


Title	Integrating Farming and Wastewater Management – A Life Cycle Assessment of Barley Production using Human Urine
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Short CV for Introduction Purposes (100 words max)	Pernilla Tidåker is a PhD-student at the Swedish University of Agricultural Sciences. Her research focuses on the interaction between wastewater management and agricultural production. By using a systems perspective, she evaluates effects on environmental impacts and resource management when sewage products are used as fertilisers in agriculture.
Photograph attached (jpg)	

Introduction

Source-separation of human urine is a promising technique for improving wastewater systems. By closing the nutrient loop, nitrogen and phosphorus can be used as fertilisers in agriculture, while at the same time the eutrophying emissions from treated wastewater is reduced. Human urine is the largest contributor of nutrients to household wastewater. In Sweden, with 9 million inhabitants, approximately 36 000 tonnes of nitrogen and 3300 tonnes of phosphorus are found in the urine fraction (calculated from Vinnerås et al., 2004). These figures can be compared to the use of mineral fertilisers in Swedish agriculture, which was 170 000 tonnes of nitrogen and 14 000 tonnes of phosphorus in 2003 according to Statistics Sweden. Several Swedish urine-separating systems have been evaluated using life cycle assessment (LCA) methodology (e.g. Tillman et al., 1998; Lundin et al., 2000; Jönsson, 2002). The results from an LCA are influenced by the assumptions made. In earlier studies, the reduced need of mineral fertilisers was an important aspect for the environmental outcome, but different alternatives for handling the urine on farm level were not highlighted. In many LCAs, only the operating phase has been included, and the construction phase has been disregarded. However, for wastewater systems the construction phase may contribute considerably to the total environmental load (Tillman et al., 1998; Lundin et al., 2000). Introduction of a urine-separating system supplementing an existing wastewater system will certainly require some additional investment, e.g. collection tanks, which should therefore be taken into consideration.

When using a fertiliser such as human urine, the farmer needs to take other practical considerations into account besides the plant nutrient value, e.g. how and when to spread the urine. Conflicts might be involved, e.g. nutrient utilisation versus soil compaction and costs for spreading. In-depth studies from an agricultural perspective are therefore needed to highlight the conflicts involved and to provide information on both potential and expected environmental performance when introducing source separating systems, where the sewage products are to be used as fertilisers.

The main objective of this study was to evaluate the environmental consequences when human urine replaced mineral fertiliser in barley production. Conventional spring barley production using only mineral fertilisers was compared with production using mainly source-separated human urine.

Methodology

LCA methodology was used to compare the two scenarios. An LCA evaluates the environmental aspects and potential impacts in a cradle-to-grave perspective, from raw material acquisition through production, use and disposal. The *functional unit* is a central concept in LCA as all resources used and emissions are related to this. In this study, the functional unit (FU) was defined as 1 kg of barley harvested.

Systems description

The scenario study was geographically restricted to the region surrounding the Lake Mälaren in the eastern part of Sweden. Agriculture in the region is dominated by cereal production and livestock density is low. Sedimentary clay soils are dominating. Soil compaction when performing field operations during wet conditions is a serious threat to the long-term soil productivity.

In the *reference scenario*, conventional barley production according to current practices in the region was assessed. An application rate of 80 kg of nitrogen and 15 kg of phosphorus

was assumed. The yield was set to 4400 kg per hectare, which is the standard yield in this area. In the *urine-spreading scenario*, the urine was assumed to be collected from single households with individual storage tanks in concrete, each one holding 2.8 m³ with one year of storage capacity. The concentrations of N-total, NH₄-N and P in the urine mixture were set to 2.3, 2.1 and 0.23 kg m⁻³. The urine-separation system was further assumed to be a complementary function added to an already existing conventional system with a wastewater treatment plant operating regardless of the urine separation system, treating the other wastewater fractions from the households. The reduced need for treatment, distribution and pumping of drinking water and wastewater was accounted for, as well as the reduced amount of precipitation chemicals required. Of the influent to the wastewater treatment plant, 40% of the nitrogen was assumed to be emitted with the treated water. Reduction of phosphorus in the wastewater treatment plant was set to 95%.

The urine was further assumed to be transported 10 km to a farm, stored and spread in a growing crop with a 10 m³ spreader equipped with trailing hoses. Volatilisation of ammonia from urine was set to 5% of the total NH₄-N during storage and 5% during spreading. The greater part of the mineral fertiliser was replaced by human urine. In the urine-spreading scenario, a first application of mineral fertiliser was assumed, corresponding to 30 kg of nitrogen and 5.5 kg of phosphorus. The remaining requirement of plant nutrient was applied as urine. The yield in the urine-spreading scenario was determined to be 4150 kg per hectare. The assumed difference in yield was explained by higher ammonia losses in the urine-spreading scenario as well as effects from soil compaction and wheel traffic due to the spreading of urine in the growing crop. Both the immediate effects from soil compaction and its cumulated future effects were accounted for in the yield obtained in the urine-spreading scenario as a reduction of the yield in the year under study.

A change-orientated perspective was used, focusing on changes occurring when the urine-spreading scenario was introduced compared to the reference scenario. As the urine-spreading scenario required additional pipes and tanks, these were included within the system boundaries. The capital goods were assumed to be in use for 30 years. The system boundaries are illustrated in Figure 1. A more detailed description of the scenarios is presented in Tidåker (2003).

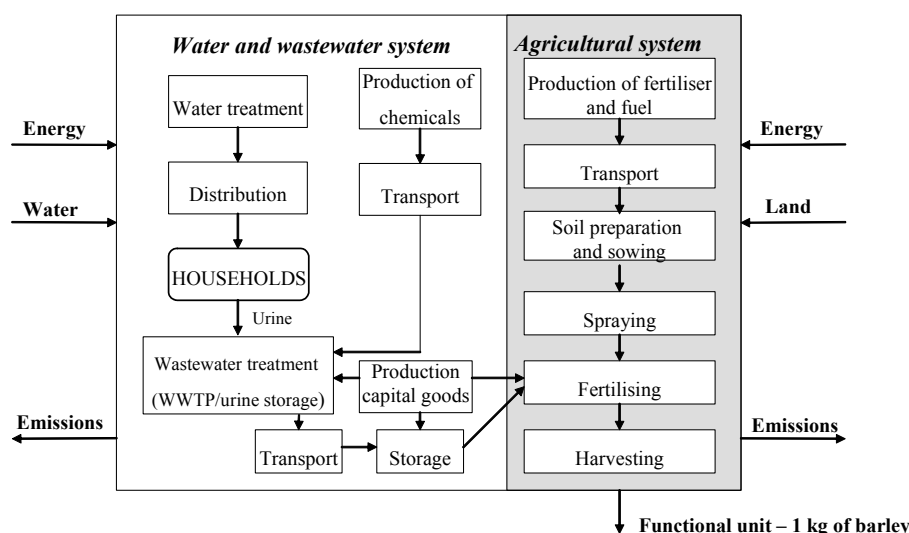


Figure 1. Flow-chart of the system studied. The reference scenario included only the agricultural system. The urine-spreading scenario included also affected parts of the water and wastewater systems in the sense that burdens avoided when separating urine were subtracted from the effects caused by the agricultural system.

Results

The use of fossil fuel was similar in the two scenarios, while the use of electricity differed. The total use of primary energy was 1.5 MJ per FU in the reference scenario and 1.1 MJ in the urine-spreading scenario (Figure 2).

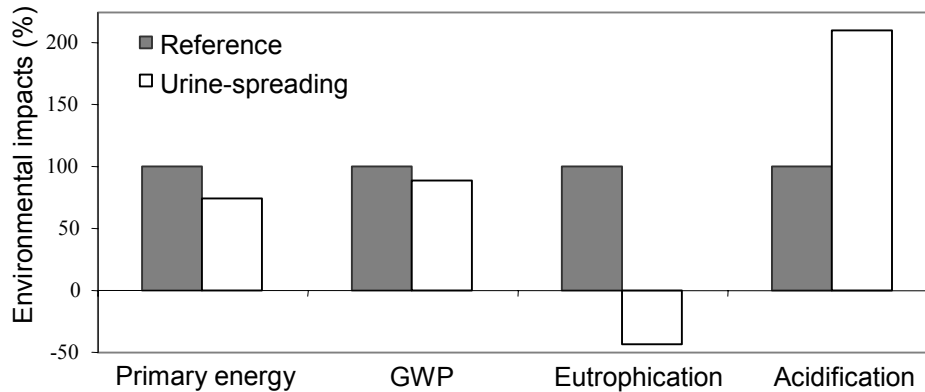


Figure 2. The environmental impacts from the urine-spreading scenario compared to the reference scenario.

The electricity saved in the urine-spreading scenario was due to a smaller quantity of drinking water produced, as well as a reduced need for pumping and treating wastewater. Production of capital goods in the urine-spreading scenario accounted for half of the total primary energy use, primarily in the form of fossil fuel. The major part of this was due to the construction of storage facilities at household level. The emissions of greenhouse gases from the two scenarios were of the same magnitude, although slightly higher from the reference scenario. Emissions of N_2O dominated the greenhouse gases. The main source of N_2O was field emissions from natural soil processes, followed by emissions from production of ammonium nitrate fertiliser. The potential contribution to eutrophication was considerably higher for the reference scenario than for the urine-spreading scenario. The difference between the scenarios was explained by the reduced emissions of nitrogen from the wastewater treatment plant when urine was separated. However, the urine-spreading scenario contributed most to acidification, assessed as a maximum scenario, through its higher emissions of NO_x and NH_3 . In particular, the emissions of NH_3 differed between the scenarios, due to ammonia losses during storage and spreading of urine.

The potential effects of a large-scale regional change from conventional barley production according to the reference scenario to the urine-spreading scenario were examined. In a normalisation, these changes were compared to figures on the total impact for Sweden. Urine from approximately one million users of separating toilets was assumed to be spread on arable land. The most noticeable change appeared in a lower discharge of nitrogen (-0.9%) and phosphorus (-0.4%) to water and decreased use of nitrogen and phosphorus fertilisers (-1% and -3%, respectively). The change in the discharge to water was relatively small compared with the total nutrient load, mainly because urine-separation was compared to conventional wastewater treatment with efficient removal of nitrogen and phosphorus. The increase of NH_3 emitted in the urine-spreading scenario was 0.3% compared to the present emission figure for Sweden.

The design of a urine-spreading scenario may be conducted in different ways as regards the collection and handling of the urine. Therefore, the assumptions made concerning the system could affect the results. The following changes in the urine-spreading scenario were made and evaluated in a sensitivity analysis.

- Spreading the urine in the spring using a spreader with higher capacity

- Spreading in the autumn before sowing
- Urine storage in plastic tanks at household level

A spreader with higher capacity will be more time-efficient, but will also increase the soil compaction, thereby reducing the yield. Hence, all environmental aspects considered in this study are affected as the functional unit is related to the yield. Calculations were made for an 18 m³ spreader during wet soil conditions, characteristic for the spring, on a clay soil. The yield reduction was 14% if both the more immediate and future accumulated effects from the soil compaction were related to the year under study. If instead urine was spread with a heavy spreader in the autumn, the corresponding yield reduction was only 5%. However, the plant nutrients in urine are poorly utilised when spread in the autumn, as most of the nitrogen may be lost through volatilisation and, later during the winter, through denitrification and leaching. Beside higher emissions of eutrophying and acidifying substances, mineral nitrogen fertiliser must replace the nitrogen lost. Calculations based on an assumption that all nitrogen required was applied as mineral fertiliser showed that the primary energy use by the urine-spreading scenario increased to 1.7 MJ. Using a 2 m³ storage tank in plastic instead of concrete increased the use of primary energy by the urine-spreading scenario to 1.9 MJ per FU.

Discussion

An optimal use of the plant nutrients in urine is essential for a sustainable use of resources. Animal farms in most cases have a surplus of phosphorus and potassium, and their need for additional plant nutrients is modest. Farms specializing in grain production are therefore more interesting from the aspect of resource use. However, the organisation responsible for disposing of the urine, e.g. a municipality, may prefer to collaborate with an animal farm, as those often have both storage facilities and spreading equipment available and therefore can offer a cheaper disposal. An analysed nutrient content and optimised use concerning crop and application technique are important factors when using urine. However, the best handling practices seems not to be used among farmers (Fernholm, 1999). The difference between what is assessed in a systems analysis and practical performance in reality is important to bear in mind when discussing the results from a systems analysis. If urine is spread to the growing crop with a small spreader equipped with trail hoses, the soil compaction is reduced while the plant nutrient efficiency is kept high. However, if only a spreader with splash plate is available, the spreading operation can be performed either in the spring or in the autumn. As illustrated in the sensitivity analysis, spreading in spring with a heavier spreader resulted in a substantial yield loss due to soil compaction. In this situation, spreading in the autumn could be a tempting alternative for the farmer, as the plant nutrient value of the urine could be lower than the cost of spreading when soil compaction is included. However, spreading in the autumn means that most of the environmental benefits of urine-separation are lost. As the handling of urine on farm level is crucial for many environmental aspects, the design of a urine-separating system should include recommendations for the agricultural management of the urine. It is also important that organisations responsible for nutrient recycling systems are aware of the different conflicts involved.

Whether a source-separating system, where urine is used as fertiliser, is more energy-efficient than a conventional system depends to a large extent on how the system is designed. By using a change-orientated perspective, major changes in the construction of capital goods could be taken into account, without considering the construction phase as a whole. Production of capital goods contributed significantly to the primary energy used in the urine-spreading scenario. The calculated lifetime for the capital goods and choice of material is therefore important. In this respect, concrete tanks were preferable to plastic tanks. The long distance sometimes required for transporting the urine has been discussed as a weakness for source-separating systems without further concentration of the urine mixture.

With the assumptions made in this study, the urine mixture could be transported 35 km (one way) before the primary energy use in the urine-spreading scenario exceeded that in the reference scenario. Concentration of urine in order to reduce the energy use required for transportation should therefore be compared to the energy use for operation and for construction of capital goods required for this process.

The environmental benefits of reduced efforts for the handling of water and wastewater were also important in the energy calculations, especially the amount of water used. To what extent water is saved due to a separating system is not easy to predict, as the variation is considerable due to different construction of the toilets and user habits. The uncertainty in water-use is therefore important to bear in mind, especially as considerable water-saving is possible also with non-separating toilets.

Conclusions

This study demonstrated that an agricultural system using human urine has several environmental benefits if the system is well designed. Emissions of nitrogen and phosphorus to water were lower in the urine-spreading scenario than in the reference scenario. A minor decrease in greenhouse gases also appeared. Due to emissions of NH₃ during storage and spreading of the urine, the contribution to acidification increased in the urine-spreading scenario. Under the assumptions given in this study, the urine-spreading scenario decreased the use of primary energy compared to the reference scenario. However, this depended on several factors and implied a long-lasting, well-functioning system where the urine was used in an optimal way. In particular, the production of capital goods contributed to the primary energy used in the urine-spreading scenario. The largest impact of a large-scale implementation of the urine-spreading scenario would be the decrease in eutrophication.

A change-orientated perspective gave interesting results on the environmental impact related to a conversion to a urine-spreading scenario. Major differences in the construction phase between the scenarios were accounted for, without any need for considering the construction of the whole system.

Using an agricultural perspective when evaluating a urine-separating system gave valuable information on how agricultural production using human urine could be designed, including effects from soil compaction and wheel-traffic. An optimal fertilising strategy concerning application time, technique and substitution of mineral fertiliser was demonstrated to be important for reducing the environmental load and avoiding soil compaction. The study also highlighted potential conflicts regarding nutrient utilisation. As the handling of urine at farm level is critical for many environmental aspects, a strategy for using human urine in practical farming needs to be integrated in the design of urine-separating systems.

Acknowledgements

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