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Title	**IMPACT OF BURIED URINE DIVERSION WASTE ON ENVIRONMENTAL QUALITY AND PLANT GROWTH**
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Photograph attached (jpg)	

INTRODUCTION

In South Africa, as in most countries with a water supply and sanitation provision backlog, in-house full-pressure water supply and flushing toilets linked to waterborne sewerage and wastewater treatment plants represent the ideal to which most of the population aspires. However, the South African government has recognised that it is neither technologically nor financially feasible, nor necessarily environmentally wise, to provide these levels of service to all. In particular, peri-urban and rural populations are unsuited to the provision of such services, owing to factors such as land ownership, housing density, mobility of the population, terrain and accessibility. On the other hand, the government has committed itself to providing free, basic, safe, acceptable and sustainable drinking water supply and sanitation to all (DWAF, 2003).

The issues of water supply and sanitation are closely linked. Where water is not reticulated to individual households or or at insufficient water pressure, sanitation by flushing toilets is not feasible. Such situations require on-site sanitation systems, *i.e.* the full treatment of waste occurs within the boundaries of the property. The Ventilated Improved Pit Latrine (VIP) has been suggested as suitable for this purpose (DWAF, 2003). However, VIPs are associated with shortcomings, previously described for South Africa in general by Wirbelauer *et al.* (2003), and for Durban in particular by Brouckaert *et al*. (2004).

A substitute for VIPS is a form of sanitation provision which relies on desiccation of waste, thereby reducing the volume to be processed, reducing odour problems and producing a residue which can be worked by individual householders using hand tools. These criteria are met by ecological sanitation (ecosan) systems. Such systems rely on separation of urine and faeces at source, desiccation of faecal waste and potential agricultural reuse of both components as fertiliser and soil conditioner, respectively (Winblad and Simpson-Hébert, 2004). However, ecosan application have not been described under conditions similar to those in Durban, particularly under combinations of high ambient temperature, high summer rainfall and high humidity (Brouckaert *et al.*, 2004).

In an attempt to address the shortfalls of VIPs, and in the face of the urgency of the need for sustainable alternatives, eThekwini Municipality has adopted a variation on the ecosan approach which uses the technology simply as an on-site sanitation system and does not at this stage consider re-use possibilities. Urine diversion toilets, as they have been dubbed, provide a dignified enclosed superstructure containing a urinal and a toilet pedestal which allows for separation of urine and faeces. Urine is disposed of to shallow soakaways. Solid waste accumulates in a vault beneath the toilet. Addition of sand after each defecation promotes desiccation and limits odour and fly problems. The eThekwini implementation makes use of double vault, with the toilet pedestal being relocated over the second, empty vault when the first vault has been filled. The contents of the first vault are allowed to stand for the period required for the second vault to fill (typically a period of approximately one year) (Brouckaert *et al.*, 2004). Thereafter, it is recommended that the waste is buried on-site at a minimum depth of 250 mm below the soil surface (EcoSanRes, 2005) and a tree planted to mark the burial site (Brouckaert *et al.*, 2004). Similar approaches have been adopted in response to similar needs in other parts of South Africa (Wirbelauer *et al.*, 2003)

A number of research questions arise from this. Since the interior of the waste heap is dominated by anaerobic conditions in the vault, it is unknown at what rate the organic component of the buried waste will degrade. It is not clear whether deep-rooted plants, planted above the site of burial, will be able to penetrate and tolerate an anaerobic waste layer. Furthermore, it is not known whether persistent pathogens potentially present in the waste, particularly the ova of the helminthic parasite *Ascaris lumbricoides*, will persist in the buried waste, will move upwards to the soil surface, or will move downwards to contaminate groundwater. This paper presents preliminary results of a collaborative project by the University of KwaZulu-Natal and eThekwini Municipality, designed to address these questions.

MATERIALS AND METHODS

Study site and experimental design

The study site selected is located on the western boundary of the Howard College (Durban) campus of the University of KwaZulu-Natal.

Empirical observations indicated that the waste layer from a full vault would fill a hole of diameter approximately 0.7 to 1 m to a depth of 0.5 m, with an additional 0.25 m required for minimum soil cover (J. Harrison, eThekwini Municipality, pers. comm.; EcoSanRes, 2005). Accordingly, concrete columns were constructed from conventional manhole pipe rings (diameter 0.75 m; height 0.25 m). A concrete base (approximately 1 m x1 m x 0.2 m) was initially laid. Once partially dry, black PVC sheeting was placed on the base, upon which the first ring was laid. Pressure was applied, thereby partially embedding it into the base. Three more rings were placed on top of the first ring and the joins sealed with bitumen. Cement was used to seal any remaining gaps between the rings (Fig. 1). Twenty-four such columns were constructed, twelve to serve as experimental treatments and twelve to serve as controls. Columns were filled with combinations of soil and urine diversion (UD) solid waste, as indicated in Table 1. UD waste was supplied by eThekwini Municipality from toilets nearing filling of the second toilet vault. Berea red soil was used as covering soil, and as substitute for UD waste in controls, because it is typical of the soil of the region and because it is relatively nutrient poor, therefore plant growth would be impacted by nutrients arising from the waste. Umgeni sand was used as the bottom layer because it displays rapid leaching properties and therefore provides a ‘worst case scenario’ for prediction of leaching of contaminants to groundwater.

Dwarf papaya (paw-paw) trees and spinach plants were selected for this study as these plants are commonly grown by local communities. Papaya trees, being deep-rooted, were selected to indicate whether root penetration of the UD waste layer occurs. Spinach plants, being shallow rooting, were selected to indicate whether surface migration of constituents, particularly nutrients, from the UD waste layer occurs.

Of the twenty-four columns, twenty were allocated to paw-paw trees (ten treatment columns, ten control columns; one plant per column). Four columns were allocated to spinach (two treatment columns, two control columns; five plants per column.

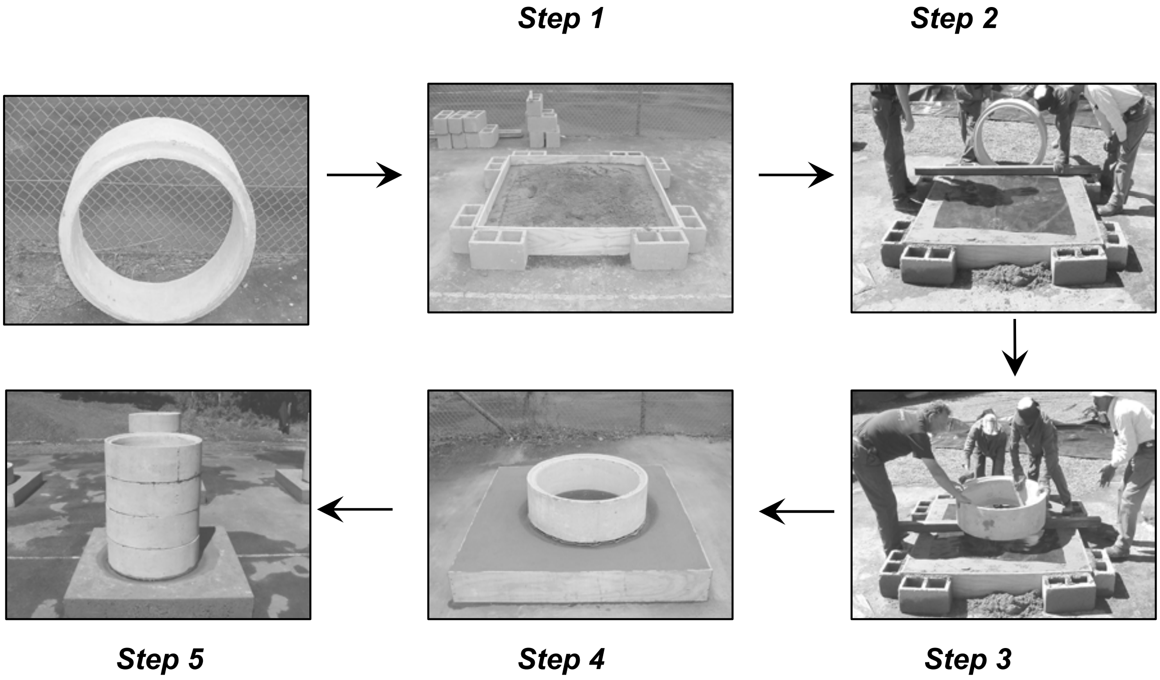

Figure 1: Construction of experimental columns. These were subsequently filled with combinations of soil and urine diversion solid waste as shown in Table 1.

Table 1: Combinations of soil and urine diversion waste loaded into experimental towers, constructed as illustrated in Fig. 1.

Depth	Treatment Columns	Control Columns
Ground level – 0.25 m	Umgeni river sand	Umgeni river sand
0. 25 – 0.75 m	UD solid waste	Berea red soil
0.7 5m -1 m	Berea red soil	Berea red soil

Monitoring and analyses

Plant growth was monitored weekly. Parameters measured included plant height, stem diameter, number of leaves, and length and width of the three largest leaves present at the time. In addition, spinach was harvested as necessary and the fresh weight of the harvested leaves recorded. Only plant height and yield data are presented in this paper.

Immediately before planting (which occurred approximately three weeks after filling of the columns, as a consequence of weather conditions) and at monthly intervals thereafter, leaching from the columns was determined by adding a constant volume of 45 litres of water to each column. Leachate was collected from each column and the volume recorded. Leachate samples were sent to the laboratories of eThekwini Municipality for microbiological analysis. Total coliforms and *E. coli* were determined by membrane filtration and subsequent incubation of the membranes on Chromocult Coliform Agar (Merck). Colonies were distinguished by colour (total coliforms: salmon pink; *E. coli*: violet). Coliphages were enumerated by a standard double layer plaque assay (Standard Methods, 1998). Presence and viability of *A. lumbricoides* ova was determined according to Gaspard and Schwartzbrod (1995). At time of writing, no coliphage or *Ascaris* results were available, therefore this paper presents results for bacterial indicators only. Leachate COD was determined at the University of KwaZulu-Natal, School of Chemical Engineering, using standard methods (Standard Methods, 1998). In addition, upper soil samples were collected from all columns immediately before planting and were sent to eThekwini Municipality laboratories for metal and nutrient analyses (Standard Methods, 1998).

RESULTS

Analysis of topsoil from experimental and control columns three weeks after filling, immediately before planting, showed that there were significant differences in levels of exchange acidity, manganese, copper and total nitrogen (Fig. 2). This demonstrates that UD waste constituents, particularly nutrients, can move upward in the soil column and therefore have the potential to affect even shallow-rooted plants which do not penetrate the waste layer. This is borne out by the stimulation of plant growth and yield, seen in Fig. 3. Furthermore, this suggests that microbial contaminants may move to the soil surface after burial and pose a potential health hazard. Surprisingly, levels of the metals manganese and copper were significantly lower in experimental columns, when compared to controls. This suggests that UD waste may have the potential to bind metals.

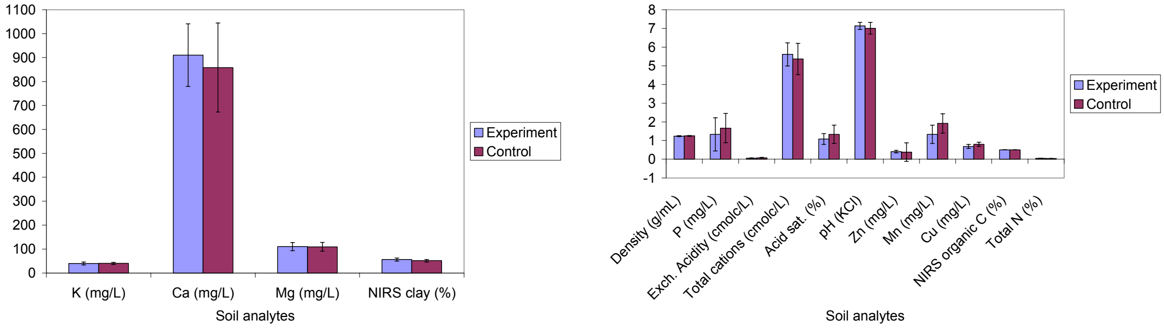

Figure 2: Physico-chemical quality of topsoil in experimental and control columns immediately before planting, approximately 3 weeks after filling columns with soil and UD waste as per Table 1. Figure shows means and standard deviations for 12 columns. Exchange acidity, Mn, Cu and total nitrogen differed significantly between experiment and control columns at $p \leq 0.05$.

Growth of spinach plants was marked boosted when growing above buried UD waste, as shown by greater plant heights and higher yields (Fig. 3). Papaya trees took longer to show as marked a difference, but the same trend was evident after 8 weeks growth and particularly by 10 weeks growth. Other growth parameters monitored, but not reported here, showed the same trend.

Analysis of the volume and quality of leachate from experimental and control columns showed that while UD waste did not significantly alter the water retention characteristics, both COD and microbial indicator organisms were significantly increased in leachate from columns containing UD waste.

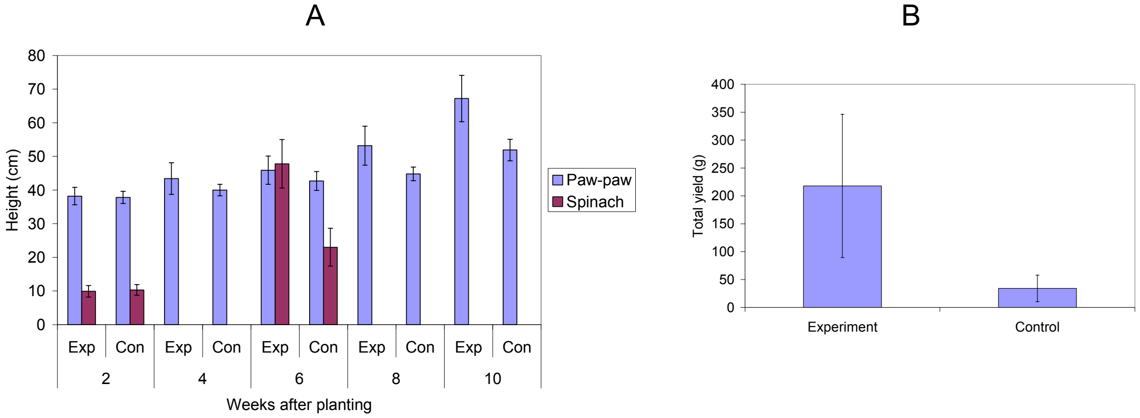

Figure 3: Height of papaya trees and spinach plants (A) and yield of spinach (B) in experiment and control columns. Fig. 4A shows mean and standard deviation for 10 plants. Fig. 4B shows mean and standard deviation for 2 harvestings from 10 plants.
In Fig. 4A, spinach heights differed significantly between experiment and control columns at week 6; papaya tree heights differed significantly between experiment and control columns at weeks 8 and 10. In Fig 4B, spinach yields differed significantly between experiment and control. In all cases, $p \leq 0.05$.

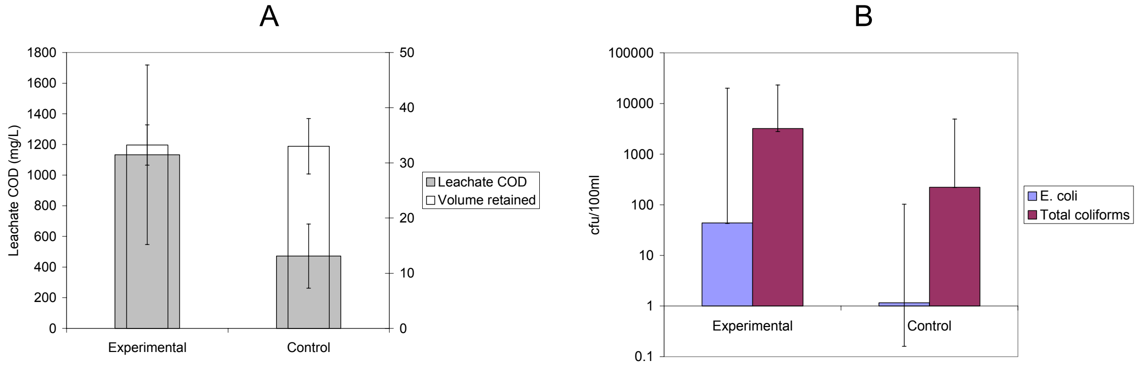

Figure 4: Volume of water retained by columns (A), and levels of COD (A), and of indicator bacteria (*E. coli*; total coliforms) in leachate from experimental and control columns (B). Fig. 2A shows mean and standard deviation for 12 columns in 3 leaching trials; Fig. B shows geometric mean and maximum/minimum for 12 columns in 1 leaching trial.
Volumes retained not significantly different between experimental and control columns. COD, *E. coli* and total coliforms significantly different between experimental and control towers at $p \leq 0.05$.

DISCUSSION

Taken together, the results reported above demonstrate that, far from being an inert mass, buried UD waste has a marked impact on the quality of soil above (and, by inference, below) the waste layer. Furthermore, leaching of UD waste constituents to water collected a short distance below the waste layer clearly occurs, indicating a potential impact on groundwater.

These results suggest that the view of buried UD waste as an essentially inert mass of predominantly anaerobic nature is overly simplistic, and the view of burial as fulfilling a simple disposal purpose needs to be revisited. Recommendations for full ecosan systems specify that solid waste excavated from toilet vaults should receive secondary treatment prior to reuse (primary treatment constituting the processes of desiccation and decomposition which occur in the vault). The main goal of secondary treatment is sanitisation of the waste to render it safe for handling and environmental application (Winblad and Simpson-Hébert, 2004). In the present application, further handling is not at issue, since the buried waste is not intended to be excavated. However, safety of environmental application requires further consideration, in light of evidence of both upward and downward migration of matter (nutrients, COD, bacteria) from the waste layer.

Evidence of movement of matter from the waste layer to the soil surface is of particular concern with respect to *A. lumbricoides* ova. Ascariasis is endemic in the eThekwini municipal region, particularly in poorer communities which are likely to be served by on-site sanitation. One of the primary purposes of any sanitation intervention is to provide a barrier between people and infectious agents present in their waste. If buried waste has the potential to release infective ova to the soil surface, it will increase – rather than decrease – the environmental load of this important pathogen. Ongoing studies in Durban by Austin and co-workers (2005) suggest that *Ascaris* ova are fully inactivated during the standing phase of solid waste in the toilet vault (complete inactivation within 97 days), which is promising in this respect. However, the same study also showed complete inactivation of faecal coliforms (broadly analogous to *E. coli*, as reported here) within 44 days. Since both total coliforms and *E. coli* were detected at significantly elevated levels in leachate from columns containing UD waste in the present study, further investigation is warranted.

Factors influencing the die-off of micro-organisms are temperature, pH, ammonia, dehydration, solar radiation, competition with other micro-organisms, availability of nutrients for bacterial growth, and availability of oxygen (Winblad and Simpson-Hébert, 2004). Of these, only competition with other micro-organisms, availability of nutrients and availability of oxygen are applicable to buried UD waste. Nutrient availability applies only to bacteria, since viruses, protozoa and helminths require animal hosts to multiply. Competition with soil micro-organisms is likely to be of considerable relevance in the soil environment. Availability of oxygen warrants further consideration since it relates directly to the assumption that the UD waste layer is predominantly anaerobic. It is probably valid to assume that the bulk of the waste heap in the toilet vault is anaerobic, even after the standing phase, since no mixing of the heap occurs to allow oxygen to penetrate into the interior of the mass. However, considerable turning and mixing occurs during excavation of the vault, transfer of the material to the burial site, and burial itself. Thus the waste layer, once buried, may not be significantly more anaerobic than the surrounding soil. Die-off of enteric organisms, reliant on an anaerobic environment for survival, is increased under aerobic conditions (Winblad and Simpson-Hébert, 2004). UD waste burial is likely to promote this process. The balance of aerobic *versus* anaerobic process in the waste layer after burial is dependent on environmental conditions such as rainfall or watering (saturation with water will exclude oxygen from the waste mass and from the surrounding soil), temperature, and penetration of the waste by soil invertebrates and plant root growth. Aerobic soil conditions and dehydration during dry spells will further enhance microorganism die-off, and aerobic soil processes will contribute to rapid degradation of the organic component of the waste (Winblad and Simpson-Hébert, 2004). Thus it appears that burial of UD waste, far from being a simple matter of disposal, represents a combination of secondary treatment and environmental application.

This leads to the question of how long after burial the waste can be considered microbiologically and environmentally ‘safe’. Present results do not allow for empiricallybased commentary, but it is possible to compare waste burial to other recognised secondary treatments and to the periods required to render waste safe by those methods. Winblad and Simpson-Hébert (2004) and EcoSanRes (2005) recognise thermal composting, alkaline treatment, storage and incineration as options for secondary treatment. Burial, with subsequent planting above the burial site, incorporates aspects of both storage and soil composting. It has been suggested that storage at temperatures up to 20°C eliminates or substantially reduces most microorganisms within two years, and that at higher temperatures this period reduces to one year (EcoSanRes, 2005). Since temperature in the buried waste was not measured, it is difficult to predict the required ‘storage’ period for buried waste. However, burial of UD waste also incorporates aspects of soil-based composting, since the waste itself has been mixed with soil (soil was used to cover faeces after each defecation) and the buried waste is surrounded by soil. In such systems, it has been suggested that most pathogenic bacteria are destroyed within three to four months (EcoSanRes, 2005). Thus burial of UD waste may be expected to inactivate pathogens in a period of six months to one year. This extrapolation from existing guidelines requires empirical validation, however. Furthermore, the extent of environmental contamination during this period remains to be clarified.

If burial of UD waste is considered, at least in part, as a treatment process, then the implementation of UD with waste burial most closely represents the Arborloo system pioneered in Zimbabwe by Peter Morgan. In this system, the UD ‘vault’ is a shallow pit which is covered with soil and above which a tree is planted once the pit is full. The toilet superstructure is relocated over a new pit. The trees may be used for fruit production or as a woodlot (Winblad and Simpson-Hébert, 2004). A similar application for buried UD waste is likely to carry minimal associated health risks since the crop is either produced well above ground level or, in the case of wood, is not intended for consumption.

The evidence of continued biological activity in the buried UD waste layer, as reported here, has both positive and negative implications. Plant growth is clearly enhanced, even when the waste is simply buried rather than incorporated into the soil, as in a full ecosan approach (Winblad and Simpson-Hébert, 2004). This suggests that urine diversion toilets implemented as a sanitation-only approach (as done by eThekwini Municipality), which does not specifically provide for agricultural reuse, may still boost growth and yield of crops grown immediately above the burial site. The microbiological safety of such crops remains to be established. Current guidelines indicate that such planting should exclude crops eaten raw (EcoSanRes, 2005).

On the other hand, organic matter in the waste layer releases both soluble COD and bacteria into water passing through it, with potentially harmful effects on groundwater quality. The appearance of COD in the leachate from columns containing UD waste may indicate that aerobic degradation is occurring in the waste layer, releasing soluble organic carbon from the predominantly solid organic matter in the waste. Evaluation of the waste layer at the end of the present study will shed further light on this. In the course of this investigation, the presence in leachate of viral indicators (coliphages) and ova of *A. lumbricoides* will also be investigated, allowing the potential hazard to groundwater to be further characterised.

ACKNOWLEDGEMENTS

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