M4: Management: Planning, Implementation and Operation

M4-7: Agricultural Aspects

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We apologize in advance if references are missing or incorrect, and welcome feedback if errors are detected.

We encourage all feedback on the composition and content of this curriculum. Please direct it either to johannes.heeb@seecon.eu or petter.jenssen@umb.no, or use the feedback form.

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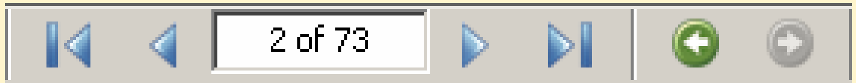

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Indicates Internet links and resources

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Indicates specific texts, files, or documents for further reading

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Shows a link to a case study that shows the connection between an abstract topic and the “real life situation” more closely.

(99)

Sources are indicated in (99) brackets. You will find the full list of references at the very end of the modules.

Glossary

This button, located at the beginning of each module, opens up the glossary in separate window. It is recommended that you keep the glossary open all the time, so you can easily look up unknown terms.

Abbreviations

With this button, located at the beginning of each module, you can open up a file with the most frequently used abbreviations and acronyms.

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K. Conradin

Glossary

Abbreviations

Executive Summary

"Recommendations for agricultural use of excreta are based on knowledge of the nutrient content of the excreta, the amounts excreted, the composition and plant availability of the fertilizer and the treatment of the excreta, which influences their properties. Relationships and data that can form a basis for adapting the guidelines to local conditions are presented in the text.

Urine and faeces are complete fertilizers of high quality with low levels of contaminants such as heavy metals. Urine is rich in nitrogen, while faeces are rich in phosphorous, potassium and organic matter. The amount of nutrients excreted depends on the amounts in the food consumed, and equations are presented for calculation of nitrogen and phosphorus in excreta based on easily available statistics on the supply of food protein. Excreta should be handled and treated according to the hygiene guidelines before use in cultivation.

Specific local recommendations for the use of urine and faeces in cultivation should be based on local recommendations for fertilization of crops. Application rates for commercial mineral nitrogen fertilizers (urea or ammonium), if available, can be used as a basis for recommendations on the use of urine. Before translating such recommendations to urine, its nitrogen (N) concentration should ideally be analysed. Urine also contains lots of phosphorus, and it will suffice to fertilize up to 600 m2 of crop per person and growing season, if the application rate is chosen to replace the phosphorus removed."

Executive Summary

"Urine can be applied neat or diluted. However, its application rate should always be based on the desired nutrient application rate and any potential need for supplementary water should be met with plain water, not diluted urine. To avoid smells, loss of ammonia and foliar burns, urine should be applied close to the soil and incorporated as soon as possible.

Urine is a quick-acting fertilizer whose nutrients are best utilized if the urine is applied from prior to sowing up until two-thirds of the period between sowing and the harvest. The best fertilizing effect is usually achieved if urine and faeces are used in combination with each other, but not necessarily in the same year on the same area.

For faeces, the application rate can be based on the local 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 visibly improved as an effect of its increased organic matter. Both organic matter and ash are often added to the faeces and they improve the buffering capacity and the pH of the soil, which is especially important on soils with low pH. Thus, depending on the application strategy, the faeces from one person will suffice to fertilize 1.5-300 m2, depending on whether they are applied according to their content of organic matter or phosphorus. Faeces should best be applied and mixed into the soil before cultivation starts." (5)

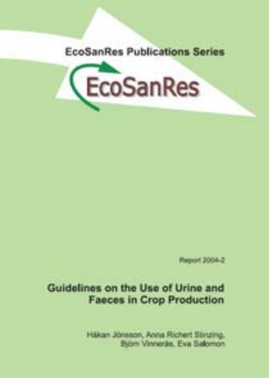
This module is closely adapted from the Guidelines on the Use of Urine and Faeces in Crop Production (Jönsson, H., Richert Stintzing A., Vinnerås, B. & E. Salomon). For more detailed information, please refer to this publication.

Note

Note: In order to apply adequate amounts of fertilizer – be it urine or treated faeces – the soil quality should be analysed. Soil quality varies greatly all over the world; thus, uniform application norms cannot be given, and it should be referred to local or national guidelines. These guidelines should be followed, also in order to avoid over-fertilization and thus potentially negative impacts on groundwater (i.e. through leaching) or surface waters (run-off).

Moreover, hygiene guidelines should be followed strictly. For this, refer to the *Ecosanres Guidelines for the Safe Use of Urine and Faeces in Ecological Sanitation Systems* (www.ecosanres.org/), or the new *WHO Guidelines on the Safe Reuse of Excreta and Greywater*, which will be published at the beginning of 2006).

This module is adapted from the *Guidelines on the Use of Urine and Faeces in Crop Production* (Jönsson, H., Richert Stintzing A., Vinnerås, B. & E. Salomon). For more detailed information, please refer to this publication. You can access it by clicking on the thumbnail to the right – it is also referred to later in this module.



Introduction

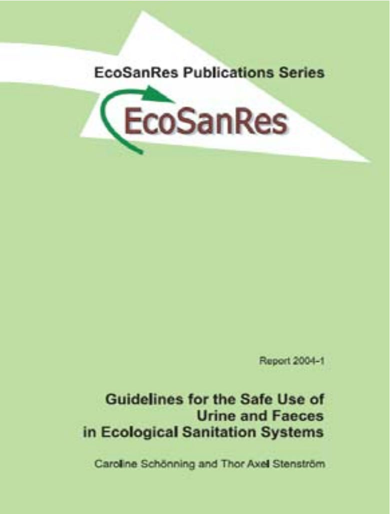
“Faeces contain disease-causing organisms called pathogens to a much higher degree than urine. Therefore, it is important to avoid cross-contamination between urine and faeces.

Organisms that can cause disease include viruses, bacteria and parasitic protozoa, as well as hookworms and other parasitic helminths (see M4-5). Some may lead to severe illness or even death. Others may not be the direct cause of any symptoms but could still lead to diarrhoea, malnutrition or increase the risk of other infections for the individual infected. In some cases the pathogens can survive for long periods outside the human body and in other cases they are readily destroyed. Factors such as heat, pH, moisture, solar radiation/UV-light, nutrient availability and presence of other microorganisms affect their survival.

To avoid the risk of being exposed to pathogens, it is important to reduce contact with the excreta, and to decrease the number of pathogens in the material. Pathogens such as protozoa and viruses will decrease naturally since they are not able to multiply outside the host, but bacteria may continue to multiply under favourable conditions.” (1)

For more information on hygienic aspects of reuse of excreta in agriculture, please refer to Module 4-5 (Health & Hygiene) and to the Ecosanres Guidelines on the Safe Use of Urine and Faeces in Ecological Sanitation Systems.

Click directly on the thumbnail to access these guidelines.



EcoSanRes Publications Series

EcoSanRes

Report 2004-1

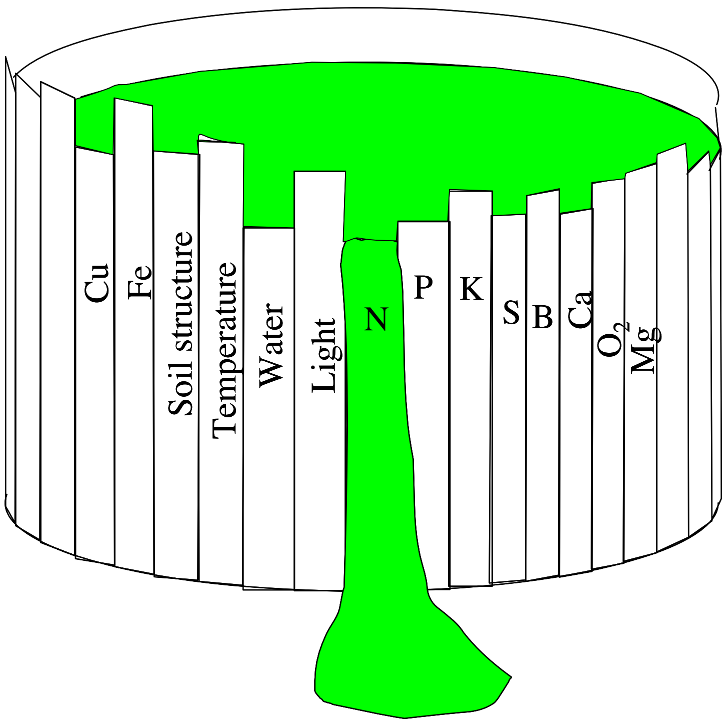
Guidelines for the Safe Use of Urine and Faeces in Ecological Sanitation Systems

Caroline Schönning and Thor Axel Stenström

Source: (1)

Requirements for Plant Growth

Source: Vinnerås (5)



“The requirements for plant growth include light, water, a structure for roots to grow in and nutrients. The limiting factors regulating the growth of plants can be illustrated as in the figure above. When the supply of the most limiting growth factor is increased, then other growth factors become important as limiting factors. If factors other than nutrients are limiting, e.g. water, light, pH, salinity, light or temperature, then adding more nutrients will not increase the yield.” (5)

Source: (5)

"Elements essential for the growth of plants are called nutrients. The nutrients used in the largest amounts are the non-mineral elements, i.e. carbon, hydrogen and oxygen. These elements are mainly taken up as carbon dioxide (CO_2) from the air, and water (H_2O) by the roots. Increasing the supply of light, carbon dioxide, water and mineral nutrients from the deficiency range increases the growth rate and crop yield.

Nutrients can be divided into the two categories; macronutrients and micronutrients. The uptake of **macronutrients** is about 100 times that of micronutrients. The six elements normally classified as macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg). These nutrients are mainly taken up from the soil by the roots in ionic form.

Micronutrients are as essential for plant growth as macronutrients, but are taken up in small (micro) amounts. The elements normally considered micronutrients are boron, copper, iron, chloride, manganese, molybdenum and zinc (6,7).

Fertilization increases crop yield only if the plant nutrient supplied is one of the most limiting growth factors (see figure above). No yield increase is to be expected when fertilizing crops that are mainly limited by factors other than nutrient supply, e.g. lack of water, too low or too high pH, etc."

For more information on nutrients in human excreta, refer to Module M2-2.

Source: (5)

Composition of Human Excreta

"Basically, the amount of plant nutrients excreted by one person almost equals that consumed. This has three important implications:

- The amount of excreted plant nutrients can be calculated from the food intake, on which the data are both better and more easily available than on excreta.
- If the excreta and biowaste, as well as animal manure and crop residues, are recycled, then the fertility of the arable land can be maintained, as the recycled products contain the same amounts of plant nutrients as were taken up by the crops.
- Differences in composition of excreta between different regions reflect differences in the uptake of the consumed crops and thus in the plant nutrient supply needed for maintained fertility.

Irrespective of the amounts and concentrations of plant nutrients in the excreta, one important fertilizing recommendation is thus to strive to distribute the excreta fertilizers on an area equal to that used for producing." (5) The table on the next slide shows the estimated excretion of nutrients per capita in different countries:

Source: (5)

Composition of Human Excreta: Nutrients

Country		Nitrogen kg/cap, yr	Phosphorus kg/cap, yr	Potassium kg/cap yr.
China, total		4.0	0.6	1.8
	Urine	3.5	0.4	1.4
	Faeces	0.5	0.2	0.5
Haiti, total		2.1	0.3	1.2
	Urine	1.9	0.2	0.9
	Faeces	0.3	0.1	0.3
India, total		2.7	0.4	1.5
	Urine	2.3	0.3	1.1
	Faeces	0.3	0.1	0.4
South Africa, total		3.4	0.5	1.6
	Urine	3.0	0.3	1.2
	Faeces	0.4	0.2	0.4
Uganda, total		2.5	2.5	1.4
	Urine	2.2	2.2	1.0
	Faeces	0.3	0.3	0.4

Source: (8)

"The exact amount of nutrients contained in human urine and faeces varies according to different diets, the digestibility of the diet (urine contains digested nutrients, while undigested fractions are excreted with the faeces) and thus varies in different parts of the world. For urine, the amount of nutrients also depends on the dilution." (5)

Source: (5)

Composition of Human Excreta: Heavy Metals & Micropollutants

"The contents of **heavy metals** and other contaminating substances such as pesticide residues are generally low or very low in excreta, and depend on the amounts present in consumed products.

A large proportion of the **hormones** produced by our bodies and the pharmaceuticals that we consume are excreted with the urine, but it is reasonable to believe that the risk for negative effects on the quantity or quality of crops is negligible. All mammals produce hormones and, during the course of evolution, these have long been excreted in terrestrial environments. Thus, the vegetation and soil microbes are adapted to, and can degrade, these hormones (which is not the case in water bodies). The amount of hormones in manure from domestic animals is far larger than the amount found in human urine. Thus, even though theoretical estimations based on tests with fish have indicated a risk of ecotoxicity from oestradiol (9) when applying urine, both fertilizer experiments and evolutionary history strongly indicate that there is no real risk.

By far the majority of all **pharmaceutical substances** are derived from nature, even if many are synthetically produced, and they are thus found and degraded in natural environments with a diverse microbial activity. This has been verified in ordinary wastewater treatment plants, where the degradation of pharmaceutical substances improved when the retention time was prolonged from a number of hours to a number of days. Urine and faecal fertilizers are mixed into the active topsoil, which has a microbial community just as diverse and active as that in wastewater treatment plants, and the substances are retained for months in the topsoil. This means that there is plenty of time for the microbes to degrade any pharmaceutical substances and that risks associated with them are small."

Source: (5)

Plant Availability of Nutrients in Urine and Faeces

"While the nutrients in urine are mostly water-soluble and thus directly available to plants, faeces contain both water-soluble and nutrients that are combined in larger particles not soluble in water. The plant availability of the nutrients in the faecal matter is lower and slower than that of the urine nutrients. This is due to the fact that the main proportion of the P and a large proportion of the N stem from undigested matter and this matter needs to be degraded in the soil to become available to plants. However the organic material in the faeces degrades and its content of organic N and P then becomes available to plants.

The organic matter contributes in several ways: by improving the soil structure, increasing the water- holding capacity and the buffering capacity, and by supporting the soil microorganisms by serving as an energy source."

Source: (5)

Urine as a Fertilizer

"Urine used directly or after storage is a high quality, low cost alternative to the application of N-rich mineral fertilizer in plant production. Urine is best utilized as a direct fertilizer for N-demanding crops and leafy vegetables. If crop- and region-specific recommendations are available for the use of N fertilizers (urea, ammonium or nitrate), a good starting point for how to use urine is to translate the recommendations to urine. The translation is simplified if the N concentration of the urine is known. If it is not then, as a rule of thumb, a concentration of 3-7 grams of N per litre of urine can be expected (8,10). Urine also contains large amounts of P and K, but due to its large content of N, its P/N and K/N ratios are lower than in many mineral fertilizers used for vegetable production.

The effect of urine, just as that of chemical fertilizers, is probably somewhat lower on a soil with a low content of organic substances than on a soil with a high organic content. Experience shows that it is beneficial for soil fertility to use both urine and faeces or other organic fertilizers on the soil, but they can be used in different years and for different crops." (5)

Urine as a Fertilizer: Dilution

Dilution

Urine can be **applied** neat (without dilution) or diluted with water. The dilution level varies between approximately 1:1 to 10:1. A dilution 3:1 seems common in agriculture, if urine is applied diluted.

− Dilution increases:

- the volume to be spread
- labour
- equipment needed
- the energy use
- risk for soil compaction
- additionally, pathogen destruction is decreased in diluted urine.

+ Dilution decreases:

+ Risk of over-application
+ Risk of toxicity to plants

⇨ "Urine must be applied at the rate corresponding to the desired application rate of N, while additional water should be applied according to the needs of the plants

⇨ Diluted urine should be handled in the same way as urine. In order to avoid smells, loss of ammonia, generation of aerosols, burns and possible contamination on plants by remaining pathogens, urine should be applied close to the soil. It is even better if urine is directly incorporated into the soil. Foliar (on leaves) fertilization is not recommended." (5)

⇨ Note: During storage, the urine should preferably not be diluted. Concentrated urine provides a harsher environment for microorganisms, increases the die-off rate of pathogens and prevents breeding of mosquitoes. Thus, the less water that dilutes the urine the better.

Source: (5)

Urine as a Fertilizer: Application Time

⇨ "In the early stages of cultivation, good availability of all nutrients is important to enhance growth. In large-scale crop production, normal fertilizing strategy is application of nutrients once or twice per growing season. If fertilizer is applied only once, this should normally be carried out prior to or at the time of sowing/planting. If the crop is fertilized twice, the second fertilization can be performed after approximately 1/4 of the time between sowing and harvest, differing depending on the needs of the crop.

⇨ The crop can also be **continuously fertilized**, e.g. if the urine is collected in smaller containers and used more or less directly. However, once the crop enters its reproductive stage it hardly takes up any more nutrients.

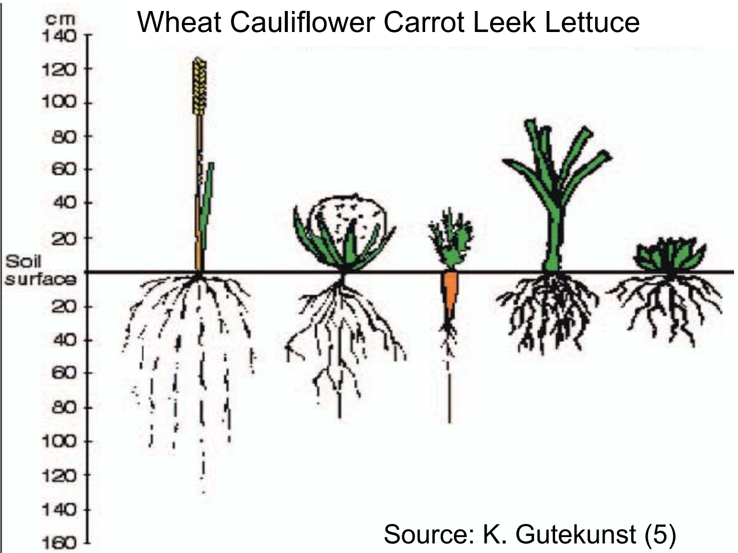
⇨ As a rule of thumb, fertilization should **stop** after between 2/3 and 3/4 of the time between sowing and harvest.

⇨ A **waiting period of one month** between fertilization and harvest is very advantageous from a hygiene point of view and recommended for all crops eaten raw (2).

⇨ In regions where there is **heavy rainfall** during the cropping season, repeated applications of urine may be an insurance against losing all the nutrients in one rainfall event.

⇨ The total applied amount of urine and whether it should preferably be applied once or several times also depends on the N need of the plant and its root size. **Root size** varies widely between different crops (Figure 3). Plants with inefficient or small root systems, e.g. carrots, onions and lettuce, can benefit from repeated applications of urine throughout the cultivation time (11)."

Source: (5)



Source: K. Gutekunst (5)

Urine as a Fertilizer: Application Technique

"For best fertilizing effect and to avoid ammonia losses, the urine should be incorporated into the soil as soon as possible after the application, instantly if possible (12, 13, 14). A shallow incorporation is enough, and different methods are possible. One is to apply urine in small furrows that are covered after application. Washing the nutrients into the soil with subsequent application of water is another option." (5)

Large Scale Application of human Urine in furrows (Sweden)

⇨ "When spreading urine, it should not be applied on leaves or other parts of the plants, as this can cause **foliar burning** due to high concentrations of salts when drying. Spraying urine in the air should also be avoided due to the risk of N loss through gaseous emissions of ammonia (12, 14) and the hygiene risk through aerosols." (5)

Foliar Burning

Source: (5)

Urine as a Fertilizer: Application Technique

- “**Drip irrigation** using urine as a fertilizer is another possible application technique. However, when this technique is used, measures must be taken to avoid blockages due to precipitation of salts forming sludge. The total amount of precipitation often increases after dilution with water, as water normally contains some magnesium and calcium.
- Some crops, e.g. tomatoes, are sensitive to having all their roots exposed to urine, at least when plants are small, while on many crops no negative effect is seen at all. Therefore, before the sensitivity of a crop is known, **it is wise not to simultaneously expose all the roots of the plant to urine**, be it neat or diluted. Instead, urine can be applied either prior to sowing/planting or at such a distance from the plants that the nutrients are within reach of the roots, but not all of them are soaked. For annual plants this distance may be about 10 cm.
- Spreading can for instance easily be done **with an ordinary watering can**, as the image to the right shows. Vegetables fertilized with urine, Sweden.” (5)


Source: B. Vinnerås


H. Jönsson, SLU

Urine as a Fertilizer: Application Rate

"A starting point for the dimensioning of urine application is the local recommendations for use of commercial mineral N fertilizers, preferably urea or ammonium fertilizers. If such recommendations are not available, another starting point can be to estimate the amounts of nutrients removed by the crop, which for some crops are given in the table below.

Urine can be recommended for most crops. Since it is especially rich in N, it may be wise to give priority to crops that have a high value and that respond well to N, such as spinach, cauliflower, ornamental flowers and maize. However, there is no reason not to use urine, if there is enough, as a fertilizer to other crops, as experiences from all over the world show good results." (5)

Crop	Amount kg/ha	Water content %	N kg/ha	P kg/ha	K kg/ha
Cereals					
Maize, dry[1]	1000	10	15.1	2.1	2.9
Maize. fresh	1000	69	6.2	1.1	2.9
Millet	1000	14	16.8	2.4	2.2
Rice. unpolished	1000	12	12.4	3.0	2.3
Sorghum	1000	11	17.6	2.9	3.5
Wheat	1000	14	17.5	3.6	3.8
Others					
Green beans. fresh	1000	90	2.9	0.4	2.4
Irish potatoes	1000	80	2.9	0.3	4.7
Lentils. dry	1000	12	38.4	3.8	7.9
Onions	1000	91	1.9	0.4	1.9
Pumpkin	1000	92	1.6	0.4	3.4
Red beans, dry	1000	11	35.2	4.1	9.9
Soybeans, dry	1000	10	59.5	5.5	17.0
Spinach	1000	94	3.0	0.3	5.6
Tomatoes	1000	93	1.4	0.3	2.1
Water melon	1000	91	1.0	0.1	1.2
White cabbage	1000	92	2.2	0.3	2.7

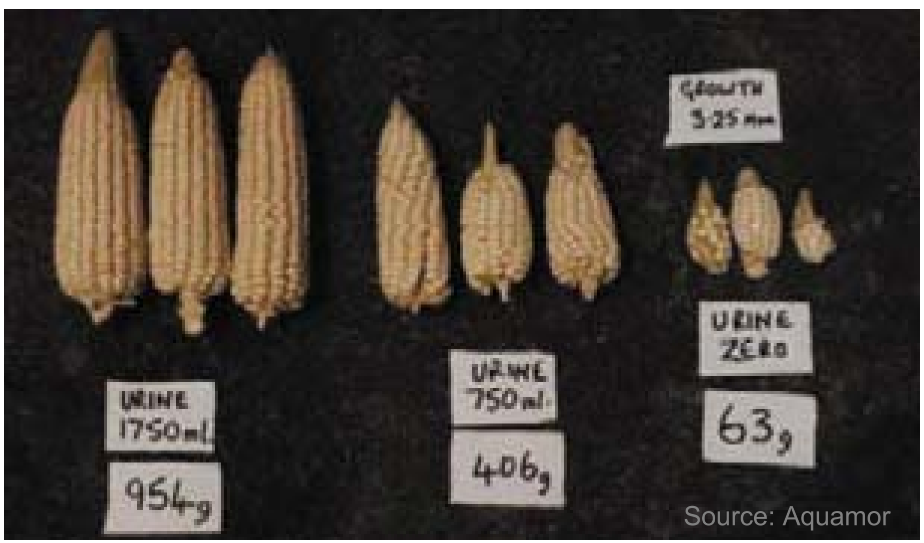
Source: (5)

[1] Source: (15)

Urine as a Fertilizer: Examples

Photo: Peter Morgan, Aquamor.

"The spinach to the left is unfertilized. The spinach to the right is fertilized with urine diluted with three parts of water to one part of urine applied two times per week." (5)



Source: Aquamor

"Maize trials using urine as a fertilizer. Urine treatments of 750 ml and 1750 ml. Growth period 3.25 months. Zimbabwe." (19)

Case Study

Practical Recommendations for Urine: Safe Application of Urine

Source: GTZ

"The **major recommendations for urine are**:

- direct use after collection or a short storage time is acceptable on the single household level
- storage should be made for larger systems (where the time and conditions, stated in the table on the next slide, are followed)
- at least one month should apply between fertilisation and harvest (see table next slide
- additional stricter recommendations may apply on a local level, if frequent faecal cross-contamination is envisaged. The recommendations for storage times is directly linked to agricultural use and choice of crop

  Additional practises to minimise the risks include the following:

  ⇨ When applying the urine precautions related to the handling of potentially infectious material should be taken. These precautions could e.g. include wearing gloves and thorough hand washing.

  ⇨ The urine should be applied with close-to-ground fertilising techniques. In that way, aerosol formation can be decreased.

  ⇨ The urine should be incorporated into the soil. This could in practise be done mechanically or by subsequent applying irrigation with water.

A close to the ground application/fertilising method is recommended to minimise aerosol formation. On a large scale this is often done by using special agricultural equipment while on a smaller scale it is often applied manually. Handling smaller volumes is often safe, and the urine should preferably not be diluted before application." (2)

Practical Recommendations for Urine: Safe Storage of Urine

Recommended guideline storage times for urine mixture[a] based on estimated pathogen content[b] and recommended crop for larger systems[c]. (3,4)

Storage temperature	Storage time	Pathogens in the urine	Recommended Crops
4°C	>1 month	viruses, protozoa	food and fodder crops that are to be processed
4°C	>6 months	viruses	food and fodder crops that are to be processed, fodder crops [d]
20°C	>1 month	viruses	food and fodder crops that are to be processed, fodder crops [d]
20°C	>6 months	probably none	all crops [e]

[a] Urine or urine and water. When diluted it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1g/l.

[b] Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognised for causing any of the infections of concern.

[c] A larger system in this case is a system where the urine mixture is used to fertilise crops that will be consumed by individuals other than members of the household from which the urine was collected.

[d] Not grasslands for production of fodder.

[e] For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

Faeces as Fertilizer

"While the total amount of nutrients excreted with faeces is lower than with urine, the concentration of nutrients, and especially P and K, is high in faeces and, when used as a fertilizer, faecal matter can give significant increases in plant yield. P is particularly valuable for the plant in its early development and important for good root development. In addition to supplying macro- and micronutrients, faeces contain organic matter, which increases the water-holding and ion-buffering capacity of the soil, serves as food for the microorganisms and is important for improving soil structure. However, the risk for high concentrations of pathogens in faeces is large and thus it is critical that the faeces are handled in such a way that the risk of disease transmission is minimized. The relevant hygiene guidelines (see M4-5) should be followed." (5)

Faeces as Fertilizer – Fertilizing Effects Depending on Treatment

"Faeces contribute to crop production both by their fertilizing effect and by their soil-improving effect. The fertilizing effect of faeces varies much more than the effect of urine. This is mainly due to the fact that the proportion of N that is in mineral form in the faeces varies largely between the different treatment strategies.

Moreover, different additives are used in the different treatments and these additives contribute to the total content of nutrients and organic matter in the treated faecal product. The soil-improvement effect consists of increased buffering capacity, moisture-retaining capacity and contribution to food for microbial activity. The soil improvement effect varies according to the same principles as stated above. In the following section, the fertilizing effects of different treatment methods are discussed shortly." (5)

Fertilizing Effects: Ash

Ash (Incineration)

“Incineration of faeces results in ash with high contents of P and K as well as the other macro- and micronutrients. However, N and S are lost with the fume gas. Thus, ash is a PK fertilizer with micronutrients and a high pH, increasing the buffering capacity of the soil. The plant availability of the nutrients in ash is good as long as the incineration temperature is not high enough for the ash to melt. If so, then the availability of the plant nutrients probably decreases drastically.

Depending on the choice of primary treatment, additions of ash, soil, lime or other desiccation materials can be made, which affects the incineration. Additional fuel may also be needed. Ash and lime contribute towards the pH-increasing effect of the product, a most desirable effect since the pH of most soils is below the optimal, 6-7 for most crops. On soils with very low pH (4-5) this is a very important effect for cropping and also for getting the full benefit from fertilizing with, for example, urine, which has been shown both in Uganda and Zimbabwe.” (5)

Fertilizing Effects: Compost

J. Heeb

"Compost from thermophilic or low-temperature composting

In many respects, composting functions like a slow and partial incineration mediated by microbes. Often some 40-70% of the organic matter and somewhat less of the N are lost. Remaining N is mainly (often about 90%) in organic form and this only becomes plant-available at the rate of degradation, which is slow as the remaining organic matter is more stable than the initial organic matter. This stable organic matter improves the water-holding and buffering capacity of the soil. The P is also to some extent, but far less than N, bound in organic forms, while the K is mainly in ionic form and thus plant-available. Compost should be applied as a complete PK fertilizer or as a soil improver.

Additions of organic waste in the composting treatment, just as additions made in the primary treatment, naturally affect the amount and characteristics of the compost." (5)

Fertilizing Effects: Desiccation/Biogas/Alkaline Treatment

Source: GTZ

Source: GTZ

“Dried faeces from desiccation and storage

If the drying is fast and a low moisture level is achieved, the losses of both organic matter and N are small. Most of the organic matter is conserved and upon application it both improves the soil and serves as food for the soil microbes. Thus, compared to composting, dry storage of the faeces recycles more organic matter and N to the soil, but the organic matter is less stable. Dried faecal matter is a complete PK fertilizer, which also contributes considerable amounts of N.” (5)

“Residues from anaerobic digestion (Biogas Production)

In anaerobic digestion, approximately the same proportion of organic matter is degraded as in composting (i.e., 40-70%). In biogas production the mineralized N is not lost, as it largely is in composting. Instead, the N remains as ammonium in the digestion residue. Some 40-70% of the N found in the residue is in the form of ammonium, which is readily plant-available. Thus, for most crops digestion residue is a well-balanced, quick-acting and complete fertilizer (17). To most digestion processes, additional substrates such as animal manure and household waste are added, which naturally affects the amount and composition of the digestion residue.” (5)

Chemical treatment with urea (alkaline treatment)

“When faeces are treated with urea, the ammonia content (NH_3) is elevated to high levels, as high or higher than in neat urine. The large content of P and K in the faeces means that this is still a well-balanced and complete fertilizer. The urea-treated faeces should be applied according to their content of mineral N. Ash and other additions during the primary treatment contribute to the properties of the product.” (5)

Practical Recommendations for Faeces: Application Time

“Irrespective of how the faeces have been treated, they should be applied **prior to sowing or planting**. This is because the faeces contain large amounts of P and the availability of P is very important for good development of small plants and of roots. The faeces need to be applied in such a way that they come in contact with the soil solution, which can dissolve and transport the nutrients to the roots. Thus, the faecal products need to be well incorporated into the soil, and this should be done before the sowing/planting in order not to disturb the small plants.

Finally, faeces initially contain lots of pathogens. Therefore barriers are desired between faeces and the food crop, to minimize the risk of disease transmission via food crops fertilized with faeces.

Several barriers against disease transmission can be identified:

1. Secondary treatment of faeces.
2. Application and thorough covering of the treated faeces before sowing/planting
3. Avoiding faeces as a fertilizer to vegetables eaten raw

In climates with a dry season before the cultivation period, the faecal product may be spread during the dry season or at the end of the preceding growth season.” (5)

Practical Recommendations for Faeces: Application Technique

"Two of the largest benefits of faeces are its content of P and organic matter. To make full use of these, the faecal matter must be

- ⇨ applied at a depth where the soil stays moist, because the P only becomes available to the plants at the rate that it dissolves in the soil liquid.
- ⇨ Likewise, the water-holding and buffering capacity of the organic matter are fully utilized only in moist conditions.

Thus, the faecal fertilizer product, irrespective of its form should be applied at such a depth and in such a way that it is well covered by the upper layer of the soil. However, the rooting depth of plants is limited, and if faeces are applied at depths exceeding the rooting depth, the plant nutrients will not be available to the plants.

The application technique differs depending on the desired application rate. If the desired application **rate is high**, i.e. large amounts are available in relation to the area to be fertilized, the faeces can be dug into the soil in a layer which is covered by surface soil not mixed with any faecal product, forming a bed. Digging is used in the small scale, while in the larger scale ploughing is preferred, since it covers the product well with unmixed soil.

If the desired application **rate is low**, the faecal product is preferably applied in furrows covered by unmixed soil. At lower application rates, the faecal product can be applied in holes close to where the plants will be growing.

The faecal product should always be well covered and placed in such a way that is within reach of the roots but not their only growing medium." (5)

Practical Recommendations for Faeces: Application Technique

“The **ammonia (NH_3) content** of digestion residues and urea-treated slurry is high. These products should be stored, handled and applied in such a way that ammonia losses are minimized. This entails storage in covered containers and rapid incorporation into the soil. Ash is a concentrated fertilizer and should be carefully distributed to utilize its nutrient content in the most effective way. Spreading ash evenly may be difficult. It is simplified if mixed with a bulking agent such as sand or dry soil.“ (5)

“The use of faeces in the production of trees is an example of how application in a hole can be used for perennial crops. When planting a tree, dried, composted or incinerated faeces may be used to increase soil fertility. A suitable way to spread the faeces is to mix in a shovel of dried or composted faeces with the soil in the pit that has been dug for the planting of the tree. This will stimulate its early growth.” (5)

Sabtenga, Burkina Faso. Mango tree fertilized with faeces at planting and doses of urine regularly during the growth season.

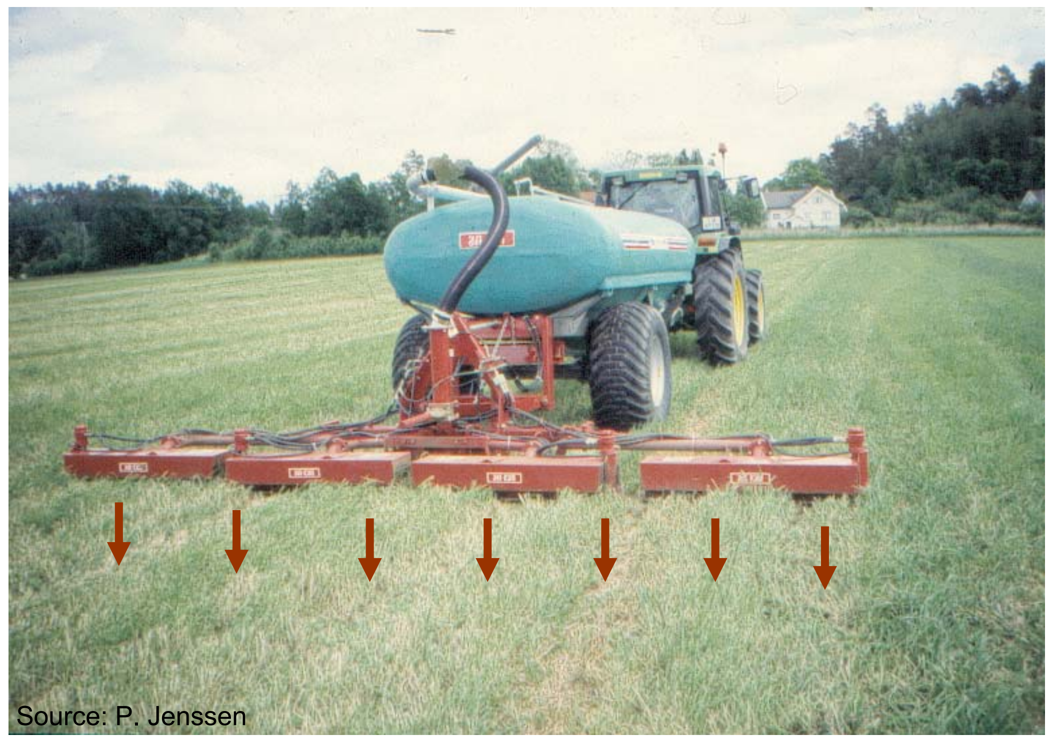
Practical Recommendations for Faeces: Application Rate

"The rates at which most faecal products can be applied span a large interval. The two most beneficial effects to be gained from most faecal products are their supply of P and of organic matter. The main benefits from these effects are gained at very different application rates. Depending on the amount of P excreted (i.e., ultimately, on the diet), and if P is applied at the removal rate of the crop, then the faecal matter from one person is enough to fertilize some 200-300 m^2 of wheat at a yield level of 3000 kg/ha per person.

However, in many places, the soil is so devoid of P that the recommended application rate is 5-10 times the removal rate, and in this case the faecal matter from one person in a year contains enough P to fertilize 20-40m^2.

When it comes to the organic matter content in the faecal product, higher rates of application are needed to achieve effects on the soil system that will in turn give higher yields. The application rate then depends on the amount of organic matter desired in the soil, and thus of its original state." (5)

For further information, refer to the Ecosanres Guidelines on the Use of Urine and Faeces in Crop Production.



Direct Ground Injection system, practiced in Norway

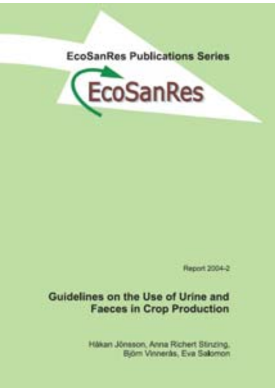
Source: P. Jenssen

Practical Recommendations for Faeces: Application Rate

“However, high and stable organic matter content of the soil is only accomplished over longer periods of time. The organic matter in the applied material, e.g. dried faeces or compost, is not as stable as the humus of the soil and will degrade in the soil. The advantage of this is that the more that it degrades, the more plant nutrients are mineralised and become plant-available. The drawback is that this degradation means that the content of organic matter decreases and therefore continued applications of organic matter are needed in order to permanently raise the soil organic matter content.

Adding highly degradable organic matter, e.g. dried faeces, means that a large proportion of the nutrients become plant-available but that the organic matter degrades quickly. Adding a more stabilized product rich in humus, e.g. compost, means that less N becomes plant-available but on the other hand the increase in soil organic matter is more durable. “ (5)

For further information, refer to the Ecosanres Guidelines on the Use of Urine and Faeces in Crop Production (click directly on the thumbnail).



Risks of high application

Practical Recommendations: Safe Reuse of Faeces

"The agricultural use practises (and recommendations) will be dependent on the preceding treatment. Even if a treatment is aimed at elimination of the risk of pathogen transmission and its potential has been proven in laboratory and/or field experiments, process steps may malfunction, resulting in a fertiliser product that is not completely hygienically safe. Therefore additional measures should be taken in order to further minimise the risk for disease transmission. Thus:

- ⇨ Equipment used for e.g. transportation of un-sanitised faeces should not be used for the treated (sanitised) product.
- ⇨ When applying faeces to soil precautions related to the handling of potentially infectious material should be taken. These precautions should include personal protection and hygiene. Hand washing should naturally be done.
- ⇨ Treated faeces should be worked into the soil as soon as possible and not be left on the soil surface.
- ⇨ Improperly sanitised faeces should not be used for vegetables, fruits or root crops that will be consumed raw, excluding fruit trees.

Incinerated faeces will be hygienically safe – but some nutrients are lost (see M4-5). The subsequent handling of the resulting ash is outside of the scope of this summary recommendation." (2)

Case Study

Adaptation to Local Conditions

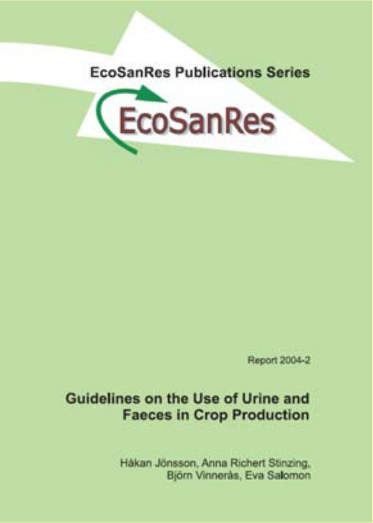
Note: These guidelines should be adapted to local conditions. Agricultural systems vary, as do the practices of humans from place to place. As a starting point, national data on nutrient content of urine and faeces as well as amounts excreted during a year can be developed based upon calculations according to the method described in the “Contents of macronutrients in excreta” section in the ‘Guidelines on the Use of Urine and Faeces in Crop Production’, supplemented with relevant measurements. The urine and faeces should then be used according to local fertilizing guidelines and recommendations.

++ Further Reading: Ecosanres Guidelines

Further reading

The *Guidelines on the Use of Urine and Faeces in Crop Production* give a more detailed insight into what has been dealt with in this module, including more exact guidelines, i.e. concerning how much fertilizer has to be applied, when and how it is to be applied etc.

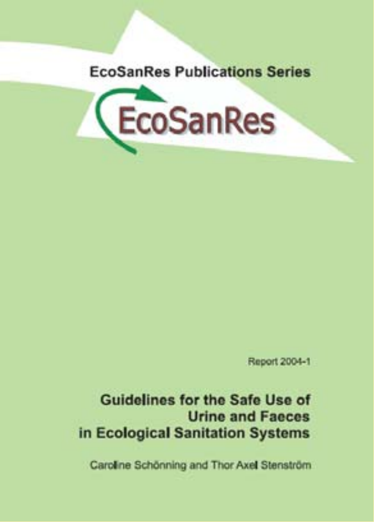
Click directly on the thumbnail to access these guidelines



Further reading

Just as important as the guidelines above are the *Guidelines for the Safe Use of Urine and Faeces in Ecological Sanitation Systems*, which deal more fondly with the hygienic aspects of reuse. Besides including a detailed description of pathogens present in urine and faeces, individual treatment methods to sanitize excreta are described in depth. They include storage, heat treatment (composting), alkaline treatment, incineration, as well as practical recommendations on the reuse.

Click directly on the thumbnail to access these guidelines

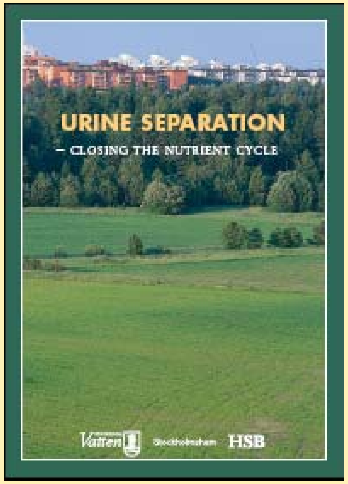


++ Further Reading: Urine Diversion

Further reading

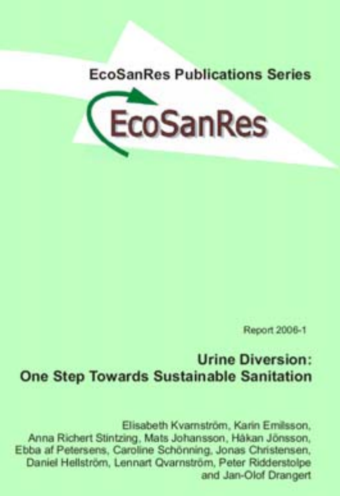
The following publication on the reuse of urine in Agriculture: *Urine Separation – closing the nutrient cycle* is also of interest. This report presents the present state of knowledge about urine-separating toilets and systems for the recirculation of urine as an agricultural fertilizer. The report describes why urine separation is an interesting technology and how a system can be constructed for recirculating urine from residential districts to farmland. It also contains concrete recommendations about planning and management of the various components of the system. The report also describes the research that has been carried out in this area. It concludes by giving concise answers to frequently asked question about urine separation.

Click directly on the thumbnail to access this report.



Further reading

Click on the thumbnail to the right to access one of the newest publication on urine diversion and reuse. “Urine Diversion: One Step Towards Sustainable Sanitation.” It states that “Urine diversion is a system solution of great potential. Closing the loop through nutrient recycling is a key sustainability challenge and this technique makes it possible without expensive treatment processes. Given the proper attention to remaining questions, such as residual pharmaceuticals and hormones, urine diversion has a large potential for sustainability.”



Another possible way how ecological sanitation systems can be integrated into “agricultural practices” is through aquaculture.

“Aquaculture is basically an approximate equivalent in fishing to agriculture – that is, the rearing of fish, and some aquatic plants to supplement the natural supply. Fish are reared under controlled conditions all over the world.” (18)

Human excreta and wastewater can be used as a resource in aquaculture just as well as in agriculture. Put shortly, wastewater which is rich in nutrients, can be used as the medium to raise aquatic plants, after it has been pre-treated adequately. Fish who are living in consume the aquatic plants, and can be consumed themselves by human beings – thus, the loop between sanitation and agriculture in the larger sense, is closed again, and food security can be increased.

Aquaculture will not be dealt with in depth here, since it is too complicated to be explained in short. However, you can find a further reading article below.

Possibilities and limits of wastewater-fed aquaculture by Dr. Ranka Junge-Berberovic

Click directly on the thumbnail to access this 9-page article.


Possibilities and limits of wastewater-fed aquaculture

Concluding Recommendations: Urine

URINE – TREATMENT AND USE

- Urine involves low risk for transmission of disease.
- Dilution of the urine should be avoided.
- Faecal contamination of urine is possible and therefore urine may contain enteric pathogens. The technical constructions should be done in ways to minimize faecal cross-contamination.
- At household level the urine can be used directly.
- Urine should, in large-scale systems, be stored for one month at 20°C before use. In addition a withholding period of one month between fertilization and harvest should be applied (table below).

Treatment	Criteria	Comment
1) Storage	Temperature >20°C during 1 month	Time should be extended at lower temperatures, pH should be >8.5
2) Additional Withholding[1]	Time > 1 month	Minimum requirement. Longer time needed if temperature requirement can not be ensured (**see slide 25**)

[1] Withholding period is the period that passes between fertilisation and harvest.

- For vegetables, fruits and root crops consumed raw, a one-month withholding period should always be applied.
- In areas where *Schistosoma haematobium* is endemic, urine should not be used near freshwater sources.
- Urine should be applied close to ground and preferably mixed with or watered into the soil.

Source: (2)

Concluding Recommendations: Faeces

FAECES – TREATMENT AND USE

- Faeces must be treated before it is used as fertilizer.
- Treatment methods need further evaluation (recommendations should be considered to be preliminary).
- Primary treatment (in the toilet) includes storage and alkaline treatment by addition of ash or lime.
- 1-2 cups (200-500 ml; enough to cover the fresh faeces) of alkaline material should be added after each defecation.
- In small-scale systems (household level), the faeces can be used after primary treatment if the criteria in the table below are fulfilled.
- The treatments in the table below, along with incineration, can be used as secondary treatment (material removed from toilet and treated) at household level. (2)

Treatment	Criteria	Comment
Storage; Ambient temperature 2-20°C	1.5 – 2 years	Will eliminate bacterial pathogens; re-growth of *E. coli* and *Salmonella* may be considered if rewetted; will reduce viruses and parasitic protozoa below risk levels. Some soil-borne ova may persist in low numbers
Storage (only treatment) Ambient temperature >20-35°C	> 1 year	Substantial to total inactivation of viruses, bacteria and protozoa; inactivation of Schistosome eggs (<1 month); inactivation of nematode (roundworm) eggs, e.g. hookworm and whipworm; survival certain percentage (10-30%) of Ascaris eggs (≥4 months), while a more or less complete inactivation of Ascaris eggs will occur within a year (21).
Alkaline treatment (= pH >9)	pH >9 during > 6 months	If temperature >35°C and moisture <25%, lower pH and/or wetter material will prolong the time for absolute elimination.

Source: (20)

Concluding Recommendations: Faeces

- “Secondary treatments for larger systems (municipal level) include alkaline treatments, composting and incineration.
- Alkaline treatment can be done by (further) addition of ash, lime or urea.
- The pH after alkaline treatment should be at least 9 and the material should be stored at this pH for at least six months to one year. (Total elimination may not occur, but a substantial reduction will be achieved).
- Composting is mainly recommended as a secondary treatment at large scale, since it is a difficult process to run. Temperatures >50°C should be obtained during at least one week in all material.

Storage at ambient conditions is less safe, but acceptable if the conditions above apply. Shorter storage times can be applied for all systems in very dry climates where a moisture level <20% is achieved. Sun-drying or exposure to temperatures above 45°C will substantially reduce the time. Re-wetting may result in growth of *Salmonella* and *E. coli*.” (2)

Treatment	Criteria	Comment
Alkaline treatment	pH >9 during >6 months	Hypothesis: If temperature >35°C or moisture <25%. Lower pH and/or wetter material will prolong the time for absolute elimination.
Composting	Temperature >50°C for >1 week	Minimum requirement. Longer time needed if temperature requirement can not be ensured
Incineration	Fully incinerated (<10% carbon in ash)	
Storage	as in the table above (preceding page)	Time modification needed based on local conditions. Large systems needs a higher level of protection. Than at household level. Additional storage adds to safety

Source: (2)

++ Main Links to ecosan

Links

ecosan services foundation: Ecosan Services Foundation is a Non-Profit Organisation Ecosan Services Foundation that runs face-to-face and e-learning training courses on ecological sanitation in cooperation with seecon international gmbh and other partners. with the objective to provide full ecological sanitation project packages including consulting, project planning, implementation, operation & maintenance and project financing.

http://www.ecosanservices.org/

Links

seecon international gmbh: seecon international gmbh is a Switzerland based environmental consulting agency working in the fields of closed loop recycling management, innovation research, development cooperation and consulting. For more than a decade, its main focus has been the promotion and spreading of sustainable sanitation approaches.

www.seecon.ch

Links

Asia Pro Eco II Ecosan Capacity Programme: ECOSAN-CAPACITY is a project funded by the European Commission as part of the component B "Capacity Building" of the AsiaProEco Programme. The main objective of this venture is to build capacity for future implementation of ecological sanitation projects in India, thus increasing the number of ecosan experts capable of planning, designing and realising sustainable sanitation projects in the region. The project, which started on the 1st of January of 2007 is carried out by six civil society, research and education organisations from each corner of the Indian nation, as well as two European institutions.

http://www.ecosan-capacity.org/

++ Main Links to ecosan

Links

GTZ ecosan website: The special website of the GTZ concerning ecological sanitation is a mine of information – conference proceedings, the latest research reports, links, graphs, and fact sheet explain almost all topics related to ecosan.

Click on the following link to access this website:

http://www.gtz.de/en/themen/umwelt-infrastruktur/wasser/8524.htm or visit www.gtz.de/ecosan

Links

EcoSanRes (Ecological Sanitation Research) is an international environment and development programme on ecological sanitation. The website contains a vast amount of PDF-files and other documents on ecosan, which can all be downloaded. As well, there is an ecosan-relevant link-list.

Click on the following link to access this website: www.ecosanres.org

Links

ecosan Norway: Link to the Norwegian University of Life Sciences. On this site, you can for instance download PowerPoint-presentations from the “Appropriate Sanitation for the Developing World” Course, which was held each year in August. As well, there is an extensive list with literary references concerning ecosan, of which some are available online.

Click on the following link to access this website:
http://www.nlh.no/research/ecosan/ or http://www.ecosan.no

Links

IRC International Water and Sanitation Centre: This website contains an enormous amount of news and information, practical advice as well research and training, on low-cost water supply and sanitation in developing countries, in English, French, Spanish and Portuguese. Many of the publications can be downloaded as PDF-files – the website is updated very frequently.

Click on the following link to access this website: http://www.irc.nl/

++ Main Links to ecosan

Links

SANICON: Sanitation Connection is an internet-based resource that gives you access to accurate, reliable and up-to-date information on technologies, institutions and financing of sanitation systems around the world. Institutions of international standing contribute to the information base by providing and maintaining a topic of their specialization.

Click on the following link to access this website: www.sanicon.net

Links

WASH: The "Water, Sanitation and Hygiene for All"-campaign ('WASH') is a concerted advocacy and communications campaign to mobilize political awareness, support and action to end the suffering of the 1.1 billion people without access to safe water, and the 2.4 billion without adequate sanitation.

The website provides detailed information about the aims, objectives, methodology and activities behind the campaign, both internationally and locally.

Click on the following link to access this website:
http://www.wsscc.org/dataweb.cfm?code=26

Links

The world toilet organisation WTO is a non-profit organization, established in Singapore in 2001. The organization communicates the need for better toilet standards in both the developed and developing economies of the world and provides a service platform for all toilet associations, related organizations and committed individuals to facilitate an exchange of ideas, health and cultural issues. Activities include:

- Research & development, Conferences
- Training academy (i.e. World Toilet College)
- Emergency disaster projects (i.e. tsunami affected areas)

Click on the following link to access this website:
http://www.worldtoilet.org/hp/wto_hp.htm

++ Main Links to ecosan

Links

International Ecological Engineering Society **IEES:** The IEES provides a common forum for diverse persons and groups involved in ecological engineering projects, including engineers, biologists, ecological economists, development workers, and many others.

The IEES is a non-profit organisation which seeks to: Promote contacts between scientists and eco-engineers from different countries and coordinate their activities; improve the cooperation between ecologists and engineers; exchange information in the field of ecological engineering among scientific and educational organizations, private enterprises, non-governmental organizations and governmental bodies.

Click on the following link to access this website: http://www.iees.ch/

END OF MODULE M4-7

FOR FURTHER READINGS REFER TO M4-7 TUTORIAL

Prof. Dr. Petter Jenssen, Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences

Dr. Johannes Heeb, International Ecological Engineering Society & seecon international

Dr. Ken Gnanakan, ACTS Bangalore, India

Katharina Conradin, seecon international

Click here to go to the further information part

BACK TO THE MAIN MENU

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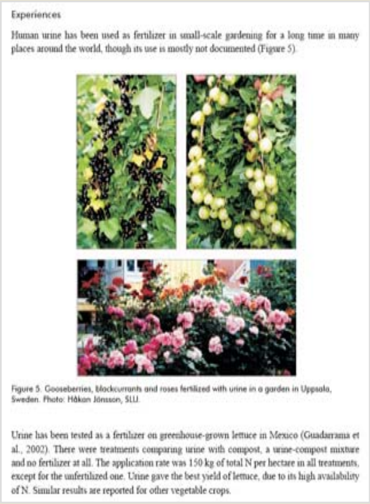
++ Further Reading: Experiences with Urine as Fertilizer

Note: For more further reading material on the agricultural use of human excreta, refer also to the further reading part of module M 2-2 (ecosan – closing the loop between sanitation and agriculture). Many of the documents presented there are also of interest for this module.

Case Study

The document to the right (4 pages) shows some more experiences of fertilizing with urine and gives examples from Mexico, Sweden, Germany, Ethiopia, and Zimbabwe. (Source: 5)

Click directly on the thumbnail to access this document



Experiences

Human urine has been used as fertilizer in small-scale gardening for a long time in many places around the world, though its use is mostly not documented (Figure 5).

Figure 5. Gooseberries, blackcurrants and roses fertilized with urine in a garden in Uppsala, Sweden. Photo: Håkan Jönsson, SLU.

Urine has been tested as a fertilizer on greenhouse-grown lettuce in Mexico (Guadarrama et al., 2002). There were treatments comparing urine with compost, a urine-compost mixture and no fertilizer at all. The application rate was 150 kg of total N per hectare in all treatments, except for the unfertilized one. Urine gave the best yield of lettuce, due to its high availability of N. Similar results are reported for other vegetable crops.

++ Risks of Applying High Rates of P or Organic Matter

"There is little risk of negative effects when applying large amounts of P or organic matter to the soil. However, the following aspects should be considered at very high application rates.

- ⇨ If there are carbon-rich easily degradable materials in the faecal product, there is a **risk of plant-available N being used up by microorganisms** in the soil, and therefore a short-term lack of N which may lead to yield depressions.
- ⇨ If large amounts of lime or ash are used as additives, then there is a small risk of negative effects at very high application rates, due to **too high (>7.5-8) resulting pH** in the soil. Such a high pH is only a risk at extremely high application rates or if the initial pH of the soil is already very high.
- ⇨ For products high in ammonium, digestion residue and urea treatment slurry, there is a risk of negative effects if the **ammonium application is too high**. Therefore, the application rate of these products should be based on knowledge of the ammonium concentration of the product and the desired application rate for N.

When the high application rates stated above are used, normally very impressive yield improvements are achieved, as the organic matter, pH and buffering capacity are increased and large stocks of P and K are supplied to the soil, enough to last for many years or even decades. However, these application rates are not resource-efficient with respect to use of nutrients in the faeces, even though the result is a very good effect on crop production.

The application rates in the examples stated above are in the approximate range of 20-150 tons of faecal product per hectare. Normal application rates for farmyard manure in agriculture re in the range of 20-40 tons per hectare." (5)

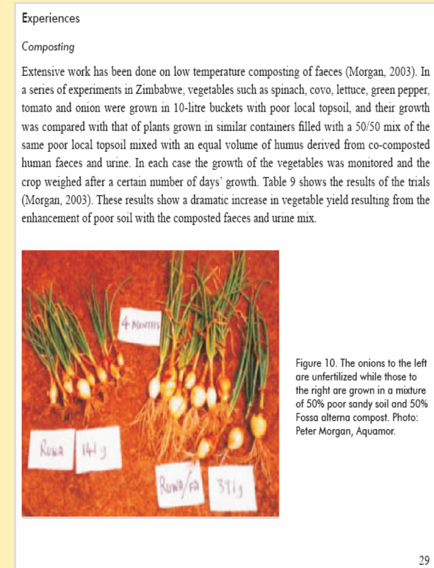
++ Experiences with Faeces as Fertilizer

Case Study

The document to the right presents three pages of experiences of using treated faeces as fertilizers, and shows examples from Sweden, Burkina Faso, Zimbabwe and other African Countries. The fertilizing effects of composted, dried (desiccation and storage) and digested faeces are discussed. As well, there is a very impressive table that shows the average yields in mixed (composted faeces and soil) soil vs. yields in topsoil only.

(Source: 5)

Click directly on the thumbnail to access this document.



Experiences

Composting

Extensive work has been done on low temperature composting of faeces (Morgan, 2003). In a series of experiments in Zimbabwe, vegetables such as spinach, covo, lettuce, green pepper, tomato and onion were grown in 10-litre buckets with poor local topsoil, and their growth was compared with that of plants grown in similar containers filled with a 50/50 mix of the same poor local topsoil mixed with an equal volume of humus derived from co-composted human faeces and urine. In each case the growth of the vegetables was monitored and the crop weighed after a certain number of days' growth. Table 9 shows the results of the trials (Morgan, 2003). These results show a dramatic increase in vegetable yield resulting from the enhancement of poor soil with the composted faeces and urine mix.

Figure 10. The onions to the left are unfertilized while those to the right are grown in a mixture of 50% poor sandy soil and 50% Fossa alterna compost. Photo: Peter Morgan, Aquamor.

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++ Glossary and Abbreviations

ACTS	Agriculture, Crafts, Trades, Studies
GTZ	German Agency for Technical Cooperation
IRC	International Water and Sanitation Centre
N	Nitrogen
K	Potassium (Lat: Kalium)
UNICEF	United Nation’s Children’s Fund
P	Phosphorus
PHAST	Participatory Hygiene and Sanitation Transformation
SSHE	School sanitation and hygiene education
WASH	Water, Sanitation & Hygiene
WELL	Water and Environmental Health at London and Loughborough
WSSCC	Water Supply and Sanitation Collaborative Council

See glossary or abbreviations for unknown terms & definitions!

Glossary

Abbreviations