TITLE	**Guidelines on use of urine and faeces in crop production**
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Short CV for Introduction Purposes (100 words max)	Håkan Jönsson is Associate Professor in Environmental Engineering at the Swedish University of Agricultural Sciences in Uppsala, Sweden, where he also earned his MSc and PhD degrees. Since 1993, his research has focused on systems and processes for recycling urban plant nutrients to crop production. His research specialities are source separating sewage systems (e.g. Ecological Sanitation, Ecosan, urine diversion), the compost process and systems analysis of waste and wastewater systems. He is co-chair of the IWA Ecosan specialist group and active within the Swedish EcoSanRes programme and the Swedish Urban Water programme
Photograph attached (jpg)	

INTRODUCTION

The harvested crop contains plant nutrients, which thus are removed from the field. To ensure sustained soil fertility and ample harvests, this loss of plant nutrients from the field needs to be replaced. Most of the plant nutrients in the crop are later found in food. Humans only retain plant nutrients in their bodies while they still grow, and even during this period it is only a small proportion of the plant nutrients that are retained. It has e.g. been calculated that Swedish youngsters between the age 2 and 17 incorporate into their bodies approximately 2% and 6% of the N and P consumed (Jönsson et al., 2004). Thus, most of the plant nutrients removed by the crop are later found in human excreta, urine and faeces. As these contain approximately the same amounts of the nutrients as was removed by the crop, recycling them as fertiliser is a conceptually simple way to increase the sustainability of food production.

Urine and faeces from human beings are valuable resources that should fertilise crops instead of being emitted to surface waters causing eutrophication. Use of urine and faeces as fertilisers can significantly contribute to food security and health and especially so in situations where chemical fertilisers are unaffordable. Separate collection of urine and faeces is achieved by sanitation systems which divert, source separate, urine, e.g. no mix systems (Winblad et al., 2004) and double flushed urine diverting systems (Johansson et al., 2001).

MATERIALS AND METHODS

These guidelines on use of urine and faeces in crop production are based on a thorough collection of experiences on reuse of urine and faeces around the world. Countries where use of human urine and faeces have been studied are Zimbabwe (Morgan, 2003), Ethiopia, Mocambique, Benin, Burkina Faso, Senegal, Cote d´Ivoire, Togo, Mali, Mexico (Guadarrama et al., 2001), China, South Africa, Sweden (Kvarmo, 1998; Johansson et al., 2001; Richert Stintzing et al., 2001) and Germany (Simons & Clemens, 2004). These experiences have been supplemented by a literature study of the current knowledge on the function of plant nutrients. To assure the quality of the guidelines a reference group consisting of international experts was used.

The complete guidelines can be downloaded at www.ecosanres.org.

The authors are grateful for comments and additional information, as the guidelines will need intermittent updating.

RESULTS AND DISCUSSION

Amounts of nutrients and contaminants

Fertilisers should be applied according to their content of plant available nutrients, which should match the requirement of the crop. Due to the mass balance over the human body, the plant nutrient content of urine and faeces reflects the diet and thus differs between countries, families and persons. Data on the average food supply in different countries is published by the FAO on their web site, www.fao.org. Based on these data, the average excretion in different countries can be estimated using Equations 1 and 2 (Jönsson et al., 2004).

N= 0.13* Total food protein *Equation 1*

P= 0.011* (Total food protein + vegetal food protein) *Equation 2*

As shown by Table 1, the amount of N and P differs quite a lot between different countries. Note that the amounts of nutrient given in Table 1 reflect the average food supply in the different countries in the year 2000. The differences in diet between different persons and communities can be quite substantial and such differences will naturally also be reflected by the excreta.

Table 1. *Estimated excretion of nutrients per capita and year in different countries*

Country	Nitrogen kg/pers, yr	Phosphorus kg/pers, yr
China	4.0	0.6
Haiti	2.1	0.3
India	2.7	0.4
South Africa	3.4	0.5
Uganda	2.5	0.4

Most of the nutrients are excreted with the urine. Of the excreted nitrogen, 70-90% is found in the urine and for phosphorus the corresponding figure normally is 50-70%. The proportion of nutrients in the urine increases with increased digestibility of the food, simultaneously as the amount of faeces decreases. Thus, in Sweden the urine is estimated to contain on average 88% of the N and 64% of P (Jönsson et al., 2005), while the corresponding numbers for China are 70% of the N and 25-60% of the P (Gao et al., 2002). The production of faecal matter is in Sweden estimated at 51 kg/person and year, while it is estimated at 115 kg/person and year for China.

Due to the mass balance over the human body and the strict control of food products, the pollution of urine and faeces by e.g. heavy metals is very low (Palmquist & Jönsson, 2004). While excreta can contain pharmaceutical residues, the risk posed by these seems to be small, due to the ability of soil microbes to degrade essentially any organic substance and due to the efficient soil-root barrier against uptake of organic molecules into the plant.

PLANT AVAILABILITY

The plant availability of urine N is the same as that of chemical urea or ammonium fertilizers. This is to be expected, as 90-100% of urine N is found as urea and ammonium. This high plant availability of urine N has been verified by several fertilizing experiments. The urine P is almost entirely (95-100%) inorganic and is excreted in the form of phosphate ions, which are directly plant-available. Thus it is no surprise that their plant availability has been found to be at least as good as that of chemical phosphate fertilisers. Potassium (K) and sulphur (S) are excreted in the urine as ions, which are directly plant-available and are the same ions as supplied by chemical fertilizers. Thus, the plant availability of the urine nutrients is the same as that of good chemical fertilisers.

The plant availability of the faecal nutrients is slower than that of the urine nutrients. This is due to the fact that large proportions of the N and P stem from undigested matter and this matter needs to be degraded by the soil micro-organisms before the nutrients become available to plants. However, as the organic material in the faeces degrades, its content of organic N and P becomes available to plants. The high concentrations of P, K and organic matter in faecal matter can give substantial yield increases on poor soils. The organic matter contributes in several ways to a good and fertile soil: by improving the soil structure, increasing the water-holding capacity and the buffering capacity, and by serving as energy supply for the soil micro-organisms.

TREATMENT AND APPLICATION

Excreta should be treated according to hygiene guidelines for safe reuse (Schönning & Stenström, 2004) before being used in cultivation. The urine fraction is normally free from pathogens when leaving the body, but in many systems it can be contaminated by faeces. When single households use their own urine as a fertilizer, there is no need for storage prior to application, while the urine in large systems, collection from different households, should be stored between one and six months depending on the crop to be fertilised and the storage temperature, before application. In both cases, the last application should be made at least one month prior to harvest.

Preferably, local recommendations for the use of commercial fertilizers, urea or ammonium, should be translated to urine and for this, the N concentration of the urine ought to be analysed. If no analysis is available, the N concentration of the undiluted urine can be estimated at 3-7 g N per litre. If no local recommendations can be obtained, a general rule of thumb is to apply the urine produced by one person during one day (24 hours) to one square metre of crop. The urine from one person will thus suffice to fertilize 300-400 m^2 of crop per year and even up to 600 m^2, if dosed to just replace the phosphorus removed by a medium yielding crop. For most crops the maximum application rate, before risking toxic effects, is at least four times the dose above.

The nutrients are best utilized if the urine is applied prior to sowing or up until two-thirds of the period between sowing and harvest, i.e. while the crop takes up most of the nutrients. The urine can be applied neat or diluted (Table 2). However, the application rate should always be based on the desired N application rate and any need for supplementary water should be met with plain water. To avoid odour, foliar burns and loss of ammonia, the urine should be applied close to the soil and incorporated into the soil or watered down into it as soon as possible after application. The amount of urine to be spread can be applied in one large dose or in several smaller doses, and under most circumstances the total yield will be approximately the same for the same total application. Drip irrigation is not recommended as the urine P precipitates upon dilution with water and thus the system easily clogs up.

Table 2. *Average yields in plant trials with urine as a fertiliser in Zimbabwe and Sweden*

Plant, number of repetitions (n)	Unfertilised yield	Fertilised yield	Relative yield fertilised/unfertilised
Barley[a], n = 3 * 3 years = 9	1850 kg/ha	4690 kg/ha	2.5
Barley[b], n = 3	1378 g	6700 g	4.9
Leeks fertilised every 14 days[c], n = 3	17 t/ha	54 t/ha	3.2
Leeks fertilised twice[c], n = 3	17 t/ha	51 t/ha	3.0
Lettuce[d], n = 3	230 g	500 g	2.2
Lettuce[d], n = 3	120 g	345 g	2.9
Spinach[d], n = 3	52 g	350 g	6.7
Covo[d], n = 3	135 g	545 g	4.0
Tomato[d], n = 9	1680 g	6084 g	3.6

a. *Field experiment, urine:flush water≈1:1-2. Johanssson et al. (2001); Richert Stintzing et al. (2001).*
b. *Pot experiment, urine:flush water≈1:1-2. Kvarmo (1998).*
c. *Field experiment, urine:flush water≈1:1.8-11. Åkerberg and Båth (2005).*
d. *Pot experiments, urine: water≈1:3. Morgan (2003).*

Faeces should be sanitised before being used as fertiliser and should be applied prior to planting or sowing as the high phosphorus content is beneficial for root formation of young plants.

For faeces, the application rate can be based on the local recommendation for the use of phosphorus fertilisers. This results in a low application rate, and the improvement due to the added faecal organic matter is hard to distinguish. Thus, faeces are often applied at much higher rates, at which the structure and water-holding capacity of the soil are visibly improved. Ash and/or lime are often added to the faeces and they help to improve the buffering capacity and the pH of the soil, which is especially important on soils with low pH. Thus, the faeces from one person will suffice to fertilise 1.5-300 m^2, depending on whether they are applied according to their content of organic matter or phosphorus. The faeces should be thoroughly covered by soil before cultivation starts. If there is a limited amount of faeces fertilizer available, it can be applied in holes or furrows close to the planned plants to

capitalize on this valuable asset.
The best fertilising effect is achieved if urine, containing lots of plant available N, P and K, and faeces, rich in organic matter and not quite as readily available nutrients, are used in combination with each other, but preferably not at the same time.

CONCLUSIONS AND RECOMMENDATIONS

- Urine and faeces are both complete high quality fertilizers. The best fertilizing effect is achieved if they are used in combination with each other, but preferably not at the same time.
- Urine is a quick-acting N-rich complete fertilizer. Its nutrients are best utilized if the urine is applied from prior to sowing, up until two-thirds of the period between sowing and harvest.
- Urine can be applied neat or diluted. However, the application rate should always be based on the desired N application rate and the urine or urine mixture should be quickly incorporated into the soil, to minimize ammonia loss. Any potential need of supplementary water should be met by plain water, not diluted urine.
- The recommended application rate and time for chemical N fertilizers (urea or ammonium if available) is the best starting point for developing local recommendations on application rate and time for urine.
- If no recommendations can be obtained, a rough rule of thumb is to apply the urine collected from one person during one day (24 hours) to one square metre of crop. If all urine is collected, it suffices to fertilize 300-400 m^2 per person and year. For most crops, the maximum application rate before risking toxic effects is at least four times the dosage above.
- For most crops and under most circumstances, the yield is constant for the same total application rate, whether it is applied in one large dose or in several smaller ones.
- Faecal matter is especially rich in phosphorous, potassium and organic matter.
- Both ash and lime, which are often added to the faeces, increase the buffering capacity and the pH of the soil, especially important on soils with low pH.
- Organic matter also improves the structure and the water-holding capacity of the soil.
- Faeces should be mixed into and covered by the soil before cultivation starts. Application in holes or furrows close to the planned plants is one way of economizing on this asset.
- For faeces, the application rate can be based on the current recommendation for the use of phosphorous-based fertilizers. This gives a low application rate, and the improvement due to the added organic matter is hard to distinguish. However, faeces are often applied at much higher rates, at which the structure and water-holding capacity of the soil are also noticeably improved.

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