STOCKHOLM ENVIRONMENT INSTITUTE

Stockholm Environment Institute, EcoSanRes Series, 2010-1

# Practical Guidance on the Use of Urine in Crop Production

Anna Richert, Robert Gensch, Håkan Jönsson, Thor-Axel Stenström and Linus Dagerskog

partner of

sustainable sanitation alliance

EcoSanRes

# Practical Guidance on the Use of Urine in Crop Production

Anna Richert[(1)], Robert Gensch[(2)], Håkan Jönsson[(1)],
Thor-Axel Stenström[(1)] and Linus Dagerskog[(1),(3)]

*With contributions from:*
Elisabeth von Muench[(4)], Martina Winker[(5)], Claudia Wendland[(6)],
Marianne Kjellén[(1)], Moussa Bonzi[(3)], Cofie Olufunke[(7)],
Almaz Terrefe[(8)] and Peter Morgan[(9)]

[(1)] Stockholm Environment Institute
[(2)] Sustainable Sanitation Center, Xavier University, Philippines; CIM; lead of SuSanA working group 5
[(3)] Centre for Low Cost Water Supply and Sanitation (CREPA)
[(4)] Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)
[(5)] Hamburg University of Technology
[(6)] Women in Europe for a Common Future (WECF)
[(7)] International Water Management Institute (IWMI)
[(8)] Society for Urban Development in East Africa (Sudea)
[(9)] Aquamor

EcoSanRes Programme
Stockholm Environment Institute
Kräftriket 2B
106 91 Stockholm
Sweden

Tel: +46 8 674 7070
Fax: +46 8 674 7020
Web: www.sei-international.org and www.ecosanres.org

This publication is downloadable from www.ecosanres.org

Head of Communications: Robert Watt
Publications Manager: Erik Willis
Research and Communications Manager, EcoSanRes Programme: Arno Rosemarin
Layout: Richard Clay

Cover Photo: Application of urine on eggplants during a comprehensive urine application field testing study at Xavier University, Philippines
© William Vergara Repulo



SEI STOCKHOLM ENVIRONMENT INSTITUTE

ISBN 978-91-86125-21-9

## CONTENTS

# FOREWORD

This book gives practical guidance on the use of urine in crop production as a vital component of sustainable crop production and sanitation systems. It also includes guidance on how to start activities that will facilitate the introduction of new fertilizers to the agricultural community. The handbook should help in establishing links between research and professionals interested in implementation of sustainable sanitation systems. It is easy to read and informative, with examples from case studies and hints on further reading for those interested.

The target group is mainly professionals and extension workers in the agricultural sector. In addition, the authors would like to see this text used by water and sanitation, planning and environment professionals in order to establish cross-sectoral links since the use of urine in crop production touches on several of these areas at the same time. Important readers are also decisionmakers on all levels, as well as the donor community.

The text has been produced as a collaborative process within the Sustainable Sanitation Alliance (SuSanA[1]) Working Group 05 on Food Security and Productive Sanitation Systems. Stockholm Environment Institute has taken the lead in the authorship, and important contributions have been made by the following people and institutions:

Anna Richert (SEI; lead author), Robert Gensch (Xavier University, Philippines; chair of SuSanA working group on food security), Håkan Jönsson (SEI), Thor-Axel Stenström (SEI), Linus Dagerskog (CREPA and SEI), Elisabeth von Muench (GTZ), Martina Winker (Hamburg University of Technology), Claudia Wendland (WECF), Marianne Kjellén (SEI), Dr Moussa Bonzi (CREPA), Cofie Olufunke (IWMI), Almaz Terrefe (Sudea), Peter Morgan (Aquamor), workshop participants.

The document has been peer reviewed by Dr Ralf Otterpohl and Mr Christopher Buzie at Hamburg University of Technology.

1 http://www.susana.org/

## READING INSTRUCTIONS

The text is based on scientific knowledge as well as practical experiences on the of urine as a fertilizer and will focus on the urine use in crop production only. Other technical aspects related to the supporting sustainable sanitation technologies and how urine is finally collected are only included if they have an implication for the use of urine as a fertilizer. For further information on technical components of the supporting sanitation systems please see for example 'Technology Review – Urine Diversion Components' (von Münch and Winker 2009) or the 'Compendium of Sanitation Systems and Technologies' (Tilley *et al*., 2008).

The guideline is divided into three major parts:

PART 1 of the guidelines gives general information and recommendations on the use of urine in crop production including information on urine composition, value and use in crop production, health risk management based on World Health Organization (WHO) recommendations as well as institutional aspects and knowledge development for the implementation of urine use in crop production on local level. The first part acts as a generic resource base related to the use of urine in agricultural production.

PART 2 gives an introduction on how this wealth of information can be translated further to the respective local site/country specific needs and conditions by giving recommendations on how locally adapted guideline versions can be developed and reasonably structured. It summarizes the most important factors that directly or indirectly influence the farming activities related to the urine use.

PART 3 is an annexed local guideline from Niger translated into English to give a colorful example of such a local guideline.

It is the intention of the authors that this guide should be used as a general resource book and as a support tool for the development of local guidelines on the use of urine in crop production. At the beginning of key chapters of Part 1 there is a short box headed "practical guidance" with practical tips indicating what is most important, and what could be included in a simplified guideline. If time for reading the entire guideline is a constraint, it is recommended to focus on the executive summary and the boxes introducing each chapter and then proceed to Part II on how to develop local guidelines.

# EXECUTIVE SUMMARY

The Practical Guidance on the Use of Urine in Crop Production is directed towards decision makers, professionals and extension workers in the agriculture, water and sanitation, planning and environment sectors, as well as the donor community. The main target group is professionals in the agricultural sector. The text gives practical guidance on the use of urine in crop production as a vital component of sustainable crop production and sanitation systems. It covers key aspects of how to use urine from productive sanitation systems as fertilizer in crop production and also includes guidance on how to initiate activities that will facilitate the introduction of new fertilizers to the agricultural community. The handbook is intended to help in establishing links between researchers in the field of sustainable sanitation and agricultural practionners, as well as end-users interested in implemented sustainable sanitation systems. It is easy to read and informative, with examples from case studies and tips on further reading for those interested.

Urine used as a fertilizer can help in the mitigation of poverty and malnutrition, and improve the trade balance of countries importing chemical fertilizers if adopted at large scale. Food security can be increased with a fertilizer that is available free for all, regardless of logistic and economical resources. Safe handling of urine including sanitization before use is a key component of sustainable sanitation as well as sustainable crop production.

Consumed plant nutrients leave the human body with excreta, and once the body is fully grown there is a mass balance between consumption and excretion. This has three important implications:

The amount of excreted plant nutrients can be calculated from the food intake, for which data is better and more easily available than for excreta.

If all excreta and biowaste, as well as animal manure and crop residues, is 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 crop fertility in the region. Irrespective of the amounts and concentrations of plant nutrients in the excreta, one important fertilizing recommendation is therefore to strive to distribute the excreta fertilizers on an area equal to that used for producing the food.

Source separation and safe handling of nutrients from the toilet systems is one way to facilitate the recirculation and use of excreta in crop production. Urine contains most of the macronutrients as well as smaller fractions of the micronutrients excreted by human beings. Nitrogen, phosphorus, potassium and sulphur as well as micronutrients are all found in urine in plant available forms. Urine is a well balanced nitrogen rich fertilizer which can replace and normally gives the same yields as chemical fertilizer in crop production. Table I shows an example of yields from field research in Burkina Faso, where yields of urine-fertilized crops did not differ from mineral fertilized crops.

The urine from one person during one year is sufficient to fertilize 300-400 m$^2$ of crop to a level of about 50-

***Table 1: Yield of vegetables as an average of three years of field trials in Burkina Faso.***

Source: CREPA

| | Egg plant (t ha$^{-1}$) | Gombo (t ha$^{-1}$) | Tomato (t ha$^{-1}$) |
|---|---|---|---|
| Unfertilized control | 2.8$^a$ | 1.7$^a$ | 2.1$^a$ |
| Mineral fertilizer | 17.8$^b$ | 2.7$^b$ | 5.7$^b$ |
| Stored urine | 17.7$^b$ | 2.4$^b$ | 5.2$^b$ |

Urine (b) and mineral fertilizer (b) gave a statistically significant yield increase compared to unfertilized control (a). However, there is no statistical difference between yields using urine (b) or mineral fertilizer (b)

*Figure I: The yield and size of vegetables improves with urine use.*

Photo: CREPA, Burkina Faso, Dr Moussa Bonzi

100 kg N/ha. Urine should be handled in closed tanks and containers and should be spread directly onto the soil, not on the plant, in N-doses equivalent to what is recommended for urea and ammonium fertilizers. In the small scale, plastic watering cans are suitable for spreading the urine, while in larger scale, spreaders for animal slurry are suitable. Air contact should be minimized in order to avoid ammonia losses and the urine should be incorporated into the soil as quickly as possible.

The economical value of the urine can be calculated by comparing with the price of mineral fertilizer on the local market or by calculating the value of the increased yield of the fertilized crop. In Burkina Faso the value of a 20 l jerrycan of urine can be estimated to 25 US cents. A person produces around 500 litres of urine per year corresponding to ~ 6-7 dollars. Including the nutient value of faeces the annual value reaches approximately 10 $US. However the increased maize yield from using this amount of fertilizer is estimated to 50 $US.

An example from Niger shows that the annual amount of plant nutrients in the excreta (urine + faeces) from one family is roughly equal to the quantity in one 50 kg bag of urea and one 50 kg bag of NPK, see figure 2. The majority of these nutrients are in the urine, which is relatively easy to collect.

Health risks associated with the use of human urine in plant production are generally low. Source separation of urine is a strong barrier against pathogen transmission since most pathogens are excreted with faecal matter. The amount of faecal cross-contamination is directly related to the health risk in the system for urine use in crop production. Collection systems for urine should be designed to minimize the risk of faecal cross-contamination. Groups that are potentially at risk are mainly collection personnel and field workers, groups that come in direct contact with the excreta. Other categories where risks

*Figure 2: The annual amount of nutrients in excreta from one family in Niger is equal to nutrients in the two bags of fertilizers.* Photo: Linus Dagerskog, CREPA/SEI

exist, however diminished, are households, local communities and product consumers.

Urine is a high quality fertilizer with low levels of heavy metals. Regarding hormones and pharmaceuticals excreted with urine, the risk of negative effects to plants or human beings is low if urine is spread on agricultural land at levels corresponding to the plants needs.

The World Health Organization (WHO) guidelines for safe use of excreta in agriculture (2006) promote a flexible multi-barrier approach for managing the health risks associated with the use of excreta. This concept

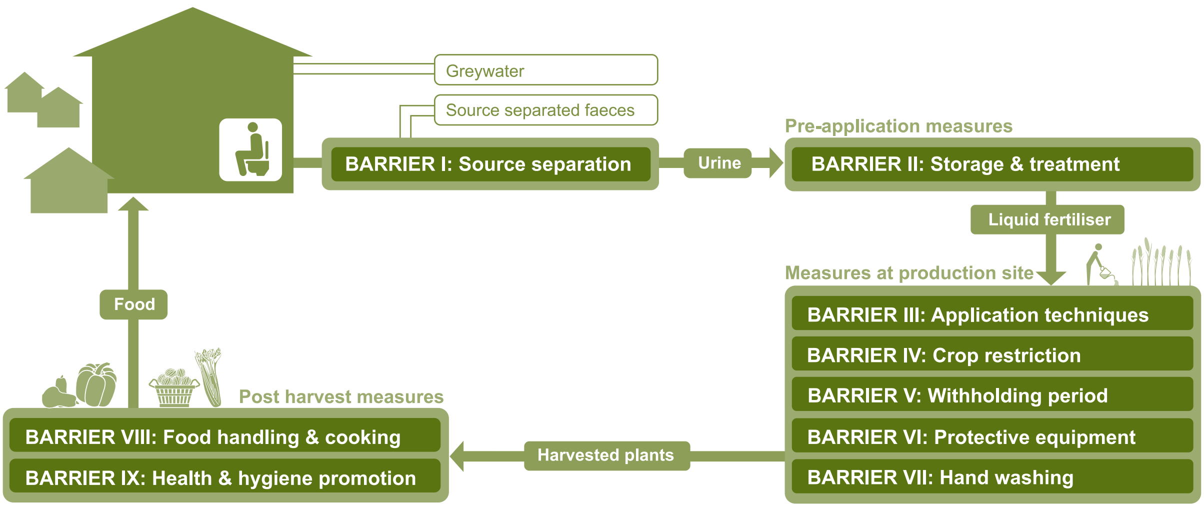



*Figure 3: Barrier concept for safe use of urine as a fertilizer.*

comprises a series of measures/barriers from 'toilet to table'. Each of the barriers has a potential to reduce health risks associated with the excreta use and it is recommended by WHO to put in place several of these barriers, if needed, in order to reduce the health risk to an acceptable minimum, see figure 3.

Barriers include, for example, storage, crop restrictions, withholding periods and reduced contact, correct handling and cooking of the food crop. The text gives examples of how urine can be handled in a safe way in order to minimize risk of pathogen transmission based on the WHO Guidelines for safe use of excreta in crop production.

Institutional aspects are increasingly important as productive sanitation systems become mainstream. A challenge is to integrate use of excreta in existing regulatory frameworks. Initially, the following activities are suggested when productive sanitation systems are implemented:

- Identify stakeholders and clarify drivers and restrictions for each one in relation to the implementation of urine use in crop production.
- Include and target the farmers in the initial planning.
- Organize an arena for feed-back and interaction between stakeholders.
- Organize local communities so that there is a structure for implementation and a structure for monitoring.

Dissemination and knowledge development on urine as a fertilizer is best gained through local demonstration experiments involving organizations that work with small scale farmers and local communities as well as local research organizations. The new fertilizer should be introduced with the same methodology as when introducing any new fertilizer in the agricultural community.

In order to be implementable in a local context there is often an additional need to further translate or adapt the wealth of information given in this text to the respective local site conditions. Part two of the book gives recommendations on how local guidelines can be developed and structured and it summarizes the most important factors that directly or indirectly influence farming activities related to urine use. It is complemented by an example of an existing local guideline from Niger that is annexed to the publication.

# PART I · GENERAL INFORMATION AND RECOMMENDATIONS FOR THE USE OF URINE IN CROP PRODUCTION

## CHARACTERISTICS OF HUMAN URINE

**Practical guidance:**

Urine is a well-balanced nitrogen-rich quick-acting liquid fertilizer. The nutrient content in urine depends on the diet. If the nitrogen content in urine is not known, then as a rule of thumb, a concentration of 3-7 grams of N per litre of urine can be expected. Phosphorus in urine is excreted in a plant-available form making urine an efficient phosphorus fertilizer as well. The quantity of urine produced by an adult depends on the amount of liquid a person drinks, a common figure is 0.8-1.5 litres per adult per day.

The text in the following section presumes that the urine is handled according to the WHO (2006) guidelines for the safe use of wastewater, excreta and greywater in agriculture and aquaculture.

Consumed plant nutrients leave the human body with excreta, and once the body is fully grown there is a mass balance between consumption and excretion, see figure in box 1. This has three important implications:

The amount of excreted plant nutrients can be calculated from the food intake, for which the data are better and more easily available than for excreta.

If all excreta and biowaste, as well as animal manure and crop residues, is 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 consumed crops and thus in the plant nutrient supply needed for maintaining crop fertility in the region.

Irrespective of the amounts and concentrations of plant nutrients in excreta, one important fertilizing recommendation is to strive to distribute the excreta fertilizers on an area equal to that used for growing the crop.

Urine is an aqueous solution made up of more than 95 per cent water, with the remaining constituents made up of urea, creatinine, dissolved ions (chloride, sodium, potassium, etc), inorganic and organic compounds or salts. Most of these remain in solution, but there can be a tendency for phosphorus-rich substances to sediment in containers that are stored for hygienization. This substance has a syrupish texture, and if urine is collected in a piping system, this “urine syrup” can sediment in pipes if the inclination is not sufficient.

### MACRONUTRIENTS – AMOUNTS AND PLANT AVAILABILITY

Urine contains significant quantities of the main macro nutrients required by plants; nitrogen (N), phosphorus (P) and potassium (K). Nitrogen occurs in high concentration (mostly as urea), whereas phosphates and potassium occur in comparatively lower concentrations, in dissolved plant available forms.

Urine used directly or after storage is a high quality, low cost alternative to the application of N-rich mineral fertilizer in plant production. The nutrients in urine are in ionic form and their plant-availability compares well with chemical fertilizer (Johansson *et al*., 2001; Kirchmann and Pettersson, 1995; Simons and Clemens 2004). Urine also contains large amounts of phosphorus, potassium, sulphur and micronutrients, but due to its high content of N, its P/N and K/N ratios are lower than in many mineral fertilizers used for crop production, and lower than what many crops need according to fertilizer recommendations.

An advantage of urine in comparison with organic fertilizers is that the phosphorus exists in forms that are plant-available. This means that urine is quite efficient as a phosphorus fertilizer, which has implications for the future with regard to the concept of Peak Phosphorus and the fact that phosphorus is a finite resource.

***Table 2: Proposed default values for excreted mass and nutrients.*** Vinnerås *et al.*, 2006

| Parameter | Unit | Urine | Faeces | Toilet paper | Blackwater (urine+faeces) |
|---|---|---|---|---|---|
| Wet mass | kg/person,year | 550 | 51 | 8.9 | 610 |
| Dry mass | kg/ person,year | 21 | 11 | 8.5 | 40.5 |
| Nitrogen | g/ person,year | 4000 | 550 | | 4550 |
| Phosphorus | g/ person,year | 365 | 183 | | 548 |

Since it is quite difficult to analyze human urine for nutrient content, there is a need for a method to calculate the composition of urine from easily available data. Such a method, which uses the FAO statistics (see www. fao.org) on the available food supply in different countries, has been developed by Jönsson and Vinnerås (2004). This method uses equations derived from the FAO statistics and an estimation of the average excretion by the Swedish population (table 2), where many measurements on excreta have been made.

Based on this estimate of average excretion, on the food supplied to the Swedish population according to the FAO statistics and on statistical analysis of different foodstuffs, relationships (equations 1 and 2) have been developed between the food supplied according to FAO and the excretion of N and P.

N = 0.13* (Total food protein) ……...............Equation 1

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

In equations 1-2 the units of N and P are the same as those of the food protein. As is shown by equation 2, there is a strong positive correlation between the contents of protein and phosphorus in the food stuffs. Furthermore, vegetal food stuffs contain on average twice as much phosphorus per gram of protein as animal ones, which is why the vegetal protein is counted twice in equation 2.

These equations are useful for estimating the average excretion of N and P in different countries. The input to such estimates are FAO statistics on food supplied, found on the FAO website. Examples of inputs and results of such estimates for a few countries are given in tables 3 and 4.

These estimates assume that the loss between the food supplied and the food actually consumed, i.e.

***Table 3: Food supply (crops primary equivalent) in different countries in 2000.*** FAO 2003

| Country | Total energy kcal/cap,day | Vegetal energy kcal/cap, day | Total protein g/cap, day | Vegetal protein g/cap, day |
|---|---|---|---|---|
| China, Asia | 3029 | 2446 | 86 | 56 |
| Haiti, West Indies | 2056 | 1923 | 45 | 37 |
| India, Asia | 2428 | 2234 | 57 | 47 |
| South Africa, Africa | 2886 | 2516 | 74 | 48 |
| Uganda, East Africa | 2359 | 2218 | 55 | 45 |

*Table 4: Estimated excretion of nutrients per capita in different countries.* Jönsson and Vinnerås 2004

| | Nitrogen (kg/cap, year) | Phosphorus (kg/cap, year) | Potassium (kg/cap, year) |
|---|---|---|---|
| China | 3.5 | 0.4 | 1.3 |
| Haiti | 1.9 | 0.2 | 0.9 |
| India | 2.3 | 0.3 | 1.1 |
| South Africa | 3.0 | 0.3 | 1.2 |
| Uganda | 2.2 | 0.3 | 1.0 |
| Sweden | 4.0 | 0.4 | 1.0 |

the food waste generated, is of the same relative size in the different countries. This assumption is verified by Chinese data. The total excretion reported by Gao *et al*., (2002) for China was 4.4 kg of N and 0.5 kg of P. These values agree quite well with those calculated in table 4, considering how difficult it is to carry out representative measurements of the excretion of a large population.

Basic data on urine composition can also be found in the following: NASA Contractor Report No. NASA CR-1802, D. F. Putnam, July 1971. This document is available online at:

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19710023044_1971023044.pdf

Table 5 below shows the calculated N, P and K values of urine and faeces and urine + faeces for the 10+ age group of rural households in the Limpopo province of South Africa (CSIR, 2008). The table shows that in these areas urine could provide a nitrogen rich fertilizer of the ratio 10:1:4 and faeces a more evenly balanced 2:1:1 fertilizer. The weighted average nutrient content, which would be the result of application of these two fertilizers derived from the same number of people during the same time, yields approximately a 7:1:3 fertilizer ratio.

## EXCRETED AMOUNTS AND VOLUME

The quantity of urine produced by an adult mainly depends on the amount of liquid a person drinks and perspires. Children produce approximately half as much urine as adults. Excessive sweating results in concentrated urine, while consumption of large amounts of liquid dilutes the urine. Vinnerås *et al*., (2006) suggested a design value for urine generation to be 1500 g/p,d based on measurements in Sweden, while Schouw *et al*., (2002) found that in Southern Thailand between 0.6-1.2 L/p,d of urine was produced.

*Table 5: N:P:K excretion of nutrients per capita per annum and the ratio for urine, faeces and urine + faeces fertilizer in South Africa* CSIR, 2008

| Product | kg/p/yr | | | Ratio | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| Urine | 3.56 | 0.34 | 1.26 | 10 | 1 | 4 |
| Faeces | 0.42 | 0.24 | 0.21 | 2 | 1 | 1 |
| Urine + faeces | 3.98 | 0.58 | 1.47 | 7 | 1 | 3 |

## ANALYZING HUMAN URINE

Correct sampling and analyzing of urine is difficult, and results of single analysis of unpooled samples should be interpreted with care. Laboratory analyses will give the most correct answers, however, such analyses may not always be possible for field conditions and absence of laboratory equipment. Simple analytical methods are available, but these have not been validated for human urine. Measurements of conductivity have been suggested, which may be an interesting possibility. A tool that has been developed for analysing animal slurry has been used successfully for human urine, however, calibration may be necessary. The method is based on the fact that ammonium dissolved in the fertilizer reacts with an additive to form gaseous ammonia. The tool measures the gas pressure that results, and indicates a rough figure for the content of ammonia nitrogen in the fertilizer (See www.agros.se).

Sampling of urine should be carried out with stringency. Urine should be well mixed because phosphorus-rich subsances in urine tend to sediment in a container during storage of urine.

A comment on the content of P and K in urine is relevant. In many countries, the K content is expressed as $K_2O$, and the P content as $P_2O_5$. Table 6 below gives conversion factors for use when needed in order to convert the formulas.

*Table 6: Conversion factors for major nutrients*

| To Convert | To | Multiply by |
|---|---|---|
| K | $K_2O$ | 1.2 |
| $K_2O$ | K | 0.83 |
| P | $P_2O_5$ | 2.29 |
| $P_2O_5$ | P | 0.436 |

## CHEMICAL POLLUTANTS

**Practical guidance:**

Source separation of urine results in one of the safest and cleanest fertilizers available to the agricultural community. Pharmaceuticals and hormones are excreted with urine, but the risk of negative effects to plants or human beings is low. When excreta is processed in a sweage treatment plant contaminants from industries, traffic and grey water are added resulting in a product of much lower quality. The following text gives some answers to frequently posed questions regarding chemical pollutants in urine. However, it needs to be noted that the risk when using urine is far lower than when using wastewater treatment sludge, and also lower than when using farmyard manure.

The information in this section is mostly based on Winker (2009). The publication of Larsen and Lienert (2007) is also recommended.

### Hormones and pharmaceuticals[2]

Hormones and pharmaceutical residues are two types of micro-pollutants which occur in urine (concentration levels are available in Winker, 2009), as human beings excrete them with their urine and faeces (as a rule of thumb: two thirds of pharmaceutical residue substances are excreted with the urine, one third with faeces, although the figures can vary widely for individual substances).

There is the possibility that if urine is reused in agriculture, these micro-pollutants would be taken up by plants and thereby enter the human food chain. This is a risk, but a small one: a full evaluation of the potential toxic effects of pharmaceuticals ingested by humans with crops is very difficult and has not yet been done. The risks need to be put in perspective compared to pharmaceutical residues contained in animal manure, or the risks resulting from pesticide use. In sewer-based sanitation systems, these micro-pollutants are discharged from sewage treatment plants into surface water bodies and can reach the groundwater in the long run. For example, detected concentrations of pharmaceutical residues in groundwater lay in the range of 50 ng/l in Germany (Heberer *et al.*, 2000).

2 From von Münch and Winker (2009)

When comparing the two approaches (mixing urine with water in conventional wastewater management versus urine application to soil), it is likely to be safer to discharge urine to soil, rather than to let it pass the conventional system. The micro-pollutants can be degraded better in the aerobic, biologically active soil layers (high concentration of micro-organisms per cubic centimetres) with long retention times than in water bodies whose ecosystems are much more sensitive. Soil is considered a more suitable medium for natural degradation of pharmaceuticals than water because:

- The oxygen levels, promoting biodegradation, are around 50,000 times higher than in water

- Exposure to UV light also helps to degrade pharmaceuticals, although this only applies to the surface (1-2 cm soil depth) and crops can shade the ground.

- Terrestrial systems are much better equipped to degrade organic compounds than aquatic ones. The high specific surface of soil particles maximises the exposure of adsorbed chemicals, maximising the kinetics of degradation such as oxidation, reduction, enzymeenhanced diagenesis, etc.

- The wide biodiversity of the fungal and bacterial flora of soil are also adapted to degrade various sorts of organic molecules, both complex and simple.

Ultimately, the potential risks from consuming crops fertilised with urine need to be compared with the risks related to pesticide use on crops, as well as antibiotics and hormones given to farm animals (poultry and cattle) which can be traced e.g. in milk and eggs. The human use of pharmaceutical substances is small compared to the amount of pesticides (insecticides, fungicides, bactericides and herbicides) used in agriculture, which are just as biologically active as pharmaceutical substances. Substance flow studies have confirmed that the dose of natural and synthetic hormones and of many pharmaceutical substances is larger when applying manure than when applying human urine (Magid, 2006; Hammer & Clemens, 2007). Although it has to be mentioned that the variety of pharmaceutical residues applied via urine is higher than via animal manure.

Urine is strongly toxic to earthworms as reported from a PhD study (Muskolus, 2008). Urine fertilization has been found to give a temporary set-back to the population of earth worms, but the effect is not permanent and after about 6 months, the population had recovered (Muskolus, 2008). It was investigated whether this response was related to ammonia or pharmaceuticals in urine, however, no such connections could be made. Soil microbial enzyme activities were not influenced by urine used as a fertilizer. (Muskolus, 2008)

### Trace metals

Human faeces and to a small extent urine contain trace metals. The amounts of harmful heavy metals in urine are miniscule and much lower than wastewater sludge or even farmyard manure (WHO, 2006). This is a result of the biological uptake being small and their excretion being even smaller (Vinnerås, 2002). Essentially all the heavy metals in the excreta from a normal population come from the food ingested and a large proportion of these metals will have been removed from the fields with the crop. Thus, it is possible to recycle excreta fertilizers, provided that they have not been polluted when handled, without threatening the sustainability of the agricultural soil (Jönsson *et al*., 2004).

## SALINIZATION

**Practical guidance:**

Urine use in areas where salinization is an issue should be monitored. Urine is a solution of salts, and salt stress can be a major constraint to plant production in arid areas. When urine is used in these areas, irrigation practices should be adapted, the urine should be watered down, and application of urine should regularly be interchanged with applications of water only.

The concentration of soluble salts in urine depends on the amount of salts excreted as well as the amount of liquid that passes through the body. A figure reported in Ganrot 2007 gives at hand that human urine contains approximately 150 mM of NaCl (sodium chloride), corresponding to a concentration of 8.8 g per litre (Ganrot *et al*., 2007). Salt stress from sodium chloride can be a major constraint in crop production, especially in arid conditions. Salt sensitivity varies

*Table 7: The relative tolerance of common plants to salinity.* Brady and Weil, 1999

| Tolerant | Moderately tolerant | Moderately sensitive | Sensitive |
|---|---|---|---|
| Barley (grain) | Ash (white) | Alfalfa | Almond |
| Bermuda grass | Aspen | Broad bean | Apple |
| Black cherry | Barley (forage) | Cauliflower | Apricot |
| Cotton | Beet (garden) | Cabbage | Bean |
| Date | Broccoli | Celery | Blackberry |
| Olive | Cow pea | Clover | Boysenberry |
| Rosemary | Fescue (tall) | Corn | Carrot |
| | Fig | Cucumber | Celery |
| | Harding grass | Grape | Grapefruit |
| | Kale | Lettuce | Lemon |
| | Orchard grass | Pea | Onion |
| | Oats | Peanut | Orange |
| | Pomegranate | Radish | Peach |
| | Rye (hay) | Rice (paddy) | Pear |
| | Ryegrass (perennial) | Squash | Pineapple |
| | Safflower | Sugar cane | Potato |
| | Sorghum | Sweet clover | Raspberry |
| | Soybean | Sweet potato | Strawberry |
| | Squash (zucchini) | Turnip | Tomato |
| | Wheat | | |

with factors such as plant species and temperature. Bernal *et al*., (1974) reported growth depression of 10 to 50 per cent grain yield of wheat when treated with a solution of 50 mM NaCl. Salt-affected soils are distributed all over the world but most of them are found in arid and semi-arid regions

Fertilizers are to a large extent soluble salts and if they are not managed properly they can contribute to or cause salinization. For example, a study made to investigate salinity and nitrogen rate effects on the growth and yield of chile pepper plants by Villa-Castorena *et al*., (2003) showed that high amounts of nitrogen application, 140 kg $ha^{-1}$ and more, increased soil salinity and in turn decreased plant growth and yield.

In a South African study on the evaluation of human urine as a source of nutrients for vegetables by Mnkeni *et al*., (2005) it was found that under South African conditions, very high rates of urine application lowered yields. This was due to increased salinity of the soil that led to high levels of sodium in plant tissue. However the rates of N-application in the study were extreme: 1600 kg N/ha, which increased the electrical conductivity of the soil, resulting to classification of the soil as a very strong saline soil after harvest. The use of this level of application is never recommended. It was also suggested that the salinity status of soils fertilized with urine should be monitored in order to detect possible salt-build up, which is reasonable.

Monitoring in arid regions would be advisable in order to get long-term data on possible salt build-up in soils and/or to keep rates of urine fertilization at a level that is well adapted to the climate and crop. Plants vary in their ability to tolerate salinity and a good selection of crop is therefore an important part of optimizing the crop yield in arid areas (table 7).

# ECONOMIC VALUE OF URINE

**Practical guidance:**

The value of the nutrients in urine can be calculated by comparing the quantity of plant nutrients in urine to the price of the same nutrients in chemical fertilizers on the local market. Depending on the current local fertilizer prices, the value of the urine produced by one person per year will usually be within the range of 4-7 Euros. To illustrate the potential of the urine use this figure can be multiplied by the number of household or village members, or even by the entire population.

Assessing the economic value of urine has many dimensions. The value of reusing urine in crop production is often much higher than the mere value of the nutrients contained in urine. The yield increase that can be attributed to the application of nutrient rich urine compared to no fertilizer application at all makes a strong case for the resource reuse in agriculture and sustainable sanitation systems. Monetary arguments are helpful when creating awareness of the potential of productive sanitation. Health and environment benefits are quite difficult to evaluate in monetary terms, while the economic value of excreta in chemical fertilizer equivalents is easier. This can be done by comparing the quantity of the plant nutrients in excreta to the price of the same nutrients in chemical fertilizers such as urea, phosphate and different NPK fertilizers.

Dimensions on the economic and financial value of soil nutrients have been explored by for example Drechsel *et al* (2004). The two main models used in developing countries focus on either the value of introduced fertilizers, which will be further developed in the text to follow; and the value of products from the studied farming systems. Both methods have limitations and potential, and the choice should be based on a decision regarding target group, quality of in-data and desired result.

A study on the marketing of urine and faeces from residential areas in Kampala, Uganda, was carried out by GTZ (Schroeder, 2010). Among the conclusions were:

- the larger the systems are designed, the higher is the economical profit;
- the profit of the systems can be influenced significantly by a variety of factors. Among them transport distance, project lifetime and nutrient/fuel prices showed the largest effects;
- the distance between residential and agricultural area should be minimised;
- economic tools are likely to help change people's perceptions and behaviours sustainably and present an option to increase the implementation efficiency of the proposed systems;
- a fertilizer will not be purchased and used by farmers if it is not competitive in terms of nutrient content and plant availability, handling/managing effort/costs and product price.

The text in box 1 (pages 8 and 9) describes a method developed by CREPA using the monetary argument to promote productive sanitation in Burkina Faso and Niger.

## Cost/Benefit analyses

Carrying out a cost/benefit analysis can provide support for planning a sanitation system including the recycling of urine and faeces to agricultural land. One such analysis has been made in a project in South Africa (CSIR, 2008) where costs and benefits of using urine as a fertilizer were compared to costs and benefits of using no fertilizer at all or using mineral fertilizer. The analysis was based on interviews with subsistence farmers in rural areas. Despite the higher installation construction cost of a urine diverting toilet, this technology option had a greater economic benefit irrespective of the manner of management of the contents of the vaults. This implies that the urine diverting toilet technology is a better option for subsistence farming areas which are attempting to improve soil fertility.

Another cost/benefit analysis was carried out in Niger (Dagerskog, personal communication), where the cost of constructing a toilet was compared to the value of the fertilizer generated in the toilet. This small comparison of figures showed that the family using the urine as fertilizers could, if they sold it on a market at slightly less than the nutrient value in the liquid, get back the money they paid to build the toilet in less than two years.

## Box 1: Calculating the economic value of urine - experiences from Burkina Faso

### How much nutrient is there in human excreta per year?

The amount of nitrogen and phosphorus in excreta is calculated using the FAO statistics for food supply (equations 1 and 2). Due to the uncertainty of FAO's statistics for individual countries, the data in figure 4 is based on the average for the ten West African countries.

The excreta generated by a family represent a substantial quantity of fertilizers. The average family in the Aguié province in Niger has nine members. Urea and NPK (15:15:15; %N: $\%P_2O_5$ : $\%K_2O$) are the common fertilizers. Interestingly, the annual amount of plant nutrients in the excreta from one family is roughly equal to the quantity in one 50 kg bag of urea and one 50 kg bag of NPK.

*Table 8: Annual amounts of nutrients in excreta compared with mineral fertilizers.*

| Nutrient | Excreta Kg per person | Excreta Kg per family (9) | Urea (50kg) + NPK15:15:15 (50kg) |
|---|---|---|---|
| N | 2.8 | 25 | 27 |
| P | 0.45 | 4 | 3.2 |
| (K) | (1.3) | (11.7) | (6.2) |

Most families cannot afford two bags of fertilizers. No surprise then that the message "one family produces the equivalent to two bags of fertilizer" has been met with great interest by the populations in rural Niger. Locally, two bags of chemical fertilizer cost roughly 80 $.

For Burkina Faso with 13.5 million inhabitants, the annual amount of plant nutrients in excreta is in the same order of magnitude as the annual amount in imported fertilizer (table 9)

*Figure 5: The family in Niger produces as much nutrients in urine and faeces as there are in the two bags of mineral fertilizers.*

*Table 9: Amount of plant nutrients per year in imported fertilizers compared to the amount in excreta for Burkina Faso.*

| | N (tons/ year) | P (tons/ year) | K (tons/ year) |
|---|---|---|---|
| Fertilizer imported* | 22 632 | 8 801 | 14 801 |
| Excreta produced | 38 024 | 5 780 | 19 265 |
| Ratio excreta/ fertilizer | 1.68 | 0.66 | 1.30 |

*FAO statistics 2005

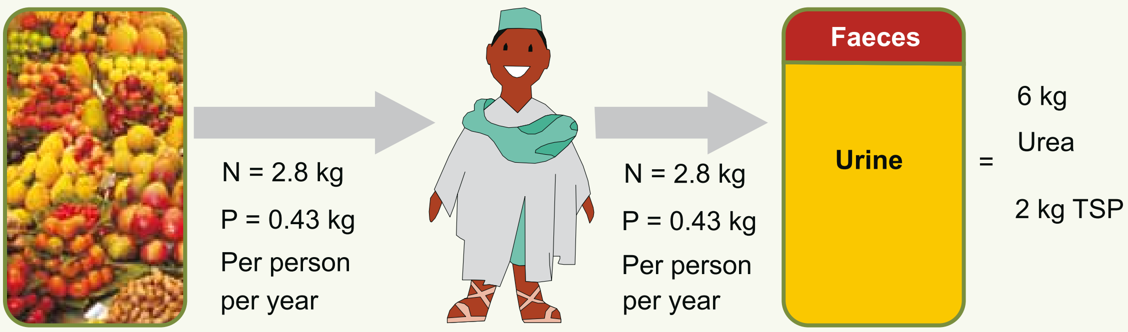



*Figure 4: The nutrient content in the excreta from an average person in West Africa (based on FAO data on food intake from 10 countries).*

**How much is it worth?**

Calculating the market price for the different nutrients can be straightforward.

*Table 10: The price of different nutrients in Burkina Faso.*

| Nutrient | Fertilizer | Price for 50 kg (CFA) | Kg nutrient per 50 kg | Price / kg nutrient (CFA) |
|---|---|---|---|---|
| N | Urea | 20000 | 23 | 870 |
| P | TSP | 20500 | 9.86 | 2079 |
| K | KCl | 22500 | 24.8 | 907 |

However, this kg-price is based on single nutrient fertilizers. Using this kg-price for the formula of the most common NPK fertilizer, shows that buying the nutrients individually is around 10% more expensive than buying them as complex NPK fertilizer. To take this fact into account, the excreta value is reduced by 10 % in table 11.

*Table 11: The annual value of nutrients from one person in Burkina Faso.*

| Nutrient | N | P | K | TOTAL |
|---|---|---|---|---|
| kg/person/year | 2.8 | 0.43 | 1.3 | |
| Price/kg | 870 | 2079 | 907 | |
| Value (CFA) | 2400 | 900 | 1300 | 4600 |
| Value - 10 % | | | | 4100 (~10 $) |

For Burkina Faso with 13.5 million people, the human fertilizer value corresponds to 135 million $ per year. In many countries chemical fertilizers are heavily subsidized. A discussion based on the figures in this text could be initiated to investigate the potential of subsidizing toilets instead of chemical fertilizers.

The incentive to use a fertilizer is primarily that the value of the extra crop produced will exceed the cost of the fertilizer. The following calculation can show this: Maize needs around 60 kg of N/ha which is possible to provide with the excreta from ~ 20 persons. A well fertilized field (60 kg N/ha) can yield 3 tons/ha, compared to 0.5 tons for the traditional field. A surplus of 2.5 tons due to the application of excreta from 20 people, or 125 extra kg of maize for each of these 20 persons. 125 kg of maize is worth around 50 $ US on the market in Burkina Faso. This can be compared with the nutrient value of the excreta (10 $ US) and with the average annual income in Burkina Faso.

**What is the value of a specific quantity of urine?**

In Burkina Faso the most common container for urine storage is the 20 litre jerry can. The fertilizer value of the urine can be estimated to 120 CFA or 0.25 $ US. It should be remembered that for correct analysis of the nutrient content of urine, the urine and its sediment has to be well mixed, and care has to be taken so that ammonia is not lost from the urine.

*Table 12: The value of nutrients in one jerrycan of urine.*

| Nutrient | g/l | Kg/jerry can | Price/ kg | Value/jerry can |
|---|---|---|---|---|
| N | 5 | 0.1 | 870 | 87 |
| P | 0.5 | 0.01 | 2079 | 21 |
| K | 1.5 | 0.03 | 907 | 27 |
| TOTAL | | | | 136 |
| TOTAL - 10 % | | | | ~ 120 FCFA |

The content of secondary macronutrients such as sulphur, magnesium and calcium, and micronutrients are seldom calculated, however, they contribute to the value of the urine since they make the urine a full fertilizer.

## CROP FERTILIZATION WITH URINE – RESEARCH RESULTS AND PRACTICAL EXPERIENCES

Research on urine as a fertilizer is carried out all over the world, in settings ranging from very applied demonstration trials to rigorous scientific studies. The following text describes some of the ongoing or concluded activities. The examples are intended to give a broad picture of results and research setup, and to inspire future work in this area.

The yield achieved when fertilizing with urine varies depending on many factors. One important aspect is the soil condition. 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.

Human urine has been used frequently as fertilizer in small scale gardening, though mostly not documented (figure 6).

*Figure 6: Small scale gardening using urine in Niger.* Photo: Linus Dagerskog

### CEREALS IN NORTHERN EUROPE

Urine was tested as a fertilizer to barley in Sweden during 1997 to 1999 (Johanssson *et al*., 2001; Rodhe *et al*., 2004). Results showed that the N effect of urine corresponded to about 90 per cent of that of equal amounts of ammonium nitrate mineral fertilizers, which is estimated to correspond to about 100 per cent of equal amounts of ammonium fertilizers, after accounting for the N lost in the form of ammonia from the urine.

Urine has been tested as a fertilizer to barley and ley in both greenhouse and field trials in Germany (Simons and Clemens, 2004). The urine in some treatments was acidified in order to reduce ammonia emissions and microbial contamination. The results from field trials showed that the fertilizing effect of urine was higher than that of mineral fertilizer in production of barley. There was no difference in yield between plots fertilized with acidified urine and untreated urine (Simons and Clemens, 2004).

*Figure 7: Spreading of urine to barley.*
Photo: Ebba af Petersens, WRS Uppsala

### CEREALS IN INDIA

Field experiments were conducted in farmers fields at Nagasandra village, Doddaballapura Tq, Bangalore district in India for one year to study the response of maize to human urine when applied to meet the nitrogen requirement (Sridevi, 2009). The treatments were control, recommended dose of fertilizers, recommended dose of nitrogen through human urine with and without gypsum and fertilizer applied to soil and different combinations of human urine and fertilizers. The results of the field experiment revealed that recommended dose of nitrogen through human urine in 6 split doses with irrigation water + gypsum increased the grain (8.10 t ha$^{-1}$) and stover (33.88 t ha$^{-1}$) yield of maize. Significant increase in the nitrogen, phosphorus and potassium content of plant samples was observed in the crops. The outcome of the investigation revealed that urine diverting toilet systems help to provide better sanitation, help farmers to save the cost on fertilizers without negatively affecting the crop yields and thus help to achieve food security.

## VEGETABLES IN SOUTH AFRICA

Pot trials were conducted in South Africa where the use of human urine on cabbage, spinach, maize and tomato was studied (Mkeni *et al*., 2006). Yield, nutrient content in soil and leaves as well as soil electrical conductivity was monitored. The urine was diluted 1:3 (urine:water). The treatments were replicated four times and arranged in a randomized complete block design. Diluted human urine was found to be a good source of nutrients, especially nitrogen, for cabbage and spinach. Maize responded more or less equally to urea and urine. Added N up to 200kg/ha in the form of urea or urine resulted in significant increase in biomass dry matter yield. However, above 200 kg N/ha there was little or no significant increase in yield. As observed for maize, tomato growth responded more or less equally to added urea and human urine. The application strategy is important, however, as risk of elevated salinity was identified in the research. Results showed that urine is to be considered as effective agronomically as urea or ammonium sources of nitrogen.

## VEGETABLES IN WESTERN AFRICA

A research project was carried out in Ghana during 2004 and 2005 to investigate the nutrient efficiency of urine in comparison with mineral fertilizer and compost and to estimate the value of cereal fertilization under local conditions (Germer *et al*., 2006). The trials were carried out north-east of Accra within Ghana's coastal savannah zone. Urine treatment was compared with unfertilized control and compound fertilizer, compound fertilizer plus water (same amount as supplied by urine) as well as compost treatment on the performance of cereals. The nutrient supply was based on the application of 667<kg ha$^{-1}$ NPK 15:15:15 compound fertilizer (100<kg N, 44<kg P and 83<kg<K). Urine and compost were adjusted by the addition of TSP, KCl and Urea to provide the same amount of N, P and K. In both years the yield of the urine and compost treatment were significantly higher than in the control ($p<0.05$). It is concluded that the fertilization with P and K enriched urine increases the yield of sorghum about 3.5 times under the given conditions. Therefore, as a nutrient source the efficiency of urine is at least comparable to mineral fertilizer. The additional sorghum grain yield of 1.4 t ha$^{-1}$ has locally a current market value of 1.000€ and sets off manifold the equivalent NPK fertilizer cost of 100€ (200€ without subsidies).

## VEGETABLES IN EASTERN AFRICA

Plant trials with urine have been carried out with various vegetables in Zimbabwe (Morgan, 2003 and

***Table 13: Average yields (grams fresh weight) in plant trials with urine as a fertilizer to vegetables in Zimbabwe.***

Morgan, 2003

| Plant, growth period and number of repetitions (n) | Unfertilized plants (g) | Fertilized, 3:1 water/urine application 3x per week (g) | Relative yield fertilized to unfertilized |
|---|---|---|---|
| Lettuce, 30 days (n = 3) | 230 | 500 | 2.2 |
| Lettuce, 33 days (n = 3) | 120 | 345 | 2.9 |
| Spinach, 30 days (n = 3) | 52 | 350 | 6.7 |
| Covo, 8 weeks (n = 3) | 135 | 545 | 4.0 |
| Tomato, 4 months (n = 9) | 1680 | 6084 | 3.6 |

2008). The following text reports one of the manyfold trials that have been carried out. Plants were grown in 10-litre cement basins and fed with 0.5 litres of a 3:1 water/urine mix three times per week. Unfertilized plants were cultivated as a comparison. The increase in production was large but no statistical analysis was performed.

*Figure 8: The spinach to the right was unfertilized. The spinach to the left was fertilized with urine diluted with 3 parts of water to one part of urine applied two times per week.* Photo: Peter Morgan, Aquamor

## VEGETABLES IN NORTHERN EUROPE

Human urine was used in trilas carried out in Finland as a fertilizer in cabbage cultivation in comparison with industrial fertilizer and nonfertilizer treatments (Pradhan *et al*., 2007). The main objectives of the study were to evaluate the use of urine fertilizer on (1) growth and pest-resistance of a crop plant, (2) chemical and microbial quality of the crop, and (3) flavor quality of a vegetable food product prepared with natural lactic acid fermentation. Urine achieved equal fertilizer value to industrial fertilizer when both were used at a dose of 180 kg N/ha. Growth, biomass, and levels of chloride were slightly higher in urine-fertilized cabbage than with industrial-fertilized cabbage but clearly differed from nonfertilized. Insect damage was lower in urine-fertilized than in industrial-fertilized plots but more extensive than in nonfertilized plots. Microbiological quality of urine-fertilized cabbage and sauerkraut made from the cabbage was similar to that in the other fertilized cabbages. Furthermore, the level of glucosinolates and the taste of sauerkrauts were similar in cabbages from all three fertilization treatments. The results show

*Figure 9: Cabbage from field trials in Finland.*
Photo: Helvi Heinonen Tanski

that human urine could be used as a fertilizer for cabbage and does not pose any significant hygienic threats or leave any distinctive flavor in food products.

In a field trial in Sweden in 2002, different application strategies for urine as a fertilizer to leeks were tested (Båth, 2003). Fertilizing with urine gave a three-fold yield increase. Neither yield nor nutrient uptake were significantly affected by whether the same total amount of urine was applied in two doses or whether it was divided into smaller doses applied every 14 days. The N efficiency (i.e. (N yield – N yield in unfertilized plots)/added N), when using human urine was high, ranging from 47 per cent to 66 per cent. This is on the same level as when mineral fertilizers are used. N efficiency for most other organic fertilizers, e.g. compost, is normally between 5 and 30 per cent.

Human urine obtained from separating toilets was tested as a fertilizer for cultivation of outdoor cucumber (Cucumis sativus L.) in a Nordic climate (Heinonen-

***Table 14: Results of a field trial using human urine as a fertilizer for leeks. There was no statistically significant difference between treatments A, B and C.*** After Båth, 2003

| Treatment | | N rate | Yield | N yield |
|---|---|---|---|---|
| | | kg/ha* | ton/ha** | kg/ha * |
| A | Urine every 14 days | 150 | 54 | 111 |
| B | Urine twice | 150 | 51 | 110 |
| C | Urine every 14 days + extra potassium | 150 | 55 | 115 |
| D | Unfertilized | 0 | 17 | 24 |

* kg/ha= gram/10 $m^2$

Tanski *et al*., 2007). The urine used contained high amounts of nitrogen with some phosphorus and potassium, but numbers of enteric microorganisms were low even though urine had not been preserved before sampling. The cucumber yield after urine fertilization was similar or slightly better than the yield obtained from control rows fertilized with commercial mineral fertilizer. None of the cucumbers contained any enteric microorganisms (coliforms, enterococci, coliphages and clostridia). In the taste assessment, 11 out of 20 persons could recognize which cucumber of three cucumbers was different but they did not prefer one over the other cucumber samples, since all of them were assessed as equally good.

## VEGETABLES IN CENTRAL AMERICA

Urine has been tested as a fertilizer to 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 control. Urine gave the best yield of lettuce, due to its high availability of N.

Urine has been tested as a fertilizer to amaranth in Mexico (Clark, personal communication). Results show that a combination of urine and poultry manure gave the highest yield, 2 350 kg/ha. Chicken manure alone gave a yield of 1 900 kg/ha. Human urine alone gave a yield of 1 500 kg/ha and the unfertilized control gave a yield of 875 kg/ha. The amount of N applied was 150 kg N/ha for the three treatments. Soil sampling showed no differences between treatments regarding physical or chemical characteristics.

## FRUIT IN INDIA

At Musiri near Trichy, Tamil Nadu, the organization SCOPE established urine diverting toilets and the National Research Centre for Banana started its research experiments, using collected human urine as fertilizer through a drip irrigation system (Jeyabaskaran, 2010). More information can be found at http://www.scopetrichy.com/banana_research.asp .In the study, Poovan banana was grown with 30, 40, 50 and 60 litre/plant of human urine applied with irrigation water (1:10) along with graded levels of commercial potassium fertilizers. Yield (number of bunches and bunch weight) was studied, as well as nutrient content in leaves, height of plants and total amount of soluble solids in banana.

The number of fruits per bunch varied significantly with application of graded levels of urine along with different levels potassium Urine application at the rate of 50 litres/plant recorded the highest average number of fruits per bunch (185) and the control (without urine application) recorded 110.3 fruits per bunch. Among the treatment combinations, application of 50 litres of urine/plant along with 75 per cent recommended dose of potassium recorded the highest number of fruits per

***Figure 10: Bananas from field trials in Trichy.***
Source: www.scopetrichy.com

bunch (223.4), which was 47.7 per cent more than that applied with mineral fertilizer.

Application of 50 litres of human urine per plant with 75 per cent of recommended dose of potassium was superior by recording 32.1 per cent more plant height, 25.6 per cent more pseudostem girth, 71.5 per cent more number of leaves and 68.8 per cent more leaf area, 25 per cent more leaf nitrogen concentration, 52.6 per cent more phosphorus concentration and 6.5 per cent more leaf potassium than normally grown banana plants without urine application (control).

Application of 50 litres of urine per plant along with 75 per cent recommended dose of potassium alone could give an additional net profit of Rs. 45,175/- per hectare when compared to mineral fertilizer alone, ie., normally grown Poovan banana without urine application.

Field experiments were also conducted in farmers' fields at Nagasandra village, Doddaballapura Tq, Bangalore district for one year to study the source separated human urine as a source of nutrients for banana cultivation (Musa paradisica) to meet the nitrogen requirement of this crop (Sridevi *et al*., 2009). The treatments were absolute control, recommended dose of fertilizers, recommended dose of nitrogen through human urine with and without gypsum and fertilizer applied to soil and different combinations of human urine and fertilizers. The results of the field experiment revealed that the highest bunch yield (30.0 t $ha^{-1}$) of banana was recorded in the treatment which received RDN through human urine (After 30 days of planting) + Gypsum applied to soil when compared to control, and other treatment combinations. The available nutrient content of harvest soil viz., N, P and K had significant influence on it. Significant increase in the nitrogen, phosphorus and potassium content of plant samples was observed in the crop. The highest total soluble solids (25.85 per cent), reducing sugars (20.93 per cent) and total sugars (23.87 per cent) were recorded in banana grown using human urine. The outcome of the present investigation revealed that ecosan system helps to provide better sanitation, help farmers to save the cost on fertilizers without affecting the crop yields and thus help to achieve food security.

## APPLICATION STRATEGIES

**Practical guidance:**

The urine from one person during one year suffices to fertilize 300-400 m² of crop to a level of about 50-100 kg N/ha. Urine should be handled in closed tanks and containers and should be spread directly onto the soil, not on the plant, in N doses equivalent to what is recommended for urea and ammonium fertilizers. Air contact should be minimized and the urine should be incorporated into the soil as quickly as possible.

When fertilizing plants, the yield first increases up to a certain application rate, and then decreases if the application rate is increased. If the optimal application rate is not known, then the application of the urine from one person during a full day per square metre (approx 1.5 litres of urine/m², corresponding to 40-110 kg N/ha) and cropping season can be used as a rule of thumb. If there is a restriction in plot size, it is usually possible to increase the fertilization up to three or four times without any negative effects on crops or environment and even larger amounts can beneficially be applied if there is no or low risk of salinization. However, both the quantity and the quality of the yield are important and high rates of available N can affect the quality, positively and negatively. For example, the quality of wheat is generally improved by a high N dose, while the quality of for example Irish potatoes may decrease since the tubers can become watery. The timing of the application is also important here since the nutrient uptake by most crops decreases after the crop enters the generative phase, such as ear setting in maize.

The practical application strategies are a part of the safe barrier approach introduced in the chapter on safe handling of urine. The following sections present different ways to apply urine in crop production.

*Figure 11: Urine fertilized sorghum to the left.*

Photo: Linus Dagerskog

### APPLICATION TIME

**Practical guidance:**

Urine should be applied according to the needs of the plants. Good availability of nutrients is important in the early stages of cultivation, though once the crop enters its reproductive stage nutrient uptake diminishes. From a health perspective this is good since increased time between application and harvest decreases risk of pathogen transmission. A waiting period of one month between fertilization and harvest should always be observed. 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.

In the early stages of cultivation, good availability of all nutrients is important to enhance growth. If fertilizer is applied only once, this should normally be carried out so that nutrients in urine are available during the first half of the time between sowing and harvest. If the crop is fertilized twice, the second fertilization can be performed after approximately 1/4 of the time between sowing and harvest, but 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 most crops do not take up substantial amounts of nutrients. An example is maize; fertilizer applied until the plants are setting ears is well utilised, but after this stage the uptake of nutrients from the soil declines. After this stage the nutrients are mainly relocated within the plant (Marschner, 1995). This is fully appreciated in recommendations on use of chemical fertilizers. E.g. in Zimbabwe, where maize is harvested 3-5 months after planting, the recommendation is to fertilize it three times, but no later than 2 months after planting. As a rule of thumb, fertilization should stop after 2/3 to 3/4 of the time between sowing and harvest. Crops not entering the generative stage, e.g. lettuce, spinach, as well as roots and tubers, e.g. Irish potatoes and sweet potatoes continue to take up nutrients throughout their growth period. However, a waiting period of 1 month between fertilization and harvest is recommended from a hygiene point of view for all crops eaten raw (Schönning and Stenström, 2004; WHO, 2006).

*Figure 12: Application of diluted urine in early stages of cultivation.* Photo: Linus Dagerskog

An often stressed aspect is the risk of leaching of nutrients. 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. However, from a eutrophication point of view, it should be remembered that the leaching after fertilization is small compared to the leaching from a pit latrine or from just letting diverted urine leach into the ground close to the toilet.

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. Plants with inefficient or small root systems, e.g. carrots, onions and lettuce, can benefit from repeated applications of urine throughout the cultivation time (Thorup-Kristensen, 2001).

## APPLICATION RATE

A starting point for the estimation of suitable urine application is the local recommendations for use of commercial mineral N fertilizers, especially of 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, where the removal of nutrients has to be adjusted for the expected yield level. Urine can be recommended for most crops.

The productive area (e.g. grass, flower beds, vegetable garden, trees) necessary per person for use of all the urine on household level depends on several factors:

- the nitrogen demand and tolerance of the crop;
- the concentration of nitrogen in the collected urine;
- the ammonia loss when applying the urine;
- how many harvests that can be taken per year;
- whether the soil already is saline or has a high risk of becoming saline.

Rules of thumbs are useful when the exact figures for the above factors are unknown. The nitrogen demand for common crops varies between 100 – 200 kg/ha, depending on type of crop and the yield. The

**Box 2: I have a flower bed the size of 1 m², how much urine do I need to fertilize it?**

The flower bed really only needs about 1.5 litres of urine for one season, but this amount can be increased by up to four times as needed, depending on the type of flower. Summer flowers (annuals) demand a good soil structure and quite a good nutrient status in the soil. Roses need low amounts of nutrients in the autumn in order to survive the winter. A good strategy would be to apply urine on a few occasions during the flower season, for example with 2-3 decilitres each time, and to water down the urine afterwards.

**Box 3: Calculation of necessary productive area in garden to maximize nutrient use in urine.**

A family of five has a plot size of 300 m$^2$ on which they want to use the urine they collect in their urine diversion toilet. The family lives in a climate allowing for two yearly crops. If we assume that they apply 4 l per m$^2$ for the first crop, and 2 l per m$^2$ for the following crops, how many m$^2$ do they need to use their urine in their garden?

**Answer:**

Since they live in an area where two crops can be taken per year and 6 l/m$^2$ can be applied yearly. Each person excretes about 550 l, but assuming that some of the time is spent outside the home, about 300 l per person is collected yearly. The result is 1,500 l of urine from a family of five. This will fertilize 250 m$^2$ since each m$^2$ will receive 6 l m$^2$/ on a yearly basis, giving a quite high level of nitrogen fertilization. Thus, the plot size would be more than sufficient to productively use the collected urine.

concentration of nitrogen in urine depends on diet. Undiluted urine will usually contain between 3 – 7 g N/l. A person excretes about 300-550 l urine per year, depending on liquid intake, climate etc. The excreted amount of N per person per year with urine varies between about 1.6 kg – 3.8 kg. If the nitrogen demand of the crop is 100 kg/ha and the N concentration in the urine is 7 g/l the urine from one person can fertilize

**Box 4: My 20 litre container for urine is full. How do I use it in the garden?**

Twenty litres of urine is sufficient for 4-13 square metres of cropping area, depending on how much nitrogen is needed or beneficially tolerated.

***Table 15: Application levels and intervals for specified crops in Burkina Faso.***

Source : Moussa Bonzi, CREPA, Burkina Faso

| Days (weeks) after planting or emergence of first plant from seedling | Eggplant | Tomato | Onion/carrot | Lettuce | Pepper | Sorghum/ millet | Corn |
|---|---|---|---|---|---|---|---|
| 14 (2) | 0.5 litres per plant | 0.4 litres per plant (when the plant starts to flower) | | 1 litre /m$^2$ (assuming 20 plants per and dilution: 1part urine to 1 part water) | 0.5 litre / plant | 0.5 litre per plant before seeding | 0.6 litre |
| 21 (3) | | | 1 litre of urine per m$^2$ (assuming 50 plants per m$^2$ and 1 part urine to 1 part water) | | | | |
| 28 (4) | | 0.4 litre per plant | | 1 litre /m$^2$ (assuming 20 plants per m$^2$ and dilution: 1part urine to 1 part water) | 0.6 litre per plant (when first fruits appear) | | |
| 35 (5) | 0.5 litre per plant | | | | | 0.5 litre per plant | 0.6 litre per plant |
| 42 (6) | | | 1 litre of urine per m$^2$ (assuming 50 plants per m$^2$ and 1 part urine to 1 part water) | | 0.5 litre per plant | | |
| 56 (8) | 0.5 litre per plant | | | | | | |

385 $m^2$ (1.5 l of urine per $m^2$), if one single crop is taken per year. If there is a restriction in plot size, it is usually possible to increase the fertilization up to three - four times, thus using up to 6 l per $m^2$ without any negative effects on crop or environment and even larger amounts can beneficially be applied, if there is no or low risk of salinization. Such large applications of urine can be beneficial for the crop yield, if excessive ammonia is lost in the application and especially on phosphorus deficient soils as the phosphorus application is increased. However, care should be taken on soils and in regions prone to eutrophication of watercourses to use nutrients in urine in the most efficient manner.

## DILUTION

**Practical guidance:**

Urine can be applied neat or diluted with water. There is no standard recommendation for dilution/non-dilution and the existing recommendations vary depending on the local conditions. Levels of dilution can vary between 1:1 (1 part urine to 1 part water) and 1:15 (one part urine to fifteen parts water). Most common dilution ratios are 1:3 or 1:5. However urine should always be applied at the rate corresponding to the desired application rate of N, while additional water should be applied according to the water needs of the plants.

Urine can be applied neat (without dilution) or diluted with water, which is practised in many places. The level of dilution varies between approximately 1:1 (1 part water to 1 part urine) to 1:15 (one part urine to fifteen parts water ), and 1:3 seems common. Dilution involves increasing the volume to be spread and thus the labour, the equipment needed, the energy use and the risk for soil compaction are all increased.

Dilution has the advantage of decreasing, or eliminating, the risk of applying urine at such high rates that it becomes toxic to the crop. However, irrespective of whether the urine is applied diluted or neat, urine is a fertilizer and should, just as the much more concentrated chemical fertilizers, 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. Thus, urine can be applied neat, or even concentrated to the soil, which then is irrigated according to crop water requirements. The urine can also be diluted into the irrigation water at a rate that depends on the need for nutrients and water by the crop. The application of a water/urine mix normally needs to be interspersed with irrigation with water only.

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, on or incorporated into the soil. Foliar fertilization is not recommended due to odour, loss of N, risk of plant toxicity and hygiene risks.

Concentrated urine has a higher pH, and consequently, dilution means that the effect of storage on pathogen content in urine will be lowered. Keep the urine concentrated during storage, and if dilution is chosen as a strategy, this should be carried out as close to application as posssible. It has been observed that if diluted urine is stored in open containers (which is not recommended), this may become a breeding site for mosquitoes that can act as disease vectors. This has never been seen in concentrated urine.

## STORAGE TECHNIQUES

**Practical guidance:**

Storage of urine should always take place in a closed container in order to avoid ammonia emissions.

Urine needs to be stored in order to achieve proper hygienization, especially if collected from many households. There is also need of storage if urine is collected when there is no cropping season. One thing that all storage systems have in common is the fact that urine must be stored in closed containers in order to avoid ammonia losses.This section presents different techniques for storage of urine. There is a need to develop low-cost storage methods for small and large scale collection of urine.

Jerry cans are the most common way of collecting urine, and a very good way to store urine for a short period. A good example was introduced by CREPA Burkina, where the jerry cans used for collection of urine were yellow, and jerry cans used for transportation of hygienized urine from storage to field were green, see figure 14.

One cubic metre tanks are also quite common in small and medium scale collection systems, figure 13. The advantage is that the tanks are also readily available, they can easily be filled and emptied, and they are durable.

For large scale storage, slurry tanks can be used (figure 16). However, these seldom have a cover that minimizes ammonia losses, and such a cover needs to be built. Ready-made tanks can also be bought for large scale storage of urine, as has been shown in Sweden (figures 15 and 17).

**Figure 13: Storage of urine in one cubic metre tank.** Photo: Anna Richert


**Figure 14: Yellow container for fresh urine, green container for stored urine to be sold to farmers.** Photo: Linus Dagerskog, CREPA/SEI

**Figure 15: Ready-made large scale storage of urine in Bornsjön, Sweden.**
Photo: Ebba af Petersens, WRS Uppsala

**Figure 16: Slurry tank in wintertime, Sweden. This slurry tank will be used for human urine, and it will be equipped with a cover to minimize ammonia losses.**
Photo: Lennart Qvarnstrzöm

**Figure 17: Storage tank during construction of housing area in Kullön, Sweden. Each tank is 12 m$^3$.** Photo: Mats Johansson, VERNA

## STORAGE IN SOIL

**Practical guidance:**

Urine can be stored in the soil if storage capacity is lacking. Storage in soil is carried out by applying urine where is will be used during a dry inter-cultivation period.

Storage of urine may be a constraint in settings where low-cost options are a neccessity. Therefore different methods to avoid storage containers have been developed. In regions where the inter-cultivation periods are dry, storage of urine nutrients in soil is an alternative for extending the storage capacity and also the labor intensive fertilization period. This is carried out by applying and incorporating the urine into the soil during the dry inter-cultivation period, followed by normal cultivation of the already fertilized soil during the cropping season. The idea is that the main portion of the nutrients remain in the soil and will be available for the plants during the growing season. Further investigations are needed to determine the loss and availability of nutrients, especially N and P, to crops during and after such storage. Results from SUDEA in Ethiopia (Terrefe, personal communication), as well as from an ongoing project in Niger (Dagerskog, personal communication) indicate that the method is an interesting alternative where storing the urine in containers until the cropping season is impossible, even though the N loss might be fairly high. During one measurement where the urine nutrients were stored 28 days in the soil, the loss of mineral N was found to be 37 per cent (Sundin, 1999). There is also a risk that some P might be bound in forms that are less plant-available during the storage, but K and S should remain fully available. An additional advantage of soil storage is that the labour of applying the urine is carried out during the dry season, which is normally less labour-intensive than the cropping season.

## APPLICATION TECHNIQUES

### Manual application techniques

The choice of application technique varies for different types of crops. For crops that are grown in rows, urine can be spread in a trench right next to the crop row. For crops that are planted in rows, with spacing between the plants, urine can be applied in a dug hole next to the crop. For trees, urine shoud be spread in a circle

**Practical guidance:**

For best fertilizing effect and to avoid ammonia losses, urine should be incorporated into the soil as soon as possible after application, instantly if possible. This also limits potential health risks of direct exposure A shallow incorporation is enough, and different methods are possible. One is to apply urine in small furrows that are covered after application. When spreading urine, it should not be applied on leaves or other parts of the plants, as this can cause foliar burning. Spraying urine in the air should also be avoided due to the risk of nitrogen loss through gaseous emissions of ammonia and the hygiene risk through aerosols. Drip irrigation with urine is another possible application technique. However, when this technique is used, measures must be taken to avoid clogging of emitters. In the larger scale, equipment for spreading of animal slurry is used.

***Figure 18: Different application techniques for urine.*** Photos: Linus Dagerskog

around the tree that corresponds to the circumference of the branches. All these application recommendations are also beneficial from a health perspective since they avoid direct contact of urine with the planted crops.

For best fertilizing effect and to lower ammonia losses and odour, the urine should be incorporated into the soil as soon as possible after the application, instantly if possible (Rodhe *et al*., 2004). 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.

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 ammonia and salts when drying as well as hygiene considerations. Spraying urine in the air should also be avoided due to the risk of N loss through gaseous emissions of ammonia (Johanssson *et al*., 2001; Rodhe *et al*., 2004), odour and the hygiene risk through aerosols.

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 at all is seen. 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.

### Large scale application techniques

Urine application in the larger scale is best done with equipment ordinarily used for farmyard slurry. In areas where soil compaction is an issue, care must be taken to keep the urine as concentrated as possible. No dilution with water is receommended here, and application is best done just before light rainfall.

### Drip irrigation

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 as the total amount of precipitation often increases after dilution, since the dilution water normally contains magnesium and calcium. Thus, when using drip irrigation, it might be a good idea, instead of mixing urine and water, to apply the neat and filtered (desludged) urine for some time and then for the rest of the time to apply only water

Drip irrigation of rice, vegetables and yam has been tested by CREPA, Ivory Coast (Comoe, personal communication). Polyethylene piping, with 30 cm between the holes, is tested on a field of 500 $m^2$. The urine flows with gravity fom a tank, through a filter, and directly to the crop. No blocking of pipes has been reported. The piping is rinsed with water after each urine application. Urine application is carried out during rainfall to facilitate urine introduction into the soil.

***Figure 19: Large scale application of urine on agricultural land.***

Photo: Ebba af Petersens, WRS Uppsala

***Figure 20: Drip irrigation of cassava in Cote d´Ivoire.***

Source: Bernard Comoe 2009, CREPA Cote d´Ivoire 2009

## ODOUR WHEN USING URINE AS A FERTILIZER

**Practical guidance:**

Urine has a distinctive smell. However, this is seldom a problem if urine is stored in closed containers and spread according to the information in this text.

Bad odour is culturally associated with pathogens. However, smell may also signal that urine contains nutrients since ammonia smells strongly. Experience shows that if the urine is spread close to and directly onto the soil and watered down there is little smell. Handling of urine is naturally a smelly activity and procedures minimizing air exposure, e.g. by using closed containers, application close to soil and immediate incorporation or irrigation, are strongly recommended. All of these measures will also contribute to minimizing ammonia losses and protecting health.

## COMBINED APPLICATION OF URINE AND ORGANIC FERTILIZERS

The combined use of urine and organic fertilizers such as faeces, compost, farmyard manure or slurry is beneficial, especially in cases where the soil is depleted and deficient in nutrients and organic matter. Organic fertilizers improve the structure of the soil, and increase microbial activity. This in itself will facilitate the uptake of nutrients inte the plant since microorganisms participate in transforming nitrogen into forms that are taken up by the plant.

When faecal matter is used, care should always be taken to follow guidelines for safe use of faeces in order to render the food chain safe and minimize the risk emanating from pathogens in the faeces. Faeces should be properly treated and hygienized.

# TREATMENT AND SANITIZATION

Urine is essentially sterile when it leaves the body. The main issue for urine use in agriculture is how to avoid faecal cross-contamination. In addition, there are diseases that in some regions in the world are spread with urine. The following section gives hints on how to handle urine in order to minimize the risk of using urine as a fertilizer. It should be noted that the advantages of using urine for food production outweighs the risk of disease transmission by far. There are a number of easily undertaken activities that will render the use of urine safe, so read on.

## HEALTH RISKS

**Practical guidance:**

Health risks associated with the use of human urine in plant production are generally low if there is no or little faecal cross-contamination. Storage of urine in closed containers will lower health risks substantially.

Health risks associated with the use of human urine in crop production are generally low. However during source separation in the toilet faecal cross-contamination of urine can occur. The amount of faecal cross-contamination is directly proportional to the health risks. If faecal matter enters urine, the urine will contain different types of enteric pathogens that can represent a potential health risk. Their presence is naturally dependent on whether the users are infected or carriers of the organisms in question. In the case of diarrhoea the risk of faecal cross-contamination is higher.

In addition a few organisms of health concern may be excreted with the urine. One example is Salmonella typhi/paratyphi. These bacteria have a short survival in stored urine, there is reduction of the risk of pathogen transmission by at least 1000 times after a week of storage. Therefore never use unstored urine when typhoid/paratyphoid cases are suspected. Another example is *Schistosomiasis Haematobium*, which is a parasite found only in Africa. However, in order to pose a risk, the eggs need to reach a watercourse and find a suitable snail-host. Use of urine in agriculture with spreading techniques recommended in this book greatly diminishes this risk. Again, a storage time for a week or longer will substantially reduce the risk, the longer the better. More information on storage times is found in the sections below. Groups that are potentially at risk comprise collection personnel and field workers, local communities and product consumers. Here the handling and application practices in the field is of importance. As regards other contaminating substances in human urine (heavy metals, hormones and pharmaceuticals) there are many indications that possible health risks are far smaller than those associated with the common sanitation system and that it is reasonable to believe that the risk for negative effect on the quantity and quality of the crops is negligible.

## MULTI BARRIER CONCEPT

**Practical guidance:**

The WHO guidelines for safe use of excreta in agriculture (2006) promote a flexible multi-barrier approach for managing the health risks associated with the use of excreta in agriculture. This multi-barrier concept contains a series of measures/ barriers along the entire sanitation system from 'toilet to table'. Each of the barriers has a certain potential to reduce health risks associated with the excreta use and it is recommended by WHO to put in place several of these barriers in order to reduce the health risk to an acceptable minimum.

The World Health Organization (WHO) guidelines for safe use of wastewater, excreta and greywater (2006) recognize the potential of using excreta in agriculture and promote a flexible multi-barrier approach for managing the health risks associated with the use of excreta in agriculture. This multi-barrier concept is comprised of a series of measures/barriers along the entire sanitation system from 'toilet to table'. Each of the barriers has a certain potential to reduce health risks associated with the excreta use and it is recommended by WHO to put in place several of these barriers if needed in order to reduce the health risk to an acceptable minimum. The reduction from each of the barriers can be added together, which then give both enhanced total risk reduction and also ensure that variabilities and insecurities in each step are balanced in the long run. Thus even insufficiently treated excreta can be reused

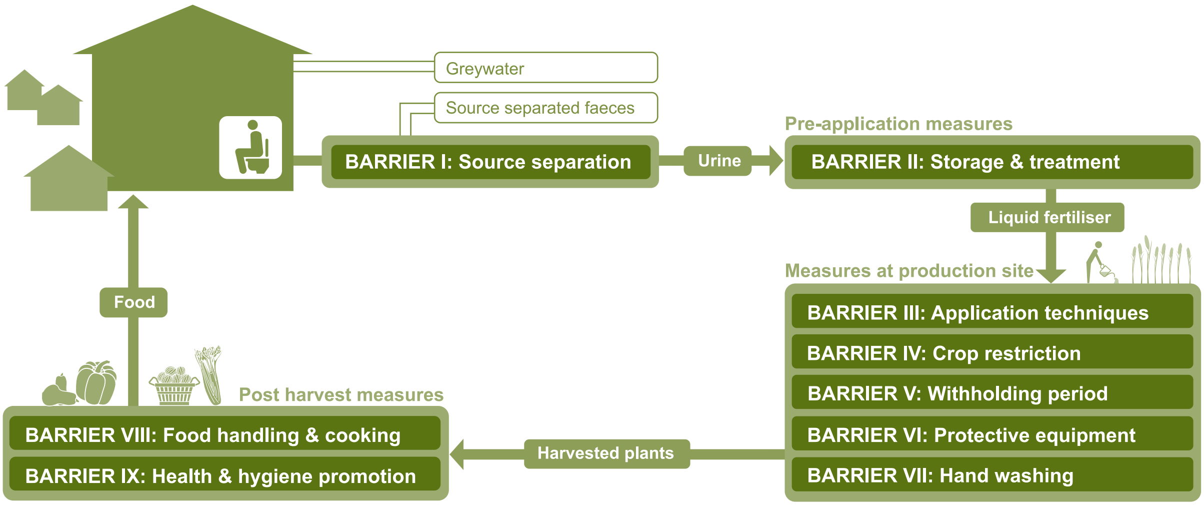



*Figure 21: The Multi Barrier Approach.*

Figure by Robert Gensch

as long as the emanating risks can be managed with subsequent barriers. Effective barriers for safe use of urine in agriculture can be found in the graphic below. For more information visit the WHO website: http://www.who.int/water_sanitation_health.

## Source Separation

Source separation is an efficient barrier to reduce the risks compared to a combined wastewater system. A key objective of urine collection is to minimize faecal cross-contamination. Urine diverting toilets should be designed in a way to minimize the cross-contamination. If urine is collected from urinals, the risk of cross-contamination is negligible. The ablution water for washers should also be considered. If this water is combined with the urine the risk of cross-contamination is increased, especially if the users have diarrhea.

The mode of collection, transport and emptying of the urine may also create situations where an exposure to humans can occur. If the urine collection chamber is flowing over, the cross-contaminated urine will be on the ground where direct contact may occur to playing children (design – have an overflow with a soak away). The containers for urine should not be used for other purposes such as fetching water or brewing beer. Transport to the field or to a secondary storage container should avoid spill. Containers for transport should have a tight-fitting lid.

**Box 5: Example of risk assessment and ablution water.**

In a school in Tanzania a very well designed sanitation system was implemented with separate collection of faecal material and urine to be used in an agricultural plot within the school. However, from a risk reduction point of view there were still substantial problems since the ablution water was lead untreated to an area that was used for the pupils to play in (direct contamination as transmission) and to a part of the agricultural plot (transmission from the produce). The ablution water normally constitutes a minor volume (100 – 500 ml/washing). If this water instead had been lead through a pipe directly into the ground to a small soak-pit the risk for groundwater contamination would have been very small due to the small volume.

## Storage and Treatment

It is recommended that prior to application urine should be treated in order to sanitize the urine and reduce microbial health risks. Storage at ambient temperature is considered a viable treatment option. The storage times should be based on temperature and the likelihood of faecal cross- contamination as well as the vulnerability of the exposed population. A single family will most probably transmit disease between each other through direct routes and not through the use of collected urine. Thus in a family, when the urine is used in a local garden and the produce is used for family purpose only, a less strict storage regime can be applied. A less strict storage (1-2 weeks) can also be applied for urinals where the faecal cross-contamination is excluded. When urine is collected from many different users as well as when the produce is sold/transferred to a third party, the microbial risk increases substantially. In these situations a longer storage time should be used, rendering the used urine safer and increasing the reduction of potential pathogens present. Recommended storage times vary depending on the system type (large-scale systems: 1-6 months, households/urinals: 0-1 month). If cross-contamination is likely to occur the storage time can be adjusted upwards, exceeding 1 month. This also applies for cold climates since the temperature is also a governing factor in the die-off. As a rule: The longer the storage the better.

Urine should be stored in sealed containers in order to prevent direct contact with the urine for humans and animals. Urine should not be diluted while stored, to provide a harsher environment for microorganisms and increase die-off rate of pathogens. Examples exist where the washing water of the toilet room has been mixed with the urine, resulting in a high dilution. This again has resulted in mosquito breeding in the highly diluted urine with open lids as well as a lowered pathogen reduction.

An interesting example of the introduction of new fertilizers to the agricultural community comes from Burkina Faso. Urine from over 1 000 households in the capital Ouagadougou is collected in yellow jerry cans (see figure 22). The urine is taken to a treatment station where it is stored in tanks for a specified amount of time. When hygienization is finished, the liquid is tapped into green jerry cans, figure 14, and sold to farmers under the name Birg Koom which means liquid fertilizer in the local language. The same concept is being used in Niger in a similar project. This is one way to demystify urine as a fertilizer and to signal that the product is safe to use in agriculture.

*Figure 22: Collection of urine from households in Ouagadougou, Burkina Faso.*

Photo: Linus Dagerskog

The storage intervals stated in table 16 are for urine collected in toilet systems where there is a risk of faecal contamination. If urine is collected from urinals, shorter storage intervals (1-2 weeks, see above) are recommended due to lower risk.

*Table 16: Recommended storage times for urine[a] based on estimated pathogen content[b] and recommended crop for larger systems[c].*

WHO, 2006

| Storage temperature | Storage time | Possible pathogens in the urine mixture after storage | Recommended crops |
|---|---|---|---|
| 4°C | ≥1 month | Viruses, protozoa | Food and fodder crops that are to be processed |
| 4°C | ≥6 months | Viruses | Food crops that are to be processed, fodder crops[d] |
| 20°C | ≥1 month | Viruses | Food 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 1 g/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 human infections of concern.

[c] A larger system in this case is a system where the urine mixture is used to fertilize 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.

## Crop restrictions

When treated urine is used no particular crop restrictions need to be applied. However, as an additional precautionary measure the urine use may be restricted to non-food crops (e.g. cotton), crops that are processed (e.g. wheat) or cooked before consumption (e.g. potato) as well as crops/trees that allow for a distance between soil and harvested part of the crop. In general it can be stated that the longer the time between application and harvest – the less risky. Thus for crops with short rotation times, like spinach, salad crops and radish the risk will be higher, and pretreatment is recommended, i.e. storage is required, but in the case of pineapples, for example, (rotation time 1-2 years) the risk is non-existent from the urine if it is spread at amounts and timing corresponding to the needs of the plants, consequently minimum 3 months before harvest.

One goal when constructing systems for the use of urine in crop production should be to reach a reasonable level of risk reduction for persons involved in the use of the system, such as field workers, households or consumers. The following matrix suggests strategies for crop choice and fertilization in order to minimize risk and maximize utilization of nutrients.

*Table 17: Risk levels in relation to crop and handling strategy.*

| Crop | Example | Inherent risk | People exposed to risk | Application time**** | Urine storage*** |
|---|---|---|---|---|---|
| Slow growing crops | Pineapple | Low | Workers | In early stages | No storage needed |
| Ornamental flowers, garden plants | | Low | Workers | Up until one month before harvest | No storage needed |
| High growing crops not picked off the ground and with "cover" | Banana. | Low | Workers | Up until one month before harvest | No storage needed |
| Grain crops processed before eating | Millet, Rice, Sorgum, Maize | Low | Workers | Up until one month before harvest | No storage needed |
| Hanging plants not in direct contact with the ground and usually not eaten raw | Egg plant | Medium | Consumers and workers | Up until one month before harvest | Storage needed |
| Fruits likely picked from the ground and eaten directly* | Mango, passion fruit, orange | Low | Workers | Outside the fruiting season** | No storage needed |
| Hanging plants partly or fully in contact with the soil and eaten raw | Tomatoes | High | Consumers and workers | Up until one month before harvest | Storage needed |
| Root crops processed/cooked | Cassava, potatoes | Low | Protection of workers | Up until one month before harvest | No storage needed |
| Root crops eaten raw | Carrots | High | Consumers and workers | Up until one month before harvest | Storage needed |
| Leafy crops on the ground that are cooked | Spinach | Low | Workers | Up until one month before harvest | No storage needed |
| Leafy crops eaten raw | Lettuce, cabbage | High | Consumers and workers | Up until one month before harvest | Storage needed |
| Energy or fibre crops | Cotton, oil crops | Low | Workers | Up until one month before harvest | No storage needed |

* If vegetables are grown under fruit trees then the measures of precaution or barriers for vegetables need to be observed.
** If fertilization takes place close to the fruiting season, then precautionary measures or barriers need to be observed such as storage of urine.
*** The storage time for urine is not indicated, since this also depends on local factors such as temperature or design of collection system (degree of faecal contamination).
****Urine application should take place considering crop needs and common practice in the region. Continuous application can take place where so noted, from a barrier point of view. A waiting period of one month should always be observed.

## Withholding period

**Practical guidance:**

The time between urine application and harvest should be at least one month.

A withholding period between the last urine application and the harvest is a barrier that provides time for pathogen die-off. Risk calculations have shown that a 1 month withholding period results in substantial risk level reduction and combined with the other barriers in the multiple barrier approach the result will be a risk far below 10-6 DALY for pathogenic bacteria, viruses and parasitic protozoa (WHO 2006). Therefore, a withholding period of 1 month between last urine fertilization and harvest is always recommended. The withholding time is based on the die-off of organisms due to external factors like drying, temperature and UV-light on the surface of leafy plants. The die-off may be lower in the soil. This does not contradict the recommendation to apply the urine in the soil. For root-crops that are eaten raw (radish, carrots, onions etc), the post-harvest handling is of importance. However, it needs to be strongly stated that in these situations use of urine still constitutes a lower risk than sludge, manure, wastewater or irrigation with contaminated surface water.

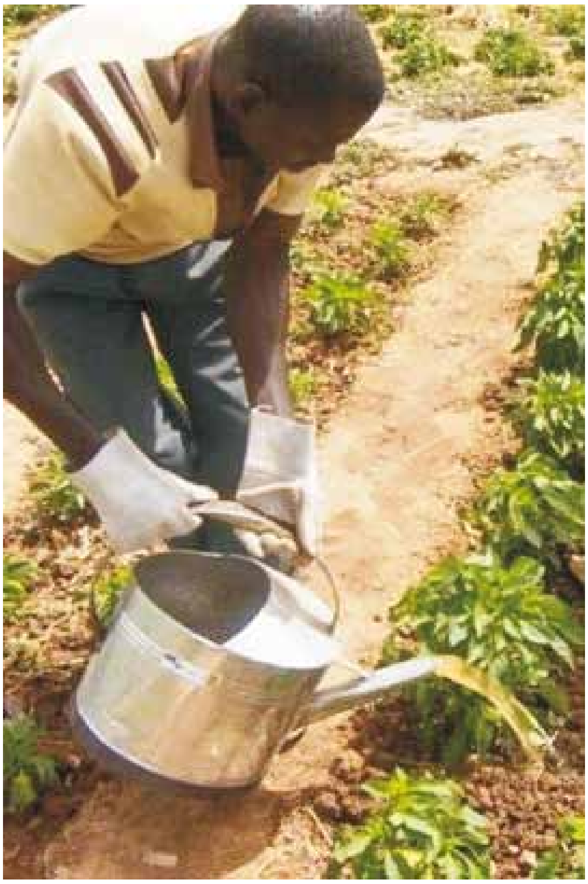


*Figure 23: Application of urine using protective equipment.* Photo: Linus Dagerskog

## Application techniques

**Practical guidance:**

Urine application close to the ground is recommended in order to reduce contact with edible parts and minimize spreading of urine drops.

Urine application close to the ground is recommended. This reduces the direct contact with the edible parts of the plants. For example – do not apply urine with a watering can on the edible or foliar parts of vegetables). The urine should be incorporated into the soil either mechanically or by subsequent irrigation with water. If urine is applied before or during sowing/planting a further die-off will occur of potential remaining pathogens (see with-holding period) and thereby the risk will be reduced.

## Protective Equipment

Although there is little risk associated with treated urine it is recommended if possible that agricultural fieldworkers wear appropriate protective clothing (shoes and gloves) as an effective barrier to reduce potential health risks. This is of importance when heavy faecal cross-contamination has occurred and is of less concern for urine than wastewater or sludge application. A heavy faecal load can lead to exposure through bare skin by hook-worms and during direct contact and subsequent contact with the mouth (the faecal-oral route) while touching the face, eating and smoking. In these situations gloves reduce the risk. Protective clothing is of concern not just for the workers but also so that contaminants are not transported to the households/families.

## Handwashing with soap after urine handling

Washing hands with soap after urine handling can be considered an additional barrier in the system. Self-evidently basic recommended health and hygiene practices like hand washing after toilet use and prior to meals should always be observed.

### Food handling and cooking

Harvested crops should always be washed before consumption. Cooking or peeling of fruits/vegetables is another effective measure to considerably reduce the associated health risks since pathogen reduction between 2-6 log units can be achieved.

### Health and hygiene promotion

Effective hygiene education and promotion should be conducted in order to inform local growers and food handlers in markets, restaurants, home and food kiosks how and why they should wash produce fertilized with urine.

### Microbial treatment of urine

Microbial treatment of urine has been introduced in order to lower smell and increase the nutrient value of urine. This has been studied in Mexico since the 1990´s (Arroyo, 2005), and in ongoing (2010) projects in the Philippines (Terra Preta Sanitation, Xavier University). The concept is to introduce microorganisms into the urine at storage. Microbial inoculation liquid or ordinary compost/vermicompost is added to the urine container prior to storage. The fermentation prevents the bacterial urease process that hydrolyses urea into ammonia and bicarbonate, which usually happens during urine storage. Added benefits may be less volatile ammonia and lower smell.

## HANDLING SYSTEM FOR USE OF URINE AS FERTILIZER

The following section describes the handling chain for urine from toilet to field, for different settings. Regarding the household, a handling system is easy to construct and major points of consideration have already been covered in the text. A good example of small scale use of urine as a fertilizer and the handling system is from the Phillipines where an allotment garden manual has been compiled (PUVeP, 2008). But for large scale settings there are few functioning examples and many see the need to explore this subject in order to move urine diversion systems into full scale and mainstream function. The text below presents two major such systems, both functioning, but with their respective drawbacks. Further development in this area is neccessary.

*Figure 24: A conventional "Honey-sucker", collecting sludge from on-site waste-water systems.* Photo: Västerviks Municipality, Sweden

### LARGER SCALE SYSTEMS

This section presents two cases to demonstrate the complexity of handling systems for urine. One case is from Sweden, where urine is collected from 250 households for use in agriculture, and one case is from Burkina Faso where more than 1 000 toilets have been built in urban Ouagadougou and urine is used in crop production.

Important aspects to consider when planning transportation of urine are choice of technique, entrepreneur, hygiene and documentation. Municipalities usually have companies that are contracted to transport waste fractions generated within the municipality, see figure 24. An interesting alternative is to contract the farmer who will be using the urine for transportation services. This way the farmer can generate some additional income from handling the urine. The hygiene aspect must be considered, and the entrepreneur must have information about measures such as proper hand hygiene after handling of urine. A mouth cover is not necessary, more important is to eleminate spill and to maintain good hand hygiene. All transport should be documented as a part of a quality control system.

An important challenge for the sustainability of large scale urine handling systems is to minimize the costs of the system towards the goal that no subsidies would be needed. Experience from Sweden and Burkina Faso show that the fertilizer value of urine, when valued as chemical fertilizer, is not sufficient to pay for additional costs in the handling system such as transportation or storage, and thus an emptying fee is probably needed from the household and/or a subsidy by the municipality to pay for the handling system. The cost of handling and applying the urine as a fertilizer is in many cases lower than the cost of flushing the urine to a wastewater treatment plant where the N and P are removed.

**Box 6: Quality control and certification**

One need for the farmers is to insure that the company buying the crops does not have objections to the choice of human fertilizers. Recent development has seen quality control systems for crop production evolving, and this is applicable for the fertilizers as well. In Sweden, certification schemes have been developed for sewage sludge, as well as digested and composted household waste, supporting the use of these fertilizers in agriculture. A similar setup for source separated urine is proposed, which would simplify more widespread use of urine in Swedish agriculture.

### Case one: reuse of urine in Vaxholm, Sweden

Kullön is located on an island in the municipality of Vaxholm, not far from Stockholm. 250 households have one or two urine diverting double flushing toilets installed. Urine is collected in groups of 10-20 $m^2$ tanks that serve from 5 to 40 houses each. The system has been described in ESR report 2006:1 by Kvarnström *et al*; http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf

Two times a year urine is collected by lorry, on commission by the household owners organised in a collective. This is a service that the household owners pay for outside their normal taxes for waste and wastewater collection which has caused conflicts in the area.

*Figure 25: Inhabitants of Kullön inspecting the urine tanks.* Photo: Anna Richert

The urine is taken to a farmer where it is stored for more than 6 months. The farmer is paid for the storage and treatment by the housing collective at Kullön, and has entered this project as a part of the business diversification of his agricultural enterprise.

The stability of the system is at stake since the municipality, who has the responsibility for collection and treatment of household waste, has not fully taken the responsibility for this. Increased costs in the system have been imposed on the households, whereas the households do not see why their sanitation system which has been proved more environmentally friendly, should cost them more.

The farmer using the urine needs to show a certificate to the buyers of his products in order to guarantee the quality and traceability of the used fertilizers. This demands documentation and analyes of the urine in initial stages.

Overall the system has taken much much work to initiate and an overlying conclusion is that the handling system from an institutional point of view was not fully taken into account when the housing area was planned, which has caused problems. However, a functional system for the use of urine in agriculture exists, and the farmer is quite content with the business that he is running.

*Figure 26: The slurry spreader comes to fill up urine for application to winter sown wheat in spring.* Photo: Anna Richert.

### Case 2: Urine collection and use in urban Ouagadougou

During 2006 to 2009, a project was implemented in Ouagadougou, Burkina Faso, with financing from the EU, GTZ and CREPA (Coulibaly, 2009). Through a broad range of activities the project aimed to support 1,000 households in obtaining appropriate and affordable closed-loop sanitation. A key point in this urban project is that it established an urban supply chain for urine and faeces from urine diverting dry toilets (UDDT). The project has so far:

- built 1000 UDDT;
- supported the establishment of two supply chains for the collection, transport and distribution of the raw and the treated excreta;
- trained 1,000 gardeners to use these products as fertilizers;
- supported 20 SMEs (small to medium enterprises) who are now involved in system operation;

- trained 100 artisans (masons etc.) to provide the necessary infrastructure, in particular the construction of the toilets.

The physical infrastructure of the ecosan system consists of:

- UDDTs at household level and at public places in four sectors of Ouagadougou;
- four treatment sites called eco-stations for urine and faeces in the same four sectors, each run by a separate association;
- collection, transport and delivery of urine, dried faeces, sanitised urine and of sanitised dried faeces;
- the use of sanitised urine and faeces in peri-urban gardening.

The vaults are emptied by the collection service workers and urine and faeces are brought to an eco-station for a further drying/storage period and for final packaging. For the transport to the eco-stations, urine is collected in 20 L yellow jerricans, and faeces are transported in plastic bags. Every full 20-L jerrican collected is replaced by an empty one. A central point of the urban ecosan system is the treatment site, or eco-station, which connects the households with the gardeners/smallscale farmer. Two of the four ecostations are built near the sites of market-gardening. The eco-stations are equipped with the sanitizing equipment required (plastic tanks for urine and storage pits for faeces) and accompanying infrastructure such as a hangar for the working material, space for the donkeys which pull trolleys of urine jerricans and a storage room for the finished fertilizer products. The number of plastic urine tanks varies from 6 (in small sectors 19 and 27) to 12 (large sectors 17 and 30). For sanitisation, urine is transferred to the eco-stations and stored for one month in closed 1 $m^3$ plastic tanks, while faeces from double vault UDDTs are stored and kept dry in chambers (total volume: 6 $m^3$) for two months.

To facilitate the collection in the households, the sectors are divided into smaller areas. Each team of collectors has to visit all latrines within 2 weeks. The collectors may have to cover distances of up to 12 km (the daily work time is estimated to 5-6 hours). In total, the four associations operate with approx. 28 people, 10 donkeys and 10 donkey carts.

At the beginning of the project, the technical team and facilitators informed the households and farmers

***Figure 27: Components of urine collection system in Ouagadougou, Burkina Faso.*** Photos: CREPA

about the benefits of using ecosan products for crop production. To raise acceptance among the users (gardeners, farmers and consumers), it was decided to rename the urine and faeces. Thus, sanitised urine is sold in green 20-L cans labelled “birg-koom” in the local language which means liquid fertilizer, while sanitised dried faeces are sold in bags labelled “birg-koenga” meaning solid fertilizer.

One important aspect of the project was to ensure the quality and the safety of the ecosan products which are to be sold to the farmers. The gardeners and small-scale farmers were trained to use the treated urine and faeces on different vegetables (e.g. Tomato, cabbage, cucumber, zucchini, carrot, salad, aubergine, strawberry, etc.). Moreover, samples of sanitised urine und dried faeces are sometimes taken and analysed by the National Water Laboratory (Laboratoire National des Eaux) for N, P and K values, and for pathogens such as E. coli. Results shown that sanitized urine is safe (without pathogens) and, used as fertilizer, has no negative impact on the environment and the health.

One important question has been the economic stability of the supply chain. As established, the costs for running the collection system are higher than the finances that are generated in the system, through a fee to the household and through selling urine and faeces at market prices. The fee for households was $US 0.60 per month and the urine was sold to the farmers from the eco station at $US 0.20 per jerry can of 20 litres, faeces at $US 0.10 per kg. This means that there is a need to cut costs without risking the safety of the reuse system.

The project is described in the SuSanA case study format: http://www.susana.org/images/documents/06-case-studies/en-susana-cs-burkina-faso-ouagadougou-uddt-2010.pdf

## GENDER ASPECTS

**Practical guidance:**

In order to achieve sustainable use of urine in crop production the gender perspective needs to be included in implementation. This can for example mean to consider the different roles of men and women regarding the production of cash crops and food for the household.

The process to integrate a gender perspective in institutions and operations is called gender mainstreaming, a process to insure that intervention effects on women and men are anticipated and deliberate. Well planned, this should lead to additional benefits that go beyond good water and sanitation performance, such as economical gain, empowerment of women, increased equality and benefits to children (African Development Bank, 1998).

The gender aspect of ecological sanitation has been described in Dankelmann (2009) and in SuSanA 2009, Working Group 12. However, regarding the specific question of how use of urine in crop production influences the gender question, very little has been done. There are important gender perspectives in agriculture linked to ecological sanitation, and further research and documentation would be valuable.

Women are responsible for basic household food security in many countries in the world. With agriculture based on ecological sanitation, families could save money by growing their own fruit and vegetables and/or selling some of the produce. This, however, has to be weighed against the significant time constraints faced by many women, particularly those who are the main or sole income- earners for their households. Moreover, women are often constrained by lower access to formal education and training, relative to men, and are often confined to the informal sector. Small scale agriculture, as a means of ensuring greater food security and potential supplementary income, is particularly attractive to women as it allows them to work close to their homes and facilitates the carrying out of other traditionally important roles, such as care of children, the elderly and the sick. The importance of ensuring that women as well as men are involved in planning and decision-making on agricultural initiatives, and have equitable access to training and extension services needs, however, to be emphasized.

*Figure 28: Harvest of urine fertilized tomatoes.*
Photo: Linus Dagerskog, CREPA/SEI

Both women and men need access to cash incomes and would be assumed to welcome the potential economic benefits of ecological sanitation, if the opportunities for small-scale entrepreneurship in construction and operation of latrines and collection systems as well as starting small market gardens are made available to both women and men. It has not yet been documented, but a potential conflict between household food production and the production of cash crops may arise as the knowledge increases of urine as a fertilizer. How this would affect the gender balance is unclear but in many situations, the household garden with implications for food security is the responsibility of the woman, and the cash crop production is the responsibility of the men in the family. There is also a question relating to the value of the urine. If urine is sold as a fertilizer, who in the family will access this financial input? Traditionally, women take responsibility for waste products in the household, but if they have a value, will this change? With regard to the issue of waste handling, to what extent will reuse of urine affect the traditional roles in this area? To what extent will the labor involved increase the women's, men's or children's work burden? How are such issues affected by whether there is a market for urine or not? Further documentation and research is recommended.

Specific attention is also needed for the hygienic needs of women and girls. During a menstrual cycle, blood will enter the urine and faeces chambers when women use a urine diverting toilet. Usually, the amount of menstrual blood is small in comparison to the amount of urine in a container. The urine may be slightly more reddish in color, but its properties are unchanged by the addition of menstrual blood and there is no threat to the sanitizing or composting process or to its future use as agricultural fertilizer. A more pressing issue is most likely the impression of the urine when it contains menstrual blood, which is closely linked to the issue of dignity and well-being of those using the system and handling the urine.

# INSTITUTIONAL ASPECTS OF AGRICULTURAL USE OF URINE

Use of human excreta often falls outside existing regulatory frameworks. This is increasingly evident for agricultural application, where the new fertilizers are often not defined in the legislatory or advisory texts of many countries. The weak legal and institutional framework in many countries makes it difficult to implement and scale up innovative sanitation solutions. The following text gives some support in the work to establish an institutional setup for use of urine in crop production.

Key aspects for establishing an institutional setup for the use of urine in agriculture

**Practical guidance:**

The following activities can help to establish an institutional setup for urine use in agriculture.
- Stakeholder analysis: Identify stakeholders and clarify drivers and restrictions for each one in relation to the implementation of urine use in crop production
- Include and target the farmers in the initial planning
- Organize an arena for feed-back and interaction between stakeholders
- Organize local communities so that there is a structure for implementation and a structure for monitoring

Institutional aspects include how to organize a system. This organization is done by defining roles, setting up a legal framework, policies and institutions to manage the system. The following points suggest activities that are of importance when implementing an institutional setup for use of urine.

**Identify stakeholders and clarify drivers and restrictions for each stakeholder.**

There are many stakeholders in a recycling sanitation system and it is important that the drivers and restrictions of each stakeholder are understood. This is especially important for farmers as they are key stakeholders. Farmers are businessmen and the recycling system can often become more sustainable if the farmers are also used as entrepreneurs for the collection and handling of the products, as this can give benefits corresponding to their business potential.


*Figure 29: Small scale entrepreneur using urine as a fertilizer.*

Photo:Linus Dagerskog, CREPA/SEI

**Include the farmers in the initial planning**

When sanitation systems are planned, farmers are frequently not involved from the start. If farmers are allowed to influence the implementation of sustainable sanitation systems from the start, problems can be avoided that would otherwise lead to sub-optimization and economic problems. If farmers are involved from the beginning, then for example the implementation of storage and collection systems can be adapted to the possibilities and constraints of the farming community.

*Figure 30: Information about productive sanitation in Niger.* Photo:Linus Dagerskog

**Organize an arena for feed-back and interaction**

It is also important that there is an arena where the different stakeholders of the system meet and communicate. This is especially so, since the systems are new and thus their improvement potential is large. An arena where agriculture stakeholders can meet stakeholders within the domains of sanitation, environment, planning, technical implementation, etc, is of vital importance.

**Organize local communities so that there is a structure for implementation and a structure for monitoring.**

Local government has a key role as facilitator and regulator, finding ways to promote innovation while holding service providers accountable and achieving a degree of protection to the environment and health

## REGULATORY FRAMEWORK

The regulatory framework is often not well developed regaring the implementation of systems for recycling of nutrients from sanitation systems. The question may often be whether there is anything that specifically prohibits the use of urine in crop production, such as there is in Germany, or if the use is simply unregulated and therefore possible. Ideally, a regulatory framework facilitates the recirculation of nutrients from sanitation systems, and sets targets for environment or health that use of urine in crop production can help in meeting.

**Box 7: Case study regulatory aspects of urine use in agriculture in Sweden**

The Swedish legislation embraces the idea of nutrient reuse and includes sustainability and protection of the environment in different pieces of legislation and policies. The Environmental Code (http://www.naturvardsverket.se/en/In-English/Menu/Legislation-and-other-policy-instruments/The-Environmental-Code ), dating from 1999, contains several opportunities for the implementation of closed nutrient loop oriented sanitation technologies for on-site sanitation in Sweden. Recycling and efficient use of natural resources are integral objectives of the Code as is the precautionary principle; the polluter pays principle and the concept of "Best Available Technology". These principles are, however, not always used by the local environmental authorities when specifying the requirements for on-site sanitation system. In accordance with the Environmental Code, urine is considered a household waste fraction and the responsibility for collection and treatment falls on the municipality. This fact has made the municipal departments (often the technical departments) responsible for solid waste in Sweden look closer into their responsibility for urine and the implications of urine collection and reuse. The Planning and Building Act gives the municipalities the ability to single-handedly decide on the spatial planning and infrastructure development in the local situation but this has never been used to enable closed-loop approaches for wastewater systems.

In parallel to the Environmental Code, National Environmental Quality Standards were established in 1999 (http://www.naturvardsverket.se/en/In-English/Menu/Legislation-and-other-policy-instruments/Environmental-quality-standards ). Sweden's Environment Policy is based on sixteen environmental quality standards for different areas. These describe what quality and state of the environment should be to be sustainable in the long term. Recirculation of natural resources (including nutrients) is included and one of the targets states that by 2015 at least 60% of phosphorus compounds present in wastewater should be recovered for use on productive land, out of which half should be returned to arable land1. Another example of the mainstreaming of nutrient recycling is the revision of the agricultural use of sludge statutes , issued by the Swedish Environmental Protection Agency in 1995, which also will regulate the use of human urine in agriculture as well as other wastewater fractions. The proposal is expected to be decided on in 2010. The background to the statutes proposal and also the background to the target of 60% P recovery are described in Kvarnström *et al* (2002).

The conclusion is that there is a relatively enabling legislative environment for recycling and reuse of nutrients from sanitation systems in Sweden. What is missing are economic incentives that could unleash the on-site sanitation market, and the integration of reuse aspects in the strategic municipal planning.

1 http://www.miljomal.nu/Environmental-Objectives-Portal/

**Practical guidance:**

Key activities to establish a regulatory framework that enables and facilitates use of urine in crop production:

- establish use of excreta in local, regional and national legislative texts for health, sanitation, environment and agriculture
- establish correct terminology on use of excreta in regulatory texts
- invite legislators on local, regional and national level to discuss the question of reuse of excreta from toilet systems
- start work in setting up policy and targets regarding use of excreta at local, regional and national level.

## URINE USE IN ORGANIC AGRICULTURE

Urine is a perfect fertilizer for organic production, where synthetic mineral fertilizers are not allowed. However, there are certain barriers to the use of urine in production systems when labelling for organic production is used. These barriers are expressed for example in regulations by the European Union. Organic agriculture is governed by the European Union regulation (EEG) 2092/91 which applies to all certified European organic agriculture. This regulation regulates among other things the inputs allowed in organic agriculture. Human urine is at present not included as a fertilizer in the EU regulation which makes it difficult for organic farmers in Europe or exporting to a European market to use human urine. The Swedish Organic Agriculture Certifying Organization (KRAV) has achieved an exemption for one farmer, who has a closed loop system where nutrients are recycled and food delivered in the same community, resting on the assumption that if there is a proximity between the community and the farmer, the risk of contamination or unsustainble practices will be diminished.

The International Federation of Organic Agriculture Movements, IFOAM, indicates that source separated human excreta which is monitored for contamination is not to be directly applied on edible parts of plants. In addition, there is a restriction in the use of human excreta on food crops, but exceptions may be made where detailed sanitation requirements are established by the standard-setting organization to prevent the transmission of pathogens (http://www.ifoam.org/about_ifoam/standards/norms/norm_documents_library/Norms_ENG_V4_20090113.pdf ).

# CROP EXPERIMENTS USING URINE AS A FERTILIZER

**Practical guidance:**

Crop experiments should be started on local level in order to establish the use of urine as a fertilizer in the local agricultural community. The level of experimentation can range from simple demonstration trials to scientifically rigorous research. In any case, demonstration trials should be started in a place that is easily accessible to farmers and househols owners.

When planning a crop fertilization experiment the first and most important question is to define the objective of the experiment. The answer to this question has a decisive influence on how the experiment should be planned, its costs and complexity. If the answer is that the desired result is increased knowledge among local population, a simple demonstration trial showing yields with urine, with mineral fertilizer and without fertilizer can be used. If the answer is increased knowledge in the farming community and for extension professionals, a more extensive experiment allowing statistical analysis is needed. The following sections describe different strategies to increase knowledge about cropping systems where urine is used as a fertilizer.

## DEMONSTRATION EXPERIMENTS

Demonstration experiments are very useful and flexible tools as they are cheap, quick and easy to set up. They can be small pot experiments or large field experiment. A good idea is often to set up small demonstration trials just outside the entrance doors to the extension office, in schools or other places in the centre of the society where many persons can be reached. There is no need for repetition and the need for documentation is small. But it is good if the results are clearly visible and therefore the fertilization level should preferably be large and the water factor well controlled. The photos below show pot experiments by Peter Morgan Zimbabwe and field experiments in Rwanda.

*Figure 31: Spinach (Swiss Chard) fertilized with urine (left) and without fertilizer (right).* Photo: Peter Morgan


*Figure 32: Field trials from Niger. Urine fertilized millet to the right.* Photo: Linus Dagerskog

## CONTROLLED EXPERIMENTS TO TEST THE FERTILIZING POTENTIAL

In this type of experiments, as many factors as possible should be controlled e.g. the amount of water , weeds, insects and fungi, and maybe even climate, and the crop should be established in the optimal way. These experiments can be done on a very small scale, pot or lab scale, and they often yield good, repeatable and reliable results. Due to this small scale, this type of experiment is actually the cheapest one for getting repeatable and reliable results. To get statistically significant and conclusive results several repetitions should be done, which due to the small scale often is fairly easy and cheap.

The advantage of this type of well controlled experiment is that the variation between years is small even if it is performed outdoors. This means that after just one experimental season the result can be fairly representative. Another advantage that this type of experiment shows the full fertilizing potential of urine to the crop in question. One disadvantage however, is that this full potential might not at all show the fertilizing effect that a farmer will experience in a real situation.

## CONTROLLED EXPERIMENTS TO TEST THE REAL LIFE FERTILIZING EFFECT

This type of experiment is much more realistic, as the same crop management procedures are followed for the experimental plots as are usually followed by the farmers. This means that if the year is very dry and the crop is not irrigated, then the crop might suffer severely and the fertilizing effect might be negligible as it is the water factor that decides the yield. Likewise, other years it might be weeds, fungi or insects, that has decisive influence on the crop yield. These experiments are often participatory and carried out on farms. Repetitions in order to carry out statistical analysis increase the possibility of drawing conclusions from this type of research, but it is often a challenge to ensure that the treatment actually is the same on the different farms involved. .

This type of experiment has the clear advantage that its results are much more realistic and more easily transferred to, and scaled up by the farmers than the fully controlled experiments previously described. It, however, also has the clear disadvantage that the yield results are very much influenced by the weather and season, which vary between years. This means that to be fairly sure to get any type of representative results normally at least 3 years and preferably 4-5 years of crop experiments are needed.

## FARM AND CROP ROTATION EXPERIMENTS

This is the most complex, realistic and most difficult and expensive type of experiment. While the two previous types of experiments normally are confined to one crop at a time, in this type of experiment, the full range of crops normally grown by a farmer each year is included in the experiment, and the effect on farm economy of fertilizing these crops is evaluated. This is a highly relevant type of experiment, especially under marginal farming conditions, but these experiments are very resource demanding, as they include several crops and need to be repeated at least 3-5 years.

## STATISTICAL CONSIDERATIONS

For all types of controlled crop experiments (not including demonstration trials), the experimental plots should be as even as possible, but even so, the comparison between the treatments should be repeated several times, if possible 3-5 times in the same field. The order of the treatments should be randomized within each repetion.

*Table 18: Example of experimental layout.*

| | | | | | |
|---|---|---|---|---|---|
| Repetition 1 | T4 | T3 | T2 | T5 | T1 |
| Repetition 2 | T4 | T1 | T2 | T3 | T5 |
| Repetition 3 | T2 | T1 | T3 | T5 | T4 |
| Repetition 4 | T1 | T5 | T4 | T2 | T3 |

In table 18, 4 repetitions with 5 treatments (T1-T5) in randomized order in each repetition are shown in a simplified experimental layout. While the whole blocks should be treated according to the plan, it is only the harvest of the central area that should be measured and allowed to influence the results, in order to minimize the edge effects of the small plots.

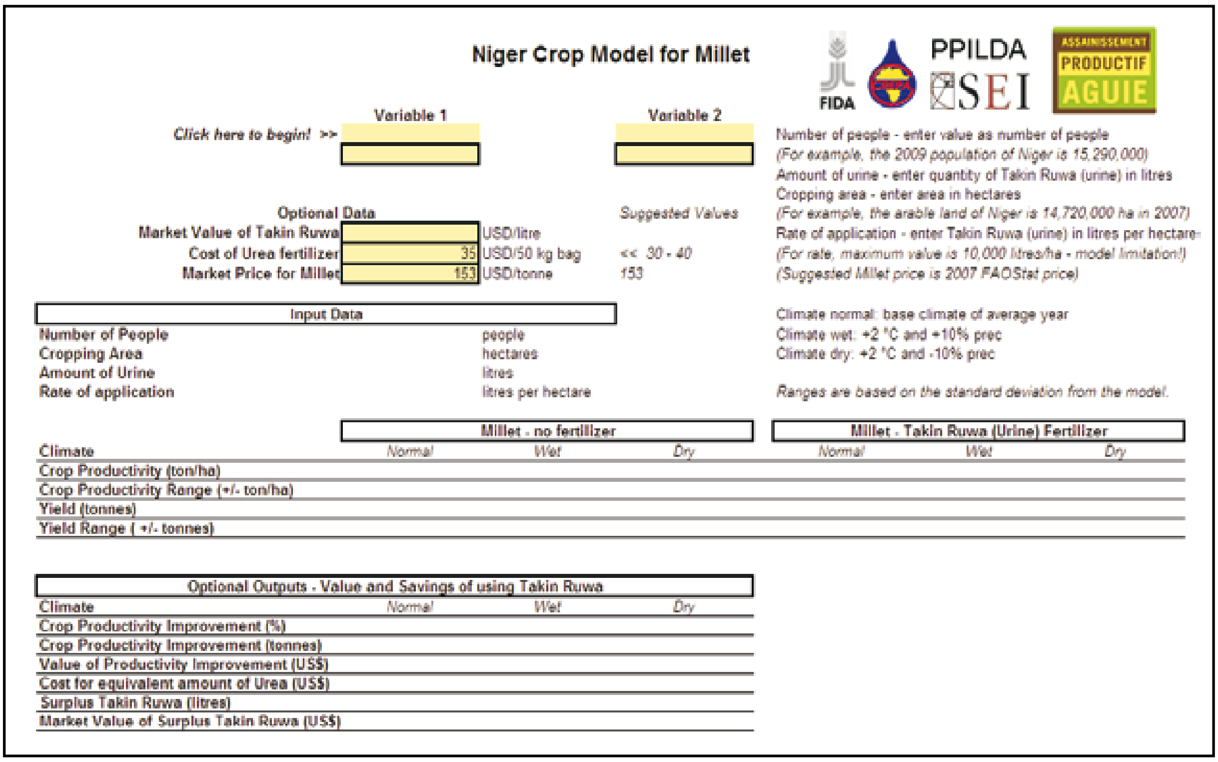
## DISSEMINATION OF RESULTS

The volume of published results from projects where urine has been introduced as a fertilizer is rapidly increasing. However, there are numerous knowledge gaps, and therefore it is important to capitalize on experimentation that is done by publishing results in fora that reach as many professionals as possible. It is quite important to reach not only agricultural professionals, but also professionals within sanitation, sociology, environment, etc. as well as the general public and local target groups.

## WEB-BASED TOOLS FOR CALCULATION

A simple excel-based tool has been developed for calculation of collected amounts as well as nutrient content and value. The tool is available at http://www.sanergy-net.de/calculator.php. Similar tools can well be developed for the extension level in order to get a view of the potential for nutrient reuse when urine is used as a fertilizer.

A simple calculator has been created (2010) to provide information on crop productivity increases from using treated urine (Takin Ruwa) as fertilizer compared to unfertilized, for millet growing in Niger. http://www.ecosanres.org/aguie/model.htm The model is built in Excel. The model requires two input variables to function. The input variables are a combination of number of people, amount of urine, cropping area and application rate. Using these input variables, the model calculates the potential crop productivity for millet. The output is given in two groupings, one for millet without fertilizer and one for millet with Takin Ruwa fertilizer. Both the crop productivity and the yield are given, including a range that is based on the standard deviation for the source data.


Niger Crop Model for Millet

FIDA PPILDA SEI ASSAINISSEMENT PRODUCTIF AGUIE

Click here to begin! >> Variable 1 Variable 2

Number of people - enter value as number of people
(For example, the 2009 population of Niger is 15,290,000)
Amount of urine - enter quantity of Takin Ruwa (urine) in litres
Cropping area - enter area in hectares
(For example, the arable land of Niger is 14,720,000 ha in 2007)
Rate of application - enter Takin Ruwa (urine) in litres per hectare
(For rate, maximum value is 10,000 litres/ha - model limitation!)
(Suggested Millet price is 2007 FAOStat price)

| Optional Data | | | Suggested Values |
|---|---|---|---|
| Market Value of Takin Ruwa | | USD/litre | |
| Cost of Urea fertilizer | 35 | USD/50 kg bag | << 30 - 40 |
| Market Price for Millet | 153 | USD/tonne | 153 |

| Input Data | | |
|---|---|---|
| Number of People | | people |
| Cropping Area | | hectares |
| Amount of Urine | | litres |
| Rate of application | | litres per hectare |

Climate normal: base climate of average year
Climate wet: +2 °C and +10% prec
Climate dry: +2 °C and -10% prec

Ranges are based on the standard deviation from the model.

| | Millet - no fertilizer | | | Millet - Takin Ruwa (Urine) Fertilizer | | |
|---|---|---|---|---|---|---|
| Climate | Normal | Wet | Dry | Normal | Wet | Dry |
| Crop Productivity (ton/ha) | | | | | | |
| Crop Productivity Range (+/- ton/ha) | | | | | | |
| Yield (tonnes) | | | | | | |
| Yield Range ( +/- tonnes) | | | | | | |

| Optional Outputs - Value and Savings of using Takin Ruwa | | | |
|---|---|---|---|
| Climate | Normal | Wet | Dry |
| Crop Productivity Improvement (%) | | | |
| Crop Productivity Improvement (tonnes) | | | |
| Value of Productivity Improvement (US$) | | | |
| Cost for equivalent amount of Urea (US$) | | | |
| Surplus Takin Ruwa (litres) | | | |
| Market Value of Surplus Takin Ruwa (US$) | | | |

***Figure 33: A sample page from the Aguie calculator for providing information on crop productivity increases from using treated urine.*** AP-Aguie 2009

# PART 2 · HOW TO DEVELOP LOCAL GUIDELINES

In order to be implementable in a local context the wealth of information given in this book so far needs to be further translated or adapted to respective local site conditions. The following chapter provides some recommendations on how local guidelines can be developed and structured and it summarizes the most important factors that directly or indirectly influence farming activities related to urine use. Not all of the listed aspects necessarily need to find their way into the final guideline version at a local level and it is very much up to local experts to finally decide on what needs to be included. However the listed aspects set the frame of what generally needs to be considered for successful local adaptation. Examples of local guidelines for urine use in crop production are presented in annexes.

The main aim of a local guideline as presented in this text is to be a national, regional or local support tool that is clearly targeted at agricultural extension workers and not the farmers. For farmer level frequently more simplification is needed, which can be done by the extension workers on the basis of the local guidelines developed using these instructions.

## THE PRODUCTIVE SANITATION APPROACH

A general understanding of the concept of reuse-oriented productive sanitation is a prerequisite for successful local implementation. If the concept is well known no further explanation is necessary. Otherwise a brief introduction on the reuse-oriented sustainable sanitation approach, the link between sanitation and agriculture, the global limitations in synthetic fertilizer production, the resource value of urine and its productive potential should be included prior to the more practical oriented recommendations.

**Links to more information:**

- SuSanA WG 05 fact sheet (food security) ® http://www.susana.org/images/documents/05-working-groups/wg05/en-wg5-factsheet-2008-05-28.pdf

SuSanA vision document I (‘towards more sustainable sanitation solutions’) ® http://www.susana.org/images/documents/04-meetings/side-events/2009-singapore/01-en-panesar-introduction-susana-wts-singapore-2009.pdf

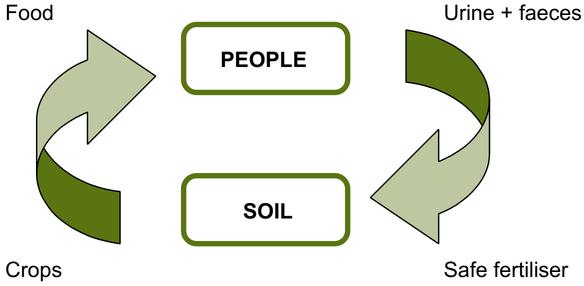



*Figure 34: Closing the loop.*

## LOCAL SITE CONDITIONS

Although people working in agriculture usually know quite well how their respective local climate, soil and water conditions are it might be relevant to include a chapter that specifically focuses on how this impacts on urine use.

### Climatic conditions

Information on climatic region, temperature, rainfall pattern, humidity and seasonal specifics. For example, in arid regions with low rainfall and high temperature evaporation might be very high or in tropical areas with high rainfall it should be recommended to apply urine more often in smaller doses.

### Water situation

General information on availability, sources and potential contamination of water that is used for plant irrigation. If data is locally not available the water situation should be at least described qualitatively.

### Soil conditions

Basic information on soil quality and general soil conditions that influence the foreseen agricultural activity. This includes soil type and texture (e.g. if soil is more sandy then more frequent fertilization is needed) soil ph (acidity/alkalinity that affects the availability of nutrients in the soil), as well as organic matter content (fertilizing effect of urine lower on soils with low organic matter content) and salinity (e.g. if soil is saline organic material should be added as a buffer or more water needs to be added). In many cases this information is locally available. In any case good agricultural practises should be observed in order to maintain the soil fertility.

## PLANT REQUIREMENTS AND NUTRIENT CONTENT IN URINE

This section of the local guideline gives instructions on type of crops, nutrient requirements, need for urine as a fertilizer and the benefits of using urine as a fertilizer. The section on benefits is especially important, and can be used as an advocacy text not only for agricultural extension personnel.

### Type of crops

The type of crop(s) determines the farming system, soil requirements as well as amount of nutrients and water required for optimal plant growth. If only urine will be used as a fertilizer it is recommended to give priority to crops that have high value and respond well to N (e.g. maize, spinach).

### Plant nutrient requirements

Demand of primary macronutrients (N,P,K) that are required for optimal plant growth and harvesting results. It will determine the amount of urine (depending on its respective local nutrients content) that needs to be applied during the planting season.

### Plant density and distance

Recommended number of plants per area and distance between crops that affects area productivity and determines the degree of competition between the plants.

### Amount of urine produced

The estimated total amount of urine that can be used for crop production should be presented since it directly affects the area size that can be fertilized and the potential value for the farmers. Depending on the amount of water consumed and on the climate conditions one adult person produces around 1 - 1.5 litre of urine per day. It should be kept in mind that in some cases only part of this amount can be collected (e.g. other sorts of toilets or no toilets are used during the day, local habits of peeing in the shower etc.)

### Nutrient content in urine

Content of macro- and micronutrients in human urine that determine the amount of urine to be applied to plants. If local data is not available the following average amounts of primary macronutrients can be assumed for the following countries:

*Table 19: Food supply (crops primary equivalent) in different countries in 2000.*

FAO 2003

| | Nitrogen (kg/cap/a) | Phosphorus (kg/cap/a) | Potassium (kg/cap/a) |
|---|---|---|---|
| China | 3.5 | 0.4 | 1.3 |
| Haiti | 1.9 | 0.2 | 0.9 |
| India | 2.3 | 0.3 | 1.1 |
| South Africa | 3.0 | 0.3 | 1.2 |
| Uganda | 2.2 | 0.3 | 1.0 |
| Sweden | 4.0 | 0.4 | 1.0 |

### Value of urine as a fertilizer

The monetary value of the nutrients in urine can be calculated by determining the synthetic fertilizer equivalent of the basic macronutrients (N,P,K) in urine times the current local synthetic fertilizer prices. To make it more demonstrative and more impressive illustrate the potential of the urine use this figure can be multiplied with the number of household members or even with the entire population.

### Value of yield increase that can be attributed to urine use

The value of reusing urine in crop production is much higher than the mere value of the nutrients contained in urine. The yield increase that can be attributed to the application of nutrient rich urine compared to no fertilizer application can make a case for the resource reuse in agriculture. Data based on local field trials if there are any such available.

## APPLICATION RECOMMENDATIONS

### Application rate

Amount of urine that should be applied per cropping season. Because of its high nitrogen content urine should be applied at a rate corresponding to the desired N requirements of the plant. A starting point for estimating the urine application are local recommendations for use of commercial mineral N fertilizers (Urea or Ammonium fertilizers). If these crop and region specific recommendations are available the amount of urine needed can then be calculated by using the data of the respective local urine nutrient content. Another option is to back-calculate the amount of urine needed from the estimated amount of nutrients removed by the crops at harvest. However, a lot of this information might not be available particularly on small-scale household level. In this case it is recommended to conduct experiments prior to the actual implementation to gain first experiences on appropriate application levels. Most farmers anyway will soon get a feel for the right amount of urine that is needed for optimal plant growth.

### Dilution

Urine can be applied neat or diluted with water and advice should be given on appropriate dilution ratios (or non-dilution respectively) depending on the local conditions. There is no standard recommendation for dilution/non-dilution and the existing recommendations vary widely depending on the local conditions. Dilution increases the volume to be spread and thus also increases labour, transport expense, equipment needed etc. particularly in larger-scale systems. Advantages of dilution include a noticeable odour reduction and a decreased risk of over-application, in order not to be toxic to the plants. Pros and cons should be properly weighed. Levels of dilution can vary between 1:15 (1 part urine to 15 parts water) and 1:1. Most common dilution ratios are 1:3 or 1:5. However urine should always be applied at the rate corresponding to the desired application rate of N, while additional water should be applied according to the water needs of the plants.

### Application time

Recommendations on when and how often the urine should be applied should ideally be given in an easy to understand schedule. Good availability of nutrients is particularly important in early stages of cultivation. 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 should always be observed. As regards the risk of nutrients leaching particularly 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 nitrogen need of the plant and its root size. Root size varies widely between different crops and plants with inefficient or small root systems (e.g. carrots, onions and lettuce) can benefit from repeated applications of urine.

### Application technique

Detailed recommendations on how the urine should be applied should be given. For best fertilizing effect and to avoid ammonia losses, urine should be incorporated into the soil as soon as possible after application, instantly if possible. 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. When spreading urine, it should not be applied on leaves or other parts of the plants, as this can cause foliar burning. Spraying urine in the air should also be avoided due to the risk of nitrogen loss through gaseous emissions of ammonia and the hygiene risk through aerosols. Drip irrigation with urine is another possible application technique. However, when this technique is used, measures must be taken to avoid clogging of emitters. Some plants (e.g. tomatoes) in their early stages are sensitive to having their roots exposed to urine, 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. For annual plants this distance may be about 10 cm.

### Combined application

Urine is a valuable nutrient source (particularly for N) but due to its comparably high N and low organic matter content it is often recommended to complement urine application with other nutrient and organic matter sources. The most obvious source that can be recommended would be, of course, source-separated faeces due to its high organic matter content and the high P and K concentrations given that it is acceptable for the users and associated health risks can be properly managed. Another organic matter source would be humus/compost that could be applied prior to planting time. If the P and K demand of the plant cannot be met with urine alone other P- and K-rich mineral fertilizers might be a good complementary solution.

## RISK MANAGEMENT

### Health risks

Health risks associated with the use of human urine in plant production are generally low. The objective of a section on health risks is to present credible information on how to minimize the health risks when using urine as a fertilizer. Groups that are potentially at risk comprise collection personnel and field workers, households, local communities and product consumers. As regards other contaminating substances in human urine (heavy metals, hormones and pharmaceuticals) possible health risks are far smaller than those associated with the common sanitation system and the risk for negative effect on the quantity and quality of the crops is negligible.

### WHO Multi-barrier approach

In local guidelines it can be relevant to mention that the WHO has presented international guidelines on the use of urine in agriculture. The 'WHO guidelines for the safe use of wastewater, excreta and greywater use in agriculture and aquaculture (2006) promote a flexible multi-barrier approach for managing the health risks associated with the use of excreta in agriculture. This concept comprises a series of measures/barriers from 'toilet to table'. Each of the barriers has the potential to reduce health risks associated with the excreta use and it is recommended by WHO to put in place several of these barriers if needed in order to reduce the health risk to an acceptable minimum. The local guidelines should then present barriers that are relevant to the local context, see section in Part 1 of this book. For more information visit the WHO website: http://www.who.int/water_sanitation_health.

**Barrier I: Source separation**

Source separation is an efficient barrier for reducing the risks compared to a combined wastewater system. A key objective of urine collection is to minimize faecal cross-contamination.

**Barrier II: Storage and treatment**

It is recommended that prior to application urine should be treated in order to sanitize the urine and reduce microbial health risks. Storage at ambient temperature is considered a viable treatment option. Recommended storage times vary depending on the system type. This also applies for cold climates since the temperature is also a governing factor in the die-off. As a rule: The longer storage, the better.

Urine should be stored in sealed containers in order to prevent direct contact with the urine for humans and animals . Urine should not be diluted while stored, to provide a harsher environment for microorganisms and increase die-off rate of pathogens.

**Barrier III: Application techniques**

Urine application close to the ground should always be recommended. This reduces the direct contact with the edible parts of the plants.  For example – do not apply urine with a water can on the edible or foliar parts of vegetables. The urine should be incorporated into the soil either mechanically or by subsequent irrigation with water. If urine is applied before or during

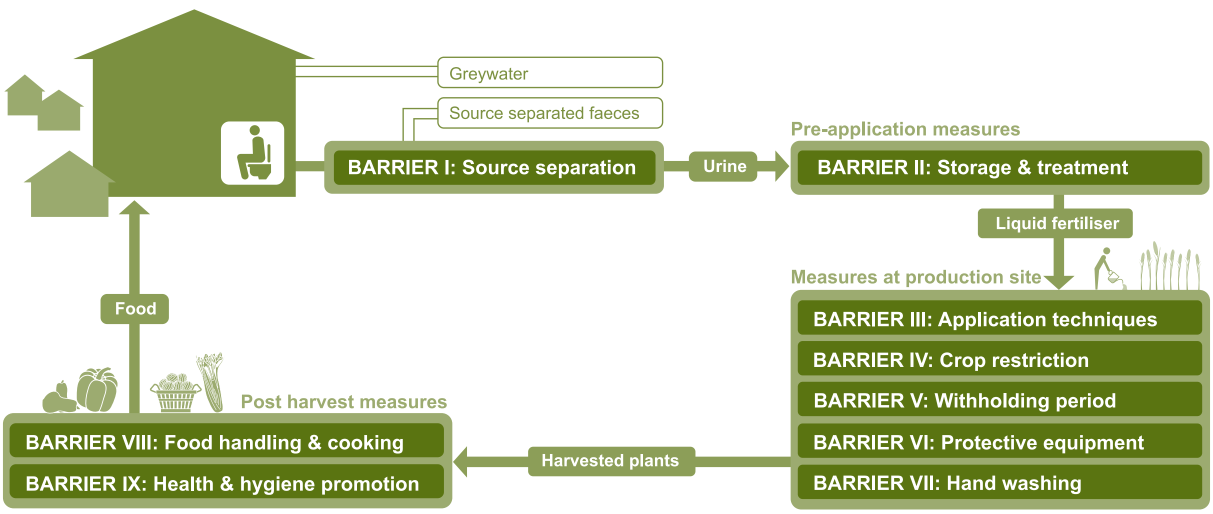



*Figure 35: Barrier concept for safe use of urine as a fertilizer.*

sowing/planting a further die-off will occur of potential remaining pathogens and thereby the risk.

**Barrier IV: Crop restriction**

When treated urine is used no particular crop restrictions need to be applied. However as an additional safety feature the urine use may be restricted to non-food crops (e.g. cotton), crops that are processed (e.g. wheat) or cooked before consumption (e.g. potato) as well as crops/trees that allow for a minimum distance between soil and harvested part of the crop. In general it can be stated that the longer the time between application and harvest – the less risky. Thus for crops with short rotation times, like spinach, salad crops and radish the risk will be higher, and the pretreatment should be better, but in the case of for example pineapples (rotation time 1-2 years) the risk from urine is nonexistent.

**Barrier V: Withholding period**

A withholding period of one month between the last urine application and the harvest is a barrier that provides time for pathogen die-off, and is always be recommended.

**Barrer VI: Protective equipment**

Although there is no high risk associated with treated urine it is recommended if possible that agricultural fieldworkers wear appropriate protective clothing (shoes and gloves) as an additional effective barrier to reduce potential health risks.

**Barrier VII: Handwashing with soap after urine handling**

Washimg hands with soap after urine handling can be considered an additional barrier in the system. Self-evidently basic recommended health and hygiene practices like hand washing after toilet use and prior to meals should always be observed.

**Barrier VIII: Food handling and cooking**

Harvested crops should always be washed before consumption. Cooking or peeling of fruits/vegetables is another effective measure to considerably reduce the associated health risks (pathogen reduction between 2-6 log units)

**Barrier IX: Health and hygiene promotion**

Effective hygiene education and promotion should be conducted in order to inform local growers and food handlers (in markets, restaurants, home and food kiosks) how and why they should wash produce fertilized with urine.

## Handling systems

Information should be given here on the specifics of the locally used collection, treatment and transport components of the sanitation system.

## Demonstration experiments and dissemination strategy

Information should be taken and summarized from local experimentation and the generic chapter.

# *PART 3 - EXAMPLE OF A LOCAL GUIDELINE*

## *GUIDELINE FOR APPLICATION OF SANITIZED URINE (TAKIN RUWA) IN THE AGRICULTURAL CONDITIONS OF NIGER*

*April 2010*

### SUMMARY



### Foreword

This guide was put together within the project "Productive Sanitation – Aguié" which was executed from October 2008 to February 2010. The project was mainly financed by IFAD. CREPA, PPILDA and SEI have been project partners during the implementation phase.

This guide was put together by professor Moussa Baragé, independant consultant, in collaboration with the SEI. It is destined towards agriculture extention officers as well as other persons and organizations interested in the possibilities of reuse of human urine as a fertilizer the Niger context.

***Figure 36: Urinals.***

Different simple urinals that allow for urine collection. The three photos to the left show the "bidur" (jerry can with urine ). It is made of a jerry can, funnel and a light bulb that avoids odors and nitrogen losses. The urinal can be off the ground or dug down according to preference.

*Figure 37: Latrines.*

During defecation, only the urine is canalized towards the recipient (jerry can) outside the toilet. The separation facilitates the treatment and reduces problems with odors and flies in the toilets.

## EXCERPTS FROM THE GUIDELINE

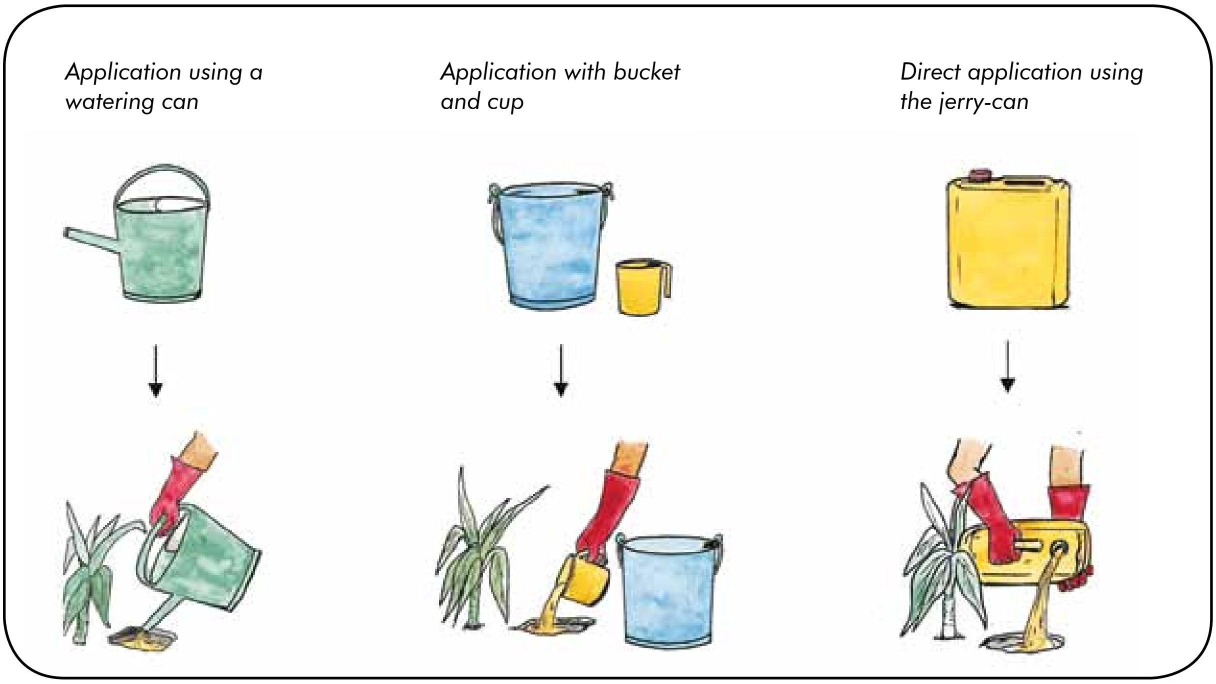
### Urine collection

Urine is easy to collecte either from urinals (figure 36) or from latrines (figure 37) that allow for separation of urine and faeces.

### Method for Takin Ruwa (sanitized urine) application

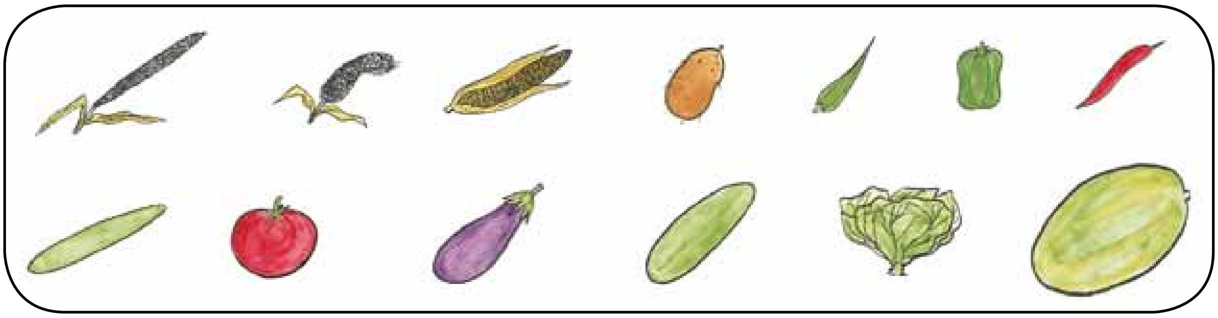
**Application technique**

Takin Ruwa can be applied with a watering can, bucket or directly from the jerry can. Metal easily rusts in contact with urine, and should be well washed after use. Use a recipient of known volume to facilitate the application of the recommended  dose

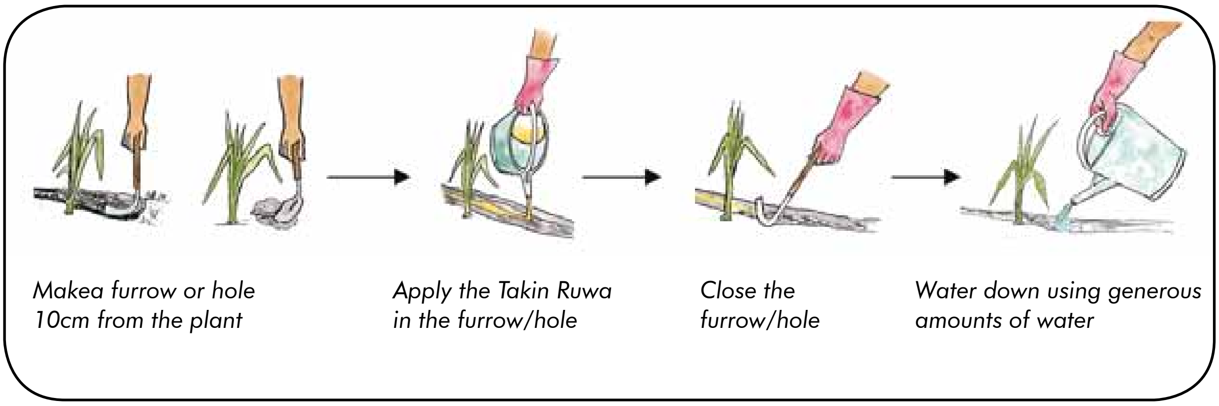


**Application to crops with space between the plants**

To apply to single plants, make a furrow beside or around the plant or just a hole around 10 cm from the plant. Apply the Takin Ruwa, and close the furrow or hole. The application is followed by watering to avoid toxicity effects (option 1). The alternative is to apply the Takin Ruwa after a good rain (option 2)

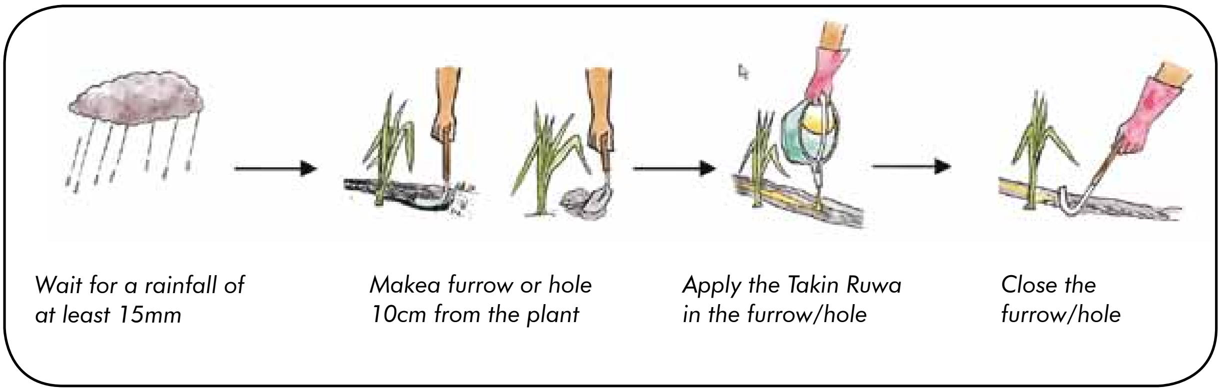


### *Option 1: Application of Takin Ruwa followed by generous watering*



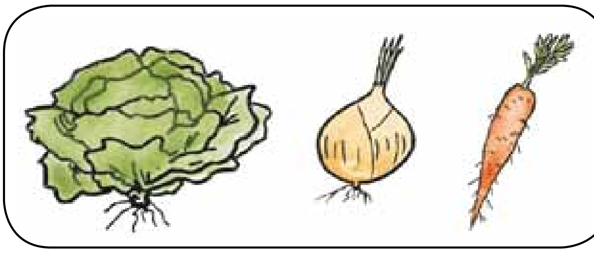

### *Option 2: Apply the Takin Ruwa after a good rainfall*

For crops grown during the rainy season (millet, sorghum etc…) the applications can be done after a good rainfall of at least 15 mm.



**Application to crops planted densely**

If possible make furrows in a quadratic fashion with a hoe, and apply the Takin Ruwa before closing the furrows. If the crops are very dense, dilute the Takin Ruwa at least 200 per cent (at least two volumes of water for every volume of Takin Ruwa), and apply in a uniform manner immediately followed by abundant watering of the leaves (see drawings).



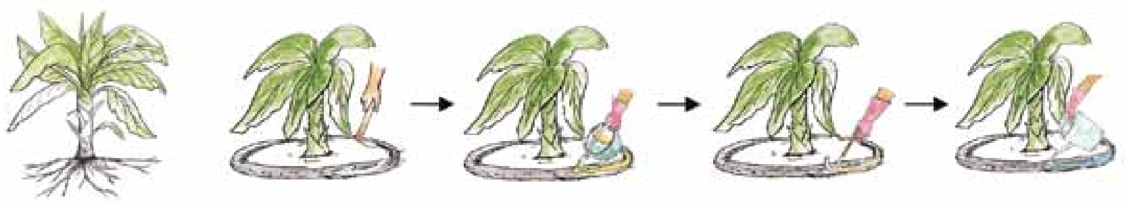
*Dilute the Takin Ruwa with water*

*Apply the dilution to the plants*

*Water the plants immediately after the Takin Ruwa application*

**Fruit trees**

For fruit trees, make a furrow 5-10 cm deep around the tree starting from the distance of the canope line. The width of the furrow can be half the canope width, measured from the edge towards the centre. The application of Takin Ruwa should be combined with compost or manure application to supply enough oligo elements.



*The roots generally have the same length as the branches.*

*Make a furrow around the tree proportional to the line of the canopy. The furrow should not reach the trunk.*

*Apply Takin Ruwa in the furrow all around the tree.*

*Cover the Takin Ruwa with some soil.*

*Water abundantly in the furrow.*

### Application of sanitized urine (Takin Ruwa) – recommended periods and doses for different crops

The different doses and franctions presented in the table on this page is based on the reults obtained from two stations as well as the recommendations for nitrogen fertilization in Niger, the nitrogen concentration of Takin Ruwa being around 4.5 gN/l (the content of P, K and oligoelements is lower) and finally the plants nitrogen need. Bear in mind however that Takin Ruwa is mainly a fast acting N-fertliizer and should be complemented by the addition of P and K or an organic base fertilizer. These Takin Ruwa recommendations are also preliminary ; ongoing research will enrich this technical guideline.

*Table 20: Periods and doses of sanitized urine for different crops.*

| Application period | Tomato | Aubergine | Pepper | Potatos | Lettuce | Onion, garlic | Gombo | Melon /marrow | Cucumber |
|---|---|---|---|---|---|---|---|---|---|
| Two weeks after sowing or planting | 0.5 litre / plant | 0.5 litre / plant | 0.6 litre / plant | 2.5 litres / $m^2$ | Sandy soil: 1 litre / $m^2$ Clayey soil: 0.7 litre / $m^2$ | 1 litre / $m^2$ | 0.5 litre / plant | 0.5 litre / plant | 0.5 litre / plant |
| Start of the flowering (3 weeks after the first application) | 0.5 litre / plant | 0.7 litre / plant | 0.7 litre / plant | 2.5 litres / $m^2$ applied at the start of the of tuberization (around 4 weeks after the first application) | Sandy soil: 1 litre / $m^2$ Clayey soil: 0.7 litre / $m^2$ (2 weeks after the first application) | 1.5 litres / $m^2$ (at the start of the bulb forming, around 4 weeks after the first application) | 0.7 litre / plant | 1 litre / plant | 0.7 litre / plant |
| During fructification (3 weeks after the 2nd application) | 0.3 litre / plant | 0.3 litre / plant | 0.5 litre / plant | | | | 0.3 litre / plant | 0.5 litre / plant | 0.3 litre / plant |

*(Table 20 cont…) Periods and doses of sanitized urine for different crops.*

| Application period | Cabbage | Carrot | Millet | Sorghum | Mango | Orange | Goyava | Papaya | Banana |
|---|---|---|---|---|---|---|---|---|---|
| Two weeks after sowing or planting | 2 litres / m² | 1 litres / m² | 0.8 litre* / plant (start of tillering) | 0.7 litre* / plant (start of tillering) | Growth fertilizer (tree aged 0-4 years): apply 2 litres/tree 4 times per year. (start of rainy season, during the rainy season, start of cold season and during the cold season). | Growth fertilizer (tree aged 0-4 years): apply 1.5 litres/tree 4 times per year. (start of rainy season, during the rainy season, start of cold season and during the cold season). | Growth fertilizer (tree aged 0-2 years): apply 1 litres/tree 4 times per year. (start of rainy season, during the rainy season, start of cold season and during the cold season). | 3 litres / tree 1 month after sowing | 3 litres / pied en couronne 1 mois après plantation |
| Start of the flowering (3 weeks after the first application) | 2 litres / m² | 1.25 litres / m² | 0.7 litre* / plant (Fin montaison | 0.7 litre* / plant (Fin montaison – début épiaison, soit 4 | Production fertilizer (trees aged > 4 years) : Apply 6 litres per tree, 4 times per year (start of rainy season, during the rainy season, start of cold season and during the cold season). | Production fertilizer (trees aged > 4 years) : Apply 5 litres per tree, 4 times per year ((start of rainy season, during the rainy season, start of cold season and during the cold season). | Production fertilizer (trees aged > 2 years) : Apply 4 litres per tree, 4 times per year (start of rainy season, during the rainy season, start of cold season and during the cold season). | 4 litres / tree 1.5 months after the 1st application<br><br>(NB: make the same application for the next production cycle) | 4 litres / tree 1.5 months after the 1st application<br><br>(NB: make the same application for the next production cycle) |
| At the start of the fructification | | | | | | | | 4 litres / tree 1.5 months after the 2nd application | 3 litres / tree 1.5 months after the second application |

*The recommended doses for millet and surghum, are based on the results from the first tests in Torodi. In Aguié the dose has been 0.5 litres, fractioned into 0.25 litres per application. This is aligned with the local recommendations for urea as a source of nitrogen.

# REFERENCES

ADB (1998) *Gender Guidelines in Water Supply and Sanitation*. Checklist. Asian Development Bank, Manila.

Arroyo (2005) Organoponics - the Use of Human Urine in Composting. *RUAF Urban Agriculture Magazine 10* - Appropriate (Micro) Technologies for Urban Agriculture. http://www.ruaf.org/sites/default/files/Organoponics.pdf.

Bernal, C.T., Bingham, F.T. and Orehi, J. (1974) Salt tolerance of Mexican wheat. ll. Relation of Variable Sodium chloride and length of growing season. *Proc. Soil Sci. Soc. Am.*, 38: 777-780.

Brady, Nyle C., Weil, Ray R. (1999) *The nature and properties of soils: twelfth edition*. Upper Saddle River, NJ: Prentice Hall.

Båth, B. (2003) *Field trials using human urine as fertilizer to leeks* (In Swedish). Manuscript, Department of Ecology and Plant Production Science, Swedish University of Agricultural Sciences. Uppsala, Sweden.

Clark, G.A. (2003) *A test of the production of organically fertilised amaranth in Tehuixtla, Morelos, Mexico*. Manuscript available from esac@laneta.apc.org.

Coulibaly, Chiaka. (2009) *Management of EcoSan System in Urban Areas: "EcoSan_UE Project Case Study" in four sectors of Ouagadougou, BF*. Presentation to the West Africa Regional Sanitation and Hygiene Symposium, Accra, Ghana, 10-12 November 2009.

CSIR (2008) *Human Excreta and Food Security in South Africa*. Project report Nr 59P1039, Submitted to L Austin, CSIR – Built Environment, PO Box 395, Pretoria, South Africa, 0001.

Dankelman, I. (2009). *Making Sustainable Sanitation Work for Women and Men. Integrating a Gender Perspective into Sanitation Initiatives*, eds. J. Muylwijk, C. Wendland and M. Samwel. Utrecht, Annemasse and Munich: WECF, Women in Europe for a Common Future).

Drechsel, P., Giordano, M., Gyiele, L. (2004) *Valuing Nutrients in Soil and Water: Concepts and Techniques with Examples from IWMI Studies in the Developing World*. IWMI Research Report nr 82. International Water Management Institute, P O Box 2075, Colombo, Sri Lanka.

FAO (2003) *FAOSTAT Nutrition data – Food Supply – Crops Primary Equivalent*. http://apps.fao.org/page/collections?subset=nutrition , visited 2003-02-28.

Ganrot, Z., Dave, G., Nilsson, E. (2007) Recovery of N and P from human urine by freezing, struvite precipitation and adsorption to zeolite and active carbon. *Bioresource Technology* 98, 3112-3121.

Gao, X. Zh., Shen, T., Zheng, Y., Sun, X., Huang, S., Ren, Q., Zhang, X., Tian, Y. and Luan, G. (2002) *Practical manure handbook*. (In Chinese). Chinese Agriculture Publishing House. Beijing, China.

Germer, J., Sauerborn, J., (2006) *Exploring the Potential for Recycling Nutrients from Waste Water to Enhance Agricultural Productivity - the Example of Valley View University in Accra, Ghana*. Presentation at the Tropentag 2006 - International Research on Food Security, Natural Resource Management and Rural Development. University of Bonn, October 11-13.

Guadarrama, R. O., Pichardo, N. A., Morales-Oliver, E. (2001) *Urine and Compost Efficiency Applied to Lettuce under Greenhouse Conditions in Temixco, Morales, Mexico*. In Abstract Volume, First International Conference on Ecological Sanitation 5-8 November 2001, Nanning, China.

Hammer, M. and Clemens, J. (2007) A tool to evaluate the fertilizer value and the environmental impact ofsubstrates from wastewater treatment. *Water Science and Technology* 56 (5): 201-209.

Heberer, Th., Fuhrmann, B., Schmidt-Bäumler, K., Tsipi, D., Koutsuba, V., Hiskia, A. (2000) *Occurrence of Pharmaceutical Residues in Sewage, River, Ground and Drinking Water in Greece and Germany*. In Symposia Papers: Issues in the Analysis of Environmental Endocriine Disruptors.

American Chemical Society, San Francisco March 26-30, 2000.

Heinonen-Tanski, H., Sjöblom, A., Fabritius, H., Karinen, P. (2007) Pure human urine is a good fertilizer for cucumbers. *Bioresource Technology*, Volume 98, Issue 1, January 2007, Pages 214-217.

Jeyabaskaran, K.J. (2010) *Utilization of human urine as liquid organic manure in banana cultivation*. National Research Centre for Banana, Tiruchirapalli – 620 102 Tamil Nadu, India.

Johansson, M., Jönsson, H., Höglund, C., Richert Stintzing, A. and Rodhe, L. (2001) *Urine separation – closing the nutrient cycle.* Stockholm Water Company. Stockholm, Sweden. Available at: http://www.swedenviro.se/gemensamma_se/documents/Urinsep_eng.pdf.

Jönsson, H. and Vinnerås, B. (2004) *Adapting the nutrient content of urine and faeces in different countries using FAO and Swedish data*. In: Ecosan – Closing the loop. Proceedings of the 2nd international symposium on ecological sanitation, incorporating the 1st IWA specialist group conference on sustainable sanitation, 7th-11th April 2003, Lübeck, Germany. Pp 623-626.

Kirchmann, H. and Pettersson, S. (1995) Human urine – chemical composition and fertilizer efficiency. *Fertilizer Research* 40:149-154.

Kvarnström, E., Emilsson, K., Richert Stintzing, A., Johansson, M., Jönsson, H., af Petersens, E., Schönning, C., Christensen, J., Hellström, D., Qvarnström, L., Ridderstolpe, P. and Drangert, J.-O. (2006) *Urine Diversion - One Step Towards Sustainable Sanitation*. Report 2006-1, EcoSanRes Programme, Stockholm Environment Institute, Stockholm, Sweden, http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf.

Larsen, T. A. and Lienert, J. (2007) *Novaquatis final report. NoMix – A new approach to urban water management*. Eawag, Dübendorf, Switzerland, www.novaquatis.eawag.ch/ publikationen/final_report_E.

Magid, J. (2006) *Estrogen in the Environment. In: Blackwater systems – Nordic Inventory.* Full report in Swedish, English summary in Appendix 2. www.nmr.org.

Marschner, H. (1995) *Mineral nutrition of higher plants.* Academic Press, Second Edition.

Mkeni, P; Jimenez Cisneros, B; Pasha, M; Austin, L. (2006) *Use of Human Excreta from Urine Diversion Toilets in Food Gardens.* Agronomical and Health Aspects. Volume 3, Report to the Water Research Commission. WRC Report No 1439/3/06.

Morgan, P. (2003) *Experiments using urine and humus derived from ecological toilets as a source of nutrients for growing crops*. Paper presented at 3rd World Water Forum 16-23 March 2003. Available at: http://aquamor.tripod.com/KYOTO.htm.

Morgan, Peter. (2008) *Toilets that make compost.* http://www.ecosanres.org/toilets_that_make_compost.htm SEI 2008.

von Münch and Winker (2009) *Technology Review - Urine diversion components: Overview of urine diversion components such as waterless urinals, urine diversion toilets, urine storage and reuse systems.* Available at: http://www.gtz.de/en/dokumente/gtz2009-en-technology-review-urine-diversion.pdf.

Muskolus, A. (2008) A*nthropogenic plant nutrients as fertilizer.* PhD thesis, Institut für Pflanzenbauwissenschaften, Humboldt-Universität zu Berlin, Berlin, Germany. URL: http://edoc.hu-berlin.de/dissertationen/muskolus-andreas-2008-04-18/PDF/muskolus.pdf.

PUVeP (2008) *Philippine allotment garden manual with an introduction to ecological sanitation.* Periurban Vegetable Project (PUVeP), Xavier University College of Agriculture, Cagayan de Oro City, Philippines, http://puvep.xu.edu.ph/publications.htm or http://www2.gtz.de/Dokumente/oe44/ecosan/en-philippine-allotment-garden-manual-2008.pdf.

Pradhan, K.S., Nerg, A., Sjöblom, A., Holopainen, J., Heinonen-Tanski, H. (2007) Use of Human Urine Fertilizer in Cultivation of Cabbage (Brassica oleracea)—Impacts on Chemical, Microbial, and Flavor Quality *J. Agric. Food Chem*., 55 (21), 8657-8663• DOI: 10.1021/jf0717891.

Rodhe L., Richert Stintzing A. and Steineck S., (2004) 'Ammonia emissions after application of human urine to clay soil for barley growth'. *Nutrient Cycling in Agroecosystems*, 68:191-198.

Schouw, N.L., Danteravanich, S., Mosbaeck, H., Tjell, J.C. (2002) Composition of human excreta—a case study from Southern Thailand. *The Science of the Total Environment* 286, 155–166.

Schroeder, E. (2010) *Marketing human excreta, a study of possible ways to dispose of urine and faeces from slum settlements in Kampala*, *Uganda*. GTZ, Eschborn, Germany.

Schönning, C. and Stenström, T.-A. (2004) *Guidelines for the safe use of urine and faeces in ecological sanitation systems*. EcoSanRes Publications Series, Report 2004-1, www.ecosanres.org/pdf_files/ESR_Publications_2004/ESR1web.pdf.

Simons J. and Clemens J. (2004) *The use of separated human urine as mineral fertilizer,* 595-600; in (eds.) Werner *et al*.: ecosan-closing the loop, 7.-11. April, 2003, Lübeck, Germany, ISBN 3-00-012791-7.

Sridevi, G., Srinivasamurthy, C.A., Bhaskar, C., Viswanath, S. (2009) Evaluation of Source Separated Human Urine (ALW) as a Source of Nutrients for Banana Cultivation and Impact on Quality Parameter. *Journal of Agricultural and Biological Science* Vol. 4, No. 5, September 2009 ISSN 1990-6145 ARPN.

Sridevi, G., Srinivasamurthy, C. A., Bhaskar, S. and Viswanath, S. Studies on the effect of anthropogenic liquid waste (human urine) on soil properties, growth and yield of maize. *Crop Res*. 38 (1, 2 and 3) : 11-14 (2009). Department of Soil Sciences and Agricultural Chemistry University of Agricultural Sciences, GKVK, Bangalore (Karnataka), India.

Sundin, A. (1999) *Humane urine improves the growth of Swiss chard and soil fertility in Ethiopian urban agriculture.* Thesis and Seminar projects No 112, Department of Soil Science, Swedish University of Agricultural Sciences.

SuSanA (2009) Working Group 12 Draft Fact Sheet: Integrating a gender perspective in sustainable sanitation, http://www.susana.org/images/documents/05-working-groups/wg12/en-fact-sheet-wg12-gender-first-draft-2009-01-20.pdf.

Thorup-Kristensen, K. (2001) Root growth and soil nitrogen depletion by onion, lettuce, early cabbage and carrot. *Acta Horticulturae*. 563: 201-206.

Tilley, *et al.*, (2008) *Compendium of Sanitation Systems and Technologies*. http://www.eawag.ch/organisation/abteilungen/sandec/publikationen/compendium_e/index_EN.

WHO (2006) *Guidelines for the safe use of wastewater, excreta and greywater use in agriculture and aquaculture*. Socio cultural, environmental and economic Aspects.3 (7). World Health Organisation (Online access 2006-10-26). www.who.int/sites.

Villa-Castorena, M., Ulery, A.L., Catalán-Valencia, E.A., Remmenga, M.D. (2003) Salinity and Nitrogen Rate Effects on the Growth and Yield of Cile Pepper Plants. *Soil Science Society of America Journal* 67:1781-1789. Soil Science Society of America.

Winker, M. (2009) *Pharmaceutical residues in urine and potential risks related to usage as fertilizer in agriculture*. PhD thesis, Technical University of Hamburg-Harburg, Institute of Wastewater Management and Water Protection, Germany, http://doku.b.tu-harburg.de/volltexte/2009/557.

Vinnerås, B. and Jönsson, H. (2002) The potential of faecal separation and urine diversion to recycle plant nutrients in household waste water. *Bioresource Technology* 84:3, 275-283.

Vinnerås, B., Palmquist, H., Balmer, P. and Jönsson, H. (2006) The characteristics of household wastewater and biodegradable solid waste—A proposal for new Swedish design values. *Urban Water,* 3(1): 3-11.

SEI - Africa
Institute of Resource Assessment
University of Dar es Salaam
P.O. Box 35097, Dar es Salaam
**Tanzania**
Tel: +255-(0)766079061

SEI - Asia
15th Floor Witthyakit Building
254 Chulalongkorn University
Chulalongkorn Soi 64
Phyathai Road Pathumwan
Bangkok 10330
**Thailand**
Tel: +(66) 22514415

SEI - Oxford
Suite 193
266 Banbury Road,
Oxford, OX2 7DL
**UK**
Tel: +44 1865 426316

SEI - Stockholm
Kräftriket 2B
SE -106 91 Stockholm
**Sweden**
Tel: +46 8 674 7070

SEI - Tallinn
Lai 34, Box 160
EE -10502, Tallinn
**Estonia**
Tel: +372 6 276 100

SEI - U.S.
11 Curtis Avenue
Somerville, MA 02144
**USA**
Tel: +1 617 627-3786

SEI - York
University of York
Heslington
York YO10 5DD
**UK**
Tel: +44 1904 43 2897

## The Stockholm Environment Institute

SEI is an independent, international research institute. It has been engaged in environment and development issues at local, national, regional and global policy levels for more than a quarter of a century. SEI supports decision making for sustainable development by bridging science and policy.

**sei-international.org**

ISBN 978-91-86125-21-9

Practical Guidance on the Use of Urine in Crop Production

Richert, Gensch, Jönsson, Stenström and Dagerskog

SEI