilization in agriculture instead of treated it by traditional waste water treatment methods, we have collected and compared the most important advantages and disadvantages of traditional wastewater treatment, separated handling of greywater and excreta as well as human urine's agricultural utilization.

Key words: human urine, human excreta, agriculture, wastewater treatment, dry toilets, urine-diversion dry toilets, sustainable development.

INTRODUCTION

Nowadays one of the most important topic in environmental protection is sustainable development and environment, and part of that are the problems of wastewater treatment and the inappropriate treatment of human excreta.

Distribution of pollution load of urban wastewater shows that 99% of bacteria originates from faeces; 11% of N-content originates from faeces, 87% from urine and 2% from greywater (GW); 40% of P-content originates from faeces, 50% from urine, 10% from GW; 47% of organic matter content originates from faeces, 12% from urine, 41% from GW (Toilettes du Monde, 2009). So 99% of bacteria, 98% of N-content, 90% of P-content and the total amount of drug residues and hormones are in the human excreta, which is less than 2% of the total wastewater volume. We dilute these 2% human excreta to 15–20% black water because of flush toilets, and after this, the 15–20% blackwater is mixed with 80–85% of greywater (exact proportion of greywater and blackwater depend on the types of toilet tanks and household water consumption habits).

Because of these dilutions, the total amount of wastewater needs to be treated by the well-known treatment technologies. Greywater would not require this degree of purification. Qualitative characterization (total solids, biochemical oxygen demand, dissolved organic carbon, nitrate, phosphate, potassium, calcium, sodium, microelements etc.) of household-generated GW streams (collected from bathing, laundry and cooking) of Hungary showed high variability for the analysed parameters (Bodnar et al., 2014), but have much more lower content than blackwater has. Nevertheless, black water and greywater are together in the sewer systems and in wastewater treatment plants.

We got into a vicious circle discharging human excreta to freshwater: waste water treatment converts human excreta to water pollutant, while we replace missing nutrients to soils artificially, which leads to the exploitation of soils in the long run.

Annual amount of urine and faeces of one person consists equal amount of nutrients than what is needed to grow grain for one person's annual food requirements (Malkki, 1995).

The solution should base on the separation of waste water at the source. Greywater contains soap, washing liquids etc., while blackwater contains human excreta. Using traditional wastewater collection and treatment methods, these two wastewater types are mixed. The key of sustainable water management is that we have to separate the handling of grey water to human excreta. To reach this goal, a wide variety of dry toilets or even urine-diversion dry toilets can be used, latter in the case if we would like to separate also human urine and faeces.

We presented segments of these problems and possible solutions in our previous works (Zseni, 2014; Nagy & Zseni, 2015; Zseni, 2015a; 2015b; Zseni & Nagy, 2015a; Nagy & Zseni, 2016; Zseni & Nagy, 2016a; 2016c). In this paper we would like to focus on urine, as an efficient fertilizer product in agriculture.

With the application of dry toilets, human faeces and urine do not get to the sewer system, so they can be used as a natural fertilizer. According to the newest research and experiments in Sweden and Finland, the most suitable method to substitute the artificial fertilizer is the usage of human urine in agriculture. Human urine as a crop fertilizer is studied for the first time in Finland on a large scale. As a natural circle, human nutrient circle was previously a closed system and the nutrients of excreta were utilized in cultivation. We just have to return back to ancient times, and recover the human nutrient circle (Huuhtanen & Laukkanen, 2009).

We would like to draw attention how much valuable material is lost if we regard human excreta as a waste. We make comparison between traditional wastewater treatment and separated handling of greywater and human excreta. Our aim is to confirm the necessity of utilization of human excreta and especially urine in the agriculture.

MATERIALS AND METHODS

To know, how much valuable material is lost when we regard human excreta as a waste, we have to know its nutrient content. There are several data concerning with quantity and composition of excreta. Therefore we collected, methodized and reviewed the data in literature (Tanguay, 1990; Malkii, 1995; Schouw et al., 2002; Jöhnsson et al., 2005; Vinnerås et al., 2006; Niwagaba, 2009). In this paper we present only the data of urine's macro and microelement content and we use the Scandinavian data representing the eating habits of developed world and literature which gives extremes according to the different eating habits. For better comparison of data we have calculated all of them in the same unit (g $person^{-1}$ $year^{-1}$ and mg $person^{-1}$ $year^{-1}$), in the form of elemental C, N, P, K, S, Ca, Zn, Cu, Ni, Cr, Pb, Cd and Hg. Based on the calculations we have estimated the material content of urine of the 10 million Hungarian people.

To confirm our previous opinion about the necessity of agricultural utilization of urine instead of being treated in waste water treatment plants, we have collected and compared the most important advantages and disadvantages of traditional wastewater treatment, separated handling of greywater and human excreta and human urine's utilization in agriculture.

RESULTS AND DISCUSSION

Our conviction is that it would be more reasonable to use human excreta for agricultural purposes not only because of the harmful effects of inappropriate waste water treatment on freshwater bodies, but also because the basic materials of the artificial fertilizer will be exhausted in the future. It is not a new idea to use human excreta for agricultural purposes, rather it was – some place now still is – the part of everyday life. The method of utilization basically can be two types: faeces and urine are collected and used together, or they are separated. The requirement of proper use is to separate the collected excreta from the water supply network. Many solutions exist, prevalent or spread for reaching this goal, for instance traditional latrines, modern dry toilets or separating toilets.

Human urine as a nutrient source

Amount, appearance, physical and chemical features of human excreta heavily depend on human health, the quality and quantity of food and fluid consumed, the sweat, even climate. Faeces encompass water, indigestible materials passing through the intestinal track (e.g. fibres), gland secretion (e.g. gall), as well as pathogenic viruses, bacteria, helminth eggs. Urine mostly contains water and also plant nutrients in water-soluble form.

As this paper focuses on urine, only the results which are concerned in urine are presented here. Data about faeces can be found in our previous works (Zseni & Nagy, 2015b; Zseni & Nagy, 2016b; Zseni & Nagy, 2016d).

The amount of urine is about 1–1.3 l person^{-1} day^{-1}, whose moisture content is 93–96%, dry matter content is 50–70 g person^{-1} day^{-1} depending on meal habits (Feachem et al., 1983; Tanguay, 1990). Other literature data on the amount of urine (total liquid) present 1,500 g person^{-1} day^{-1} (Vinnerås et al., 2006), 610–1,090 g person^{-1} day^{-1} in Switzerland (Jönsson et al., 1999), 600–1,200 ml person^{-1} day^{-1} in Thailand (Schouw et al., 2002). There are 15–19% nitrogen (N), 2.5–5% phosphorous (P_2O_5), 3.0–4.5% potassium (K_2O), 11–17% carbon (C), 4.5–6% calcium (Ca) in the dry matter content of urine, depending on meal habits (Tanguay, 1990). According to Swedish data, urine contains 3,700–3,830 g person^{-1} year^{-1} N, 250–340 g person^{-1} year^{-1} P, 820–1,190 g person^{-1} year^{-1} K (Vinnerås et al., 2006). Jönsson et al. (2005) had processed several literature data and recommended 11 g person^{-1} day^{-1} N, 0.9 g person^{-1} day^{-1} P, 2.4 g person^{-1} day^{-1} K in urine of Swedish people. According to Malkki (1995), the amount of urine is 500 l person^{-1} year^{-1} and it contains 5.6 kg person^{-1} nitrogen, 0.4 kg person^{-1} phosphorus and 1.0 kg person^{-1} potassium annually.

For the comparability of the above presented data we have calculated and converted them into the unit of g $person^{-1}$ $year^{-1}$, for elemental carbon (C), nitrogen (N), phosphorous (P), potassium (K), sulphur (S) and calcium (Ca). Urine contains microelements such as heavy metals, too, but the quantity of them is negligible (Jönsson et al., 2005; Vinnerås et al., 2006; WHO, 2006). Pharmaceuticals are also present in urine, but at extremely low levels (Rich Earth Institute, 2016). In Tables 1, 2 our calculations are summarised.

Table 1. Calculated average macro element content of urine (g $person^{-1}$ $year^{-1}$)

Urine	Based on Tanguay (1990)	Based on Jönsson et al. (2005)	Based on Vinnerås et al. (2006)	Based on Malkki (1995)
C	2,008–4,344	no data	no data	no data
N	2,738–4,855	4,015	3,687–3,833	5,600
P	201–559	329	248–339	400
K	453–953	876	821–1,190	1,000
S	no data	256	no data	no data
Ca	588–1,095	no data	no data	no data

Table 2. Calculated average microelement content of urine (mg $person^{-1}$ $year^{-1}$)

Urine	Based on Jönsson et al. (2005)	Based on Vinnerås et al. (2006)
Zn	110	14.6
Cu	36.5	36.5
Ni	4.02	3.65
Cr	3.65	3.65
Pb	4.38	0.73
Cd	0.18	0.37
Hg	0.30	0.37

As there is no measured and published Hungarian data for the exact nutrient content of excreta of Hungarian people, we used our calculated data based on Tanguay (1990). According to our conviction the extremes express better the various eating habits of people. The maximum value is characteristic for a meat eater who eats a lot, while the minimum value indicates the nutrient content of excreta of a little eater, vegetarian people. Population of Hungary is almost 10 million people. It means, that urine of Hungarian people contains about 20–43 thousand tons of carbon (C), 27–49 thousand tons of nitrogen (N), 2–5.6 thousand tons of phosphorous (P), 4.5–9.5 thousand tons of potassium (K) and 6–10 thousand tons of Ca in a year. For comparison, the active ingredient content of fertilizers sold in Hungary in a year is: 358 thousand tons of N, 81 thousand tons of P and 80 thousand tons of K (Central Statistical Office, 2016). In the case of microelements, according to data in Table 2, urine of 10 million people contains about 150–1,100 kg Zn, 365 kg Cu, 36–40 kg Ni, 36 kg Cr, 7–44 kg Pb, 2–4 kg Cd and 3–3.7 kg Hg in a year.

Utilization of human urine in agriculture

As urine contains the greater part of excreted nitrogen, phosphorus and potassium, and its handling seems to be easier than faeces, researches on practical treatment and utilization of excreta pay attention mainly to urine. There are substantial amount of literature dealing with treatment and utilization of urine for agricultural purposes (Jöhnsson et al., 2004; Maurer et al., 2006; Niwagaba, 2009; Pradhan et al., 2010; Richert et al., 2010; Wohlsager et al., 2010; Semalulu et al., 2011; Anderson, 2015).

Because of many factors, separate collection of urine is favourable according to some literature. Separation of urine from the solid excrement makes handling of excrement easier and reduces the load derived from excreta by e.g. reducing the volume of excreta, reducing the odour problems and decreasing the runoffs of pathogens and nutrients (e.g. nitrates) to soil, ground water and surface waters (Malkki, 1995; Höglund, 2001; Schönning & Stenström, 2004).

Solid excrement is easier to treat if it is dry and pathogens can die faster than in the wet mixture of urine and faeces. Urine can be considered as almost perfect nutrient solution: nitrogen is mainly in the form of urea, phosphorous as superphosphate and potassium in ionic form what is useful for plants. In addition urine contains micronutrients in a well-balanced way. Using separate collection, nutritional value of urine is directly recovered. If urine is not separated, its nutritional value is partly lost due to runoffs and evaporation and furthermore the nutrients can end up in water bodies (Malkki, 1995; Höglund, 2001; Schönning & Stenström, 2004).

Urine can be utilised either undiluted or diluted, depending on the target. Although, diluted form is more favourable because it has more advantages (Huuhtanen & Laukkanen, 2009).

Urine contains most of the excreta's nutrients and is normally bacteria less. If microorganisms are found in urine, they usually die rather quickly and do not pose any threat to further utilisation of urine as soil fertilizer. Usually the problem is not urine itself but solid excrement that has accidentally mixed with urine (Malkki, 1995; Schönning & Stenström, 2004; Vinnerås et al., 2008; Chandran et al., 2009).

However, there are some problems with the application of urine as well. To eradicate possible pathogens from urine it needs to be stored in closed containers before utilization. If urine is used in household's own purposes e.g. in garden or is added to the compost, it can be used already after a couple of days of storage. If urine is not utilized in own household, the storage should be at least one month when used for food and fodder plants that are not consumed untreated and even six months when used for all plants. Because after six months storage the rotavirus infection and viral infection will be reduced. Also, a total inactivation of *Ascaris* (parasitic worm) was recorded within six months. While storing urine, special attention needs to be paid on the tightness of the containers, because the nitrogen in urine is volatile and due to evaporation valuable nutrients are lost (Höglund, 2001; Schönning & Stenström, 2004).

Therefore storage is an important factor when we are using human urine. Another problem is the large volume of urine. An adult usually produces even 500–570 litres of urine annually. This large volume makes it difficult to store and transport to farms where it can be used, particularly if urine is collected in cities far from agricultural areas. A variety of strategies (distillation, evaporation, freeze/thaw and reverse osmosis) have been tried for removing water from urine and reducing its volume to create a concentrated product. The most energy efficient is reverse osmosis, some newest ongoing research focuses on new techniques to increase the effectiveness of reverse osmosis (Rich Earth Institute, 2016).

Another problem is, that if we focus only on the utilization of urine, than the environmental problem is not totally solved, as faeces has high organic and nutrient content as well, and it is also a very good fertilizer after composting. In our opinion, either we separate faeces to urine, or we collect and treat them together, the main goal has to be the agricultural utilization of both. We have to seek after the best solution, which can differ in different situations (e.g. urban or rural areas, arid or wet climate).

Comparison of different waste water treatment methods

We have collected the advantages and disadvantages of the traditional wastewater treatment and the advantages and disadvantages of separate handling of grey water and human excreta. Our summarised opinion can be found in Tables 3, 4.

Table 3. Advantages and disadvantages of traditional wastewater treatment when greywater and blackwater are treated together

Advantages	Disadvantages
An existing, established system	Expensive to build, operate and maintain
We have a lot of knowledge and information about the system	Great energy demand, which may create great co_2 emission
Old, well known waste water treatment methods / technologies	Water consumption for flushing the toilet
Sewage sludge can be utilised	Soil pollution
Existing technological devices (decantation machines, filters, chemicals), specialists	Underground water pollution
People are comfortable with using the flush toilets	Carbon content of excreta as co_2 gets released to the atmosphere to some degree according to the wastewater and sewage sludge treatment methods used
	Freshwater pollution, which may cause eutrophication
	Changes in natural water cycle
	Household-generated greywater must be treated like blackwater, unnecessarily
	Hormones and medicines are not degraded during wastewater treatment processes
	Non sustainable use of natural resources (water, human excreta)
	The nutrient and organic matter content of human excreta is wasted
	There is no way of humus forming from the organic matter content of the human excreta
	Natural cycles are upset
	Use of artificial fertilizer is needed to enhance soil productivity and this generates negative impacts on the environment and demands energy and mineral resources
	The future food production is threatened

* In developed countries the electrical consumption of the waste water treatment plant is about 20% of the communal electrical consumption, if we are not calculate the waste water treatment plant's own electrical production (Christ & Mistsdoerffer, 2008).

Table 4. Advantages and disadvantages of separate treatment of greywater and human excreta

Advantages	Disadvantages
Wastewater treatment becomes more simple if we just treat the greywater itself	The idea is hard to implement in urban areas
Less energy demand, less CO_2 emission	It takes more time to take care about the system
Water consumption decreases	We have to be more educated to know why and how we have to use the system
Soil pollution, water pollution and eutrophication decrease significantly	
Amount of waste water sludge decreases significantly	
There is a possibility of humus forming from the organic matter content of the human excreta	
Nutrients in human excreta is not wasted as natural fertilizer can be made of human excreta	
Nutrient content of human excreta goes back to the natural biological cycles	
Low costs of maintaining and operation	
Use of artificial fertilizer may decreases, so its unfavourable environmental effects and use of energy and mineral resources also decrease	
Food production becomes more sustainable	
High variety of techniques, adaptable for different conditions (types of dry toilets, composting methods etc.)	

Separate treatment of grey water and human excreta has a lot more advantages, than disadvantages. Technical solution for utilization of excreta can be the composting of human excreta after collection. It offers appropriate and suitable technology to take back our excreta into the natural cycles and the well-known environmental problems caused by flush toilet based infrastructure can be reduced or even eliminated (PereiraNeto et al., 1987; Schönning & Stenström, 2004; Bracken et al., 2007; Wichuk & McCartney, 2007; Niwagaba, 2009; Országh 2014; Cameron et al., 2015; Polprasert, 2016).

Another question is that faeces and urine has to be used together or just human urine itself as a fertilizer in the agriculture. In Table 5 the advantages and disadvantages of separate using of urine is presented.

Table 5. Advantages and disadvantages of separate utilization of human urine

Advantages	Disadvantages
In fresh excrement many kind of bacteria, viruses and worm eggs may be found*, but urine is normally bacteria less	While storing urine, special attention needs to be paid on the tightness of the containers because the nitrogen in urine is volatile and due to evaporation valuable nutrients are lost
Reducing the odour problems	Treatment and utilization of separately collected faeces has to be solved, too
Nitrogen is mainly in the form of urea Phosphorous as superphosphate and potassium in ionic form in urine what is useful for plants	

* One gram of fresh excreta contains ca 100 million bacteria where among the most common are *Escheria coli* and *faecal streptococci* (*Streptococcus faecalis* etc.), *Shigella-*, *Salmonella-*, *Clostridium-* and *Campylo-species* and especially in the developing countries *Vibrio cholera* (causes cholera). In addition e.g. protozoa and helminths can spread through excreta (Malkki, 1995; Schönning & Stenström, 2004).

CONCLUSIONS

Operation and maintain of flush toilet based water infrastructure has high environmental load. However, the remediation of harmful environmental effects is still concentrated to water pollution. During waste water treatment the valuable organic components of the human excreta are transformed into water loading inorganic N and P compounds. The improvement of end of pipe – waste water treatment – technologies is believed for perfect solution in solving this problem. However, this loading is not the most harmful environmental effect of flush toilets. The greatest environmental harm of flush toilets is the withdrawal of the very valuable organic matter and nutrient content of human excreta from the cycle of biosphere.

More widespread agricultural utilization of human excreta is needed in any case in the future, regarding the annually loss of soil mass and soil fertility on the Earth, and the cost, material and energy demand of fertilizer production and utilization. In this paper we have presented the human urine as a possible and usable natural fertilizer in agriculture.

To sum up, we can say that we have to change our traditional wastewater collection and treatment methods, have to demonstrate the problems and solutions and have to introduce these problems and solutions to as many people as we can. The main goal should be to have an effect on people thinking, so they could realize how important is to make changes in our own life, to make our environment more liveable and to build a sustainable environment. Separately collected grey water and excreta has a lot of favourable advantages, for example: soil and water pollution may reduce, the nutrients in human excreta would not be wasted, natural fertilizer could be made of human urine, and wastewater treatment methods would be simpler if only grey water has to be treated. Using of human urine in the agriculture has a lot of advantages but for the spreading use of urine as fertilizer in the future, it would be important to find the best and cost effective method how to concentrate the different nutrients in urine and how to reduce the volume of urine.

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