USE OF HUMAN EXCRETA FROM URINE-DIVERSION TOILETS IN FOOD GARDENS: AGRONOMIC AND HEALTH ASPECTS

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USE OF HUMAN EXCRETA FROM URINE-DIVERSION TOILETS IN FOOD GARDENS: AGRONOMIC AND HEALTH ASPECTS

Volume 3

Report to the

WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

BACKGROUND

This report forms part of the output of Water Research Commission project number K5/1439 entitled "Strategy for the furtherance of knowledge and good practice of ecological sanitation (ecosan) technology in South Africa". The aims of this research project were as follows:

- To establish the current "state of the art" in ecological sanitation (ecosan).
- To determine:
  (a) the nature of processes taking place in the vault of a urine-diversion (UD) toilet; and
  (b) the relevant pathogen destruction parameters in order to increase understanding of the health aspects of UD toilet operation and maintenance (O&M), as well as safety criteria for use of the processed excreta.
- To explore appropriate practices for faeces collection and disposal, in order to facilitate the abovementioned safe O&M of the toilets.
- To produce a report describing the research conducted for the project, with conclusions and recommendations for improving the future implementation of UD sanitation projects.

REPORT STRUCTURE

The literature review of this study was published by the Water Research Commission as Report no. TT246/05. The other outputs emanating from this study are presented in four separate volumes.

The four volumes are:

- Volume 1: 1439/1/06 – Pathogen destruction in UD sanitation systems
- Volume 2: 1439/2/06 - Use and acceptance of UD sanitation systems in South Africa
- Volume 3: 1439/3/06 - Use of human excreta from UD toilets in food gardens: Agronomic and health aspects (this volume)
- Volume 4: TT275/06 - Guidelines for the design, operation and maintenance of UD sanitation systems.

SUMMARY OF THIS VOLUME

This volume is presented in four chapters:

Chapter 1: Introduction

The background and content of the whole project is described, in order that this volume can be put into context.

Chapter 2: Field and glasshouse trials: Use of human excreta in agriculture and food gardens

Due to the emphasis on use of human excreta from ecosan toilets in many countries, there is a fair amount of international literature on the subject of increased crop yields resulting from this practice. Prior to this project, however, no work had been done in South Africa on the subject and the intention of this part of the research was to go some way in addressing the matter. An important motivational issue was the need to find ways of reducing poverty and improving family nutrition in South Africa, particularly among the poor.

Agronomic investigations were conducted into the use of dehydrated faecal material from UD toilets for growing of spinach and cabbage. This was followed by trials using human urine on cabbage, spinach, maize and tomato.

Application of dehydrated human manure from UD toilets resulted in better cabbage and spinach yields than goat kraal manure, but was inferior to inorganic fertiliser. The human manure was a better source of phosphorus for both cabbage and spinach than goat kraal manure, indicating that its use would improve the nutrition of crops in most areas of South Africa where soils are inherently deficient in phosphorus. In addition, when ash is used as a bulking/sanitising agent, the human manure has an alkaline pH and thus has a liming effect on acidic soils, which has the potential for improving crop growth.

Diluted human urine was also found to be a good source of nutrients, especially nitrogen, for cabbage and spinach. The application rate is important, however, as too frequent applications tend to depress yields through increased soil salinity. Good results were also evidenced in maize and tomato crops and urine is considered to be as effective agronomically as urea or ammonium sources of nitrogen.

It was concluded that, provided pathogenic tests proved the use of human manure and urine to have a low potential for disease transmission, the use of these products in agriculture and food gardens should be encouraged. Conclusions regarding health aspects are considered in chapter 3.

Chapter 3: Field trials: Microbiological effects on food crops fertilised with faecal material from urine-diversion toilets

As a logical extension to the previous chapter there was a need to establish the safety, from a health point of view, of using faecal material originating from UD toilets as a soil amendment for crop growing purposes. Pathogens can be recycled to humans if improper agricultural practices are implemented.

The same faecal material used for the field investigation described in Volume 1 of this report was used as a soil amendment in the cultivation of spinach and carrots. Detailed microbiological tests were conducted on this material as well as on the in situ soil before sowing and after harvesting, on the irrigation water, and on the harvested crops.

Faecal material extracted from UD toilets in the eThekwini region of South Africa and left in a heap exposed to the weather for four months, after being stored in the toilet vaults for between one and six months, had a microbial content comparable to sludge classified as Type B in the current South African regulations. This complies with the standard for use in agriculture considering some restrictions to minimise human exposure. Applying different rates of material to spinach and carrots, two common edible crops, it was found that the bacteria and fungi content were only noticeable for the higher application rates (>35t/ha), while the helminth ova content varied, both in leaves and stems, depending on the quantity of material applied.

Helminth ova content was, for both crops, more prevalent in leaves, suggesting that the ova adhere preferentially to plants rather than soil. Some health risks are therefore inherent in the handling and consumption of food crops grown in soils amended with faecal material from UD toilets.

Faecal material that has been stored for a shorter time will in all likelihood exhibit different results in terms of pathogen transfer to these crops. To assess the actual health risk of helminth ova consumption, for instance, the storage time and final viability on crops need to be considered as well as the infective dose for farmers and consumers and the daily diet of vegetables in the region.

Chapter 4: Conclusions

Application of dehydrated human manure from urine-diversion (UD) toilets on cabbage and spinach crops resulted in better yields than goat kraal manure, but was inferior to inorganic fertiliser. The human manure was also a better source of phosphorus for both cabbage and spinach than goat kraal manure. In addition, when ash is used as a bulking/sanitising agent, the human manure has an alkaline pH and thus has a liming effect on acidic soils.

Diluted human urine was also found to be a good source of nutrients, especially nitrogen, for cabbage and spinach. The application rate is important, however, as soil salinity may be a problem in some soils. Good results were also evidenced in maize and tomato crops. Urine is thus considered to be as effective agronomically as urea or ammonium sources of nitrogen.

It is concluded that, provided pathogenic tests prove the use of human manure and urine to have a low potential for disease transmission, the use of these products in agriculture and food gardens should be encouraged.

Faecal material extracted from UD toilets was applied at different rates to spinach and carrot crops. It was found that the bacteria and fungi content were only noticeable for the higher application rates (>35t/ha), while the helminth ova content varied, both in leaves and stems, depending on the quantity of material applied. Helminth ova content was, for both crops, more prevalent in leaves, suggesting that the ova adhere preferentially to plants rather than soil. Some health risks are therefore inherent in the handling and consumption of food crops grown in soils amended with faecal material from UD toilets.

While the use of human urine and human manure were seen to be effective agronomically, suitable precautions should be taken, for health reasons, to sanitise the excreta (particularly faecal material) before applying them to cropland.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

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- Volume 4: TT275/06 - Guidelines for the design, operation and maintenance of UD sanitation systems.

1.3 PROJECT OUTPUT

Volume 1: Pathogen destruction in UD sanitation systems

This section of the report covers the following study objectives:

- Determination of the environmental factors affecting the survival of excreted pathogens in dehydrated faeces and how application of NaOH, ash and pasteurisation reduces the numbers of pathogens in these faeces;

- Determination of the biocidal effect of urine in relation to storage temperature and pH.
- Determination of the minimum vault storage time for faecal material commensurate with safety for handling. In essence, this research was aimed at determining pathogen die-off rates under different conditions of faecal storage. Parameters investigated included storage time, effect of various lid materials on vault temperature, effect of ventilation, and effect of various bulking agents.

Volume 2: Use and acceptance of UD sanitation systems in South Africa

The terms of reference for this section of the project were to assess the knowledge, attitudes and practices of people using UD toilets in various parts of the country. The results of this research are intended to provide information to assist implementation of the technology in all areas of the country. Surveys were carried out in four provinces, namely Eastern Cape, Northern Cape, North West and KwaZulu-Natal.

Volume 3: Use of human excreta from UD toilets in food gardens: Agronomic and health aspects (this volume)

Due to the emphasis on use of human excreta from ecosan toilets in many countries, there is a fair amount of international literature on the subject of increased crop yields resulting from this practice. Prior to this project, however, no work had been done in South Africa on the subject and the intention of this part of the research was to go some way in addressing the matter. An important motivational issue was the need to find ways of reducing poverty and improving family nutrition in South Africa, particularly among the poor.

Field and glasshouse investigations were conducted into the use of dehydrated faecal material from UD toilets for growing of spinach and cabbage. This was followed by trials using human urine on cabbage, spinach, maize and tomato.

As a logical extension to this work there was a need to establish the safety, from a health point of view, of using faecal material originating from UD toilets as a soil amendment for crop growing purposes. Pathogens can be recycled to humans if improper agricultural practices are implemented. The same faecal material used for the field investigation described above was used as a soil amendment in the cultivation of spinach and carrots. Detailed microbiological tests were conducted on this material as well as on the in situ soil before sowing and after harvesting, on the irrigation water, and on the harvested crops.

Volume 4: Guidelines for the design, operation and maintenance of UD sanitation systems

A large store of knowledge has been gathered on UD sanitation systems in South Africa, not only during the course of this particular project but also since the technology was first implemented in the country in 1997. Much has been learned from overseas experience as well. The guidelines contained in this volume are based on best practices that have been observed and documented, as well as the conclusions and recommendations contained in the various sections of the research report.

Additional project output: Some alternative models for the management of faeces from UD toilets

Initially, this part of the project was to include the establishment, on a pilot basis, of a business opportunity to provide a faecal collection concern in a community with urine-diversion toilets. For various reasons it was not possible to establish such a business at the time. The WRC Research Manager instead requested the project

team to conduct a theoretical desktop study on the potential for entrepreneurial business development for faeces collection from UD toilet systems. It was decided to disseminate the findings of this study in the form of a journal paper or article.

Two scenarios were considered:

- The use of an independent agent to collect faeces from UD toilets, transport to a collection station or directly to a disposal area within 10 km of the target community for the permissible disposal by the relevant local authority.

- The use of an independent agent to collect faeces from UD toilets, transport this product to a designated site (eco-station) within 10 km of the target community for the manufacture of compost and sale of this compost to the local authority.

CHAPTER 2

FIELD AND GLASSHOUSE TRIALS: USE OF HUMAN EXCRETA IN AGRICULTURE AND FOOD GARDENS

2.1 BACKGROUND

The Department of Agronomy at the University of Fort Hare (UFH) was approached to participate in this project to work on the Research Protocol "Use of human excreta in agriculture and food gardens". The Department was already engaged with various projects on the use of animal manure and industrial and municipal organic wastes in agriculture, so the work was seen as a logical extension to this. It was arranged for faecal material from existing urine diversion (UD) toilets in the Umtata area to be brought to the university for agronomic testing. For the urine trials, however, urine was collected from student hostels at UFH using containers.

The faecal material was supplied in April 2003 following which arrangements were made for the field trials to commence in June of the same year. Cabbage was used as a test crop. A second trial to evaluate residual effects was established on the same plots in July 2004 using spinach as the test crop. Section 2.2 summarises the results obtained over the two cropping seasons.

Preparations for urine collection were made during May 2004 and urine was collected in June 2004. Trials were subsequently set in the glasshouse using cabbage, spinach, maize and tomato as test crops. Sections 2.3 and 2.4 summarise the results obtained.

2.2 EVALUATION OF HUMAN MANURE AS A SOURCE OF NUTRIENTS FOR CABBAGE AND SPINACH

2.2.1 Materials and methods

(a) Field experiment

The trial site was the KwaSomgxada Community garden at Ntselamanzi location next to the University of Fort Hare in Alice. The site has been characterized for its fertility status by the Advisory Service of the Dohne Agricultural Development Institute in Stutterheim which made fertiliser recommendations for different crops as shown in Table 2.1. The experiment was set up on 18 June 2003 and consisted of the following treatments:

1. 0 kg N ha^{-1} – Control
2. 50 kg N ha^{-1} (as dry faeces)
3. 100 kg N ha^{-1} (as dry faeces)
4. 200 kg N ha^{-1} (as dry faeces)
5. 400 kg N ha^{-1} (as dry faeces)
6. 50 kg N ha^{-1} (as LAN) +95 kg P ha^{-1} (as TSP) + 90 kg K ha^{-1} (as muriate of potash)
7. 100 kg N ha^{-1} (as LAN) +95 kg P ha^{-1} (as TSP) + 90 kg K ha^{-1} (as muriate of potash)
8. 200 kg N ha^{-1} (as LAN) +95 kg P ha^{-1} (as TSP) + 90 kg K ha^{-1} (as muriate of potash)
9. 400 kg N ha^{-1} (as LAN) +95 kg P ha^{-1} (as TSP) + 90 kg K ha^{-1} (as muriate of potash)
10. 100 kg N ha^{-1} (as kraal manure)
11. 95 kg P ha^{-1} (as TSP) + 90 kg K ha^{-1} (as muriate of potash)

The nutrient sources were dry faeces (hereinafter referred to as human manure) brought from UD toilets in the Umtata area, goat kraal manure (taken from the UFH livestock farm), lime ammonium nitrate (LAN) as an N carrier, triple super phosphate (TSP) as a P carrier, and muriate of potash (KCl) as the K carrier. The chemical composition of the human manure and kraal manure is presented in Table 2.2. The rates of application were based on nitrogen since this is often the most limiting nutrient. The amounts of human manure and LAN applied were calculated to supply the equivalent of 0, 50, 100, 200 and 400 kg N ha^{-1} so as to be able to get a response curve. Only one rate of kraal manure (100 kg N ha^{-1}) was included for comparative purposes. Basal applications of P and K were applied in combination with inorganic fertiliser treatments at the recommended rates for cabbage (Table 2.1). A P and K treatment at the recommended rate for cabbage was also included to determine crop performance in the absence of nitrogen. The potential nutrient contribution by different rates of human manure and kraal manure is shown in Table 2.3.

The experimental design was a randomised complete block design with 4 replications using plot sizes of 3 m x 3 m. The test crop was cabbage transplanted on 18 June 2003 at a spacing of 50cm x 50cm resulting in a plant population of 36 plants per plot. Harvesting was done on 19 November 2003 from a net plot area of $4m^2$ achieved by disregarding the outer (guard) rows in each plot. The harvested cabbages were weighed on site (Figure 2.1) but were later transported to the laboratory where sub-samples were taken for dry matter determination and nutrient (N, P and K) analysis. Soil samples were taken from each plot after harvest and analyzed for organic carbon, soil pH, electrical conductivity, and selected macro- and micronutrients.

Figure 2.1: General layout of the cabbage field experiment as captured at harvest time.

Efforts to establish a maize crop on the same plots during December 2004 failed due to late onset of the seasonal rains and inadequate water for irrigation. A decision was therefore taken to plant spinach instead during winter 2004. The spinach crop was therefore established on the same plots on 7 July 2004. A spacing of 30cm x 30cm was used. The layout of the experiment is shown in Figure 2.2. The crop was harvested on 28 October 2004. Fresh weight measurements were taken and samples taken for dry weight determinations. Samples were also ground and analyzed for N, P and K as described for cabbage.

Figure 2.2: Layout of spinach field experiment

(b) Analytical procedures

Organic C in manure and soil samples was determined by the Walkley-Black method while pH and electrical conductivity were measured in water at a ratio of 1:2,5 as described by the Non-Affiliated Soil Analysis Working Committee of South Africa (1990). Total elemental composition of manure samples was determined following procedures described by Okalebo et al (1993) after samples were digested in a mixture containing concentrated H_2SO_4, $LiSO_4.H_2O$, Selenium powder and 30% H_2O_2 for 2 h at 360°C. Extractable P, Ca, Mg, Fe, Cu, and Zn were determined following extraction by the AMBIC-1 method as described by the Non-Affiliated Soil Analysis Working Committee of South Africa (1990). Phosphorus was read on a colorimeter using the molybdenum-blue method; potassium was determined from the extract directly on a flame photometer while Ca, Mg and micronutrients were determined using an atomic absorption spectrophotometer.

2.2.2 Results and discussion

(a) Chemical composition of the manures

Both goat kraal manure and human manure had comparable pH and electrical conductivity (EC) values (Table 2.2). The EC values were very low suggesting that soil application of both amendments should not cause salinity problems. The pH of the manures was slightly alkaline indicating that their application to acidic soils would have a liming effect. Human manure had consistently lower nutrient composition than goat kraal manure (Table 2.2) suggesting that it would be a poorer source of nutrients. The C:N and C:P ratios of the two manures were well below the cut-off ranges for decomposition of organic materials and release of N and P. However, the C:N and C:P ratios of kraal manure were lower than those of human manure suggesting that goat kraal manure could decompose and release its N and P more readily.

(b) Effects of amendments on cabbage and spinach growth

Inorganic fertiliser significantly increased cabbage yields above the control and manure treatments at mid season (Table 2.4) and at harvest time (Table 2.5, Figures 2.3 and 2.4). The highest yield was obtained with the application of 100 kg N ha^{-1} inorganic N and not 200 kg N ha^{-1} as suggested by the soil test results (Table 2.1). Observations showed that rates above 100 kg N ha^{-1} supported bigger plants but these failed to head properly as a result of the lush growth. In sharp contrast to inorganic fertiliser, rates of human manure application equivalent to 50-200 kg N ha^{-1} increased yield only slightly and more or less to the same extent (Table 2.5, Figure 2.3). Only the highest rate (400 kg N ha^{-1} = 22,4 t ha^{-1}) of human manure application caused a substantial increase in yield. This could be explained by the fact that nutrients in inorganic fertiliser are immediately available to growing plants, whereas a large proportion of nutrients in both human and kraal manures are organically bound and become only slowly available through mineralisation. This conclusion is confirmed by results of the residual study with spinach (Figure 2.3 and Table 2.6) which showed that yields increased with each increment of human manure application, which was not the case with the mineral fertiliser. The results, however, suggest that for human manure to have an effect on cabbage yield on the year of application, more than 20 t ha^{-1} has to be applied. This compares favourably with the Chinese practice of applying 20 to 30 t ha^{-1} of night soil annually (Drangert 1998, quoting FAO results).

Human manure resulted in slightly but consistently better cabbage yields than kraal manure at mid season (Table 2.4) and at harvest time (Figures 2.4(a), 2.6(a)). The observed yield differences were not related to tissue N data (Table 2.5) as both kraal manure and human manure produced similar levels of N in the plants. It was contrary to expectations that kraal manure would have resulted in higher tissue N levels in plants as a result of its higher N content and narrower C:N ratio (Table 2.2). Human manure did, however, result in greater P and K concentration in plants than kraal manure (Table 2.5, Figure 2.5) suggesting that observed differences in yield could have been, at least partially, influenced by differences in the release patterns and availability of these nutrients. A similar pattern of response was observed in spinach yields where human manure had better residual effectiveness than either kraal manure or NPK fertiliser (Figures 2.4(b), 2.6(b), Table 2.6). Of the three elements investigated, it appears that phosphorus had more to do with the superior performance of human manure relative to kraal manure. Each increment in human manure application was accompanied by a corresponding increase in the tissue P concentrations for both cabbage and spinach while tissue N and K concentrations showed largely inconsistent trends (Figure 2.7).

Table 2.1: Fertiliser and lime requirements of different crops at the KwaSomgxada community garden in Ntselemanzi location, Alice.

Crop	Yield targets	Nitrogen fertilizer required	Sample density	Phosphorus			Potassium			Lime		
				Soil test		Fertilizer required	Soil test		Fertilizer required	Acid Saturation		Lime required
	Kg ha^{-1}	kg N ha^{-1}	g ml^{-1}	Sample	Optimum		Sample	Optimum		Sample	Optimum	
				mg l^{-1}		kg ha^{-1}	mg l^{-1}		kg ha^{-1}	%	%	kg ha^{-1}
Cabbage	Optimum	200	1,23	30	48	95	165	200	90	2	5	None
Potato	45 000	175	1,23	30	29	80	165	200	90	2	30	None
Carrot	Optimum	50	1,23	30	48	95	165	150	0	2	1	250
Spinach	Optimum	100	1,23	30	48	95	165	200	90	2	5	None
Pumpkin	Optimum	100	1,23	30	39	45	165	135	0	2	5	None

Table 2.2: Chemical composition of the human manure and goat kraal manure used in the study

Manure type	pH	EC (ms cm^{-1})	C:N	C:P		Total elemental composition							
	(1:2,5 manure:water)				C	N	P	K	Ca	Mn	Fe	Cu	Zn
					---------- (%) ----------					---------- (mg kg^{-1}) ----------			
Human manure (6:1:15 N:P:K)	7,5	3,3	13	80	24	1,8	0,3	4,4	0,4	35	52	6,3	33
Goat kraal manure (7:1:12 N:P:K)	7,5	3,1	10	63	25	2,6	0,4	4,6	0,7	48	73	7,6	37

Table 2.3: Potential nutrient contribution of different rates of human and goat kraal manure used in the field experiment.

Manure type	Amount Applied	Nutrient element							
		N	P	K	Ca	Mn	Fe	Cu	Zn
	($t\ ha^{-1}$)	($kg\ ha^{-1}$)				($g\ ha^{-1}$)			
Human manure	2,8	50	8,4	123	11	98	146	18	92
	5,6	100	16,8	246	22	196	292	36	184
	11,2	200	33,6	493	44	392	584	72	368
	22,4	400	67,2	986	88	784	1168	144	736
Goat kraal manure	3,8	100	15,2	174	26	182	278	28	140

Table 2.4: Mean fresh and dry mass (kg) of the four young cabbage plants sampled per plot at mid-season.

Treatment	Fresh mass*	Dry mass*
Control	2,83 b	0,34 b
Kraal manure	3,05 b	0,37 b
Human manure	3,27 b	0,41 b
Inorganic Fertiliser	4,95 a	0,57 a

*Figures in a column followed by the same letter are not significantly different at $p < 0.05$.

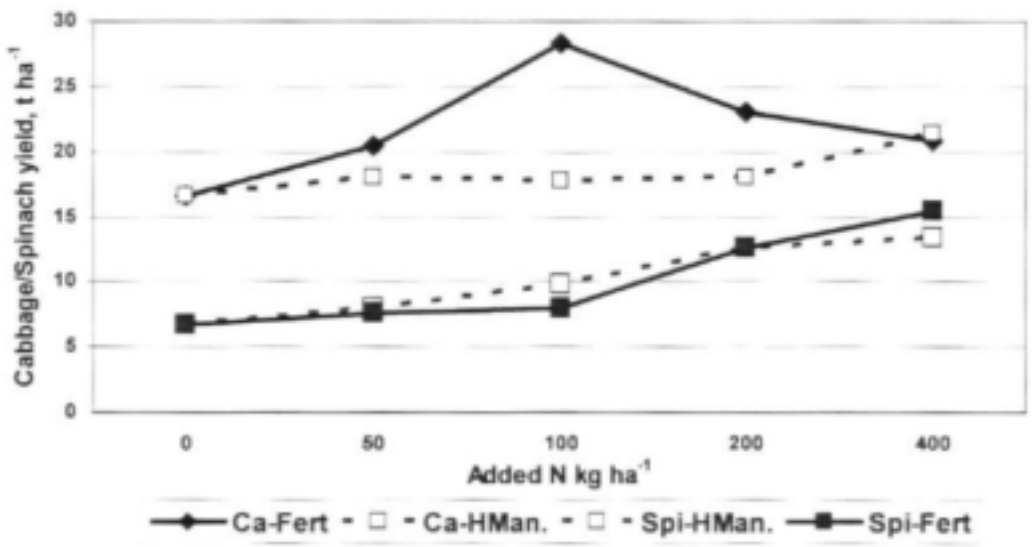


Figure 2.3: Response of cabbage and spinach to NPK fertiliser and human manure

Table 2.5: Mean fresh and dry matter yield and N, P and K nutrient content of cabbage at harvest time.

Treatment	Quantity of dry manure	Fresh yield t ha^{-1}	Dry matter yield (DMY) t ha^{-1}	N %	P %	K %
Control		16,6 bc	1,2 bc	2,0 d	0,13 e	1,95
Basal P & K		4,2 c	1,0 c	2,2 cd	0,15 cde	2,04
LAN+Basal P&K						
- 50 kg N ha^{-1}		20,5 bc	1,5 bc	2,7 b	0,19 ab	2,42
- 100 kg N ha^{-1}		8,3 a	2,0 a	2,9 b	0,17 bcd	2,37
- 200 kg N ha^{-1}		23,0 ab	1,7 ab	3,5 a	0,21 a	2,46
- 400 kg N ha^{-1}		20,8 abc	1,5 bc	3,5 a	0,20 a	2,64
Human manure	(t ha^{-1})					
- 50 kg N ha^{-1}	2,7	18,0 bc	1,3 bc	2,1 d	0,14 de	2,12
- 100 kg N ha^{-1}	5,4	17,8 bc	1,3 bc	2,0 d	0,18 abc	2,33
- 200 kg N ha^{-1}	10,8	1,0 bc	1,3 bc	2,2 cd	0,16 bcd	2,50
- 400 kg N ha^{-1}	21,6	21,4 abc	1,6 ab	2,6 bc	0,18 abc	2,62
Goat kraal manure						
- 100 kg N ha^{-1}	4,0	15,7 bc	1,1 bc	2,0 d	0,15 cde	2,08
LSD (0,05)		12,5		0,5	0,03	0,54

Figures in a column followed by the same letter or none at all are not significantly different at the 5 percent level.

Table 2.6: Fresh weight yield and N, P and K nutrient content of spinach at harvest time.

Treatment	Quantity of dry manure	Fresh yield t ha^{-1}	N g/kg	P g/kg	K g/kg
Control		10,6 ab	21	1,5 d	28
Basal P & K		8,0 b	21	2,9 ab	35
LAN+Basal P&K					
- 50 kg N ha^{-1}		7,6 b	22	3,0 a	33
- 100 kg N ha^{-1}		8,0 b	21	2,9 ab	28
- 200 kg N ha^{-1}		12,6 ab	23	1,8 cd	32
- 400 kg N ha^{-1}		5,5 a	29	1,9 cd	20
Human manure	(t ha^{-1})				
- 50 kg N ha^{-1}	2,7	8,0 b	21	2,2 bcd	31
- 100 kg N ha^{-1}	5,4	9,9 ab	21	2,1 bcd	27
- 200 kg N ha^{-1}	10,8	12,6 ab	21	2,2 bcd	34
- 400 kg N ha^{-1}	21,6	13,4 ab	22	2,6 abc	29
Goat kraal manure					
- 100 kg N ha^{-1}	4,0	9,0 b	22	1,7 d	32
LSD (0,05)		5,1	0,5	0,1	12

Figures in a column followed by the same letter or none at all are not significantly different at the 5 percent level.

(c) Effects of amendments on soil properties

Inorganic fertiliser consistently decreased pH relative to the control (Table 2.7) even though the N source used was lime ammonium nitrate (LAN), which contains some lime. Its continued use without additional lime could therefore worsen the acidity problem at this site. By contrast, human manure had no effect on pH at low rates of application but increased it at the highest rate of application showing that its regular use could have a liming effect in acidic soils. This effect was consistent with its slightly alkaline pH (Table 2.2). The alkalinity of the human manure could have been contributed by the wood ash (pH 10,0) sprinkled over the faeces by toilet users after each defecation. Both fertiliser and manure treatments had no consistent effect on organic carbon (OC), electrical conductivity (EC), Ca, Mn, Zn or Cu (Table 2.7). However, the fertiliser and manure treatments maintained consistently higher levels of extractable P relative to the control. Levels of extractable P in the fertiliser treatments were, as expected, more or less the same since they received a uniform rate of P application.

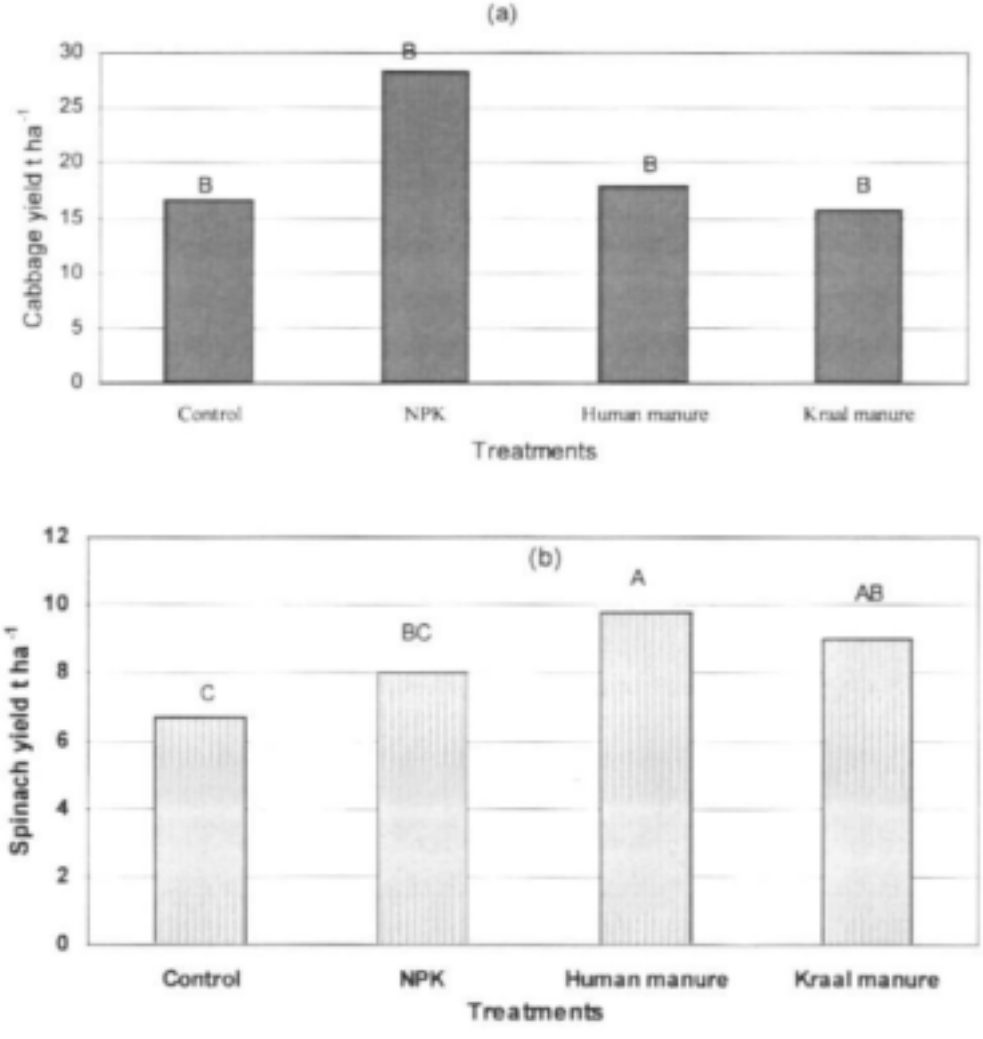


Figure 2.4: Fresh cabbage (a) and spinach (b) yields from NPK, human manure and kraal manure treatments applied at a rate of 100kg N ha^{-1} when compared to the control. (Bars bearing the same letter are not significantly different at p < 0,05).

Comparison of treatments applied at the same rate (Figure 2.8) showed that human manure resulted in higher levels of extractable P in the soil compared to kraal manure even though the total potential P contribution of human manure at different rates of application was slightly lower than that of kraal manure (Table 2.3). This further indicated that the superior crop growth and tissue P concentration associated with human manure when contrasted with kraal manure (Figure 2.5) could be attributed to the greater ability of human manure to decompose and release available P in the soil. This effect could be attributed to the fact that human manure consists of less lignaceous materials than kraal manure and is thus more susceptible to decomposition. However, the readily available P in human manure could also have been contributed by the ash which is often used as a dehydrating/sanitizing agent in the UD toilets from which the human manure was collected from. These results, however, indicate that the P in human manure, obtained from UD toilets in Umtata, is more readily available than that in goat kraal manure, suggesting that human manure can be expected to have a positive effect on crop growth in P deficient soils that are quite common in South Africa.

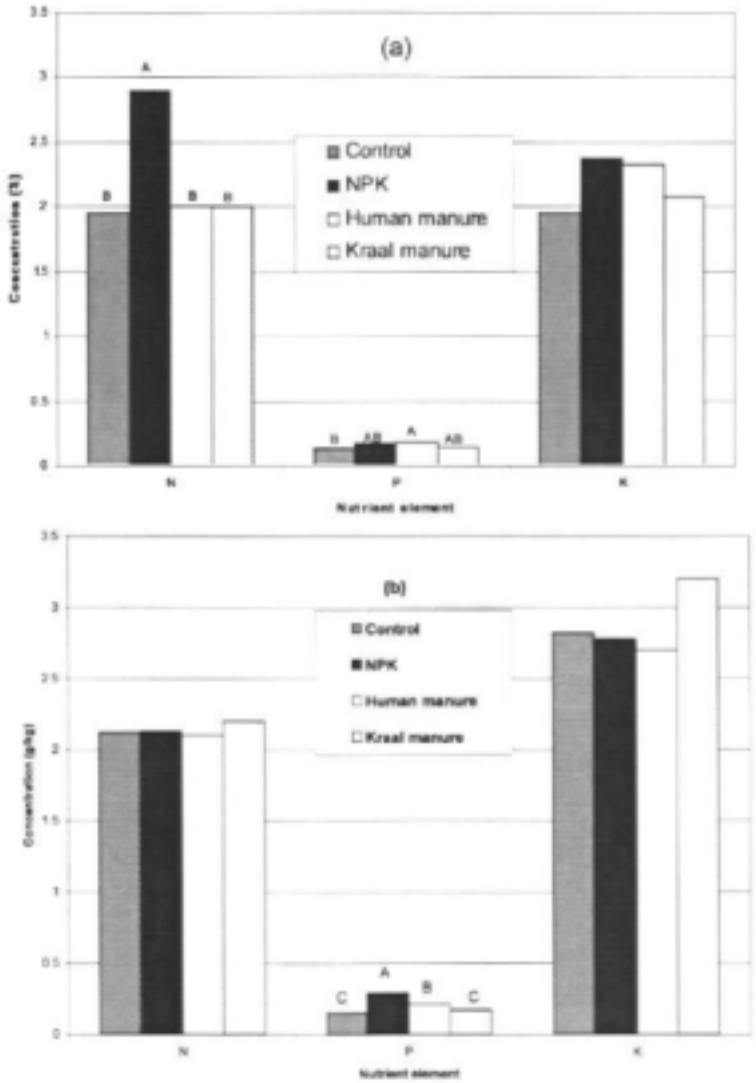


Figure 2.5: Tissue N, P and K contents of cabbage (a) and spinach (b) grown on soil amended with NPK fertiliser, human manure or kraal manure applied at a rate of 100kg N ha^{-1} (Bars bearing the same letter or none at all are not significantly different at $p<0,05$).

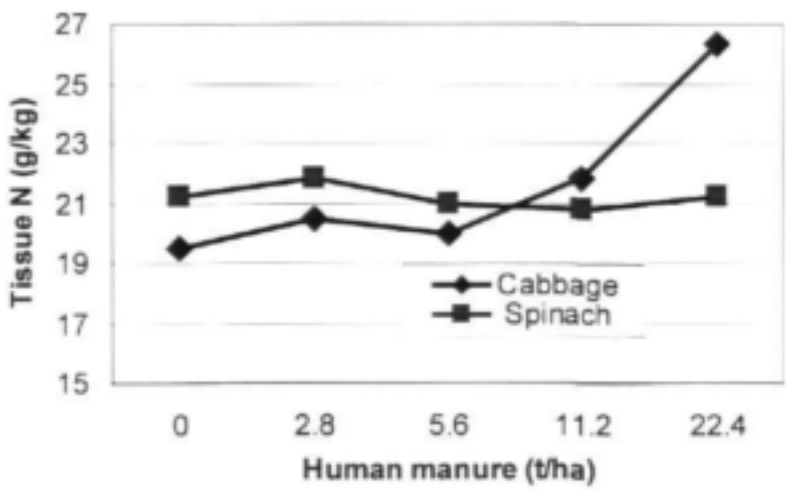
(a)

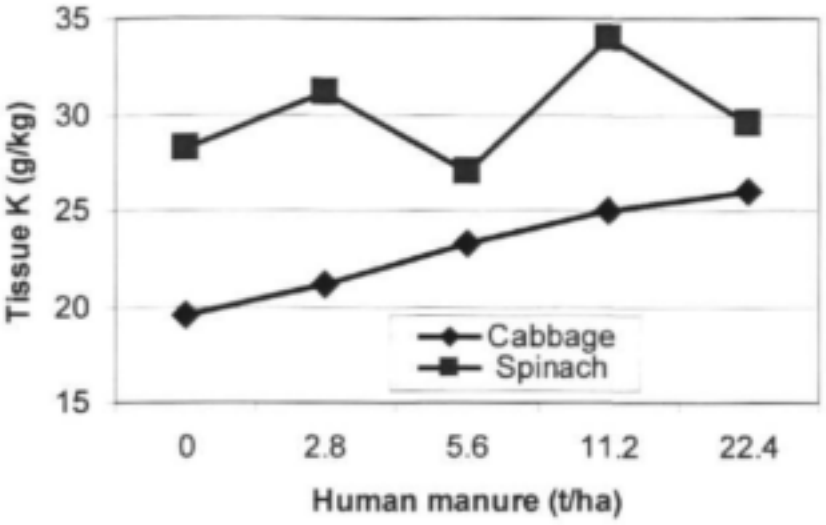
Control Human manure Kraal manure

(b)

Control Human manure Kraal manure

Figure 2.6: Performance of cabbage (a) and spinach (b) growing on plots that received 100kg N ha^{-1} as human manure or kraal manure compared to a control treatment





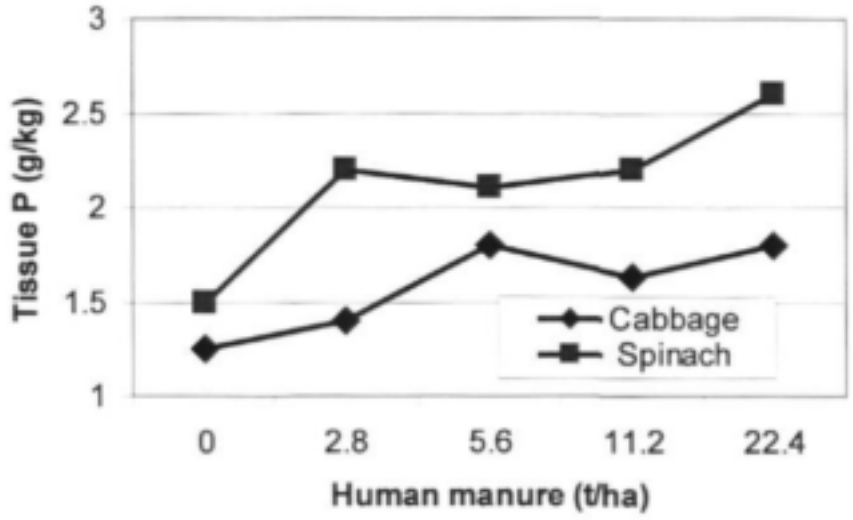


Figure 2.7: Tissue N, P and K concentration in cabbage and spinach as influenced by increasing rates of human manure application

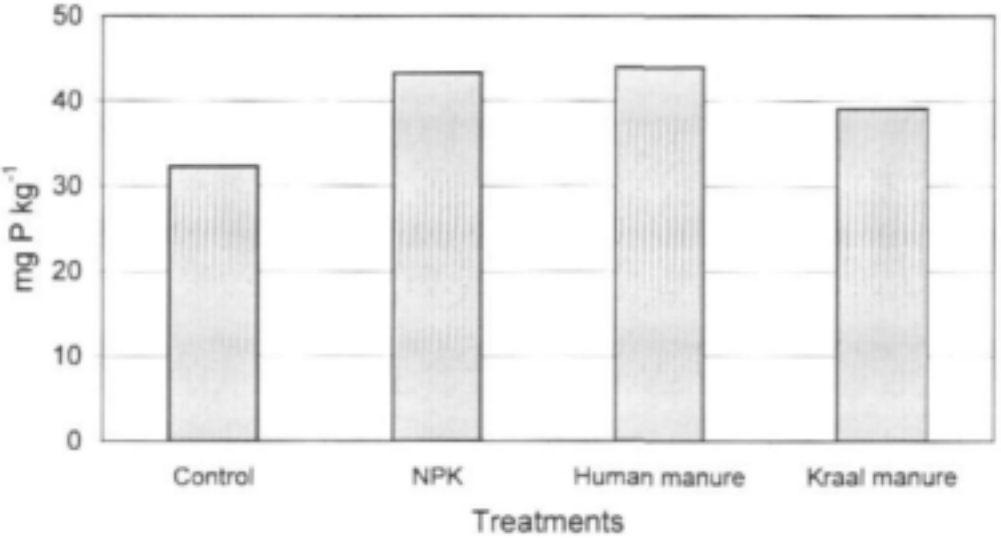


Figure 2.8: Mean Ambic-1 extractable P in soil amended with NPK fertiliser, human manure or goat kraal manure applied at a rate of 100kg N ha^{-1}

Table 2.7: Effects of human manure, kraal manure and inorganic fertiliser on soil organic carbon, electrical conductivity, pH and Ambic 1 extractable macro- and micronutrients.

Treatment	OC	EC	pH	P	K	Ca	Mg	Zn	Cu
	(%)	µS cm^{-1}		mg kg^{-1}					
Control	1,6	111	6,3 abc	32,3	68,5	181	137	91	10,0
Basal P & K	1,4	95	6,1 efg	36,8	60,5	157	131	108	9,1
LAN+Basal P&K									
- 50 kg N ha^{-1}	1,4	106	6,2 cdef	45,1	52,5	149	132	107	10,3
- 100 kg N ha^{-1}	1,5	100	6,1 efg	43,3	48,4	165	121	115	9,7
- 200 kg N ha^{-1}	1,5	141	6,0 fg	42,6	58,4	167	156	103	10,7
- 400 kg N ha^{-1}	1,5	103	5,9 g	46,1	54,4	167	149	100	10,8
Human manure									
- 50 kg N ha^{-1}	1,4	120	6,3 abc	36,6	56,4	165	137	117	10,0
- 100 kg N ha^{-1}	1,4	98	6,3 abc	44,0	58,5	162	136	98	11,1
- 200 kg N ha^{-1}	1,5	112	6,3 abc	37,5	64,5	158	135	89	9,5
- 400 kg N ha^{-1}	1,4	119	6,5 a	40,8	60,4	154	148	89	11,8
Goat kraal manure									
- 100 kg N ha^{-1}	1,4	129	6,4 ab	39,1	52,4	157	130	114	9,1
LSD (0,05)	0,3	38	0,2	13,8	23,2	23,8	33,3	25	2,6

Figures in a column followed by the same letter or none at all are not significantly different at the 5 percent level.

2.2.3 Conclusions

- Application of dried human manure from ecosan toilets resulted in better cabbage and spinach yields than goat kraal manure but was inferior to inorganic fertiliser. The human manure was a better source of P for both cabbage and spinach than goat kraal manure indicating that its use would improve the P nutrition of crops in most areas in South Africa where soils are inherently deficient in phosphorus.

- Both human and goat kraal manure had alkaline pH and increased soil pH in amended soils. Both types of manure thus have the potential of improving crop growth in acidic soils through their liming effect as well.

- If pathogenic tests reveal a low risk of disease transmission, then human manure from urine-diversion toilet systems has good potential for use in agriculture in South Africa. More field trials involving other test crops are recommended in order to further substantiate these findings.

2.3 PRELIMINARY STUDIES ON THE EVALUATION OF DILUTED URINE AS A SOURCE OF NUTRIENTS FOR CABBAGE AND SPINACH

2.3.1 Materials and methods

The urine used in the study was collected from male students' hostels at the University of Fort Hare Alice campus, over a two week period in June 2004 using 25 litre containers fitted with flexi-funnels. Following collection, the urine was stored in a cold room at a temperature of 16°C until needed for use. The experimental soil used was collected from the same site used for the human manure field trial. The soil was sampled from the plough layer (0-15 cm), air dried, sieved through an 8 mm sieve and 12kg soil placed in 10 litre pots for use in the tunnel house study.

The experimental protocol for work done in Zimbabwe (Morgan 2003) utilising urine diluted 1:3 (urine:water) was followed. The treatments included three rates of the diluted urine (once, twice and thrice per week); inorganic fertiliser N application at the recommended rate for spinach (100kg N/ha ≡ 0,6gN/12 kg pot) and cabbage (200kg N/ha ≡ 1,2g N/12 kg pot) applied as urea, and a control treatment in which only tap water was used. The treatments were replicated four times and arranged in a randomized complete block design. The inorganic fertilizer treatment was applied before the seedlings were transplanted, while the urine treatments commenced 5 days after the seedlings were transplanted on 12 August 2004. Two spinach seedlings were planted per pot while only one seedling per pot was planted in the case of cabbage.

The diluted urine application commenced on 16 August 2004 and terminated on 20 September 2004. A rate of 500 ml per pot per application was used for 3 weeks but this rate had to be reduced to 250 ml due to cooler weather that resulted in less evapo-transpiration during this period. The diluted urine had a pH of 8,6 and an electrical conductivity (EC) of 2,0 mS/cm while tap water had a pH of 7 and an EC of 0,02 mS/cm. The N concentration of the diluted urine was 0,18% so the cumulative application for the different treatments over the period translated into 3,6; 6,4 and 9,6gN/12 kg pot, respectively for one, two and three applications per week. This translated to 600, 1067 and 1567 kg N/ha, respectively. Regular watering of the pots was done during the trial with the addition of tap water as necessary to maintain the soil at approximately field capacity. All withered leaves from both crops in each pot were recovered in a well labeled sampling envelope and kept beside each pot.

The first harvesting of spinach was done on 28 September 2004 by neatly cutting well matured leaves at the base of the plant and close to the soil surface, while leaving the very young tender leaves for re-growth. The fresh weight of the leaves was taken; thereafter they were thoroughly washed and oven dried at 65°C to a constant weight for dry matter determination. Daily watering (250ml per pot) was continued; with no further addition of diluted urine. The spinach re-growth and the cabbage were harvested exactly one month after the first spinach harvest (28 October 2004), while a second re-growth was allowed for the spinach. Both crops were harvested by neatly cutting the leaves close to the soil surface. The number of leaves harvested as well as fresh biomass weight per pot were also taken and recorded. Harvested samples were thoroughly washed, oven dried at 65°C to constant weight and dry matter weight recorded.

After the second spinach harvest, soil samples were taken at different positions and depths from each pot, bulked and processed for laboratory determinations. Regular watering of the pots was continued until the final harvesting on 30 November 2004 following similar procedures as described for the first and second harvests. Following the complete harvesting of each crop, the soil from each pot was pulverized, air dried and samples taken for analysis after grinding. Ground samples were digested and analyzed for total P, K and Na as described by Okalebo et al (2002). The total N content in the soil and plant samples was determined using a LECO Truspec C&N Analyser.

Soil samples were analysed for pH and electrical conductivity in a soil:water ratio of 1:2,5. The contents of total C&N in each sample were determined using the LECO Truspec C&N analyser. Extractable P, K, Ca, Mg, Zn, Cu, Mn, and Fe were determined using the Ambic-1 extraction procedure described by Van der Merwe et al (1984). All data generated were subjected to statistical analysis using the MSTATC statistical package.

2.3.2 Results and discussion

(a) Effects of diluted human urine on spinach growth

Application of diluted urine once a week (3,6g N/pot) resulted in the highest yields at the first harvest (Figures 2.9 and 2.10). Higher rates of diluted urine application, twice (6,4g N/pot) and thrice (9,6g N/pot) a week, also resulted in significant yield increases relative to the control but the yields were much lower when compared to when the diluted urine was applied only once a week. By the second harvest the situation changed somewhat in that the highest yields were now recorded where urine was applied twice a week (Figure 2.9) even though the urine application was terminated before harvest 1. However, diluted urine application three times a week (9,6g N/pot) still resulted in the lowest yields relative to the other urine treatments. A similar pattern of response was observed at the third harvest except that at this stage there was a slight improvement in spinach yield from pots that received diluted urine three times a week. The observed increases in yields as a result of diluted urine application once or twice per week appeared to be largely related to the ability of the urine to supply nitrogen to the growing plants. This is reflected in increased tissue N levels of nitrogen in spinach at each harvest (Figure 2.11). The depressive effects of higher rates of urine application on yield, on the other hand, seemed to have been caused by higher salinity (electrical conductivity) levels in pots treated with higher levels of urine (Table 2.8). The high salinity levels in turn resulted in high tissue levels of sodium (Figure 2.12). The severity of this effect decreased with each successive harvest as reflected by correspondingly lower tissue Na levels in the third harvest (Figure 2.12). The application of urine had a minimal effect on soil pH (Table 2.8).

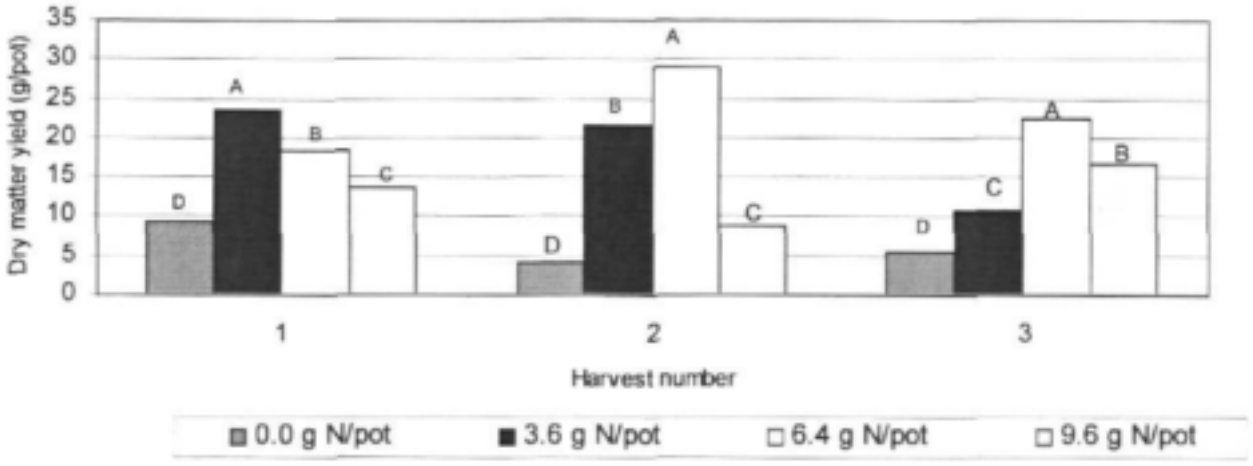


Figure 2.9: Effects of added urine on the growth and re-growth of spinach. (Bars within each N source bearing the same letter or none at all are not significantly different at p < 0,05)

Figure 2.10: Effects of human urine application on spinach growth

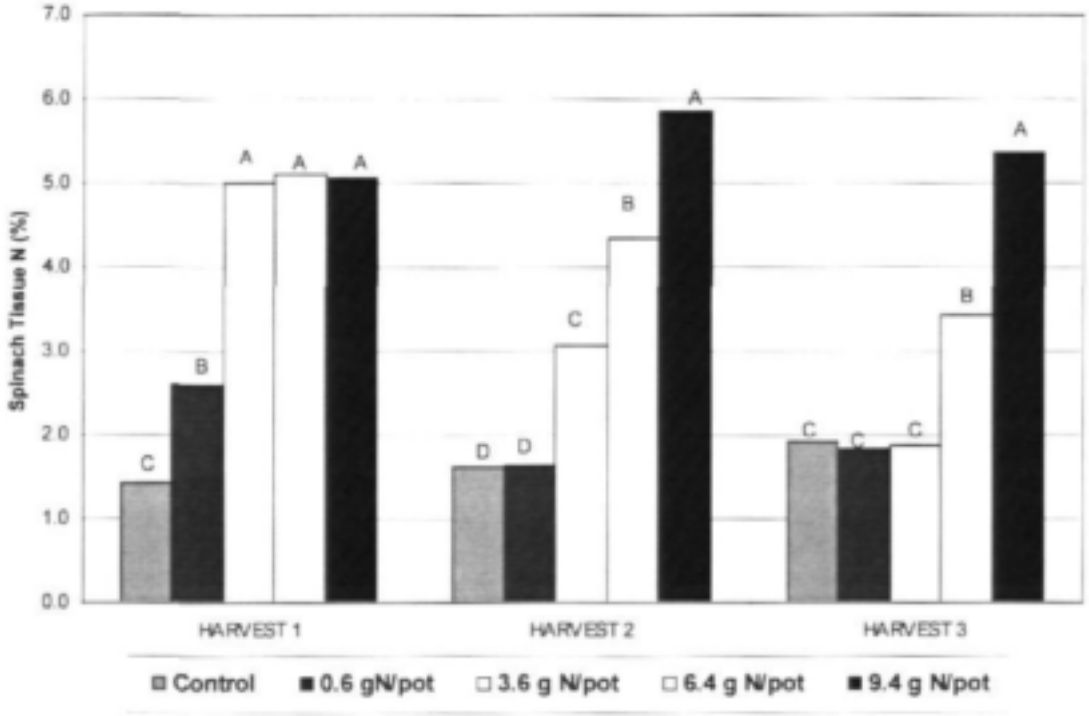


Figure 2.11: Effects of diluted human urine on the nitrogen concentration of three successive spinach harvests. (Bars within each N source bearing the same letter or none at all are not significantly different at $p < 0,05$)

Table 2.8: Effects of added urine on soil pH and electrical conductivity (EC)

Treatment	Soil pH		Electrical Conductivity (mS/cm)	
	Cabbage	Spinach	Cabbage	Spinach
Control	6,5 a*	6,5 a	1,3 d	2,0 b
0,6 g Urea N/pot	-	6,3 ab		1,8 b
1,2 g Urea N/pot	5,9 bc	-	1,9 d	
3,6 g Urine N/pot	6,1 b	5,7 c	5,8 c	1,4 b
6,4 g Urine N/pot	5,8 bc	5,6 c	10,2 b	1,7 b
9,6 g Urine N/pot	5,7 c	5,9 bc	18,8 a	17,7 a

* Means within each column followed by the same letter are not significantly different at $p < 0,05$.

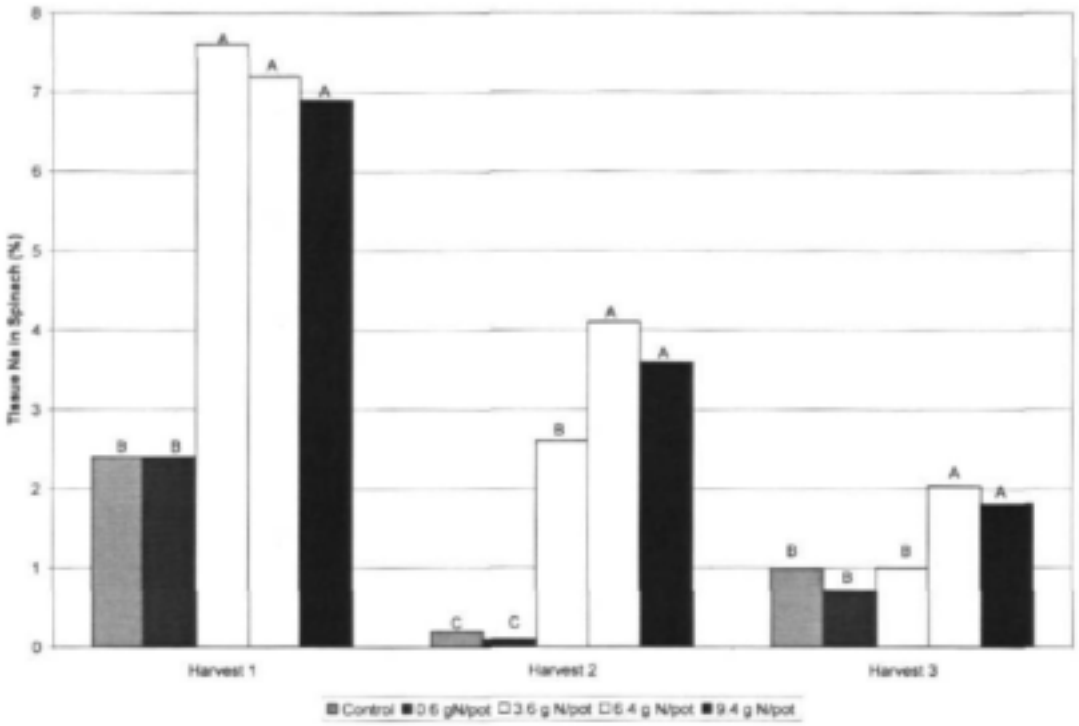


Figure 2.12: Effects of diluted human urine application on spinach tissue Na concentration. (Bars within each N source bearing the same letter or none at all are not significantly different at $p < 0.05$)

(b) Effects of diluted human urine on cabbage growth

Application of diluted urine had more or less the same effects on cabbage growth as observed for spinach. The application of diluted urine once a week (3,6 g N/pot) had the largest effect on cabbage growth (Figures 2.13, 2.14 and 2.15). The yield was increased by more than 5 times. However, higher rates of urine application had a depressing effect on yield even though they resulted in increased tissue nitrogen concentration (Figure 2.16). The diluted urine application had little or no effect on the tissue P and K concentration (Figure 2.16) but increased tissue levels of Na substantially (Figure 2.17) possibly as a result of its effect to increase salinity in soil (Table 2.8).

As observed for spinach, the application of urine had an acidifying effect on soil pH (Table 2.8). This was largely a result of the hydrolysis of urea, which is the main nitrogen bearing compound in urine. This effect may not have affected crop growth in this study because the soil used had a nearly neutral initial pH, however, it could have a negative effect on plant growth in soils that are already acidic to begin with.

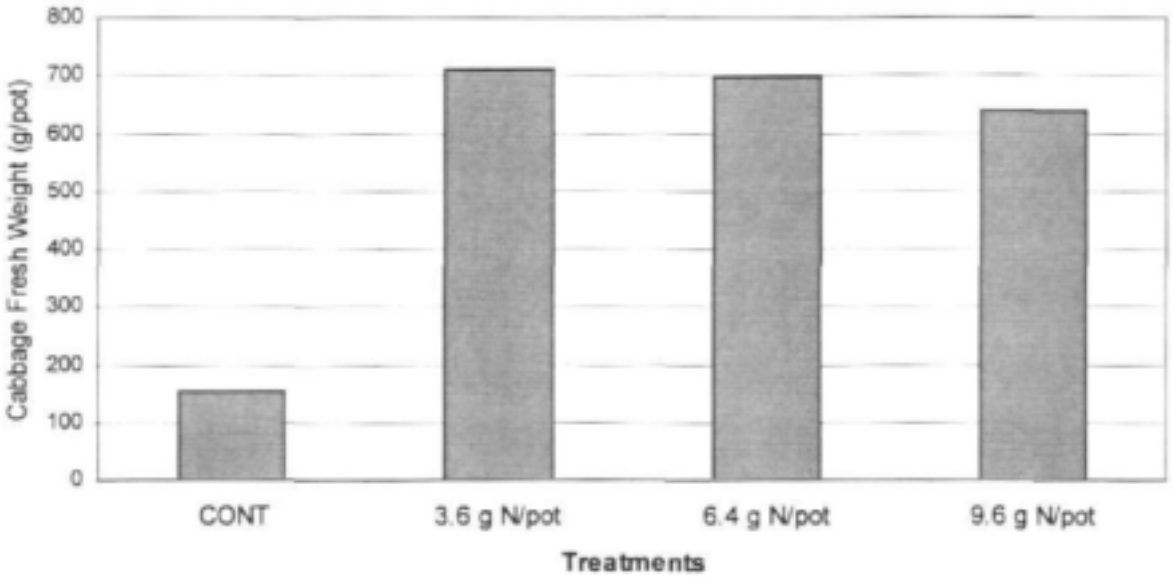


Figure 2.13: Effects of diluted human urine application on cabbage yield

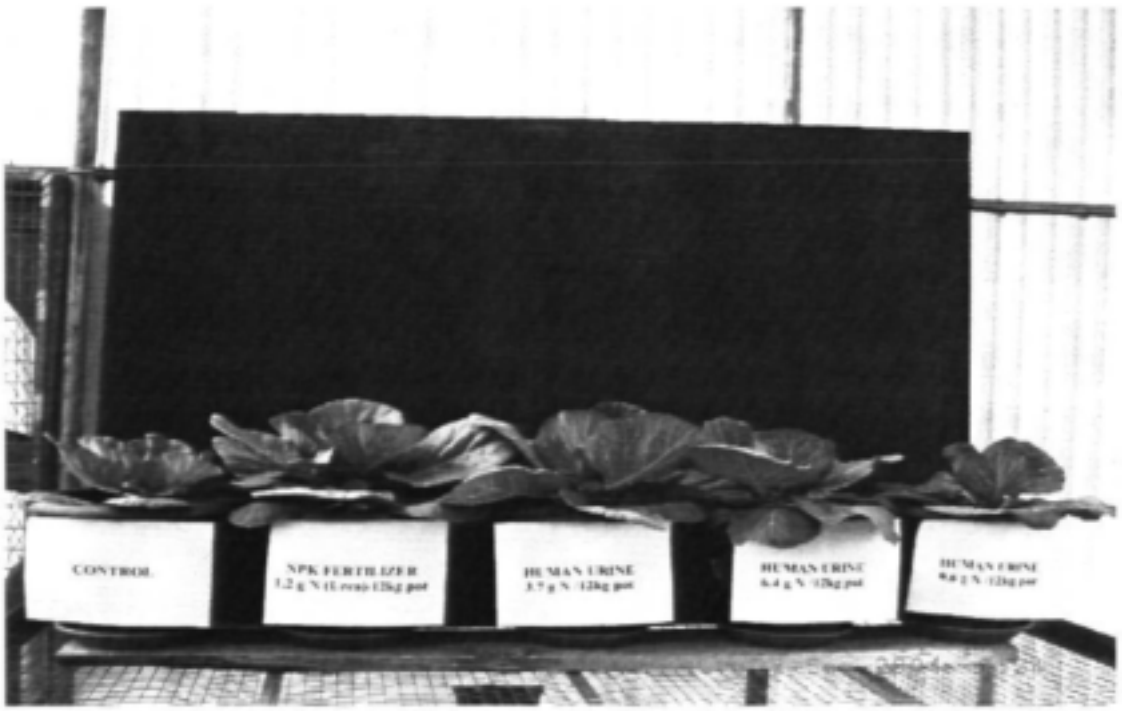


Figure 2.14: Effects of diluted human urine on cabbage growth

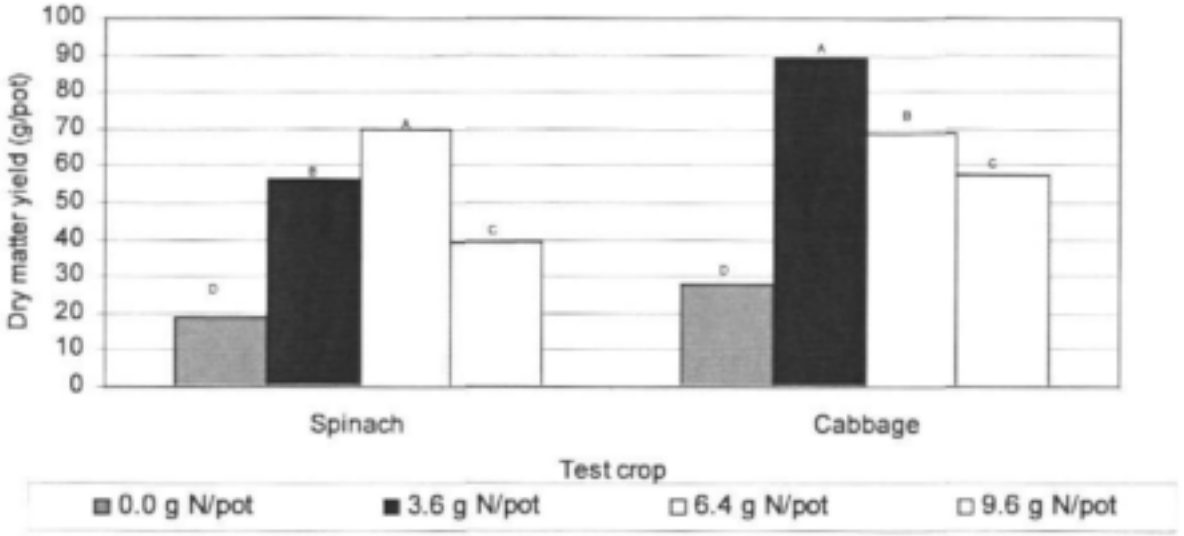


Figure 2.15: Effects of diluted human urine application on the combined dry matter yield of spinach (3 harvests) and that of cabbage. (Bars within each N source bearing the same letter or none at all are not significantly different at p < 0,05)

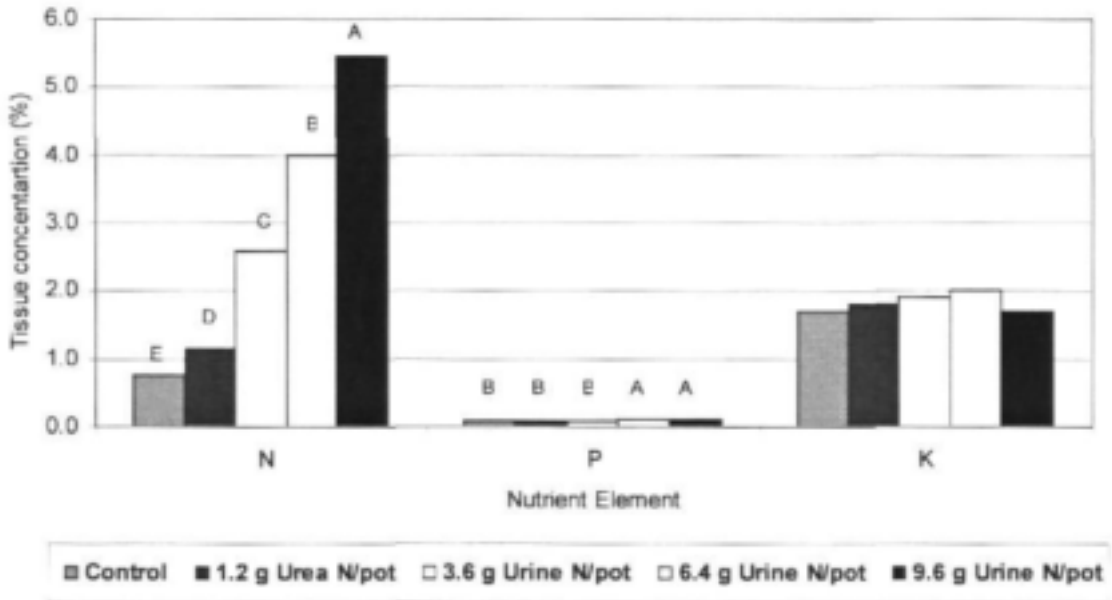


Figure 2.16: Effects of diluted human urine application on the cabbage tissue N, P, and K concentrations. (Bars within each N source bearing the same letter or none at all are not significantly different at p < 0,05)

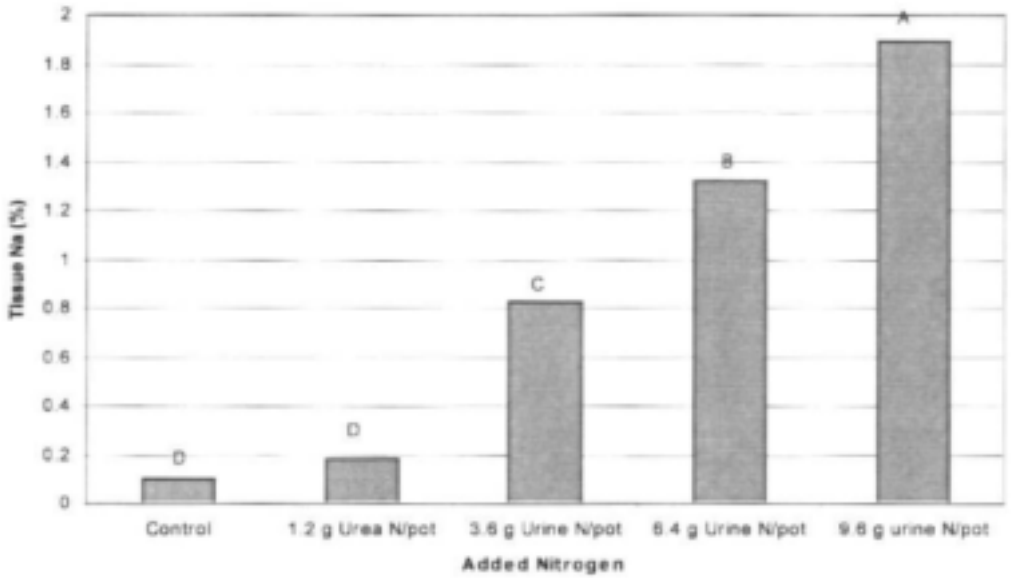


Figure 2.17: Effects of diluted human urine application on cabbage tissue Na concentration. (Bars within each N source bearing the same letter or none at all are not significantly different at $p < 0,05$)

2.3.3 Conclusions

Diluted urine was found to be good source of nutrients, especially nitrogen, for spinach and cabbage when applied once a week for about a month. Higher rates of application, through more frequent applications, tended to depress yields.

- The main reason for yield depression at high rates of diluted urine application appeared to be increased salinity in soils, which in turn led to rather high levels of sodium in the plant tissues.
- The application of diluted urine had an acidifying, but possibly inconsequential, effect on soils. The acidifying effect was due the hydrolysis of urea, which is the main form of nitrogen in urine.
- This study needs to be repeated under field conditions for meaningful and realistic recommendations.

2.4 EVALUATION OF HUMAN URINE AS FERTILISER FOR MAIZE AND TOMATO UNDER TUNNELHOUSE CONDITIONS

2.4.1 Materials and methods

The experimental soil used for this study was also collected from the same site used for the human manure field trial. The soil was sampled from the plough layer (0-15 cm), air dried, and sieved through an 8 mm sieve. Six kilograms of soil were then placed in pots for use in the glasshouse study. The urine used was the same as used in the spinach trial reported earlier. It was analysed and found to have a nitrogen content of 0,74%, and was used without dilution with water. Commercial urea fertiliser (46% N) was used as the source of inorganic nitrogen.

The treatments were 0, 50, 100, 200 and 400 kg N/ha for both urine and urea. These rates translated into 0, 20, 40, 80, and 160 ml of the urine and 0; 0,33; 0,66; 1,32,

and 2,64g urea, respectively per 6,0kg soil. Thus, the experiment had a total of 10 treatments per test crop. The treatments were replicated four times and arranged in a randomised complete block design in the tunnel house. The urea was added and thoroughly mixed with the soil in each pot, watered to near 80% field capacity moisture content and allowed to equilibrate for 8 hours before seeding (for maize) or transplanting in the case of tomatoes. Urine treatments were applied by measuring the required urine quantity into 100 ml water, and then uniformly pouring onto the potted soil followed by additional water to bring the soil to approximately 80% of the soil's water holding capacity.

Five treated white maize seeds variety PAN 6479 were sown on 17 November 2004 into each pot and thinned to two seedlings per pot 10 days after germination. For the tomato trial, one seedling each of the Money Maker tomato variety was transplanted into each pot at the evening of the same day to avoid heat stress and thus minimise the transplanting shock. Weeding was done by pulling out weeds as they emerged in each pot. The maize was harvested on 19 January 2005 at which time fresh biomass yields were recorded. The tomato trial was terminated on 28 January 2005 at which time fresh biomass and fruit yields were recorded. Dry matter yields in both cases were recorded following oven drying at 65°C to constant weight. Plant samples were ground to pass through a 2mm sieve and analysed for nutrients as described for the spinach experiment.

Soil samples were taken from each pot at the end of the trial for laboratory determinations of pH, electrical conductivity, total N, P, K Ca, Mg and Na contents after drying and processing. All data generated were subjected to detailed statistical analysis using the MSTATC statistical program.

2.4.2 Results and discussion

(a) Effects of added urea and human urine on maize growth

The response of maize to added urea and urine as reflected by the dry matter yield (stover + leaves) is shown in Figure 2.18. Maize responded more or less equally to urea and urine. Each increment in added N up to 200kg/ha in the form of urea or urine resulted in significant increase in biomass dry matter yield. However, above 200kg N/ha there was little or no significant increase in yield. Leaf N concentration at harvest was, however not influenced by the treatments possibly because the N had been redistributed to other plant parts. The biomass yield results, nevertheless, indicate that human urine was as good as the urea fertiliser as a source of nitrogen for maize.

(b) Effects of added urea and human urine on tomato growth

The effects of added urea and human urine on tomato biomass (stalks and leaves) and fruit yields are shown in Figures 2.20 and 2.21. As observed for maize, tomato growth responded more or less equally to added urea and human urine. Each increment in added nitrogen, in the form of either urea or urine, produced a significant increase in biomass yield. Increases in fruit yield, were, however, only significant at the highest level of N application. This was possibly because the plants were growing in a rather limited volume of soil so by fruiting time, nitrogen had become a limiting factor especially at lower levels of N application. Nevertheless, these results together with those observed for maize support conclusions of other researchers (e.g. Kirchmann and Pettersson (1995)) that human urine is agronomically as effective as chemical urea or ammonium fertilisers.

(c) Effects of added urea and human urine on soil pH and electrical conductivity (EC)

The effects of added urea and urine on soil pH and electrical conductivity are shown on Figures 2.22 and 2.23 respectively. Both urea and urine had an acidifying effect on the soil, though this effect was more prominent in the case of urea. The acidification is believed to be a result of the hydrolysis of the urea in urine (75-90%) and fertiliser, to ammonium and subsequent nitrification of the ammonium in the soil, which results in the production of hydrogen ions as byproducts:

$$CO(NH_2)_2 + 3H_2O \xrightarrow[Urease]{} 2NH_4^+ + OH^- + HCO_3^-$$

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_20$$

The urea and human urine, however, had contrasting effects on soil electrical conductivity. The urea tended to decrease the EC while urine increased it at the highest rate of application (Figure 2.23). The increase in soil salinity with the application of urine resulted in high tissue levels of Na in tomato leaves (Figure 2.24), consistent with observations made with spinach (Figure 2.12). The increased salinity did not, however, depress yields in contrast to observations made with spinach. This could be due to the fact that the repeated application of the diluted urine in the spinach trial resulted in higher rates of urine application (≡ 600kg N/ha once a week, 1097kg N/ha twice a week and 1567kg N/ha three times a week) than the highest urine application (400kg N/ha) used in the present study. Thus although yields were not depressed in the present study, the observed high EC and leaf Na concentration at the highest rate of urine application, suggest that high application rates of urine, as a once-off application or through repeated application, could lead to the salinisation of soil. This is likely to be a greater problem in semi-arid environments where evapo-transpiration usually exceeds precipitation.

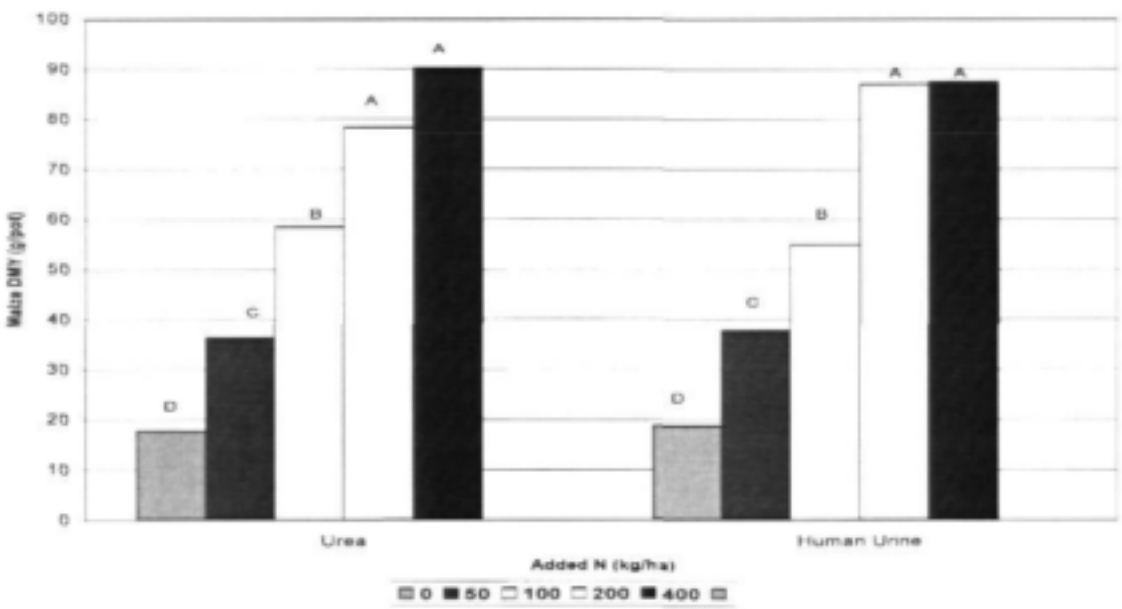


Figure 2.18: Response of maize to added urea and human urine.

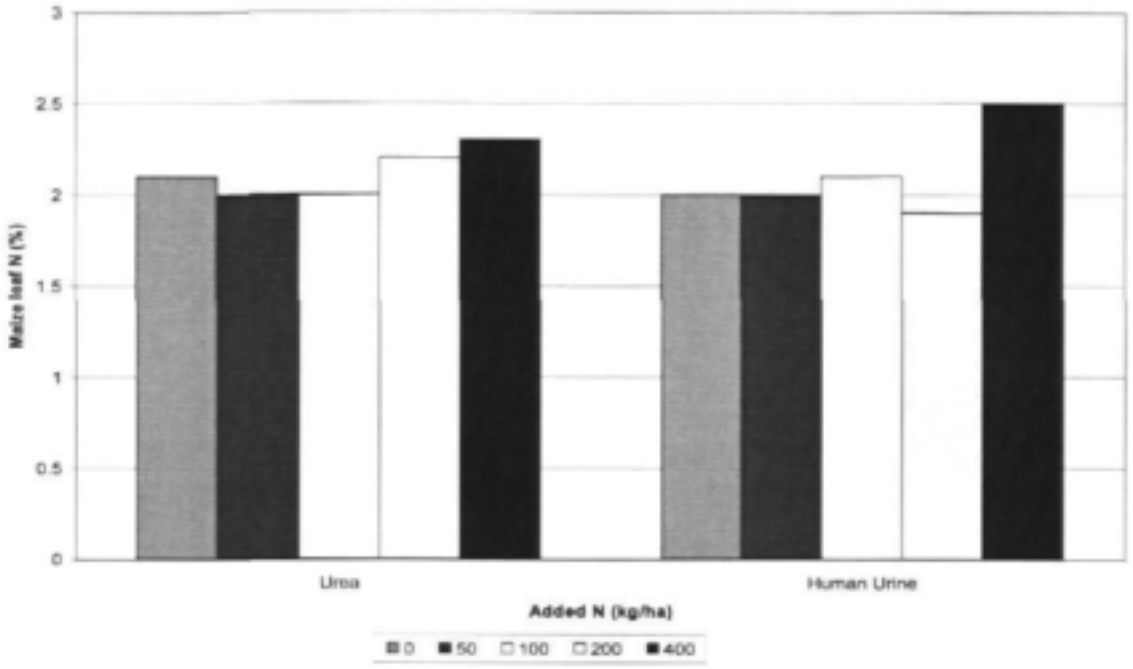


Figure 2.19: Leaf nitrogen content as influenced by added nitrogen in the form of urea or human urine. (Bars within each N source bearing the same letter or none at all are not significantly different at p < 0,05)

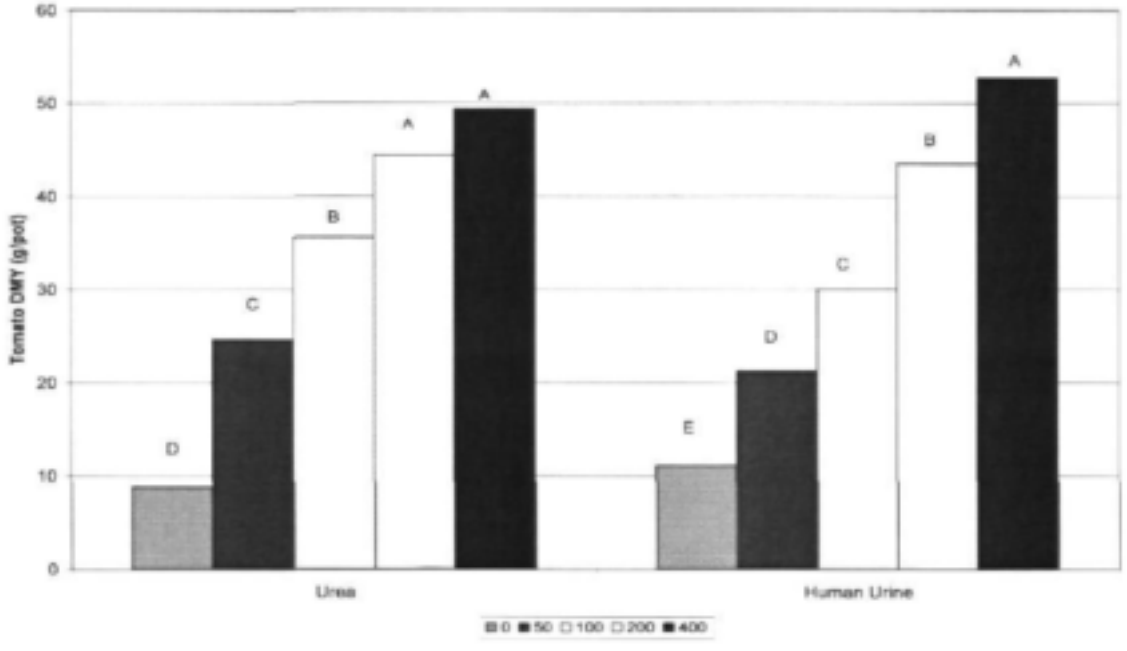


Figure 2.20: Effect of added nitrogen in the form of urea and human urine on tomato dry matter yield. (Bars within each N source bearing the same letter or none at all are not significantly different at p < 0,05)

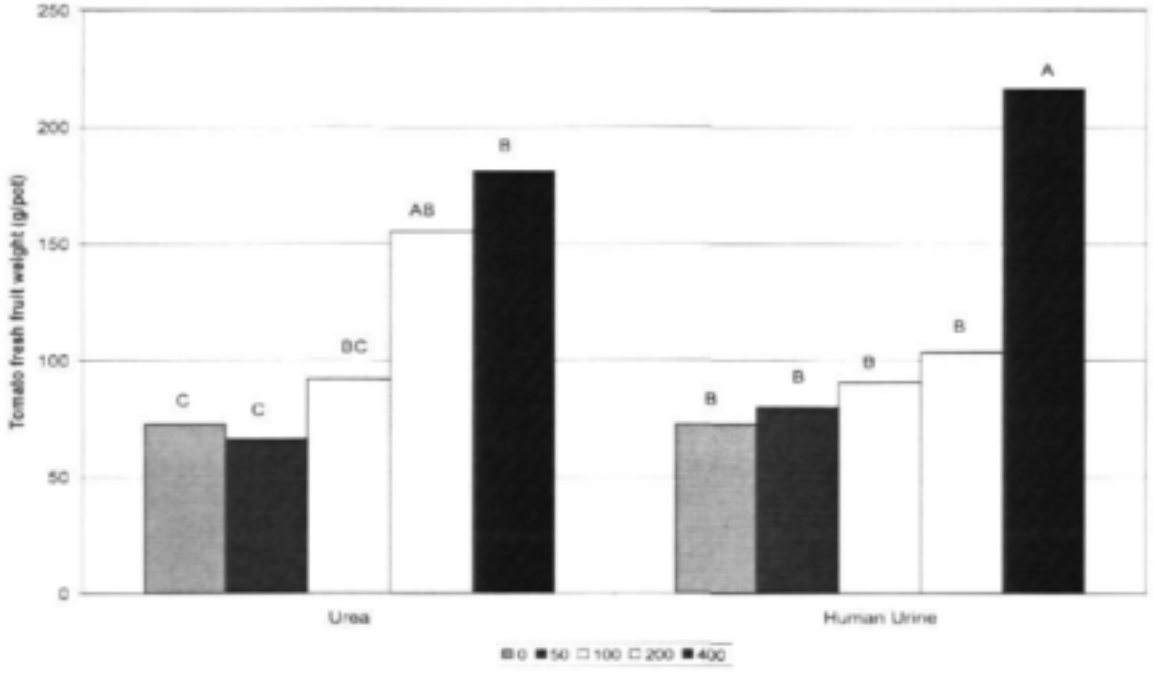


Figure 2.21(a): Effects of added nitrogen in the form of urea and human urine on tomato fresh fruit weight. (Bars within each N source bearing the same letter or none at all are not significantly different at p < 0,05)

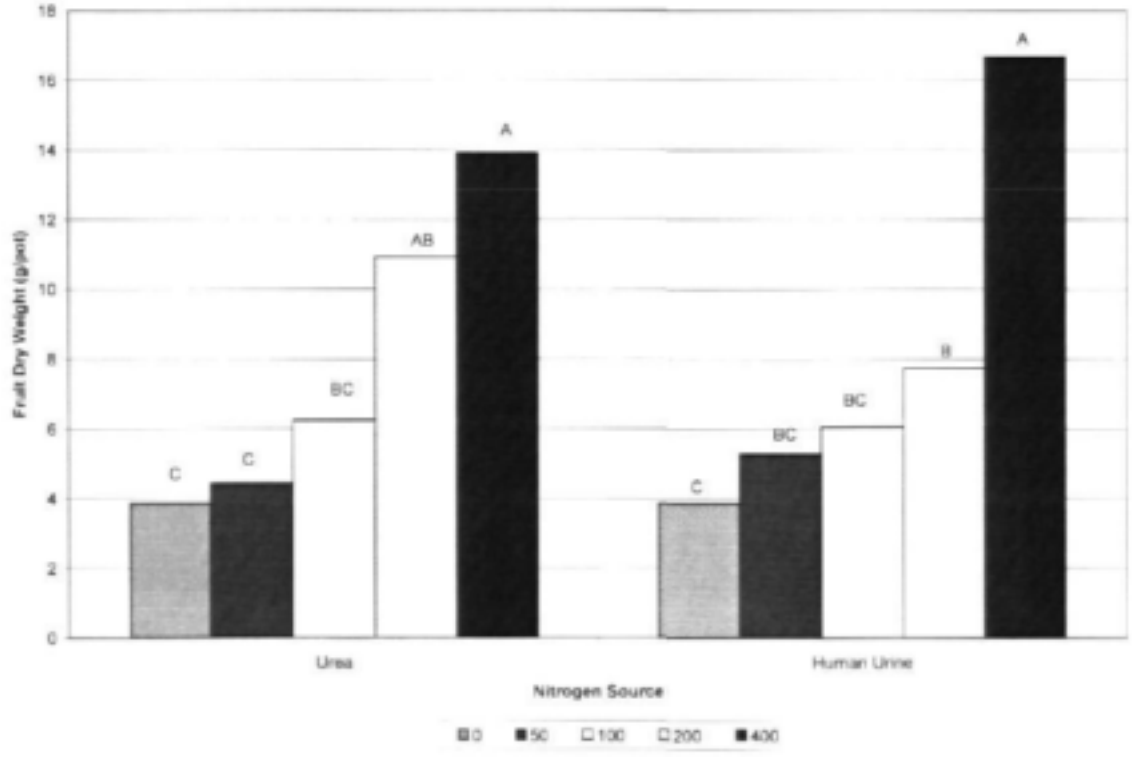
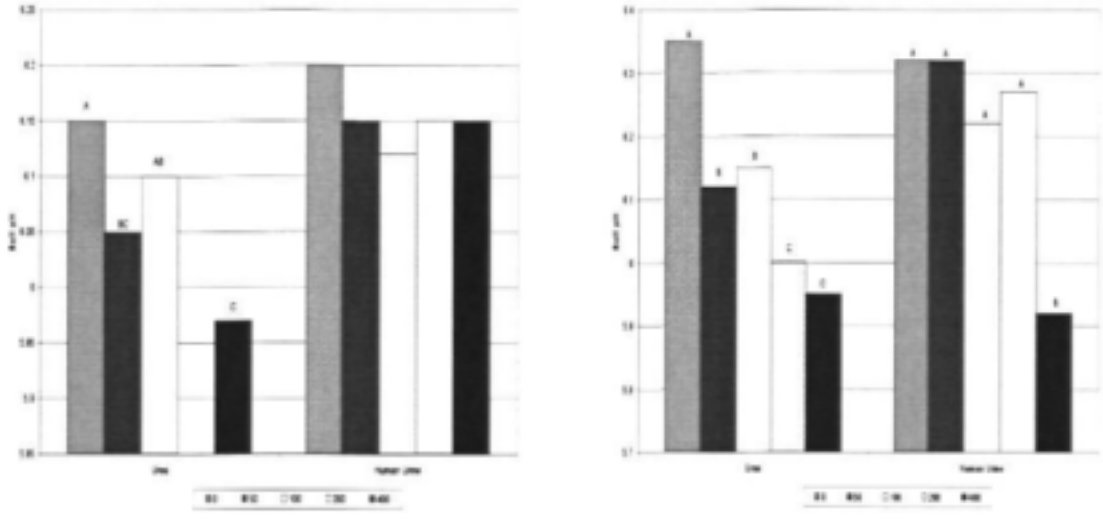
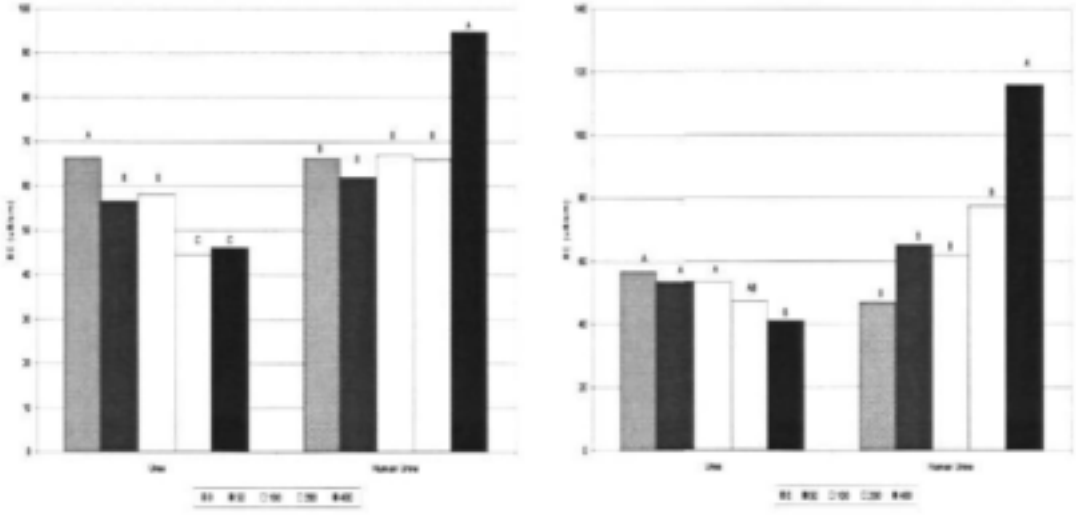


Figure 2.21(b): Effects of added nitrogen in the form of urea and human urine on tomato fruit dry weight. (Bars within each N source bearing the same letter or none at all are not significantly different at p < 0,05)



(a) (b)

Figure 2.22: Effect of added nitrogen to maize (a) and tomato (b) in the form of urea and human urine on soil pH. (Bars within each N source bearing the same letter or none at all are not significantly different at $p < 0,05$)



(a) (b)

Figure 2.23: Effect of added nitrogen to maize (a) and tomato (b) in the form of urea and human urine on soil electrical conductivity (EC). (Bars within each N source bearing the same letter or none at all are not significantly different at $p < 0,05$)

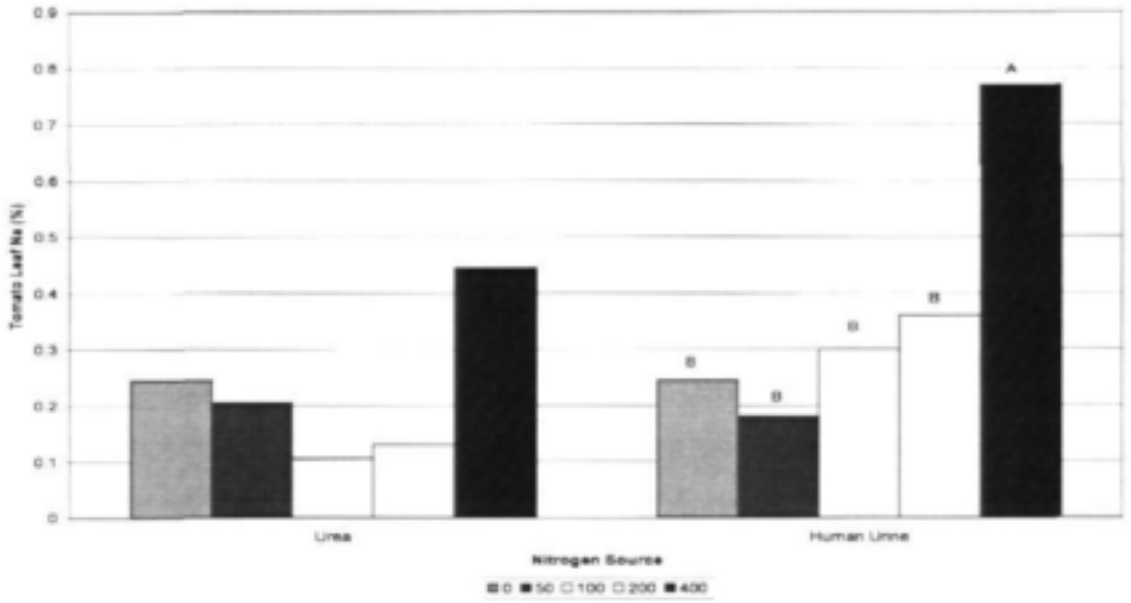


Figure 2.24: Effects of added nitrogen in the form of urea and human urine on the concentration of Na in tomato leaves at harvest. (Bars within each N source bearing the same letter or none at all are not significantly different at $p < 0,05$)

2.4.3 CONCLUSIONS

- The results of the maize and tomato experiments have confirmed results reported in the literature that human urine is as effective agronomically as urea or ammonium sources of nitrogen. Thus if pathogenic tests prove a low risk of disease transmission, it should be seriously considered for use where urine-diversion toilets are in use. Field trials are, however, recommended to establish optimum rates of application in areas where its use is envisaged.

- The use of human urine at high rates of application can result in soil salinisation. Therefore, the use of human urine should not be recommended for soils that are known to have salinity problems. Furthermore, the salinity status of soils that are regularly fertilised with urine should be monitored to guard against salt build-up.

2.5 BIBLIOGRAPHY

Drangert J0 (1998). Fighting the urine blindness to provide more sanitation options. *Water SA*, **24**,157-164

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

Mkile Z (2001). *The use and agronomic effectiveness of kraal manures in the Transkei region of the Eastern Cape, South Africa.* M Sc (Agric) dissertation, University of Fort Hare, Alice.

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

Non-Affiliated Soil Analysis Work Committee (1990). *Handbook of Standard Soil Testing Methods for Advisory Purposes*. Soil Science Society of South Africa. Pretoria.

Okalebo JR, Gathua KW and Woomer PL (1993). *Laboratory Methods of Soil and Plant Analysis: A Working Manual*. TSBF Program UNESCO-ROSTA Soil Science Society of East Africa Technical Publication No. 1, Marvel EPZ Ltd., Nairobi, Kenya.

CHAPTER 3

FIELD TRIALS: MICROBIOLOGICAL EFFECTS ON FOOD CROPS FERTILISED WITH FAECAL MATERIAL FROM URINE-DIVERSION TOILETS

3.1 INTRODUCTION

One of the advantages of ecological sanitation is that faecal material can be advantageously applied to soils (Esrey et al 1998). At present, however, faecal material from urine-diversion toilets in South Africa has not been classified in the current South African norms that define four types of sludges (WRC 1997). These are Type A (raw, cold digested, oxidation tank and septic tank sludges); Type B (anaerobic, heat digested, surplus activated or humus tank sludges); Type C (pasteurised, heat treated, lime stabilised, composted or irradiated sludges) and Type D (same origin as Type C). Due to its characteristics Type A sludge is not suitable for agricultural use. Types B and C may be used for this purpose but with controls to minimise human exposure to pathogens, while only Type D is for unrestricted use. Crop growing is limited to fenced areas with access only to authorized persons and it is forbidden to grow products involving meat, milk or egg production (WRC 1997). For sludge Type D (the best quality type) a maximum application rate of 8 tons per hectare per year is permitted, in order to avoid leaching of nitrogen to aquifers. Considering the widespread use of urine-diversion technology in South Africa, it has become important to assess the possible uses or acceptable disposal methods of the faecal material produced, and for that reason information concerning the quality of this material and of its effects under different management options is important.

3.2 BACKGROUND

Urine-diversion involves the storage of faeces in dry conditions that inactivate the microorganisms to such an extent that a safe soil conditioner is produced (Esrey et al 1998). When applied to land, this material increases agricultural yields (Esrey et al 1998; Austin and Duncker 2002, Kouraa et al 2002), because human excreta contains organic matter, phosphorus and nitrogen compounds that are essential plant nutrients. The use of dry human excreta is not new. It was documented in the 12th century in China (Schönning 2001) and until the second half of the 19th century in Finland (Olsson 2001). Because this material originates in toilets based on the principle of separating urine from faeces, it dehydrates quite rapidly. Compared to traditional latrine sludge (and even to sludge produced in conventional wastewater treatment systems) faecal material from urine-diversion toilets displays a lower moisture content that contributes to microorganism inactivation (Esrey et al 1998, Schönning 2001, Austin 2001).

Recycling excreta to soils reduces the need for chemical fertilisers; however, pathogens are recycled to humans if improper agricultural practices are implemented (Höglund 2002). Concerns about using faecal material include higher pathogenic content in developing countries compared to that from developed countries (Jimenez et al 2002 & 2004). This material, as well as that from other sanitation alternatives in small-scale systems, demands more personal involvement from the users (including handling of the waste), which constitutes a higher human exposure level compared to that from conventional piped systems. Nevertheless, it is considered that where the

material can improve agricultural productivity, it can contribute to improving the nutritional status of the population, thus improving public health (Höglund 2001; IMWI 2003). According to Peasey (2002), although ecosan technology is spreading all over the world, and with it the intention to recycle excreta to soils, few researchers have addressed the problems associated with the revalorization practice or documented the pathogen die-off. Moreover, little data about the microbial quality of ecosan faecal material from developing countries (where the health risks are the highest) are available. The objective of this research was to characterise urine-diversion faecal material from the microbial point of view as well to investigate the health effects on edible crops.

3.3 METHODOLOGY

A 25kg composite sample of dry faecal material mixed with some topsoil was collected from the main heap of experimental material described in Volume 1 of this report. For microbial characterisation, four bacteria, one fungus as well as helminth ova were measured. Total coliforms were measured due to their presence in faeces, faecal coliforms and faecal *streptococci* because they are considered as good indicators of faecal pollution by most authors (e.g. Feachem et al 1983) and *Salmonella* spp. because it is often considered in sludge regulations. For fungi there is not a universal indicator; *Aspergillus spp.* was used because it is an opportunistic pathogen belonging to a group of moulds that is found worldwide. Finally, helminth ova were monitored due to their high persistence in the environment and because they are considered as quality indicators for most faeces use practices (WHO 1989). Helminth ova cause diarrhoea, mechanical deterioration, tissue damage, toxic effects and blood loss, while *Ascaris* and *Trichuris* alone infect over one third of the population in developing countries (WHO/UNICEF 2000). Helminths are commonly associated with sanitary risks when sludge is used as an agricultural fertilizer (Asaolu and Ofoezie 2003). To analyse total coliform, faecal coliform, faecal *streptoccoci*, *Aspergillus spp.* and *Salmonella spp.* a serial dilution technique was used (Islam et al 2004 & 2005). The technique used for *Salmonella* was replaced during the second phase of the study with a standard technique (APHA, AWWA, WEF 1995). TS (total solids), pH, and nitrogen were also determined using standard techniques (APHA, AWWA, WEF 1995). For Helminth ova (HO) detection the Ayres technique modified by Jiménez et al (in press) was used.

Analyses were performed to characterize the following:

- the faecal material prior to its application;
- the soil before sowing and after harvesting;
- the irrigation water during the study; and
- the crops after harvesting.

To assess the microbial effects of the faecal material in agriculture, two kinds of crops were selected, namely spinach and carrots. These crops were considered because they are usually eaten in South African rural areas, are often consumed raw, and for spinach the edible parts grow above the ground, while for carrots they grow below the ground. 2m x 9m plots at the experimental farm of the University of Pretoria were used. Each crop was planted in two plots, one being used as control while the other was divided into three sections. Each plot was treated with a different application rate.

To determine the amount of faecal material to be added, the following criteria were taken into account:

- the nitrogen demand of crops (50kg N/ha for carrots and 100kg N/ha for spinach);
- application rates above and below 8t/ha, which is the maximum permissible value in South Africa; and
- three different helminth ova rates.

Following these criteria, the material was applied on carrots at 0; 7; 12,5 and 35t/ha corresponding to 0; 1; 1,7 and 4,8 HO/cm^2, while for spinach 0; 1,3; 19,0 and 37,5t/ha equivalent to 0; 0,18; 2,6 and 5,1 HO/cm^2 were used.The helminth rate was defined as the quantity of total helminth ova applied per square centimeter. The material was mixed to a depth of 10cm. Seeds were planted in the second week of November 2005 (summer). The pattern within the blocks was in rows 300mm apart and the seeds were spaced 50mm apart within the rows. Spinach was harvested in January (after 7 weeks) and carrots in March (after 12 weeks). In each case, the whole plant was pulled from the soil and cut to collect roots and leaves separately. For faecal material and soil analyses 1g samples were used. To analyse bacteria and fungi, 5g of crop samples were taken, while for helminth analyses the sample size was 30g.

3.4 RESULTS AND DISCUSSION

3.4.1 Sludge characterisation (Table 3.1)

While the TS content was high (43 ± 2%) and hence the moisture content low, the N content (0,2 - 0,34%) was within the common range for domestic sludges (0,2 - 0,6%) if the N contribution due to urea was subtracted (90% of the value according to Metcalf and Eddy (2003)). The N content was low compared with other sludges, and this implied higher quantities of material needed to be added to fulfill the nutrient demand of the crops. This would not have been important if the material had no microbial content. However, this was not the case.

Concerning helminths, the value found (29,8 ± 2,9 total helminths) indicated that the concentrations were not as high as could be expected for sludges from developing countries (ranging from 67 to 735 ova/gTS according to Jiménez and Wang 2005) and were even comparable to those obtained from anaerobic digester sludges in South Africa (2 to 40 *Ascaris*/gTS – Snyman et al 2003), which are sludges classified as Type B and therefore allowed to be used for agriculture with some restrictions to minimise human exposure. However, the faecal material had already been exposed to sunlight in the heap for about four months, which accounted for much of the pathogen die-off that had already taken place.

Table 3.1: Ecosan sludge characterisation

Parameter	Mean value
N content, %	0,2 - 0,34
Total coliforms, CFU/g TS	$2,2x10^5$
Aspergillus spp, CFU/g TS	$3,9x10^3$
Faecal *streptoccoci*, CFU/gTS	$2,1x10^6$
Faecal coliforms, CFU/g TS	$1,8x10^6$
Salmonella spp, CFU/gTS	$2,2x10^5$
Total *Ascaris*, ova/gTS	25,3 ± 4,4
Total helminths, ova/gTS	29,8 ± 2,9
Viability, %	88,8 ± 0,5

Table 3.2: Initial soil characteristics

Parameter	Value
pH	7,7 ± 0,21
TS content (moisture)	86% ± 2 (14 ± 2)
Total coliforms	$8,1x10^3$ - $2,7x10^5$
Faecal *streptococci*	0, absent
Faecal coliforms	$2,6 x10^3$ - $1,1x10^4$
Salmonella spp	0, absent
Aspergillus spp	0 - $7 x 10^1$
Total helminths, ova/gTS	1,4 ± 0,5
Viability, %	0 - 10%

3.4.2 Irrigation water

Water used for irrigation came from a borehole and was stored in open tanks. The water was not disinfected and very often birds were drinking water from the tanks. This is possibly the reason why some microbial pollution was found, although at very low concentrations. Total coliforms ranged from 0,1 to 0,3 CFU/100 ml, faecal coliforms from 0,2 to 0,9 CFU/100 ml, faecal *streptococci* from 0 to 0,1 CFU/100 ml, while *Salmonella spp* and helminth ova were not detected in any of the five samples analysed.

3.4.3 Initial soil conditions (Table 3.2)

Soils were slightly alkaline (pH 7,7) and contained microorganisms such as total and faecal coliforms. The first are commonly considered as native in soils, while the second have been reported as native in water in high-temperature countries and therefore could be present in soils (Hazen and Toronzos 1990). Faecal *streptococci* and *Salmonella* (using the APHA, AWWA, WEF method) were not found in the soil while helminth ova were present in low concentrations (1,4 ± 0,5 HO/gTS) and with very low viability (0 to 10%). According to the records of the farm, the plots had not received any manure application (which can contain helminth ova) for at least 1,5 years. Concerning the genus, almost all the eggs found were *Ascaris* although *Toxocara* was sometimes also found.

3.4.4 Crop results

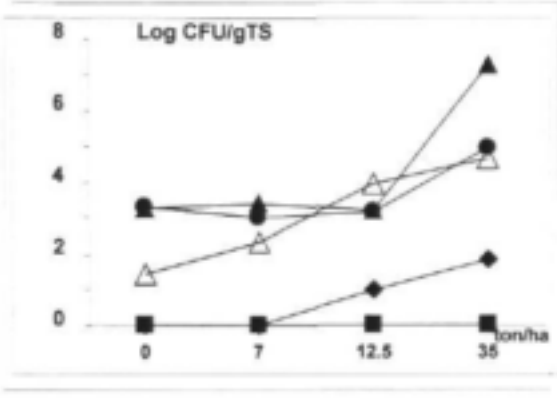


Figure 3.1(a): ▲Total Coliform; •Faecal Coliform; ΔFaecal *Streptoccoci*; ▪*Salmonella spp.*; and ♦*Aspergillus spp.*

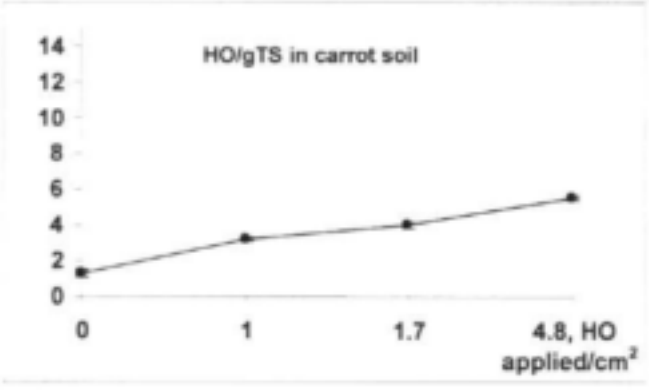


Figure 3.1(b): Helminth ova content in carrot soil after harvesting

The quantities of faecal material applied were equivalent in terms of the actual viable helminth eggs to application rates of 0,9; 1,5 and 4,3 HO/cm^2 for carrots and 0,2; 2,3 and 4,5 HO/cm^2 for spinach. These values should be compared to that of 0,016 viable HO/m^2 for sludges having 1 viable helminth ova/gTS and applied at a rate of 8t/ha as established in South African regulations as well as with application rates of 0,4 for carrots or 0,8 HO/cm^2 for spinach obtained using USEPA norms to fulfill the nitrogen demand by crops with sludges containing 0,25 viable helminth ova/gTS. Figure 3.1 shows the microbial effects of the sludge application on carrot soil. Total coliforms, faecal *streptococci* and faecal coliforms (Figure 3.1(a)) were present in the soil in similar concentrations for all the application rates, and only for the highest value a noticeable increase can be seen. Similar results were obtained for spinach soil, although the increase for the highest sludge application rate was less noticeable. In the case of *Salmonella*, the results in spinach soil were erratic, indicating that the Islam et al (2004) analytical technique was not appropriate. For carrots using the APHA, AWWA, WEF (1995) technique, *Salmonella* results were negative in all cases. Helminth ova in soils for both carrots and spinach (Figure 3.1(b), only for carrots) shows a clear correlation with the rate of faecal material applied: the larger the sludge application rate the greater the number of helminth ova found in soils.

In soils, a surprising result was the diminishing helminth ova viability from the original value of 88,8% to 52 ± 3% for spinach soil and to 39 ± 7% in carrot soil. The greater decrease of viability in carrot soil was likely due to the longer time taken to monitor carrot soil (12 weeks) than for spinach soil (7 weeks). The decrease in viability can be explained, although not conclusively, by the high temperature registered during the summer time in Pretoria (ranging from 27-38°C during the day) but also to possible prior damage suffered by the eggs during their earlier dehydration in the UD toilets as well as during further exposure to the elements in the main heap, as mentioned above and as described in Volume 1 of this report. *Ascaris* have been reported to die rapidly at temperatures over 40°C in different types of media including water, soil, sewage and crops (Feachem et al 1983). The temperature limit could be less if high temperatures are combined with other negative environmental conditions such as high ammonia content or low moisture (Heinonen-Tanski and Van Wijk-Sijbesma 2004).

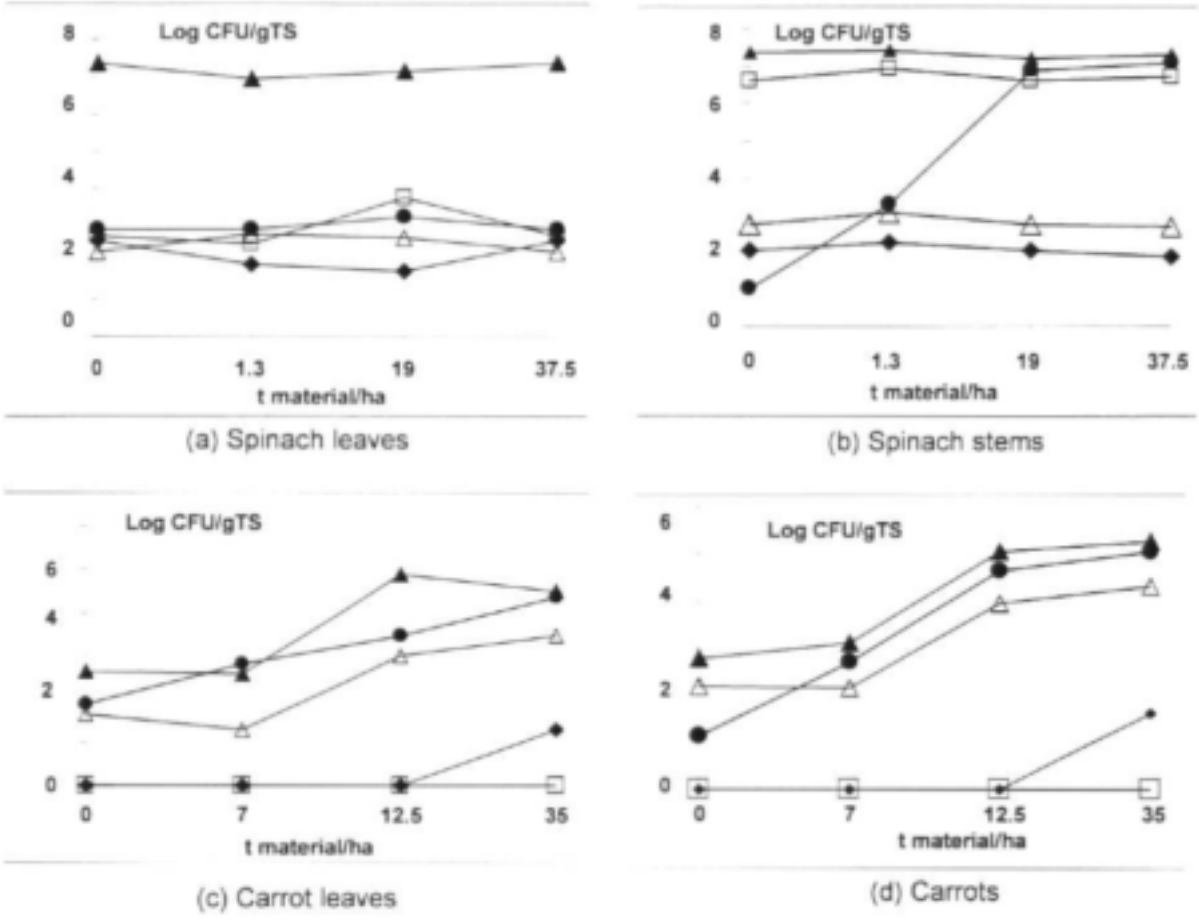


Figure 3.2: ▲Total Coliform; •Faecal Coliform; ΔFaecal Streptoccoci; ▪*Salmonella spp.*; ♦*Aspergillus spp.* in crops after harvesting

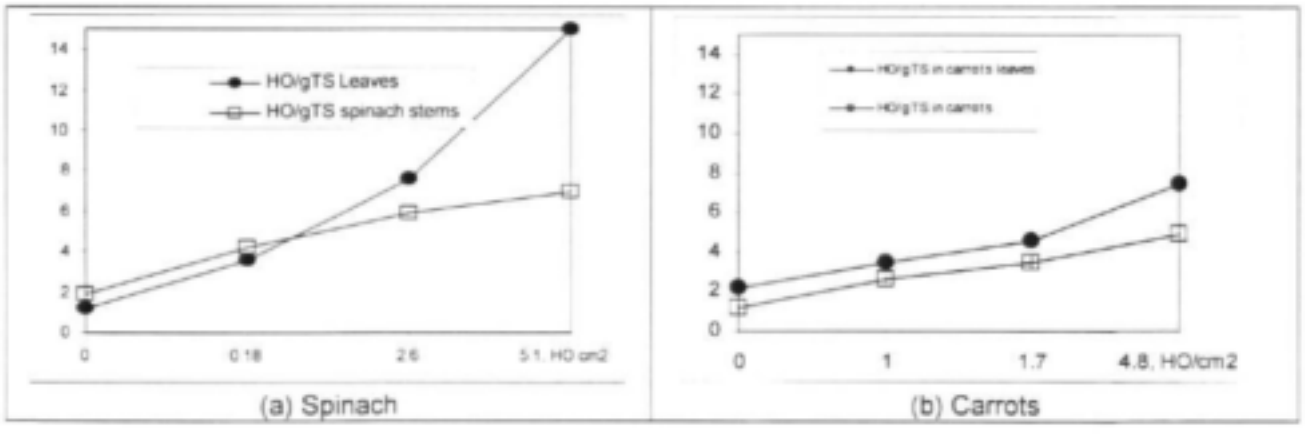


Figure 3.3: Helminth ova content in crops

Figure 3.2 shows the results of the bacteria numbers in spinach leaves (a) and stems (b). There was not a clear relationship between the quantity of faecal material applied and the total microbial number in leaves or stems. For faecal coliforms in stems, the results seem to indicate that bacteria can survive underground but not on top of the soil where UV sunlight is available to kill the organisms. In carrots, total and faecal coliforms as well as faecal *streptococci* increased as the faecal material application rate increased (Figure 3.2(c)). *Aspergillus spp* and *Salmonella spp* were present in low numbers at all the different treatments. Concerning helminth ova, increasing concentrations were found in both stems and leaves (Figure 3.3(a) and (b)) as the quantity of material applied (and hence that of helminths) increased. Contamination is seen to be more important in leaves than in stems, seeming to indicate that helminth ova are preferentially attached to plants rather than to soil.

Although these results show that crops were polluted even using the smallest application rate, understanding the health significance would require proper epidemiological or toxicological studies that consider the probability of microorganisms, especially helminth ova, actually infecting the host. This would depend on the viability of eggs, the quantity of microorganisms consumed by a person through conventional daily diets in the region and the infective dose. Concerning viability, for spinach crops the data was not obtained, but in carrot leaves it was 25 ± 5% while in carrots it was 20 ± 8%. This indicated that although present, they were mainly in an inactive state, thus reducing the risk of spreading the disease through consumption.

3.5 CONCLUSIONS

Faecal material extracted from urine-diversion toilets in the eThekwini region of South Africa and left in a heap exposed to the weather for four months had a microbial content comparable to sludge classified as Type B in the current South African regulations (WRC 1997). This complies with the standard for use in agriculture considering some restrictions to minimise human exposure. Applying different rates of material to spinach and carrots, two common edible crops, it was found that the bacteria and fungi content were only noticeable for the higher rates (>35 t/ha), while the helminth ova content varied, both in leaves and stems, depending on the quantity of material applied. Helminth ova content was, for both crops, more prevalent in leaves, suggesting that the ova adhere preferentially to plants rather than soil.

To assess the actual health risk of helminth ova consumption, the final viability on crops needs to be considered as well as the infective dose for farmers and consumers and the daily diet of vegetables in the region. The actual age and storage conditions of the faecal material used is also an important consideration.

3.6 BIBLIOGRAPHY

APHA, AWWA, WEF (1995) Standard methods for the examination of water and wastewater, 20th ed. Washington D.C.

Austin A (2001). *Health aspects of ecological sanitation.* Internet Dialogue on Ecological Sanitation. CSIR.

Austin A and Duncker L (2002) Urine-diversion ecological sanitation systems in South Africa. CSIR, Pretoria.

Asaolu SO and Ofoezie IE (2003). The role of health education and sanitation in the control of helminth infections. *Acta Tropica* **86**: 283-294.

Esrey S, Gough J, Rapaport D, Sawyer R, Simpson-Hébert M, Vargas J and Winblad U (1998). *Ecological Sanitation.* Sida. Stockholm.

Faechem R, Bradley J, Garelick H and Mara D (1983). *Sanitation and disease: health aspects of excreta and wastewater management.* John Wiley and Sons, Washington D.C.

Heinonen-Tanski H and Van Wijk-Sijbesma C (2004). Human excreta for plant production. *Bioresource Technology* **96**:403-411.

Hazen T and Toranzos G (1990). *Drinking water microbiology.* Springer Verlag, pp 32-53.

Höglund C, Vinnerås B, Stenström T and Jönsson H (2000). Variation of chemical and microbial parameters in collection and storage tanks for source separated human urine. *Environmental Science and Engineering* **35**: 1463-1475.

Höglund C (2001). *Evaluation of microbial health risks associated with the reuse of source-separated human urine.* Swedish Institute for Infectious Disease Control, Stockholm.

IMWI (2003). *Water Policy Briefing Issue 9: Putting research knowledge into action.*

Islam M, Morgan J, Doyle MP, Phatak SC, Millner P and Jiang X (2004). Persistence of *Salmonella enterica* Serovar Typhimurium on lettuce and parsley and in soils on which they were grown in fields treated with contaminated manure composts or irrigation water. *Foodborne Pathogens and Disease* **1**, (1): 27-35.

Islam M, Doyle MP, Phatak SC, Millner P and Jiang X (2005). Survival of *Escherichia coli* O157:H7 in soil and on carrots and onions grown in fields treated with contaminated manure composts or irrigation water. *Food Microbiology* **22**: 63-70.

Jiménez B, Maya C, Sanchez E, Romero A, Lira L and Barrios JA (2002) Comparison of the quantity and quality of the microbiological content of sludge in countries with low and high content of pathogens. *Water Science and Technology.* **46**(10) 17-24

Jiménez B, Barrios J, Mendez J and Diaz J (2004) Sustainable management of sludges in developing countries, *Water Science and Technology* **49**(10) 251-258.

Jiménez B and Wang L (2004) Sludge treatment and management. *Municipal wastewater management in developing countries*, chapter 12. Ujang Z and Henze M Eds. IWAP.

Jiménez B, Maya C and Schwartzbrod J (in press). Comparison of techniques for the detection of helminth ova in wastewater. *Journal of Water and Environment Research*.

Kouraa A, Fethi F, Fahde A, Lahlou A and Ouazzani N (2002). Reuse of urban wastewater treated by a combined stabilisation pond system in Benslimane (Morocco). *Urban Water* **4**: 373-378.

Metcalf and Eddy (2003) *Wastewater engineering, treatment and reuse*. Fourth Ed. McGraw Hill, USA.

Peasey A (2002). *Health aspects of dry sanitation with waste reuse*. Task No. 324. WELL Studies in Water and Environmental Health.

Olsson G (2001). The struggle for a cleaner urban environment: Water pollution in Malmo. *Ambio* **30**: 287-291.

Schönning C (2001). Hygienic aspects on the reuse of source-separated human urine. *Water and Environmental Microbiology*. Swedish Institute for Infectious Disease Control.

Snyman H and Van der Walt S (2003). *Laboratory and field scale evaluation of agricultural use of sewage sludge*. Final report of WRC Project number K5/1210 Biosolids management at 18 waste water treatment plants in South Africa – optimization strategies.

WHO/UNICEF (2000). *Global water supply and sanitation assessment report*. Joint monitoring program for water supply and sanitation. World Health Organization. Geneva.

WRC (1997). *Permissible utilization and disposal of sewage sludge*. Water Research Commission Report no. TT 85/97.

CHAPTER 4

CONCLUSIONS

Application of dehydrated human manure from urine-diversion (UD) toilets on cabbage and spinach crops resulted in better yields than goat kraal manure, but was inferior to inorganic fertiliser. The human manure was also a better source of phosphorus for both cabbage and spinach than goat kraal manure. In addition, when ash is used as a bulking/sanitising agent, the human manure has an alkaline pH and thus has a liming effect on acidic soils.

Diluted human urine was also found to be a good source of nutrients, especially nitrogen, for cabbage and spinach. The application rate is important, however, as soil salinity may be a problem in some soils. Good results were also evidenced in maize and tomato crops. Urine is thus considered to be as effective agronomically as urea or ammonium sources of nitrogen.

It is concluded that, provided pathogenic tests prove the use of human manure and urine to have a low potential for disease transmission, the use of these products in agriculture and food gardens should be encouraged.

Faecal material extracted from UD toilets was applied at different rates to spinach and carrot crops. It was found that the bacteria and fungi content were only noticeable for the higher application rates (>35t/ha), while the helminth ova content varied, both in leaves and stems, depending on the quantity of material applied. Helminth ova content was, for both crops, more prevalent in leaves, suggesting that the ova adhere preferentially to plants rather than soil. Some health risks are therefore inherent in the handling and consumption of food crops grown in soils amended with faecal material from UD toilets.

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VIP toilets, correctly engineered and implemented, are a good means of providing a dry sanitation service, but these systems are not without their problems. If a dry toilet (i.e. not requiring water for its operation) is designed and constructed in such a way that the faeces vault can be quickly, easily and safely emptied, then one of the biggest maintenance problems will be obviated. If the processed excreta can also be productively and safely used for agriculture, the technology will become even more attractive. In South Africa, where many rural communities rely on subsistence agriculture, often in poor soils, and with urban agriculture becoming more common, this is an important aspect. Urine-diversion ecological sanitation (ecosan) systems address the above problems. They have been successfully implemented in many countries, including South Africa where about 3 000 of these toilets are already in existence. However, despite much research having been carried out internationally and locally, various questions still remain, particularly on the health aspects of operation, maintenance, and excreta reuse or disposal. Not enough is currently understood about the processes taking place inside the faeces vault, and there is still disagreement on safe retention periods and stability of the final product. The roles of dryness, pH, temperature and time in pathogen destruction need to be further clarified.

Furthermore, institutional aspects associated with widespread implementation and management of ecosan are largely unresearched in South Africa, and this will be a handicap to large-scale implementation unless efforts are made to address the matter. A need has thus been identified to create further competence in this area of sanitation in South Africa, and to increase knowledge concerning the technology. Ecosan technology is still at a conceptual and development stage, yet all indications are that it has the potential to provide benefits in the provision of sanitation. The technology is increasingly being introduced in a manner which consists of faulty design, poor implementation and improper use.

This study aims to develop strategies and guidelines, through monitoring and evaluating existing schemes, which would provide fundamental answers in the sustainable management of this technology.

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