



Nutrient levels, heavy metal concentrations and bacterial contamination of crops when using urine, dry toilet compost and septic tank sludge as fertilizers

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ABSTRACT

The large scale agricultural reuse of human excreta is not an option in EU countries today. The restrictions are based on the risks of bacterial infection from the excreta or an increase in heavy metal levels or excessive phosphorus in soils. The aim of this study is to survey the fertilizing value of these components and possible risk of exposure to heavy metals and pathogens under Finnish agricultural conditions. A greenhouse scale study was performed at Tampere Polytechnic, University of Applied Sciences, where separated urine, dry toilet compost, septic tank sludge (STS) and commercial inorganic fertilizer were used to fertilize carrots (*Daucus carota* var. Napoli) and barley (*Hordeum vulgare* var. Scarlett). Nutrient analyses were carried out for total nitrogen and potassium. Heavy metals (Cd, Cu, Pb, Ni, Zn) were also analysed. Total coli form amounts and occurrence of *Salmonella* spp. were used as indicators of pathogenic contamination. The results show that heavy metal and pathogenic risk is low when using separated urine and composted faeces as fertilisers, although at the expense of nutrient content and growth. When using STS the risk of heavy metal uptake and exposure increases. Carrots seem to be more sensitive to pathogen contamination and heavy metal uptake than barley. It appears that dry sanitation and urine separation is worthwhile when considering human excreta for fertiliser use. As a pilot study these results opened many new questions which are suggested for further studies.

INTRODUCTION

Human excreta, once valuable source of nutrients in the western world, have become almost hazardous waste. Due to urbanisation and the use of flushing toilets, mixing human excreta and leading it out of sight via sewer networks makes the use of excreta for fertilising almost impossible. In 2004, Finland used inorganic fertilizers to the extent of 108 kg/ha, or 721 million kg in total. Of that amount 69 % was nitrogen, 8 % phosphorus and 24 % potassium [1]. We produce on average 50 kg of faeces and 500 kg



of urine every year. They contain approximately 5.7 kg of nitrogen, 0.6 kg of phosphorus and 1.2 kg of potassium [2]. This means that for example in Finland our population produces on average 30 million kg of nitrogen, 3 million kg of phosphorus and 6 million kg of potassium every year.

Human urine contains very little heavy metals and other toxic compounds, since our nutrition is fairly free from heavy metals, and kidneys are very effective at removing them from urine. Normally, urine is also pathogen-free, which makes it an excellent fertilizer. Heavy metals are normally excreted with faeces. The concentrations are however, usually far below the limit values set for sewage sludge [3]. Therefore, human excreta would be possible to use as fertilizer, without any significant risk for heavy metal exposure. In addition with proper handling and composting, the risk for spreading pathogens can be reduced remarkably.

In this pilot study, separated urine, composted faeces, septic tank sludge and commercial inorganic fertilizers were used to grow carrots and barley in greenhouse conditions. The risk of heavy metal and pathogenic contamination due to the fertilisers used and the nutrient content of substrate and plants were estimated.

METHODS

Barley (*Hordeum vulgare* var. Scarlett) and carrots (*Daucus carota* var. Napoli) were used as model plants. Plants were grown in a greenhouse (Figure 1). The growing substrate was a mixture of horticultural peat and sand (3:1). Lime (2.2 kg/m³) was added to adjust the pH to 6.5. Plants were sown on November 8, 2005 and the total duration of the experiment was 14 weeks ending February 9, 2006. Conditions of the greenhouse were adjusted to correspond to the average climatic conditions of June in Southern Finland. The light/dark cycle was initially 20:4 hours and after December 19, 19:5 hours. The intended daytime temperature was 20 °C and night-time 15 °C. This was not however always achieved since the cooling system's capacity was not enough to lower the temperature, and for that reason, plants grew faster than desired (Figures 2 and 3). The night-time temperatures varied between 12.5-22 °C and daytime temperatures between 26-30 °C.



Figure 1. The greenhouse used in the experiment. The figure on the left shows the carrot and barley crates inside the greenhouse immediately after sowing.

The growth substrates were fertilized with urine, composted faeces, septic tank sludge (STS) and commercial inorganic fertilisers (“Kevätviljan Y3” for barley and “Puutarhan kevät” for carrots). The nitrogen (N) content of commercial inorganic fertilisers was used as a determining factor for the amounts of organic fertilisers. For barley the recommended amount of N was 50 g/m^2 and for carrots 80 g/m^2 . Thus the amounts of fertilisers were as follows:

- Urine 0.98 kg/m^2 for barley and 0.62 kg/m^2 for carrots
- Faeces 1.75 kg/m^2 for barley and 1.1 kg/m^2 for carrots
- STS 22.7 l/m^2 for barley and 14.5 l/m^2 for carrots

Thinning was carried out on November 25 to ensure good growth of the plants (Figure 3).



Figure 2. Carrot (left) and barley (right) crates in the greenhouse one week after the start of the experiment.



Figure 3. Thinning of barley two weeks after the start of the experiment.

Concentrations of heavy metals (Cd, Cu, Pb, Ni, Zn) [4,5] and main nutrients (N, K) [6] from the substrates were analysed at the beginning and end of the experiment. In addition, the occurrence of *Salmonella* bacteria and the amounts of total coli form bacteria were analysed two weeks after beginning of the experiment and again at the end of the experiment. Coli forms were analysed by a modified method of standard SFS 3950 [8] and instructions provided with chromogenic Compact Dry CF plates, which were used for the quantitative detection of coli forms. Samples from the substrate were taken three times during the experiment: 1-2 days after sowing, 2 weeks after sowing and at the end of the experiment. The occurrence of *Salmonella* bacteria was analysed by the instructions provided with the Compact SL plates, which were used for the qualitative detection.

At the end of the experiment, the plants also were collected and analysed as described above. In addition, the growth of barley and carrots by different treatments was determined by measuring average mass and length of the plants, and in the case of barley, grain size and yield was measured.

RESULTS

Heavy metals

No significant amounts of heavy metals were found from the growth substrates at the beginning of the experiment. In every case, heavy metals discovered were far below limit values set for agricultural soils by the Council of the State [7]. In tables 1 and 2 the



heavy metal concentrations of different treatments of barley and carrots measured at the end of the experiment are presented. All other values remained far below the limit values except for Cd concentration in carrot substrate treated with STS, which slightly exceeded the limit value.

Table 1. Mass fractions of the heavy metals in substrates of different treatments of barley at the end of the experiment and limit values set by the Council of the State [7]. BDL= below detection limit.

Heavy metal	Mass fraction (mg/kg)				
	Fertiliser	Faeces	Urine	STS	Limit value
Cd	0.09	0.36	0.25	0.26	0.5
Cu	3.7	3.3	2.6	2.8	100
Pb	2.8	3.0	1.3	2.6	60
Ni	2.1	2.1	2.2	1.9	60
Zn	15	13	14	14	150

Table 2. Mass fractions of the heavy metals in substrates of different treatments of carrot at the end of the experiment and limit values set by the Council of the State [7].

Heavy metal	Mass fraction (mg/kg)				
	Fertiliser	Faeces	Urine	STS	Limit value
Cd	0.38	0.41	0.44	0.58	0.5
Cu	3.0	2.3	2.2	2.5	100
Pb	4.0	4.1	2.5	2.3	60
Ni	2.5	1.7	1.8	1.9	60
Zn	14	14	14	14	150

In all plants the heavy metal concentrations were very low. Only the concentrations of Cd and Pb are limited by regulations for foodstuffs [9] and only Zn has a recommended maximum daily intake value. Cd concentrations found in the plants were below limit values by approximately 50 % in barley and any Pb value that was above detection limit on barley was also 50 % below the limit value. Cd concentrations in carrots exceeded the limit value 3-fold with all treatments except STS where Cd concentrations were ten times higher than the limit value. Table 3 shows the results of heavy metals in barley and carrots as mass fractions mg/g DW.



Table 3. Mass fractions of heavy metals in barley and carrots at the end of the experiment. BDL= below detection limit, NA = not analysed.

	Mass fraction (mg/kg)			
	Fertiliser	Faeces	Urine	STS
Barley				
Cd	0.018	0.050	0.068	0.048
Cu	2.4	1.4	2.4	3.0
Pb	BDL	0.11	BDL	BDL
Ni	0.409	0.17	0.16	0.21
Zn	29	25	24	32
Carrot				
Cd	1.0	1.1	NA	3.3
Cu	0.64	0.72	NA	0.82
Pb	0.10	0.12	NA	0.76
Ni	0.37	0.50	NA	0.42
Zn	8.4	9.5	NA	14

Main nutrients and growth

The analyses of main nutrients from the growth substrate at the end of the experiment show that there were some differences between treatments. In urine and STS fertilised substrates of carrots the total N concentrations were lowest (Table 4). This was clearly seen also in growth of carrots, where the growth was clearly best with inorganic fertiliser and composted faeces, but very poor when using urine and STS as fertilizer (Figure 4).

Barley growth was clearly the best when using inorganic fertiliser, where the average length of straw and number of grains were highest. With the other treatments the values of the growth indicators were clearly lower than with inorganic fertiliser, but differences between them were small. The second best growth occurred with urine-fertilised barley. Based on the light colour and early ripening of barley in other treatments compared to inorganic fertiliser treatment, it appeared that barley was, to some extent, suffering from N deficiency.

Table 4. Concentrations of total N and K in growth substrates of barley and carrots at the end of the experiment.

	Mass fraction (mg/kg)			
	Fertiliser	Faeces	Urine	STS
Barley				
N	420	340	260	470
K	55	80	66	47
Carrot				
N	470	430	330	380
K	60	80	46	68

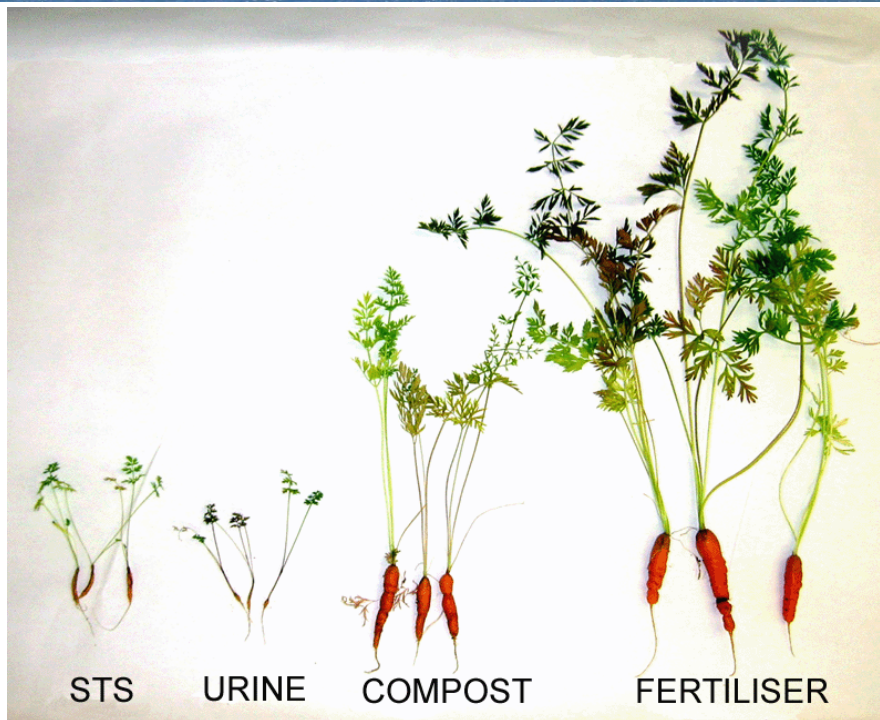


Figure 4. Carrot samples at the end of the experiment with different treatments. (STS= septic tank sludge, fertiliser = inorganic fertiliser)

Pathogens

No Salmonella bacteria were found in the samples. Total coli form bacteria amounts were at the same level with all treatments or even lower when compared to the inorganic fertiliser. The amounts reduced remarkably in the substrate of all treatments after first two weeks from the start of the experiment, showing no significant differences to inorganic fertiliser treatment. Only with STS treatment the initial total coli form bacteria amounts were clearly higher, but rapidly reduced to the same level of the other treatments (Figures 5 and 6). From barley spike samples no bacteria were found at the end of the experiment, but carrots showed increased total coli form bacteria amounts in urine and STS fertilised treatments.

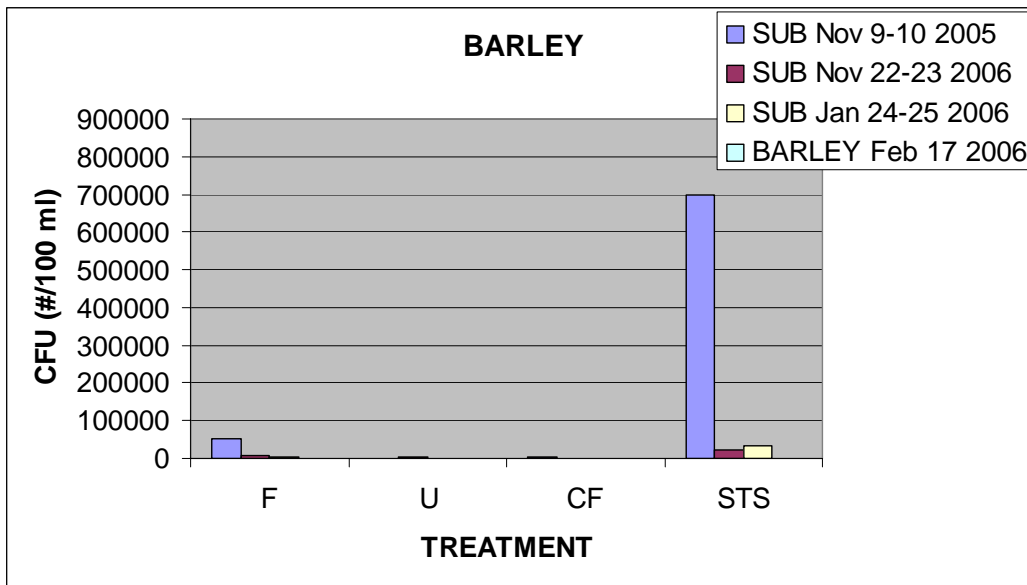


Figure 5. Amounts of total coliform bacteria in substrates and barley at different phases of the experiment and with different fertiliser treatments. F=inorganic fertiliser, U=urine, CF=composted faeces, STS=septic tank sludge, SUB=substrate

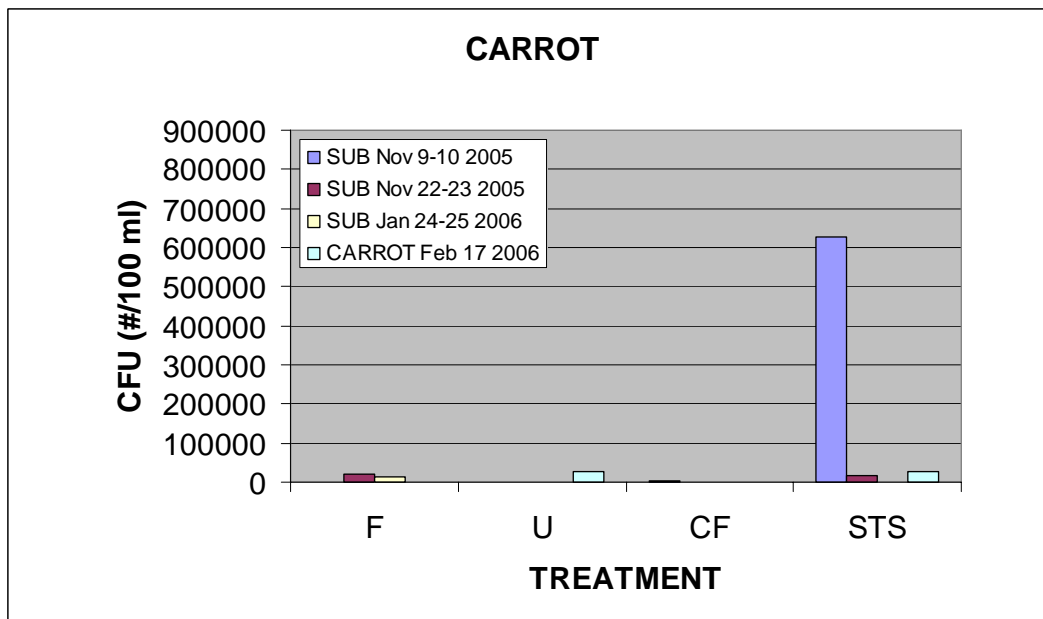


Figure 6. Amounts of total coliform bacteria in substrates and carrot at different phases of the experiment and with different fertiliser treatments. F=inorganic fertiliser, U=urine, CF=composted faeces, STS=septic tank sludge, SUB=substrate.

DISCUSSION

The heavy metal concentrations in plants by uptake, was one of the main concerns in this experiment. There were no significant differences with heavy metal concentrations of growth substrates compared to inorganic fertiliser except for Cd concentrations with



STS treated carrots. For barley the heavy metal concentrations did not differ significantly from the inorganic fertilised treatment thus showing that human excreta does not increase heavy metal uptake when used as fertiliser for barley. For root plants the situation seems to be different, showing a slight increase in Cd uptake for carrots with STS treatment. Urine and composted faeces however did not show increased heavy metal uptake for carrots. This supports the hypothesis that dry toilet waste and separated urine are safer to use as fertilisers than excreta mixed with waste-waters.

There were differences in growth of the plants according to species and treatments. For carrots the growth was significantly lower in urine and STS treatments, but grew fairly well with composted faeces when compared to inorganic fertiliser. Growth of barley was best with inorganic fertiliser and in urine-fertilised substrate second-best. The differences were small however, between urine treatment and other treatments. Early ripening and light-green colour of barley indicated insufficiency of N in the substrates of urine, composted faeces and STS treatments. This suggests that dose and type of fertiliser should be carefully estimated and that different types of plants require the right kind of fertiliser for good growth.

From the treatments no Salmonella was found. Barley and carrot substrates showed high initial amounts of coli form bacteria especially with the STS treatment, but the amounts reduced significantly with time. From barley no coli form bacteria were found at the end of the experiment, but from carrots coli form bacteria were found. This result indicates that separated urine and composted faeces are almost as safe to use as fertilisers as commercial inorganic products, based on these indicators. STS seems to have higher risk for pathogen contamination according to the indicators studied. The results also show that root plants obviously are more sensitive to pathogen contamination than grain crops.

CONCLUSIONS AND FUTURE STUDIES

From the fertilisers studied STS seem to pose the highest risk for pathogen and heavy metal concentration. Urine and composted faeces are almost as safe as commercial inorganic fertiliser in this sense, but care should be taken when selecting the plant to grow and when estimating the fertiliser amount needed for each plant in order to ensure growth and good yield.

As a pilot test this study opened many new open questions to be studied. These are for example:

- Correct amount of composted faeces and urine for different crop plants
- Form and type of N in urine and composted faeces
- Safe treatment of STS in order to reduce pathogen risk
- Other possible pathogen indicators in urine and faeces



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