Human urine and effluents from digestion of food refuse as a fertiliser to barley - crop yields, ammonia emission and nitrate leakage

Utilisation de l'urine humaine et d'effluents issus de la digestion de déchets alimentaires en tant que fertilisant pour l'orge, émissions d'ammoniac et pertes nitriques.

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Abstract

A field trial investigating the fertilising effect of stored human urine, effluents from digested food refuse and mineral fertilisers applied to barley was performed in 1997 on a farm south of Stockholm. Nitrogen efficiency and influence on yield and grain quality was studied. Ammonia emissions were measured after application of human urine. The risk of nitrate leakage was just as high from organic as from mineral fertiliser used. A nutrient balance of nitrogen added and nitrogen removed from the fields by the crops verifies that large inputs increases residual nitrogen. These are results from just one year of field trials and more experiments are needed to study plant nutrient efficiency and to measure nitrogen losses. The study will continue in 1998.
Keywords : human urine, ammonia emission, barley yield, nitrogen utilisation, nitrogen balance, nitrate leakage.

Résumé

Un essai au champ a été réalisé pour déterminer l'effet fertilisant, de l'urine humaine stockée, d'effluents issus de la digestion de déchets alimentaires et d'engrais minéraux, épandus sur orge, en 1997 dans une exploitation située au sud de Stockholm. L'efficacité azotée et l'influence sur le rendement en grains et sur la qualité, ont été étudiés. Les émissions d'ammoniac ont été mesurées après épandage de l'urine. Le risque de pertes sous forme d'azote nitrique est aussi important à partir des apports organiques que des engrais minéraux. Un bilan azote entre les entrées et les sorties confirme que les apports massifs augmentent la teneur en azote résiduel. Ce sont des résultats préliminaires tirés de la première année d'expérimentation, qui nécessitent d'être vérifiés par d'autres essais. Nous étudierons notamment l'utilisation d'azote par la plante et les pertes azotées.
Mots-clés : urine humaine, émissions d'ammoniac, rendement orge, utilisation azote, bilan azoté, fuits nitriques.

1. Introduction

The Swedish society strives towards sustainable living with integrated solutions between consumers and producers of food. Clean refuses from restaurants and households are possible sources for energy and plant nutrients. The new challenge is to find hygienic and ”environmentally sound” solutions for recycling plant nutrients in food back to agricultural land where air and water quality is improved at the same time as nutrient resources are recycled back to the farmers as organic manure.

Swedish agriculture annually produces living animals, milk, eggs, vegetables and grain containing 65 000 tonnes of nitrogen and 11 000 tonnes of phosphorus out of which 20 per cent is lost in the food processing industry (Claesson & Steineck 1996). The food is consumed and energy is used by man, but most plant nutrients pass the human body right into the toilet. The plant nutrients are collected in waste water treatment plants and a large part enters the environment depending on the system used.

Today, many private households lack a purification system or have a deficient system. Aaltonen & Andersson (1995) showed that sand filter beds in Sweden have deficient purification efficiency. After 13 years the sand filter has become a source instead of a sink for nutrients.

Separating urine from faeces directly in the toilet is one of many solutions of making recycling of nutrients possible without unwanted pollutants. The nitrogen content in human urine in Sweden is equivalent to one fifth of nitrogen in mineral fertilisers sold in 1995. There is an interest from ecological farmers in Sweden to use human urine as liquid manure because of the content of easily soluble nitrogen, phosphorus and the low heavy metal content (Lindén, 1997). Effluents from digestion of food refuse is another example of a new organic fertiliser rich in plant nutrients. During the digestion energy is captured in methane gas. Leftovers are suitable for using as fertiliser since all plant nutrients are retained in the residual effluents.

There is a need for research on efficiency and environmental impact from new organic fertilisers. Humans excrete a larger proportion of their nitrogen and phosphorus intake in the urine than pigs. Most of the nitrogen, N, in human urine is in plant available form as ammonia nitrogen (Kirchmann & Pettersson, 1995; Claesson & Steineck, 1996). The nitrogen content in stored human urine depends on the toilet flushing capacity by dilution.

Stored human urine normally has a higher pH - 8.6-9.2 - than animal urine with a pH value of 8.4-8.8. A high pH increases the risk for ammonia losses during storage and after spreading. Ammonia emissions are both a resource problem and an environmental problem (Löfgren et al. 1998). The high pH in human urine may have a positive effect in killing infectious bacteria and virus (Höglund et. al., 1997). Effluents from digestion has a high pH 8-9 as well.

The material for digestion is pasteurised one hour in 70^{o} C before treatment in a digestion chamber. The content of nutrients in effluents from digestion depends on the material and the process. In most cases the nutrients are the same as in animal slurry.

The objective of the study was to determine the effect of application rate on grain yield, nitrogen utilisation and ammonia emissions after spreading human urine and effluents from digestion of food refuse compared to mineral fertiliser and to estimate the risk of nitrate leakage based on nitrogen in the soil in late autumn.

2. Materials and methods

Fertiliser value of human urine and effluents from digestion of food refuse was studied in a field trial with barley 1997. The experimental design was randomised blocks with three replicates. Organic manure and mineral fertiliser were applied on 21 May, and on the following day barley was sown. Human urine and effluents from digestion of food refuse were applied with a plot spreader with trailing hoses (0.25 m apart). Incorporation into the soil with a light harrow was done four hours after spreading. Eleven treatments were included in the trial. Humane urine was bandspread to barley before sowing at four different rates, 8, 21, 28 and 59 tonnes per hectare. A control treatment with no fertiliser and treatments with mineral fertiliser, NPK, were included at the rate of 0, 30, 60, 90 and 120 kg nitrogen per hectare. Applications of effluents from digestion of food refuse were done at 22 tonnes per hectare in the spring and 28 tonnes per hectare in the summer when the barley was 10 cm.

Ammonia emissions from plots treated with urine were measured at the application rates of 8, 21 and 59 tonnes of human urine per hectare. A micrometeorological method of measuring gaseous ammonia (NH_3) was used based on passive diffusion sampling close to the ground (Svensson, 1994). On each plot, measurements of ammonia emissions were carried out with two chambers to estimate the equilibrium concentration and with one ambient measuring unit to estimate the concentration of NH_3 in the ambient air. The NH_3 emissions were measured during three periods directly after spreading. The periods were 0-1 h, 1-4 h and 4-22 h after spreading. The measurements were followed by harrowing after 4 hours. Climatic conditions were registered in the field during the measurements of ammonia. Air temperature was 7.3 °C in average. Soil surface temperature was 8.8 °C and wind velocity 3.6 meters per second.

The barley was harvested at maturation, (11 September) and the weight was registered. The grain was analysed for volume weight, content of dry matter and total nitrogen. Sampling and analysis of the soil was made in the spring before sowing (4 May), before maturation (15 August) and late in the autumn (28 October) to decide nitrogen mineralisation and estimate the risk of N leakage.

The stored human urine originated from people living in ecological villages in Stockholm. They have installed urine separating toilets separating urine from faeces in the toilet (Jönsson et. al., 1997). The effluents from digestion of food refuse came from a project ”From dining table to soil”, recycling food refuse in Stockholm. Samples of urine and effluents from digestion were taken at spreading for analyses of dry matter (DM), pH, ammonia-nitrogen, total nitrogen, phosphorus, potassium and ashes. See table 1.

The field trial was located south of Stockholm. The soil in the field is a clay loam with 2.8 % soil organic matter (SOM) and with a pH 6.6.

	Dry matter content %	Ashes % of dry matter	pH	Nutrient content, kg/tonnes			
				NH_4-N	Tot-N	P	K
Human urine	0,74	83	8,9	3,4	3,7	0,3	1,0
Effluents from digestion, spring application	1,8	39	8,6	2,2	3,6	0,19	0,99
Effluents from digestion, summer application	2,3	43	8,0	2,3	3,5	0,20	0,8

Table 1.
Content of dry matter, ashes, in percent, and ammonia-nitrogen, total nitrogen, phosphorus, potassium in kg per tonnes and pH-level in human urine and effluents from digestion of food refuse.

Grain yield data were analysed by a polynomial regression model with polynomial curves with a common intercept. Significant tests were conducted for differences in the shapes of the curves.

3. Results and discussion

The yield response curves with the amount of nitrogen as dependent variable were significantly different both in the x-term ($p< 0.001$) and in the x^2-term ($p< 0.004$) for human urine compared to mineral fertiliser.

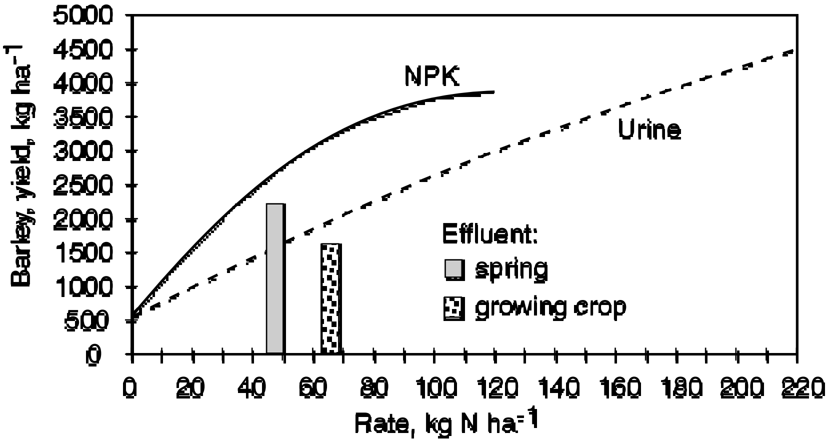

Figure 1.
Yield of barley with 15% water content after application of human urine, mineral fertiliser and effluents from digestion of food refuse. The regression polynom is for human urine $y = 588 + 22.6 * x - 0.022 * x^{2,}$ and NPK $y = 588 + 54.6 * x - 0.226 * x^{2,}$. The bars show yield response for effluents applied at two different times.

An application of human urine containing 100 kg per hectare of total nitrogen yielded 2 600 kg barley per hectare. It was 32 percent less barley than the same amount of nitrogen in mineral fertilisers yielded. A spring application of effluents from digestion of food refuse containing 48 kg nitrogen per hectare yielded 2 210 kg barley. Compared to the same amount of nitrogen in mineral fertilisers the yield was 18 percent lower. In the beginning of July when the crop was 10 cm, an application of effluents from digestion of food refuse with 66 kg nitrogen per hectare yielded 1 660 kg barley per hectare. It was 48 percent lower yield than for the same amount of nitrogen in mineral fertilisers applied at sowing.

An application of 100 kg of nitrogen in mineral fertilisers yielded 3 780 kg grain per hectare. It is lower than normal due to the weather and also the to the fact that the field was sown two weeks after normal sowing time. Excessive rain in April and May resulted in a slow drying up process of the soil. June was wet and July was extremely dry and warm. (Elmquist et al, 1998). The normal reference yield of barley for this area is 4 510 kg per hectare (SCB, 1997a). Barley yields in the trial were lower than normally thanks to the late sowing time but differences in nitrogen response in the yields were still quite evident. The field trial in 1997 was the first year of trials and results from just one year can not be used for advice. Weather conditions are dominating yields of all crops and more trials are necessary.

In the field trial as well as in pot experiments using the same human urine no toxic effects were visible in the crops (Kvarnmo, 1998).

In figure 2 the accumulated nitrogen losses of ammonia after application of human urine are shown. The highest ammonia losses occurred after the highest rate applied, 59 tonnes of human urine per hectare, and was 8.9 percent of N applied. Corresponding ammonia losses for 8 tonnes per hectare was 6.3 percent and for 21 tonnes per hectare 5.5 percent of N applied in human urine.

For the two lower application rates, the losses were small after incorporation of the urine in the soil four hours after spreading (Malgeryd, 1996). At the highest rate, ammonia emissions continued to occur in spite of incorporation into the soil, but at a lower rate.

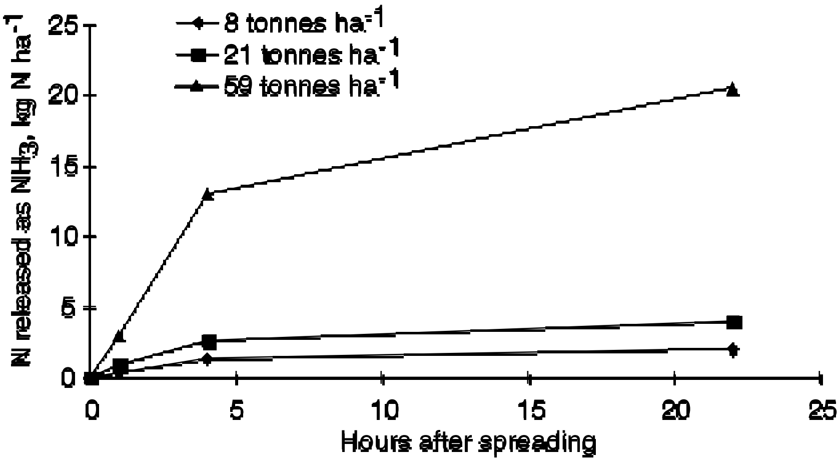

Figure 2.
Accumulative nitrogen losses as ammonia after spreading of human urine. Four hours after spreading the urine was incorporated into the soil by a light harrow and after 22 hours the measurements were finished, since it was time to sow the barley.

A comparison of ammonia emission from swine urine (Rodhe & Johansson, 1996) and human urine (Johansson, 1997) both applied in the spring before sowing, shows that losses were about the same and less than 10 percent of total nitrogen applied. Another study where cattle urine was applied to ley resulted in much higher losses, 20-86 percent of total nitrogen, depending on application time and technique (Rodhe et al, 1997).

A nitrogen balance is a useful tool to evaluate the efficiency of nitrogen when using different kinds of fertilisers and amounts of nitrogen (SCB, 1997b). The net mineralisation of soil nitrogen during the season is calculated from the control to 35 kg nitrogen per hectare, see table 2. It is calculated from nitrogen in the grain, root and straw of the barley just before harvest, plus mineral nitrogen in the soil at spring, minus mineral nitrogen in the soil before harvest.

	Application rates of mineral nitrogen	Import of total nitrogen, (mineral and organic nitrogen)	Net mineralisation of soil nitrogen	Import of nitrogen via deposition (SJV, 1997)	Export of nitrogen in barley yield	Calculated rest of nitrogen (import minus export)	Measured rest of nitrogen in the soil 0-90 cm (autumn)
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
Control		0	35	10	12	33	35
Human urine	26	28	35	10	13	60	34
Human urine	69	74	35	10	24	95	35
Human urine	98	105	35	10	40	110	35
Human urine	212	230	35	10	71	204	37
NPK	30	30	35	10	29	46	33
NPK	60	60	35	10	39	66	34
NPK	90	90	35	10	55	80	31
NPK	120	120	35	10	61	104	33
Effluents spring appl.	48	79	35	10	30	94	37
Effluents summer appl.	66	101	35	10	26	120	45

Table 2.
Nitrogen balance indicating import and output of nitrogen in the field trial in 1997 (total nitrogen in kg per hectare)

The nutrient balance of added nitrogen and nitrogen removed from the field by the crop verifies that large inputs increases residual nitrogen. It is not found in the soil as mineral nitrogen in the autumn.

According to measurements of the content of mineral nitrogen in the soil (0-90 cm) before freezing in the autumn (table 2) the risk of nitrate leaching after application of stored human urine and effluents from digestion is just as high as from mineral fertilisers.

Results from just one year of field trials are insufficient and more experiments are needed to study plant nutrient efficiency and to examine nitrogen losses. This study will continue in 1998.

In developing future systems for recycling of nutrients from the society changes have to be based on local conditions and seen in a long perspective of time.

4. Conclusions

1. Stored human urine and effluents from digestion of food refuse can be used as fertiliser in grain cultivation.
2. An application of human urine containing 100 kg per hectare of total nitrogen yielded 2 600 kg grain of barley per hectare. It was 68% of what the same amount of nitrogen in mineral fertiliser yielded.
3. Application of effluents from digestion of food refuse at sowing time in spring yielded a higher harvest than application later in the summer.

4. An application of 48 kg nitrogen in effluents from digestion of food refuse, applied in spring, yielded 82% of the yield at the same rate of nitrogen in mineral fertilisers. A summer application of 66 kg nitrogen yielded 52 % of the harvest yielded at the same rate of nitrogen in mineral fertilisers.
5. Nitrogen lost as ammonia was in the range of 5.5-8.9 percent of nitrogen applied in stored human urine. Highest ammonia losses occurred after applying 59 tonnes per hectare. Differences in percentage losses between 8 and 21 tonnes per hectare were small.
6. According to measurements of the content of mineral nitrogen in the soil before freezing in the autumn, the risk of nitrate leaching after application of stored human urine and effluents from digestion is just as high as from mineral fertilisers.
7. The nutrient balance of added nitrogen and nitrogen removed from the field by the crop verifies that large inputs increases residual nitrogen.

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