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Review Paper

Human excreta for plant production

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Abstract

Human excreta are a natural resource which is always available in all societies. Unfortunately, their value is highly underestimated in present agriculture and horticulture including in many tropical developing countries. Especially human urine is rich in nitrogen. This “free” fertiliser should be used as much as possible and needed. In many cases, human urine and composted human faeces could be fortified with wood ash and kitchen and garden waste to meet the potassium and phosphorus needs of plants and to improve soil structure. Avoiding health risks and dosage requirements are also discussed.

The ideas presented here can be used even with the cheap pit latrines that are common in the rural and peri-urban areas of developing countries. They do not require electricity and/or tap water. They may also fit conditions in areas of Eastern Europe where piped water and sewerage are absent and/or people lack money for fertilisers and maintenance of wastewater treatment plants.

Keywords: Faeces; Fertilisation; Horticulture; Hygiene; Nitrogen; Phosphorus; Pollution; Tropical countries; Urine; Waste

1. Introduction

Every day, each healthy human being produces excreta which contain chemical elements that are needed and can be used as fertiliser for plants producing human food, animal feeds, firewood, natural fibres, medical herbs, ornamentals, timber and shadow vegetation. The chemical elements circulate continuously in natural biogeochemical cycles which constitute the only truly sustainable source of soil nutrients. According to Wolgast (1993), the annual amount of human excreta of one person corresponds to the amount of fertiliser needed to produce 250 kg of cereal which is also the amount of cereal that one person needs to consume per year. The two most critical nutrient elements for agriculture and horticulture production all over the world are nitrogen and phosphorus. The third main nutrient is potassium.

Nitrogen is an essential element for protein synthesis. Plant dry matter usually contains 1–5% nitrogen (Bidwell, 1974). The need for nitrogen is highest at times of vigorous growth when leaf and seed proteins develop. Air contains 79% nitrogen, but plants cannot fix atmospheric nitrogen without specific nitrogen fixing microorganisms. Those best known live in symbiosis with leguminous plants. Microbiological nitrogen fixation is an energy needing process which consumes ATP. It is a biologically expensive reaction which is well-regulated. The microorganisms which have the ability to fix nitrogen stop doing so if nitrogen is already fixed in the soil in the form of ammonium or other nitrogen compounds.

Unfavourable soil, nitrogen and water conditions are often limiting factors in the growth of plants (Rowell, 1994). Environmental factors such as a high salinity, fungicides and spells of hot, cold or dry weather can also limit microbiological nitrogen fixation. Because ammonium contains much more energy than atmospheric free N_2, both biological nitrogen fixation and industrial production of nitrogen fertilisers require lots of energy which is one of the most limiting factors for global sustainability.

Although nitrogen is an essential element for all life it can also be a pollutant when applied in a wrong place or concentration. Nitrogen fertilisers in the soil are

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vulnerable to microbiological losses and to leaching into water. Because they must be replaced for each yield the risk increases that a surplus pollutes the soil and water environment. Urea-nitrogen pollution originated from human urine was for example found to be one reason for toxin producing dinoflagellate blooms in aquaculture (Glibert and Terlizzi, 1999), which is leading to fish deaths. Dinoflagellate toxins can also lead to human intoxication.

Phosphorus is the second element related to vegetative growth. It is an essential part of life in DNA, RNA, enzyme reactions, etc. Its need is approximately one tenth of that of nitrogen. There can be a shortage of phosphorus in the soil, because all plants use phosphorus for their yields. Typically the need is some 10–20 kg/ha for each yield. This amount of phosphorus should be replaced through fertilisation. In reality, the need can be higher in phosphorus poor soils, since part of it is bound to non-soluble salts of iron, calcium or aluminium. It is possible to apply one round of phosphorus as fertiliser for more than one yield without a great risk for water leaching. Because many toxic or non-toxic heavy metals will be detoxificated by forming immobile phosphorus salts, some excess phosphorus in the soil can be important. A wasteful application of phosphorus leads to phosphorus losses, however, and to the eutrophication and pollution of surface waters. Phosphorus pollution manifests itself in the form of algal or cyanobacterial blooming in surface water and in extreme cases in fish deaths, and fish or shellfishes may contain algae toxins that are fatal when consumed by humans (Hwang and Lu, 2000). Cyanobacterium *Anabaena* has been shown to be a reservoir for *Vibrio cholerae* O1, the agent of cholera endemic in some South-Asian areas twice a year (Islam et al., 1999).

The phosphorus resources, which are pure enough, i.e. have little or no heavy metals, and mankind can mine easily are very limited. It has been estimated that they will suffice for less than the next 100 years (Driver et al., 1999). Due to these limitations we must find new methods to better utilise all available resources for fertilisation. Animal manure, wastewaters and human excreta are such resources.

Human excreta are used frequently as night soils in some areas of the world such as China, Vietnam and Japan without any generally known problems for agricultural productivity, although improper use of human excreta causes hygiene and health problems (see the Section 2). The practice of reuse has also been common in Europe. Dry toilet latrines were emptied and its contents used regularly as fertiliser for arable farming until after the second half of 1900, for example in Finland (as the writer has seen herself) and in the Netherlands (van Wijk-Sijbesma, 1997). Evidence of the emptying of the contents of latrine pits into agricultural fields can still be seen in the soil of the experimental farm of the University of Helsinki situated at a distance of 6–8 km from Helsinki in the form of pieces of broken dishes and other crockery which were disposed off in pit latrines. Water toilets were first not accepted in some Nordic towns in about 1900, the main argument against them being that agriculture would loose its resource for fertilisation (Olsson, 2001; Lindegaard, 2001).

With a better-closed nutrient loop, many more people, including low-income farmers in the South, would be able to produce more food and other plant products. It would also reduce the pollution effects from unsafe excreta disposal and surplus use of chemical fertilisers and protect surface and groundwater and the air. A more effective utilisation of human excreta would also reduce the waterborne enteric microbiological diseases, since there would be less contaminated wastewater and the die-off of enteric microorganisms could be controlled better.

2. Human faeces and urine

Our kidneys are our main excretion organ. Each year, one person produces 500 kg of urine as compared to 50 kg of faeces. This faeces contains some 10 kg of dry matter. Thus one person produces approximately 5.7 kg of nitrogen, 0.6 kg of phosphorus and 1.2 kg of potassium per year (Wolgast, 1993). Of the human excreta, urine contains some 90% of the nitrogen, 50–65% of the phosphorus and 50–80% of the potassium. The higher figures have been published by Wolgast (1993). They are based on the human physiology and are often cited in the literature. Albold (2002) based his lower figures on measurements in Alpine leisure areas where chemical precipitation and evaporation reactions may have led to higher nutrient losses. The figures presented above depend also on the body weight of the persons involved, the climate, water intake, and diet characteristics, especially its protein content.

Fresh urine contains few enteric microorganisms, but some human pathogen microorganisms or helminth eggs can be emitted in urine. On the contrary, human faeces always contain high amounts of enteric microorganisms including many pathogens and opportunistic pathogens, even when the affected person does not experience any symptoms. The role of opportunistic pathogens is important since a considerable percentage of the world population—pregnant women, children, old people and people stressed by sicknesses, malnutrition, etc.—are extra sensitive to their impact.

Its high nutrients content and hygienic quality makes urine a much more valuable resource for fertilisation than faeces. The urine fraction utilised in agriculture for human food plants must in that case be free of faeces, however. The technical simplicity of its application makes it possible for households to use it with only a hand-hoe and watering can, implements which are typically used by small scale farmers and vegetable gardeners, especially by women.

3. Benefits from separating urine and faeces

If urine and faeces can be separated, both of these fractions can easily be treated and utilised. The separation must be done so that the urine fraction is totally free of faeces, but a small amount of urine in the faeces fraction is not a problem. Therefore baby pots containing possibly both faeces and urine should be added to the faeces fraction, since the faeces of both babies and adult people can contain the same pathogens.

To get pure urine, the separation should be made already in the toilet. If the toilet is a simple pit latrine or ventilated improved pit latrine, where the person is squatting, most of the urine passed can be diverted by a groove and pipe to a connected jerry can or an irrigation channel and the faeces can fall directly into the pit container. Separation may for example be easily practised in schools. In a school in peri-urban Hanoi, girls and boys had their own urinals which were flushed with the waste water from the hand washing basin (Fig. 1). If the urine is preserved for weeks or months, a light floating cover is recommended to avoid ammonia evaporation.

If the latrine pit is filled predominantly by faeces, the load is lessened and the intervals between pit emptying become much longer. Less frequent pit emptying is a clear benefit since in many cultures pit emptying carries a social stigma and it is not easy to find suitable and safe disposal places for matter containing raw faeces (Heinonen-Tanski and Savolainen, 2003). In heavily populated areas pit emptying and end disposal nevertheless remain necessary since the same pit must be used again. If the faeces fraction is drier, the enteric microorganisms furthermore have a lower possibility to survive. This lessens the risks of leaching and transportation of enteric microorganisms to groundwater or surface water, including during periods of flooding.

The faeces and urine, possibly mixed with kitchen and garden waste, can be composted so that there is no smell and hygiene is acceptable. Compost is a very valuable soil improver and slow-release fertiliser, although the composting process always involves a loss of nitrogen which can be as much as 70% (Uenosono et al., 2002). In comparison, losses from urea are less than 20% (Prasertsak et al., 2001). The separating toilet can thus mean a better nitrogen economy.

4. Risks of schistostoma or helminth eggs in urine and mosquito spread diseases

Some human parasitic germs such as some helminth eggs or schistosoma miracidia can enter the soil through the urine of infected persons. Because the number of infected persons in developing countries in the tropics is high it is obvious that this fact should be considered. The survival of veterinary important helminth eggs is reduced in aerobic conditions (Juris et al., 1995). This is especially the case when temperatures increase. A temperature of 40 °C is an effective barrier to the survival of helminth eggs, but in high ammonia concentrations already a temperature of 30 °C was effective (Ghiglietti et al., 1995). The importance of a high temperature as a destroying agent is also evident from the study of Gaasenbeek and Borgsteede (1998), who systematically showed that helminth eggs are rapidly destroyed when the temperature rises, if the relative humidity is low. Similarly, *Schistosoma mansoni* miracidia and their other vital host, the snail, cannot survive well if the soil is hot and dry (Andersson et al., 1982; Tchounwou et al., 1992). The survival of *S. mansoni* miracidia is reduced at a temperature of 35 °C, an increase of salinity to 0.9%, or a pH of 9 (Tchounwou et al., 1992).

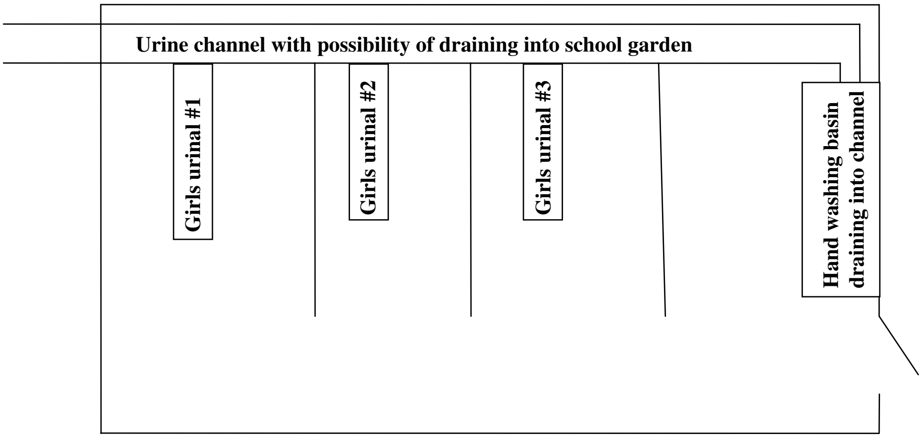

Fig. 1. Girls urinal in school in peri-urban area of Hanoi, Vietnam with waste water from handwashing flushing the urine channel.

On the basis of these facts it can be assumed that the survival of helminth eggs and schistosoma miracidia will be reduced in urine under the influence of urine salts, the increase in pH through ureolysis and the raise in temperature if the urine is preserved under a tropical sun or poured onto tropical top soil which will often have reached or surpassed the critical temperature levels. Moreover, if urine is used as fertiliser, the vegetation will grow and more water will evaporate. The resulting drying of the soil will decrease its relative humidity which will further reduce the survival chances of the pathogenic agents. In comparison with the use of septic tanks or pit latrines with a mixture of faeces, urine and some water, or with open defecation and urination resulting in the contamination of tropical freshwater, the horticultural and agricultural use of urine thus hardly constitutes an increase in risks of disease transmission through helminths and schistosoma.

In addition, the drying of soil may mean that small and temporary water bodies will be reduced so that also mosquito larva may have fewer sites to develop into mosquitoes and spread malaria and viral hemorrhagic fevers such as dengue, Japanese encephalitis and yellow fever.

5. Nitrogen and phosphorus needed for plants and plain urine used as fertiliser

Urine contains nitrogen in the form of urea. Its beneficial effects on plant production have been studied intensively. The chemical industry produces it artificially on a large scale and farmers all over the world use urea. It is equally possible to use pure urine for fertilisation. Its agricultural value has been studied with barley (*Hordeum vulgare* L.) in both pot experiments (Kirchmann and Petterson, 1995) and in the field (Steineck et al., 1999; Richert Stintzing et al., 2002), and in home gardens with grass, potatoes and different, unspecified berries, vegetables and ornamentals (Malkki and Heinonen-Tanski, 1999).

If urine fertilisation is done carefully at the correct time, the amount used is moderate, and the urine is incorporated directly into the soil, urine nitrogen has the same agricultural values as nitrogen of commercial mineral fertilisers and the barley absorbs almost all urine nitrogen (Richert Stintzing et al., 2002). Losses through evaporation can be low. Thus urine can totally replace commercial fertilisers. For barley, the nitrogen needed under Swedish climate conditions was 100 kg/ha for one growth period of 90–110 days. If there are no atmospheric losses, there can also be no smell and the loss to water will be unimportant. The intake of phosphorus from urine during the first year was 12%, which was better than that from mineral fertilisers (Kirchmann and Petterson, 1995).

Outdoor cucumber fertilised by two farmers in Finland with either urine or a corresponding amount of commercial mineral fertiliser produced very similar yields. No indicator microorganisms (coliforms, enterococci, clostridia or coliphages) could be shown in any of 8 cucumber samples in spite urine or mineral fertiliser was used as fertiliser. In a taste assessment test, the cucumbers of one farmer did not differ from each other, while those of the other farmer differed slightly in taste, but both types of cucumber, i.e. those fertilised with urine and with mineral fertiliser tasted equally good (Heinonen-Tanski et al., in press).

Although the chloride content of human urine can be rather high, it seldom contains elements with a high risk to human health (Kirchmann and Petterson, 1995). Private Swedish and Finnish persons have not reported any problems from eating food for whose production they have used urine or urine-containing compost (Malkki and Heinonen-Tanski, 1999). Rowell (1994) also reports that (animal) urine fertilisation does not increase the chloride content of the soil to an unacceptable level.

Human urine is not totally sterile, but as shown in Table 1 the amounts of different enteric microorganisms can be so low that adding urine to the soil can readily be accepted. The urine may have a slight smell but this is not repulsive. There can also be some precipitation, which may be a consequence of the formation of insoluble phosphate salts. The Swedish practice has sometimes been to store urine for some months before use in order to wait for the die-off of possible enteric microorganisms. Because the survival time of microorganisms

Table 1
Numbers of some enteric microorganisms as plaque forming units/ml or colony forming units/ml in urine fraction Finnish urine-separating eco-toilets (Heinonen-Tanski et al., in press)

	Somatic coliphages	RNA-coliphages	Faecal coliforms	Enterococci	Sulphite reducing clostridia
A kindergarten	13	3	170	70	33
Cafe	630	l.d.l.	l.d.l.	l.d.l.	l.d.l.
Private household A	l.d.l.	l.d.l.	l.d.l.	16,000	l.d.l.
Private household B	l.d.l.	l.d.l.	l.d.l.	40	14
Private household C	l.d.l.	l.d.l.	l.d.l.	l.d.l.	l.d.l.
Mixed compiled sample of all the above	420	2	1	2700	20

l.d.l. = less than the detection limit, which was 1 microorganisms/ml.

is always shorter at higher temperatures (Mitscherlich and Marth, 1984), the storage time of urine up the time when it is needed as fertiliser can be minimised in tropical climates.

It is not recommended to stir the urine fraction during utilisation, since stirring increases the evaporation of ammonia to the air which leads to an unpleasant smell and the microorganisms that are precipitated during sedimentation may be lost (see also Table 1).

In practice, plain urine can be assumed to contain approximately 1% of nitrogen or less. At this level, the fertilisation need of nitrogen for barley (approximately 100 kg/ha) corresponds to 10 m^3 urine/ha or 1 l urine/m^2. The assumed 1% differs slightly from the figures published by Steineck et al. (1999) and Albold (2002) since the urine fractions of European ecotoilets are more diluted due to the use of water for flushing and the evaporation of ammonia since urine must be preserved in Sweden for even one year as in its cold climate it can be spread only once a year.

In tropical climates with their vigorous vegetation growth, the need of N fertilisation is often higher than 100–250 kg N/ha for each vegetation period and the latter can be three to four months (Rowell, 1994) instead of one year. For rice, the need would be 120 kg/ha (corresponding to 12 m^3 urine/ha) during one monsoon period (Kumar and Kandasamy, 1984). Tables 2 and 3 contain examples of urine needs for a variety of plants. These figures have been calculated as if there were no losses of nitrogen. For a single tree growing rapidly and producing seeds and leaves, such as a coconut tree or other tall trees with a high productivity, the nitrogen need can constitute a high percentage of the urine produced by one person. Its precise needs can be estimated roughly from the colour of its leaves. The leaves of vegetation suffering from a shortage of nitrogen tend to be pale green, while those of plants or trees with enough nitrogen are dark green. The need of nitrogen can also be estimated by the vegetative growth. In previously flooded soils nitrogen levels are low due to the solubility of nitrogen compounds. In such cases, new nitrogen must be added to the soil in order to get a better vegetation growth and make the soil more resistant to erosion. Only ornamental flowers usually do not need high amounts of nitrogen as this will stimulate leaf growth rather than the development of flowers.

Besides nitrogen, coconut trees and other crops may also need higher amounts of potassium and phosphorus (Srinavasa Reddy et al., 2002), which can be achieved by adding wood ash and/or compost. If the nitrogen needs are totally or partly compensated through the application of urine, farmers would only need to add phosphate (Dahanayake et al., 1995) and potassium.

6. Application of urine to soils

Nitrogen occurs in fresh urine as urea, which is useful for plants and often present in commercial fertilisers. Urea degrades easily by microorganisms to ammonium, which is also useful for plants. In a slightly alkaline solution, part of the ammonium can, however, evaporate easily as ammonia. This evaporation can be noted in the form of an unpleasant smell. If the urine solution would be acid, ammonia would not be formed. Because the adjustment of pH is both difficult and costly, this is not recommended for private households. Instead, the urine should be poured into a 1–4 cm deep hoed furrow with a watering can and covered with soil soon thereafter. This simple practice mimics the successful injection technique used by Richert Stintzing et al. (2002) to avoid ammonia losses. It is recommended further that

Table 2
The need of nitrogen g/one plant and urine (l) nitrogen for some tropical plants

Plant species	N g/one plant	Urine l/one plant	Reference
Dwarf banana	300	30[a]	Suresh et al. (2002)
Banana	5 × 100 during 5 weeks 5–6 months after planting	5 × 10[a]	Gopimony et al. (1979)
Coconut	1000[a]	100[a]	Srinavasa Reddy et al. (2002)
Jasmine	100	10	Bhattacharjee (1985)

The referred knowledge is underlined and urine need has been calculated according to this.

[a] The plant has a need for phosphorus and potassium. Use therefore in addition wood ash or/and compost.

Table 3
The need of nitrogen kg N/ha and urine to be spread m^3/ha for some tropical plants

Plant species	Nitrogen kg/ha	Urine m^3/ha	Urine l/m^2	Reference
Banana	400	40	4	Israeli et al. (1985)
Cane	200	20	2	Chapman and Haysom (1991)
Indian mustard	100 at sowing + 1 month after	10 + 10	1 + 1	Jagpal-Singh and Gangasaran (1993)

The referred knowledge is underlined and urine need has been calculated according to this.

urine is applied as a fertiliser just before irrigation or during the rains so that it spreads more perfectly. It can also be applied in the evening when the evaporation will be lower.

7. Avoidance of over-fertilisation

Too high a use of nitrogen as fertiliser must be avoided, since there is especially a risk that vegetables will then contain too much nitrate (Dich et al., 1996) or that the groundwater will be contaminated by nitrite and nitrate.

If the land area of a household is very small in comparison with the amounts of urine produced by its members, its horticultural production and the corresponding needs for nitrogen can be increased by cultivating trees and tall climbing plants. The cultivation of plants on terraces in pots and hanging baskets may add to the productivity of the land area and the absorption capacity of the household's urine production.

A private household or school which produces more urine than needed can also decrease the nitrogen content by adding some wood ash or lime to it. Both these components precipitate some calcium phosphate and increase the pH of the urine, so that ammonium will transform to ammonia. The ammonia will then evaporate and cause some smell and air pollution and therefore this treatment can not be recommended generally. On the other hand ammonium and high pH are important factors in destroying enteric microorganisms such as Salmonella (Heinonen-Tanski et al., 1998) and many viruses (Turner et al., 1999).

From areas with a dense population the plain urine could be transported to the countryside or to tree nurseries to produce park or forest trees. Transportation is also possible by pipes because plain urine is easy to pump. If there is a very high production of urine such as in big cities and transportation is not a feasible option; it is also possible to recover the most valuable nutrients from urine by struvite crystallisation (Lind et al., 2000). This can be done by adding MgO so that it forms with urine-originating ammonium, potassium ion and phosphate struvite $[Mg(K,NH_4)(PO_4)\cdot 6H_2O]$. Struvite will precipitate and the supernatant liquid, which still contains some nutrients, can be used in combination with irrigation water.

8. Composting of human faeces

Human faeces is rich in phosphorus and potassium, which are important plant nutrients, and it also contains carbon, which can increase the fraction of organic matter in soils. More organic matter in soils is especially important to improve the soil structure in tropical countries so that it becomes more resistant to droughts and to erosion from heavy rains and floods. It is also known that an increase in organic matter through the use of compost can make plants more salt-tolerant as shown in Swiss chard and common beans (Smith et al., 2001) and apple trees (Engel et al., 2001). Thus this fraction is also valuable.

Before using human faeces as a fertiliser, they must be made safe because the number of enteric bacteria, viruses, protozoa and helminth eggs in faeces can be high. Composting is the best way for doing so. Composting is also a method to balance the relation of carbon and nitrogen and if there is excess nitrogen its portion will be reduced. Composting can be done in the latrine pit or in a separate heap alone or together with other household organic wastes. If the composting is done in the latrine pit, there should be another pit so that the contents of the first pit can be left for composting when it is full.

If there is only one pit, something which is quite usual in densely populated areas in the South, a separate composting heap or pit would be highly recommended, since it allows the continued use of the latrine after having partly emptied the pit. The partial emptying is less repulsive when the urine and faeces have been separated already in the toilet than when a mixture of faeces and urine must be taken out. In the first case it will be easy to see which part of the mixture is older and which is fresher and to take only the older part of the fraction for composting.

When the composting is done in a separate composter, this should be divided into two parts so that one part is used and the contents of the other, previously filled part are left for ripening. Each batch of compost should reach and keep a temperature of 55–60 °C for several days so as to make the compost safe for use as a fertiliser. In Swedish summers, the time needed to reach and maintain the temperature levels required for the proper composting of separated faeces or faeces and food waste was only 10–15 days (Vinnerås et al., 2003). It can be assumed that in a tropical environment this process would still be more rapid.

To avoid nutrient losses a compost heap or pit should be protected against rainwater. The composting of plain faeces alone or with household and/or garden wastes is easier if this material is relatively dry, since the air can then penetrate better (Malkki and Heinonen-Tanski, 1999). If the material is too dry, some urine can be added. An ideal wetness is achieved when the amount of water is approximately 50–60% of the overall water-holding capacity. An indicator of this situation is that no water is liberated when the compost mass is pressed by hand, but the mass itself is still wet to the touch (Malkki and Heinonen-Tanski, 1999). After composting the contents can be used as fertiliser.

9. Improvements in cases of non-separation of faeces and urine

Many households in the South have a latrine with a single pit and no possibility to add another pit. There may also be no readiness to utilise pure urine as a fertiliser, which is an incentive for separation. The form of the latrine pit is usually either cylindrical or cubical and older and fresher faeces are mixed when the latrine is used. The mixture of urine and faeces is a bad-smelling slurry with a high number of enteric microorganisms (Heinonen-Tanski and Savolainen, 2003). The microorganisms immediately deplete the oxygen of air and the inner parts of the pit can be anaerobic in spite of ventilation. As a result, no aerobic respiration and heat formation are possible. Sanitary conditions are inadequate and the persons emptying the pits are exposed to enteric pathogens, which can also spread to the environment. The bad smells also contribute to non-use and to the negative reputation of pit latrines that hamper access to sanitation for all pursued under the Millenium Development Goals (United Nations, 2002).

Poor composting, bad smells and risks to contamination can be partly reduced by adding ash, dry kitchen and garden wastes and soil to the pit so that the water percentage of the mixture will be decreased up to a level that there is no more visible liquid and composting can start. Good ventilation is important in this case. Heat formation, with its accompanying evaporation and composting can be improved further by increasing the heating impact of the sun, e.g. if the latrine is open to the sky and/or slab and walls are painted dark.

The entire mixing of old and fresh faeces can also be avoided if there is a partial dividing inner wall in the pit so that the fresh faeces will fall in one part of the pit and the mass in the other part will be older and have less health risks (Fig. 2). Only the older mass should be emptied and used. This kind of composting may especially be possible in the sanplat latrines that were designed by Brandberg (1991, 1997) as their lighter weight facilitates shifting the slab opening over that part of the pit that is in use.

10. Towards the future

As presented in this paper, private households which cultivate vegetables or ornamental plants and farmers in rural and semi-urban areas could quite easily utilise urine as fertiliser and so save expenditures and raise incomes. The environment would be improved since the risks of water pollution by enteric microorganisms and nitrate leaching to groundwater would be reduced. A more widespread use of urine as fertiliser would also have positive impacts on the global environment since its use would reduce the consumption of energy. The 5.7 kg of nitrogen which one person produces per year would in the fertiliser industry need at least 10 kg of oil to make ammonium using the Haber–Bosch synthesis process. The transportation of the ready product further adds to energy demands. The fertiliser industry with its emissions of nitrogen oxides (NO_x) and its oil consumption increases global heating which raises the levels of seawater, a process that can be fatal for many coastal zones and islands. The potential for promotion and testing on a sufficiently large scale to make an impact seems greatest in areas with a tradition of fertilisation with human excreta, a low latrine coverage and interest in and demand for a latrine programme.

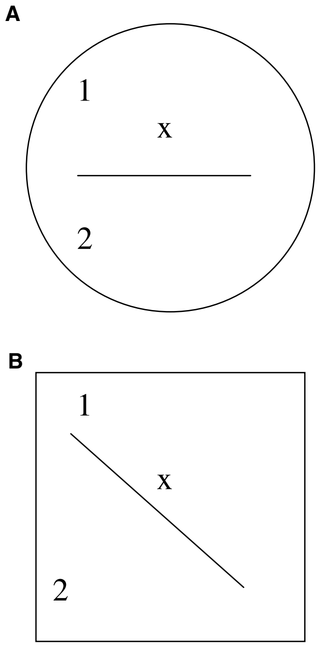

Fig. 2. Two types of latrine pits seen from above and divided into two parts to be filled on side 1 and to be emptied on side 2. The heap where faeces comes, has been marked as x.

11. Conclusions

Four main conclusions can be drawn from the above observations:

1. Promote pit latrines that allow the separation of urine and faeces so that the urine fraction is clean of faeces.
2. Promote the use of pure urine as an effective and free fertiliser.
3. Promote the effective composting of faeces taken out of latrine pits with kitchen and garden wastes and where available animal manure wastes in a compost heap while protecting them against rain water.
4. If the separation in latrines is not possible, improve the heat formation and aeration in the pit with adding organic kitchen and garden wastes so that there

seems to be no free liquid so that composting will take place, bad smells are reduced and the hygiene of the pit content will be improved.

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References

Albold, A., 2002. Urine separation in mountainous regions. Mitteilungen on-site wastewater solutions for remote areas. Institut für Umwelttechnik. Leopold-Franzens-Universität Innsbruck.

Andersson, R.M., Mercer, J.G., Wilson, R.A., Carter, N.P., 1982. Transmission of Schistosoma mansoni from man to snail: experimental studies of miracidal survival and infectivity influence to larval age, water temperature, host size and host age. Parasitology 85, 339–360.

Bhattacharjee, S.K., 1985. The response of *Jasminium grandiflorium* L. to N, P_2O_5 and K_2O fertilisation (2nd trial). Singapore J. Primary Ind. 13, 102–111.

Bidwell, R.G.S., 1974. Plant Physiology, Macmillan, New York. p. 643.

Brandberg, B., 1991. The SanPlat system: lowest cost environmental sanitation for low income communities based on experiences from Mozambique, Malawi and Angola. SBI Consulting International, Trollhättan, Sweden.

Brandberg, B., 1997. Latrine Building: A Handbook for Implementing the SanPlat System. ITDG Publishing, London, UK.

Chapman, L.S., Haysom, M.B.C., 1991. Nitrogen fertilisation for fields with sugar cane crop residues. Proc. Australian Soc. Sugar Cane Technol. Np 13, 53–58.

Dahanayake, K., Ratnayake, M.P.K., Sunil, P.A., 1995. Potential of Eppawala apatite as a directly applied low-cost fertiliser for rice production in Sri Lanka. Fertiliser Res. 41, 145–150.

Dich, J., Järvinen, R., Knekt, P., Penttilä, P.L., 1996. Dietary intakes of nitrate, nitrite and NDMA in the Finnish mobile clinic health examination survey. Food Addit. Contam. 13, 541–552.

Driver, J., Lijmbach, D., Steen, J., 1999. Why recover phosphorus for recycling, and how? Environ. Technol 20, 651–662.

Engel, A., Kunz, A., Blanke, M., 2001. Effects of compost and wood chippings on soil nutrients and on vegetative and reproductive growth and fruit quality of apple to overcome the replant problem. Erwerbsobstbau 43 (6), 153–160.

Gaasenbeek, C.P., Borgsteede, F.H., 1998. Studies on the survival of *Ascarius suum* eggs under laboratory simulated field conditions. Vet. Parasitol. 28, 227–234.

Ghiglietti, R., Rossi, P., Ramsan, M., Colombi, A., 1995. Viability of *Ascarius suum*, *Ascarius lumbricoides* and *Trichuris muris* eggs to alkaline pH and different temperatures. Parassitologia 37, 229–232.

Glibert, P.M., Terlizzi, D.E., 1999. Cooccurrence of elevated urea levels and Dinoflagellate blooms in temperature Estuarine Aquaculture Ponds. Appl. Environ. Microbiol. 65, 5594–5596.

Gopimony, R., Marykutty, K.C., Kannan, K., 1979. Effect of top dressing with urea at flower initiation time in *zanzibar* variety of banana. Agric. Res. J. Kerala. 17, 293–295.

Heinonen-Tanski, H., Niskanen, E.M., Salmela, P., Lanki, E., 1998. Salmonella in animal slurry can be destroyed by aeration at low temperatures. J. Appl. Microbiol. 85, 277–281.

Heinonen-Tanski, H., Savolainen, R., 2003. Disinfection of Septic Tank and Cesspool Wastewater with Peracetic Acid. Ambio 32, 358–361.

Heinonen-Tanski, H., Sjöblom, A., Fabricius, H., Holopainen, P. Virtsa sopii avomaakurkun lannoitteeksi (Urine can be used for fertiliser of outdoor cucumber). Vesitalous, in press (in Finnish).

Hwang, D.F., Lu, Y.H., 2000. Influence of environmental and nutritional factors on growth, toxicity, and toxin profile of dinoflagellate *Alexndrium minutum*. Toxicon 38, 1491–1503.

Islam, M.S., Rahim, Z., Alam, M.J., Begum, S., Moniruzzaman, S.M., Umeda, A., Amako, K., Albert, M.J., Sack, R.B., Huq, A., Colwell, R.R., 1999. Association of *Vibrio cholerae* O1 with the cyanobacterium *Anabaena* sp. Elucidated by polymerase chain reaction and transmission electron microscopy. Trans. R. Soc. Trop. Med. Hyg. 93, 36–40.

Israeli, Y., Hagin, J., Katz, S., 1985. Efficiency of fertilizers as nitrogen sources to banana plantations under drip irrigation. Fertiliser Res. 8, 101–106.

Jagpal-Singh, H.B., Gangasaran Singh, J., 1993. Studies on the weed management and nitrogen fertilisation in mustard (*Brassica juncea* L. Czern and Coss.). Proc. Indian Soc. Weed Sci. Int. Symp. III, 94–97.

Juris, P., Plachy, P., Laukova, A., 1995. Devitalization of bacterial and parasitic germs in sewage sludge during aerobic digestion under laboratory conditions. Vet. Med. 40 (5), 157–162.

Kirchmann, H., Petterson, S., 1995. Human urine—chemical composition and fertiliser use efficiency. Fertiliser Res. 40, 149–154.

Kumar, R.J., Kandasamy, P., 1984. Effect of different sources and levels of nitrogen fertilisation on yield of rice var. IR20. Madras Agric. J. 71, 132–133.

Lind, B.-B., Ban, Z., Byden, L., 2000. Nutrient recovery from human urine by struvite crystallization with ammonia adsorption on zeolite and wollastonite. Bioresource Techol. 73, 169–174.

Lindegaard, H., 2001. The debate on the sewerage system in Copenhagen from the 1840s to the 1930s. Ambio 30, 323–326.

Malkki, S., Heinonen-Tanski, H., 1999. Composting toilets in permanent houses. In: Use of municipal organic waste. Proc. NJF seminar 292. DIAS-report 13. pp. 147–154.

Mitscherlich, E., Marth, E.H., 1984. Microbial survival in the environment: bacteria and rickettsiae important in human and animal health. Springer-Verlag, Berlin. p. 802.

Olsson, G., 2001. The struggle for a cleaner urban environment: water pollution in Malmö 1850-1911. Ambio 30, 287–291.

Prasertsak, P., Freney, J.R., Saffigna, P.G., Denmead, O.T., Prove, B.G., 2001. Fate of urea nitrogen applied to banana crop in the wet tropics of Queensland. Nutr. Cycl. Agroecosystems 59, 65–73.

Richert Stintzing, A., Rodhe, L., Åkerhielm, H., Steineck, S., 2002. Human urine as a fertiliser—plant nutrients, application technique and environmental effects. In: Venglovsk, J., Gréserová, G., (Eds.), Proc. 10th Int. Conf. Ramiran 2002 Network. FAO European System of cooperative Research Network. pp. 161–162.

Rowell, D.L., 1994. Soil Science Methods and Applications. Addison Wesley, Longman Limited, Harlow, England.

Smith, D.C., Beharee, V., Hughes, J.C., 2001. The effects of composts produced by a simple composting procedure on the yields of Swiss chard (*Beta vulgaris* L. var. *flavescens*) and common bean (*Phaseolis vulgaris* L. var. *nanus*). Scientia Horticulture 91, 394–406.

Srinavasa Reddy, D.V., Upadhyay, A.K., Gopalasundraram, P., Hameed Khan, H., 2002. Response of yielding coconut variety and hybrids to fertilization under rainfed and irrigation conditions. Nutr. Cycl. Agroecosystems 62, 131–138.

Steineck, S., Richert Stintzing, A., Rodhe, L., Elmquist, H., Jakobsson, C., 1999. Plant nutrients in human urine and food refuse. In: Proc. NJF seminar 292. DIAS-report 13. pp. 125–130.

Suresh, C.P., Bidhan-Ray, Hasan, M.A., Roy, B., 2002. Leaf N, P and K contents and their correlation with yield of Dwarf Cavendish banana (Musa AAA) in relation to N and K nutrition. Res. Crops 3, 390–397.

Tchounwou, P.B., Englande Jr., A.J., Malek, E.A., 1992. The influence of selected environmental parameters on the toxicity of Bayluscide to Schistosoma mansoni miracidia. Arch. Environ. Contam. Toxicol. 23, 223–229.

Turner, C., Williams, S.M., Burton, C.H., Cumby, T.R., Wilkinson, P.J., Farrent, J.W., 1999. Pilot scale thermal treatment of pig slurry for the inactivation of animal virus pathogens. J. Environ. Sci. Health., Part B 34, 989–1007.

Uenosono, S., Takahashi, S., Nagatomo, M., Yamamuro, S., 2002. Labelling of poultry manure with 15N. Soil Sci. Plant Nutr. 48 (1), 9–13.

United Nations, 2002. UN Millenium Development Goals (MDG). http://www.un.org/millenniumgoals/[downloaded 11 September 2003].

van Wijk-Sijbesma, C.A., 1997. Men and women, water and waste: gender aspects in the Dutch water sector. IHE UNESCO Institute for Water Education SUMWS/012. unpublished report.

Vinnerås, B., Björklund, A., Jönsson, H., 2003. Thermal composting of faecal matter as treatment and possible disinfection method—laboratory-scale and pilot-scale studies. Bioresource Technol. 88, 47–54.

Wolgast, M. 1993. Rena vatten. Om tankar i kretslopp. Crenom HB, Uppsala. (in Swedish).