COST-BENEFIT ANALYSIS OF THE USE OF HUMANURE FROM URINE DIVERSION TOILETS TO IMPROVE SUBSISTENCE CROPS IN THE RURAL AREAS OF SOUTH AFRICA

M.J. Wilkinson*, J.G. Crafford*, H. Jönsson** and L. Duncker***

*Sustento Development Services, 53 Woodpecker Avenue, Newlands, Pretoria, South Africa, 0181, Tel 012 348 0458; Fax 012 3480319; Mobile: 0832920371; Email: mel@sustento.co.za; j.crafford@primeafrica.net)
** Swedish University of Agricultural Sciences (SLU), Department of Energy and Technology, Box 7032, SE-750 07 Uppsala, Sweden (Email: Hakan.Jonsson@et.slu.se)
***CSIR-Built Environment, Meiring-Naude Road, Brummeria, Pretoria, South Africa (Email: LDuncker@csir.co.za)

Many South African's still suffer from food insecurity, which can only be addressed through an improvement in food availability; food access and food utilisation. The South African government has initiated a number of interventions to address food insecurity, including (1) food fortification programmes; (2) nutrition education; and (3) food production programmes. Food production initiatives fall chiefly under the ambit of the Department of Agriculture, Forestry and Fisheries (DAFF), which has the agricultural mandate to improve crop production, specifically household food production, for food security. Linked to this mandate, one of DAFF's objectives is to promote and support household income generation and food production with the aim of increasing food production by 2% at household level (DAFF, 2009). To achieve the DAFF target, an increase in crop production will be required from household subsistence farmers in the country. Although synthetic fertilizers have already, and will continue in future, to contribute to maintaining and increasing soil fertility in many areas of South Africa, there is a number of factors which prevent the wide-spread use of these types of fertilizers at a household level by poor subsistence farmers. Improving crop production at a household level will therefore require innovative means, other than using synthetic fertilizer, to increase yields. The application of organic fertilizers needs to be considere,d including the use of humanure.

Urine Diversion (UD) toilets have been successfully installed by a number of South African municipalities. The opportunity exists to reclaim the human excreta collected in UD toilets for conversion into fertilizer and soil conditioner. Urine is an excellent soil fertilizer that is rich in nitrogen (N), while faeces are rich in phosphorus (P) and potassium (K).

The research question addressed in this paper is that, if using the ecological and health benefits, what are the benefits of the use of humanure from Urine Diversion toilets to food security of poor subsistence farming households in South Africa. The study uses a cost-benefit analysis (CBA) to compare selected health, economic and environmental effects of the use of humanure for subsistence cropping in the country. The nitrogen, phosphorus and potassium of humanure is discussed in the context of the quantities of these macro-nutrients required for home production of subsistence crops in the Limpopo province.

INTRODUCTION

In South Africa, despite the country being self-sufficient in food production, an estimated 1,5 million children are believed to suffer from malnutrition and 14 million people are vulnerable to food insecurity (National Treasury, 2003; de Klerk *et al.*, 2004). Household food insecurity is defined as *the inability to acquire or consume an adequate quality or sufficient quantity of food in socially acceptable ways, or the uncertainty that one will be able to do so.* (ADA, 2003). Thus to address food insecurity in South Africa three basic elements are required; namely that all people have safe, nutritious and culturally appropriate food *available* in consistently sufficient quantities to achieve a healthy life, that all people in the country have *access* to food, including through own production, and that all citizens have appropriate *utilisation* of the food supplies to meet their dietary needs (Riely *et al.*, 1999; ADA Position, 2003; Faber and Wenhold, 2007).

The South African government has initiated a number of interventions to address food insecurity (Rose and Charlton, 2002), including (1) food fortification programmes which aim to improve the nutritional quality of the food available to households; (2) nutrition education that focuses on dietary diversification; and (3) food production initiatives (i.e. food gardens) that are designed to improve access to certain types of foods.

Food fortification and nutritional education programmes fall within the ambit of the Department of Health, while food production initiatives are chiefly the responsibility of the Department of Agriculture, Forestry and Fisheries (DAFF). Although the diet of poor rural communities has changed over the past decades with the gradual introduction of processed foods, subsistence crops farming remains an important source of nutrients in the rural diet (Walker, 1996). The DAFF has the agricultural mandate to improve crop production, specifically household food production, to achieve food security (DAFF, 2009). Linked to this mandate, one of DAFF's objectives is to *promote and support household income generation and food production* with the aim of increasing food production by 2% at household level (DAFF, 2009). However, South African cultivated soils, including those under subsistence farming, are generally low in organic matter, are susceptible to wind erosion and acidification and are particularly low in bio-available phosphorus (ARC-ISCW, 2004 in FAO, 2005). Culitvated crops, therefore, rely on nitrogen fertilizing and liming during cropping, usually by the application of synthetic fertilizers (FAO, 2005). To achieve the DAFF target of increasing home food production will require an increase in subsistence cropping and yields in the country.

Although synthetic fertilizers have already, and will continue in future, to contribute to maintaining and increasing soil fertility in many areas of South Africa, there are a number of factors that prevent the wide-spread use of these types of fertilizers at a household level by poor subsistence farmers (Mkhabela, 2006). These factors include:

(a) that synthetic fertilizers produce variable crop yields responses under small-scale conditions; and
(b) the high, and increasing, cost of synthetic fertilizers, i.e. the price of fertilisers, increased by 46,8 % in 2007/2008 (DAFF, 2009).

Improving crop production by 2% at a household level will therefore require innovative means, other than using synthetic fertilizer, to increase yields. The application of organic fertilizers should be considered, including the use of humanure.

The opportunity exists to improve agricultural production by subsistence farmers through the production of fertilizers and soil conditioners from human excreta (humanure). Humanure is human excrement (faeces and urine) that is recycled for agricultural or other purposes. Human urine is an excellent soil fertilizer that is rich in nitrogen (N), while faeces are rich in phosphorus (P) and potassium (K) (Jönsson, *et al.,* 2004). Although nutrient content in faecal material is lower than that of urine, it can act as a valuable soil conditioner (Jönsson, *et al.,* 2004). The use of humanure can results in improved agricultural production of subsistence crops, which would improve food security through increased food availability and improved access to food through own production, as well as the possibility of selling additional produce.

Humanure is relatively simple to produce as the main requirement for production is a Urine Diversion (UD) toilet. A UD toilet differs from other dry sanitation facilities, such as the VIP toilet, in that it has a specially designed pedestal that separates urine and faecal material into separate storage compartments (Figure 1). The faecal matter is captured in a vault below the pedestal (toilet bowl) while the urine may be diverted to a soakaway near the toilet or into a storage container below the pedestal.

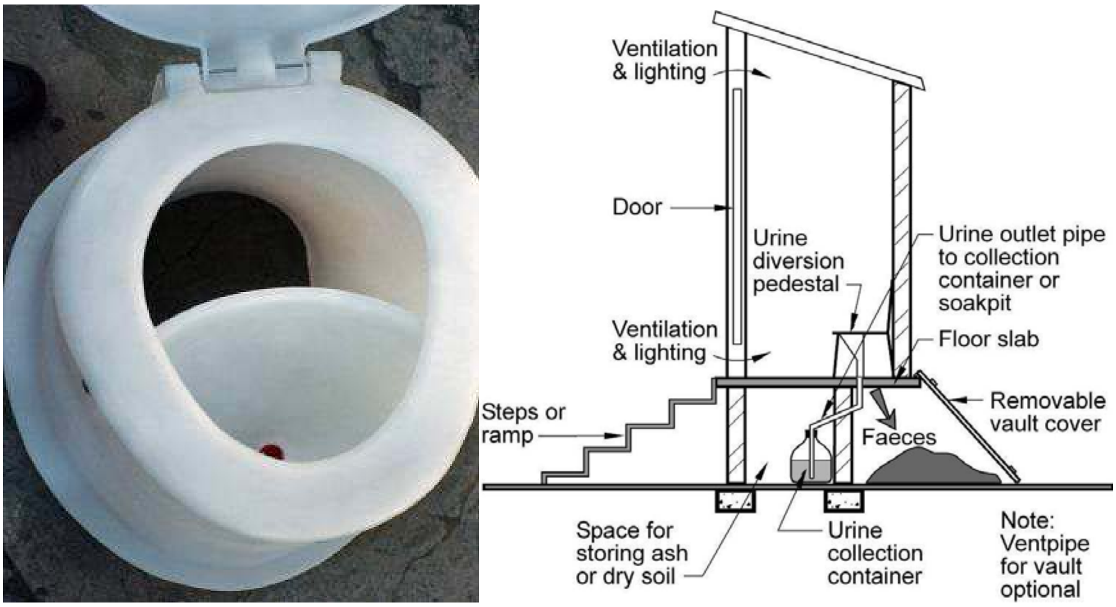

Figure 1: (left) UD pedestal and (right) technical components of a UD toilet (UNEP,undated)

Most UD toilets in South Africa have a double-vault system; once the first vault is full with feacal matter, the pedestal is moved over the second vault. The vault opening of the first vault is covered and the contents are allowed to dry for at least a year, after which the dry contents of the vault can easily be removed, by the householder, using a spade and a rake. Once the contents have been collected in a container (bucket, bin bag, wheelbarrow), it is either buried (discarded) or is applied to agricultural lands as a humanure.

The research question addressed in this paper is that, if *using the ecological and health benefits, what are the benefits of the use of humanure from Urine Diversion toilets to food security of poor subsistence farming household in South Africa.* The study uses a cost-benefit analysis (CBA) to compare selected health, economic and environmental effects of the use of humanure for subsistence cropping in South Africa. Social barriers to the provision and use of the UD systems were not part of this study. The research assumed that the UD system is accepted by the households and that social barriers to the use, operation and maintenance have been addressed.

METHOD

Method of CBA

A detailed description of the method of conducting the CBA can be found in Wilkinson, *et al.* (2009) and Wilkinson, *et al.* (undated). A brief description of the salient points of the CBA are provided below and some clarity on the method to estimate the nitrogen, phosphors and potassium quantities in humanure and the crop requirements and application of humanure is provided.

A cost-benefit analysis (CBA) was conducted by comparing 2 scenarios of different combinations of toilet types and fertilizer with a base-case hypothetical rural village of 100 households in the Limpopo Province of South Africa. The CBA analyses the net benefit (= benefit-cost) of

1. the base case (no fertilizer; VIP toilets) compared to scenario 1 (synthetic fertilizer; VIP toilets) and scenario 2 (humanure; UD toilet)
2. scenario 1 (synthetic fertilizer; VIP toilets) compared to scenario 2 (humanure; UD toilet).

The following data was necessary to conduct the CBA:

- Subsidy costs for provision of toilets.
- Carbon emissions costs from the production of the materials necessary to build the toilets and from the production of synthetic fertilizer.
- Costs of maintenance (emptying) of the toilets.
- The health risk cost of maintaining the toilets.
- Crop yields per hectare of land under cultivation.
- Income from crops.

In line with the national size of an average household in the country, 4 toilet users are used in the hypothetical village, amounting to collection, storage and treatment of excreta of 400 individuals (StatsSA, 2003).

The mean size of each household's field in the hypothetical village is assumed to be 1.7 hectares, a homestead garden 0.2 hectare, and thus the mean size of all cultivated land is 1.9 hectares per household. The households in the hypothetical village of the CBA grow a combination of maize and vegetables in field and homestead gardens, respectively. The crops cultivated by households in the base-case hypothetical village are those typical to subsistence farming in South Africa; namely beans, beetroot, cabbage, maize, onions, potatoes, pumpkin, sweet potatoes, and tomatoes. Each household would cultivate 1.6 hectares of maize and 0.4 hectare of each of the 8 other crops, thus for the base-case hypothetical village a total of 160 hectares of maize and 30 hectares of the other 8 crops, in equally sized areas, are cultivated.

Description of the base-case hypothetical village

The CBA assumes that the 100 households in the base-case hypothetical village will be provided, through the MIG-funded subsidy systems, with a VIP toilet at a capital cost of construction of R2 945 per toilet. A once-off subsidy of R294 596 is necessary to provide the 100 toilets in the base-case village (Table 1).

Table 1: Life cycle carbon dioxide emissions for the construction of 100 VIPs or UD toilets in the base-case hypothetical village.

		Ventilated Improved Pit Toilet			Urine Diversion Toilet		
Emissions category	**Material items**	Material Cost (ZAR)	CO2 Emission of material (tonnes)	Footprint (tons carbon) (ZAR)	Material Cost (ZAR)	CO2 Emission of material (tonnes)	Footprint (tons carbon) (ZAR)
Concrete block and brick manufacturing	Blocks and Bricks	R 144 540.00	0.044	R 4.44	R 84 480.00	0.0257	R 2.60
Engineered wood member and truss manufacturing	Wooden door and frame Roof beams	R 20 360.00	0.000	R 0.02	R 31 570.00	0.0003	R 0.03
Plastic pipe, fittings, and profile shapes	Vent pipe	R 3 300.00	0.000	R 0.05	R 31 560.00	0.0044	R 0.45
Plastic plumbing fixtures and all other Plastic products	Seat and lid Emptying tools	R 9 050.00	0.001	R 0.11	R 34 325.00	0.0041	R 0.41
Ready-mix concrete manufacturing	Cement	R 72 000.00	0.095	R 9.56	R 75 500.00	0.0991	R 10.02
Rolled steel shape manufacturing	Reinforcement and wire Door frame and lock Emptying rake and shovel	R 18 491.18	0.001	R 0.07	R 21 000.00	0.0008	R 0.08
Sheet metal work manufacturing (zinc roof)	Roof galvanized sheet	R 14 000.00	0.001	R 0.14	R 25 400.00	0.0024	R 0.25
Steel wire drawing (fly screen)	Fly screen	R 1 000.00	0.000	R 0.03	R 2 000.00	0.0007	R 0.07
Stone mining and quarrying	Sand and stone	R 11 071.00	0.008	R 0.79	R 26 400.00	0.0185	R 1.87
Turned product and screw, nut, and bolt manufacturing	Screws Vault cover frame	R 784.00	0.000	R 0.01	R 20 620.00	0.0022	R 0.22
TOTAL		**R 294 596.18**		**R 15.21**	**R 352 855.00**		**R 15.99**

The carbon footprint of the construction of the VIP toilets, shown in Table 1, is calculated using the material costs of the toilet, grouped into categories for which life-cycle emission factors could be determined from the Carnegie Green Design Institute (Eiolca, 1997). The carbon footprint of providing 100 VIPs to the base-case village is R15.21.

Pits of the VIP toilet in the base-case village are expected to fill every five years and will have to be emptied manually, with the sludge being moved to a municipal treatment facility. The cost of emptying 100 VIP toilet is R77 000 every 5 years.

It is estimated that workers emptying VIP toilets, who are constantly exposed to pathogens, could experience at least one diarrhoeal event per week, or 30 events during the duration of the pit-emptying project. This is an 8% increase in diarrhoeal events in the whole village, at a cost of R6 062 per year.

In the absence of better data, current agricultural yield for each of the crops cultivated on the 190 hectares in the base-case hypothetical village is based on the yield figures presented in Table 2. These yields were regarded as the maximum possible yields that a subsistence farmer could achieve. It is, however, possible that the agricultural yields of subsistence farmers are lower than these levels.

Table 2: Crop yields, selling price and income from fields without fertilizer in the base-case hypothetical village.

Crop	Yield per hectare unfertilized fields (tonnes ha-[1])	Seling price of crop	Income from the entire village crop (190 ha) (Rand)
Beetroot	14.0	R 1 330.0	R 69 825.00
Cabbage	40.0	R 707.0	R 106 050.00
Dry beans	1.0	R 7 616.0	R 28 560.00
Maize	2.0	R 1 261.4	R 403 648.00
Onions	15.0	R 1 890.0	R 106 312.50
Potatoes	15.0	R 1 169.0	R 65 756.25
Pumkins	12.0	R 679.0	R 30 555.00
Sweet potatoes	14.0	R 1 281.0	R 67 252.50
Tomatoes	60.0	R 2 233.0	R 502 425.00
TOTAL			**R 1 380 384.25**

The selling price of each crop in Table 2 is estimated according to the market prices at the Johannesburg Fresh Produce (JFP) market on 4 June 2008, and reduced by a factor of 0.7 to account for transport costs and the margin retained by the JFP. The CBA was conducted on the entire crop, consumed and sold. Table 2 shows that income for the crops in the base-case hypothetical village is R1 380 384 per year.

Description of Scenario 1

The village in Scenario 1 is also provided with VIP toilets. The estimates of capital costs of construction of the toilet, the emptying cost, the health risk and carbon footprint for this scenario are the same as that for the base-case hypothetical village. This Scenario 1 village differs from the base-case hypothetical village in that synthetic fertilizer is used to maximise crop production. Scenario 1 also assumes that the use of synthetic fertilizer will increase total agricultural production by 28% per year, with an income of R1 766 892 per year (Table 3).

Table 3 Crop yields and income from fields fertilized with synthetic fertilizer and humanure.

Crop	Yield per hectare (tonnes ha^{-1})		Income from the entire village crop (190 ha) (Rand)	
	Syntheic fertilizer	Humanure	Syntheic fertilizer	Humanure
Beetroot	17.9	15.4	R 89 376.00	R 76 807.50
Cabbage	51.2	44	R 135 744.00	R 116 655.00
Dry beans	1.3	1.1	R 36 556.80	R 31 416.00
Maize	2.6	2.2	R 516 669.44	R 444 012.80
Onions	19.2	16.5	R 136 080.00	R 116 943.75
Potatoes	19.2	16.5	R 84 168.00	R 72 331.88
Pumkins	15.4	13.2	R 39 110.40	R 33 610.50
Sweet potatoes	17.9	15.4	R 86 083.20	R 73 977.75
Tomatoes	76.8	66	R 643 104.00	R 552 667.50
TOTAL			**R 1 766 891.84**	**R 1 518 422.68**

Households will have to purchase synthetic fertilizer in this scenario. The cost of the synthetic fertilizer is calculated to be R101 713 for the 190 hectares.

The carbon footprint of manufacturing synthetic fertilizer is calculated in a similar manner as the construction cost, resulting in CO_2 emission for manufacturing of synthetic fertilizer of R6 482.

Description of Scenario 2

The hypothetical village in Scenario 2 differs from the base-case hypothetical village in that UD toilets are provided to the 100 households. This scenario requires a slightly higher capital input for the UD toilets, with a once-off subsidy of R 352 855 for construction of toilets (Table 1).

The health risk, the cost of emptying and the carbon footprint of this scenario also differ from that of the base-case hypothetical village. Health risks of emptying UD toilets are negligible as it is assumed that faecal matter and urine have been sanitised through storage for the required year and 50 days, respectively.

Table 1 shows that, due to higher material costs, the carbon footprint for Scenario 2 is higher, at R15.99 for the 100 UD toilets.

The emptying cost in Scenario 2 is much lower than that for the base-case hypothetical village, as the contents of a UD toilet can easily be removed using only a spade and rake. In this scenario we assume that the households use the UD contents as humanure. The cost of UD toilet-emptying is thus the cost of humanure production. It is estimated that it takes a household approximately 1.5 hours to empty the vault contents and urine is collected in a container, at R3 000 per year for the village, starting from the second year of use of the toilet. All the sanitised urine and faecal matter from the 100 UD toilets is assumed to be used as humanure on the 190 hectares of agricultural area in the village.

The calculation of income from crop production in Scenario 2, shown in Table 3, is based on the same assumptions as the base case hypothetical village; however, a 10% increase in crop output is assumed. Agricultural income for Scenario 2 is R1 518 423.

Net present value calculation

The cost benefit analysis scenarios were compared by calculating the net present values of the net costs and benefits over the analysis period. Net present value is an aggregated value used in cost benefit analyses to measure the resultant financial and economic benefit of a good or a service when all costs and benefits are taken into consideration. NPV calculations first discounts each future cost and benefit value to a present value, using an assumed discount rate, and then aggregates the set of present values into a single number that represents the outcome of a particular scenario. A positive NPV indicates a net benefit and a negative NPV a net loss for a particular scenario (Schuen *et al.*, 2009). Scenarios can also be compared – those with higher NPV values are the more favourable.

NPK value of humanure and crop application requirements

The CBA is used to show the importance of humanure to subsistence cropping in South Africa. To understand the benefits of humanure to the individual crops grown by these farmers, the nitrogen, phosphorus and potassium content of humanure needs to be determined and this then related to crop macronutrient requirements and application rates.

The N, P and K content of humanure is calculated in the following manner: According to Jönsson, *et al.* (2004) the plant nutrients, consumed by the 400 individuals in the base-case hypothetical village of the CBA, would leave the human body together with excreta, once the body is fully grown (Jönsson, *et. al.*, 2004). Therefore, the quantities of nitrogen (N), phosphorus (P) and potassium (K) consumed on a daily basis by the 400 individuals is essentially equal the amount of N, P and K excreted into a 100 VIP or UD toilets in the village. Using data, collected by Nel and Steyn (2002), related to the main foods items consumed on a daily basis by individuals in the rural areas of the Limpopo province (Table 4), the N, P and K values in excreta is calculated. The P and K values for each food item were determined from Geigy scientific tables in milligrams per 100 gram edible portion (CIBA-GEIGY, 1981). However, the Geigy scientific tables do not provide nitrogen content per edible portion of food. These quantities were thus calculated for each food item by converting the protein content, given in the Geigy tables for each food item, into nitrogen content using the following formula from Sosulski and Imafidonx (1990):

$$N = (1/6.25) \times \text{Total food protein}$$

All N, P and K values were later converted to milligrams per person per day.

Table 4: Commonly consumed food groups and portion sizes for the 10+ age group studied in the rural areas of South Africa. Food items have not been included when less than 3% of the population consumed them (adapted from Nel and Steyn, 2002). Only foods consumed in quantities greater than 5g per person per day are shown.

Description of food item	N (mg/p/d)	P (mg/p/d)	K (mg/p/d)
Maize porridge and dishes	4700.9	931.8	2518.4
Tea	56.9	8.9	56.9
Brown bread/rolls	1487.3	234.9	224.7
Cooked wild leaves (marog, amaranth, beetroot, pumpkin)	143.3	16.3	232.0
White bread/rolls	429.9	33.4	34.5
Dried beans (sugar, kidney, haricot)	1080.3	136.0	415.3
Coffee	12.3	1.3	20.5
Cooked fresh tomato and onion stew	71.6	14.4	82.7
Full cream liquid milk	94.0	16.3	25.5
White sugar	0.0	0.0	0.5
Chicken Meat	551.3	33.6	40.3
Cooked cabbage	37.9	4.7	38.4
Beef (steak, fillet, sirloin etc)	571.0	33.2	58.9
Chicken eggs	288.8	28.9	19.7
Raw peeled banana	22.2	3.5	46.6
Low fat processed milk (buttermilk, cured)	70.3	11.9	18.4
Cooked potatoes	32.5	5.4	41.6
Cooked skinned sweet potato	26.1	4.5	50.9
chicken stew, dishes, pies	344.1	14.4	14.6
Cooked white/brown rice	25.0	2.2	3.0
margarine (salted)	2.8	0.7	7.3
Chicken heads and feet	197.1	5.3	2.0
Mutton	175.7	13.0	17.7
Fresh cooked sea fish	172.8	11.6	17.7
Canned sea fish	135.1	17.8	23.0
Chicken giblets	77.6	3.0	6.7
Brick Margarine	1.6	0.3	0.1
Non dairy creamer, condensed milk, orley whip	22.0	3.5	5.3
Jam and marmalade	1.6	0.2	1.9
Smooth style peanut butter	66.2	5.9	10.7
Medium/low fat spread	0.9	0.2	0.1

Using the quantities of N, P and K consumer per person per day, the N, P and K content in the excreta of an individual in the base-case hypothetical village is estimated to be 3.98 kgN/person/year, 0.58 kgP/person/year and 1.47 kgK/person/year (Wilkinson *et al.*, 2008). The weighted average nutrient content of humanure yields approximately a 7:1:3 NPK ratio.

Before deciding the application rate of humanure for each of the subsistence crops, the recommendation for use of conventional N, P and K fertilizer is assessed. The Fertilizer Handbook of the FSSA is used to give the N, P and K requirements of each of the 9 crops (Table 5). Minimum yields in optimal soil conditions are shown in the table based on the assumption that minimums shown are for crops grown by commercial farmers under ideal conditions. Subsistence farmers will not always have these conditions, i.e. the technology, superior seed varieties, fertilizers, etc., and thus it is assumed that the minimum commercial yield would be attainable by these farmers with these less than ideal conditions.

Table 5: N, P and K requirements per subsistence crop (based on FSSA, 2007 and Department of Agriculture and Environmental Affairs, KwaZulu-Natal, undated)

Crop		Guideline for primary nutrient requirement (kg ha^{-1})		
		N	P	K
Maize	2.2	33	9	23
Beans	1.1	35	18	28
Potatoes	16.5	86	110	234
Tomato	66	200	92.5	300
Pumpkin*	13.2	100	70	60
Onion*	16.5	165	90	80
Sweet potato*	16.5	100	60	50
Cabbage*	44	210	70	120
Beetroot*	15.4	120	70	80

* yields taken from Department of Agriculture and Environmental Affairs, KwaZulu-Natal, undated.

The following assumptions are made when discussing the nutrient requirement of crops using humanure:

- Urine and faecal matter will be handled according to hygiene guidelines.
- No dilution of urine will be necessary.
- Urine and faecal matter are applied directly as a humanure.
- Faecal matter is not mixed (composted) with other organic matter.

Using the above crop nutrient requirements (Table 5) and the nutrient values estimated for humanure discussed above, it is possible to determine the quantity of humanure and the number of people from whom urine and faecal matter are required to provide the recommended fertilization levels given in Table 5. This calculation can be made using the requirement and content of nitrogen, phosphorus and potassium, respectively. It is also possible to determine the hectares of crop that can be produced from the 100 households in the hypothetical village. The number of people required to provide the N needed for each crop is calculated by dividing the N requirement for the crop by the kilograms of nitrogen produced by an individual per year.

RESULTS AND DISCUSSION

What the CBA tells us

The net present value (NPV) of income streams is used to compare the base-case hypothetical village and the 2 scenarios in the study. The NPV values over a ten-year period are shown in Table 6 below. The CBA comparison of the base-case hypothetical village and the various scenarios (in R-thousands) shows the following:

- **Base-case (100-household village provided with VIP toilets, and no use of fertilizer):** the net present value (NPV) of this income stream over a ten-year period is R8216.
- **Scenario 1 (100-household village provided with VIP toilets, using synthetic fertilizer)**: The net present value of the resultant income stream over a ten-year period is R7417.
- **Scenario 2 (100-household village provided with UD toilets, but which uses humanure)**: The net present value of the resultant income stream over a ten-year period is R9089.

Table 6: The net present value (NPV) of income stream of the base case and three scenarios in the study over a ten-year period (in R-thousand)

	Year		0	1	2	3	4	5	6	7	8	9	10
	Discount rate		8.0%										
Base case	Agricultural income			1 380	1 380	1 380	1 380	1 380	1 380	1 380	1 380	1 380	1 380
	Municipal subsidy		-295	0	0	0	0	0	0	0	0	0	0
	Emptying			0	0	0	0	-77	0	0	0	0	-77
	Fertiliser cost			0	0	0	0	0	0	0	0	0	0
	CO2 footprint		-0	0	0	0	0	0	0	0	0	0	0
	Health effect			0	0	0	0	-6	0	0	0	0	-6
NPV		*R 8 216*	*-295*	*1 380*	*1 380*	*1 380*	*1 380*	*1 297*	*1 380*	*1 380*	*1 380*	*1 380*	*1 297*
Scenario 1	Agricultural income			1 767	1 767	1 767	1 767	1 767	1 767	1 767	1 767	1 767	1 767
	Municipal subsidy		-295	0	0	0	0	0	0	0	0	0	0
	Emptying			0	0	0	0	-77	0	0	0	0	-77
	Fertiliser cost			-509	-509	-509	-509	-509	-509	-509	-509	-509	-509
	CO2 footprint		-0	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6
	Health effect			0	0	0	0	-6	0	0	0	0	-6
NPV		*R 7 417*	*-295*	*1 252*	*1 252*	*1 252*	*1 252*	*1 169*	*1 252*	*1 252*	*1 252*	*1 252*	*1 169*
Scenario 2	Agric income			1 518	1 518	1 518	1 518	1 518	1 518	1 518	1 518	1 518	1 518
	Municipal subsidy		-353	0	0	0	0	0	0	0	0	0	0
	Emptying			0	-3	-3	-3	-3	-3	-3	-3	-3	-3
	Fertiliser cost			0	0	0	0	0	0	0	0	0	0
	CO2 footprint		-0	0	0	0	0	0	0	0	0	0	0
	Health effect			0	0	0	0	0	0	0	0	0	0
NPV		*R 9 089*	*-353*	*1 518*	*1 515*	*1 515*	*1 515*	*1 515*	*1 515*	*1 515*	*1 515*	*1 515*	*1 515*

The low net present value of R7417, shown in Table 6, for Scenario 1 confirms that, despite a 28% increase in yields and income due to the use of synthetic fertilizers in the Scenario 1 hypothetical village, the combination of the cost of the health risk of emptying VIP toilets, the high synthetic fertilizer purchase price and the carbon footprint of producing the fertilizer results in Scenario 1 having the lowest NPV and thus being the least attractive scenario. The result confirms that the cost of fertilizer purchasing exceeds the benefits of higher production through fertilizer application. Improving crop production by 2% at a household level will therefore require innovative means, other than synthetic fertilizer, to increase yields. The application of organic fertilizers should be considered, including the use of humanure.

Similarly, despite the higher capital cost of a UD toilet, Scenario 2, which includes the use of humanure from the toilet, has a much higher NPV than the base-case hypothetical village. This shows that in a scenario of subsistence farming where increased crop yields are required, the provision of UD and the use of humanure from this toilet to improve crop production is the most attractive scenario. This confirms that the provision of a UD toilet and the use of the humanure for agriculture production is the most economically viable scenario for subsistence farmers in the hypothetical village of the Limpopo province.

The value of humanure as a fertilizer

Based on the calculated N, P and K content of humanure, the numbers of people required per annum to fertilize a specific crop, are shown in Table 7 below. Table 7 shows three different doses, i.e. three different values for the number of people required per hectare.

Table 7: Number of people's urine or faecal matter required to provide recommended N, P and K requirements for a minimum yield of subsistence crops.

Crop	Yield (t ha^{-1})	Guideline for urine application per hectare (people per year)		
		N	P	K
Maize	2.2	9	26	18
Beans	1.1	10	52	22
Potatoes	16.5	24	321	185
Tomato	66	56	270	238
Pumpkin*	13.2	28	204	48
Onion*	16.5	46	262	63
Sweet potato*	16.5	28	175	40
Cabbage*	44	59	204	95
Beetroot*	15.4	34	204	63

Crop	Yield (t ha^{-1})	Guideline for faeces application per hectare (people per year)		
		N	P	K
Maize	2.2	79	37	109
Beans	1.1	84	75	133
Potatoes	16.5	207	458	1112
Tomato	66	481	385	1426
Pumpkin*	13.2	241	292	285
Onion*	16.5	397	375	380
Sweet potato*	16.5	241	250	238
Cabbage*	44	505	292	570
Beetroot*	15.4	289	292	380

* yields taken from Department of Agriculture and Environmental Affairs, KwaZulu-Natal, undated.

It would appear, at first glance, from Table 7 that the K values in faeces would be the determining factor for application, if the whole recommended dose of N, P and K (Table 5) should be applied with humanure only. Urine and faecal matter would have to be collected from large numbers of people to fulfill the recommended K application (Table 7).

Table 8 compares the nutrient application resulting from total fertilization of all humanure to the actual crop requirements as specified by FSSA. The weighted average humanure is nitrogen rich. Total fertilization application was therefore calculated based on the specified recommendation for application of N. It is evident from Table 8 that the humanure is a good source of nitrogen, but additional P and K are required to achieve the recommended application of nutrients. The additional P and K is needed for soil improvement and is thus a requirement in addition to what is necessary for absorbtion by the plant.

The **total requirement** for each crop (kg ha^{-1}) was then converted to the number of hectares fertilizable in a 100 household community, with an average household size of 4. The absolute value of fertilizable hectares for each of these crops per 100 households varies between 8 and 48 ha per 100 households for some of the vegetables and for maize, respectively.

Table 8: Calculation of the number of hectares of various crops that can be fertilized from the human excreta of a 100 household village calculated from the recommended N dose (Table 1).

Crop	Yield (t ha^{-1})	Source of nutrients	Crop nutrient requirements (kg.ha-1)			# People required per hectare per year	Fertilisable (ha for a 100 household village**)	Additional P and K required for the urine+faeces fertilizable ha from 100 household village (kg)	
			N	P	K			P	K
Maize	2.2	Total urine-faeces fertilization Recommended dose	33 33	5 9	12 23	8	48	201	520
Beans	1.1	Total urine-faeces fertilization Recommended dose	35 35	5 18	13 28	9	45	585	684
Potatoes	16.5	Total urine-faeces fertilization Recommended dose	86 86	13 110	32 234	22	19	1 802	3 740
Tomato	66	Total urine-faeces fertilization Recommended dose	200 200	29 93	74 300	50	8	503	1 798
Pumpkin*	13.2	Total urine-faeces fertilization Recommended dose	100 100	15 70	37 60	25	16	881	366
Onion*	16.5	Total urine-faeces fertilization Recommended dose	165 165	24 90	61 80	41	10	635	182
Sweet potato*	16.5	Total urine-faeces fertilization Recommended dose	100 100	15 60	37 50	25	16	722	206
Cabbage*	44	Total urine-faeces fertilization Recommended dose	210 210	31 70	78 120	53	8	297	320
Beetroot*	15.4	Total urine-faeces fertilization Recommended dose	120 120	18 70	44 80	30	13	695	472

* yields taken from Department of Agriculture and Environmental Affairs, KwaZulu-Natal, undated.
** Assuming an average household size of 4.

CONCLUSION

The research clearly shows that humanure can contribute to home food production and food security in South Africa. This is despite the higher input costs required for the provision of UD toilets.

Fertilizer, including humanure, application in agriculture is a complex science/practice and depends on a number of climate, soil and management variables that are unique to every farming unit. In this analysis, these variables are assumed to be constant and the different nutrient requirements of the key crops produced by rural household farmers, namely maize, beans, potatoes, tomatoes, pumpkin, onion, sweet potato, cabbage and beetroot, have been analysed.

The area for each of these crops that can be fertilized per 100 households varies between 8 and 48 ha for some of the vegetables and for maize, respectively. Fertilizing with humanure will contribute significantly to nutrient recycling in subsistence farming. In the case of all subsistence crops, fertilization with humanure can contribute the full crop absorbtion of N and on average also the full absorbtion of P, but there seems to be some deficiency for K. However, on most soils, application of additional amounts of P and K fertilizers are recommended to obtain optimum yield and to improve the soil fertility in the long term.

It should be noted, however, that there is a number of technical barriers to the use of humanure in South Africa (Wilkinson *et al.*, 2009). Many of the technical constraints to using humanure are similar to the problems with application of manure as a fertilizer. It is important to also recognize that significant social and cultural barriers to the use of humanure may exist;

however, this study has a purely technical focus and does not evaluate social and cultural issues. The use and success of humanure as a food security intervention in South Africa may require significant education, to change local government perception of the technology and the household's perceptions of human excreta as a 'waste' product. It may ultimately depend on whether these perceptions can be overcome through the realization of the economic benefits of using humanure to ensure food security in poor households in the country.

REFERENCES

ADA (2003) Addressing World Hunger, Malnutrition and Food Insecurity. Journal of the American Dietetic Association 103:1046-1057.

CIBA-GEIGY, 1981. *Geigy Scientific Tables. Excerpts from the Eighth Edition*. Switzerland: Ciba-Geigy Limited.

DAFF (2009). Agriculture strategic plan for the Department of Agriculture, Forestry and Fisheries. http://www.nda.agric.za/doaDev/topMenu/StratPlan09/DoAStratPlan_2009-10.pdf (accessed 26 January 2010)

de Klerk, M., Drimie, S., Aliber, M., Mini, S., Mokoena, R., Randela, R., Modiselle, S., Vogel, C., de Swardt, C. & Kirsten, J. (2004) Food Security in South Africa: Key Policy Issues for the Medium Term.

Dovie, D.B.K., Witkowski, E.T.F., and Shackleton, C.M. 2003. Direct-use value of smallholder crop production in a semi-arid rural South African village. *Agriculture Systems*, Vol 76:1, pg 337-357

EIO-LCA, 1997. Carnegie Green Design Institute. [Online]. Available: http://www.eiolca.net/

FAO, 2005. Fertilizer use by crop in South Africa. [Online]. Available: http://www.fao.org/docrep/008/y5998e/y5998e00.htm

Fenwick, L. J. and Lyne, M.C. 1999. The relative importance of liquidity and other constraints inhibiting the growth of small-scale farming in KwaZulu-Natal. *Development Southern Africa*, Vol 16:1, pg 141 — 155

FSSA, 2007. *FSSA Fertilizer Handbook. Sixth revised edition 2007*. Pretoria: The Fertilizer Society of South Africa.

Gillmani, B.M. 2005. Smallholder agriculture as local economic development (led) strategy in rural South Africa: exploring prospects in Pondoland, Eastern Cape. University of Stellenbosch, MSc Thesis

Jönsson, H., Stintzing, A.R., Vinnerås B. and Salomon, E., 2004. *Guidelines on the Use of Urine and Faeces in Crop Production*. EcoSanRes Publication Series Report 2004-2. Stockholm: Stockholm Environmental Institute.

Kirsten, J and Moldenhauer, W. 1999. Measurement and Analysis of Rural Household Income in a Dualistic Economy: The Case of South Africa.

Kirsten, J., Townsend, R. and Gibson. C. 1998. Determining the contribution of agricultural production to household nutritional status in KwaZulu-Natal, South Africa. *Development Southern Africa*, 15:4, 573 — 587.

Makhura, M.T., Goode, F.M. and Coetzee, G.K. 1998. A cluster analysis of commercialisation of farmers in developing rural areas of South Africa. *Development Southern Africa*, 15:3, 429 — 448

Mkhabela, T.S. and Materechera, S.A., 2003. Factors influencing the utilization of cattle and chicken manure for soil fertility management by emergent farmers in the moist Midlands of KwaZulu-Natal Province, South Africa. *Nutr Cycl Agroecosyst*, Vol 65, pg 151-163.

Mkhabela, T.S., 2006. A review of the use of manure in small-scale crop production systems in South Africa. *Journal of Plant Nutrition*, Vol 29, pg 1157–1185.

National Treasury (2003) Intergovernmental Fiscal Review 2003. Pretoria: Government Printer

Nel, J.H. and Steyn, N.P., 2002. *Report on South African food consumption studies undertaken amongst different population groups (1993-2000): average intakes of foods most commonly consumed*. Pretoria: Department of Health.

Riely F, Mock N, Cogill B, Bailey L & Kenefick E (1999). Food security indicators and framework for use in the monitoring and evaluation of food aid programs. FANTA, Washington.

Rose D & Charlton KE (2002). Prevalence of household food poverty in South Africa: results from a large, nationally representative survey. Public Health Nutrition 5:383-389.

Schuen, R. and Parkinson, J. (2009). Study for Financial and Economic Analysis of Ecological Sanitation in Sub-Saharan Africa. Water and Sanitation Program-Africa, The World Bank: Nairobi, Kenya

Sosulski , F.W. and Imafidonx, G. I. 1990. Amino acid composition and nitrogen-to-protein conversion factors for animal and plant foods. *J. Agric. Food Chem*. **38**: 1351-1356.

Timmermans, H.G., 2004. Rural livelihoods at Dwesa/Dwebe: poverty, development and natural resource use on the wild coast, South Africa. Rhodes University, MSc Thesis.

Walker, A., 1996. The nutritional challenges in the new South Africa. *Nutritional Research Review.* Vol 9:33-65.

Wenhold, F. and Faber, M. (2007) nutritional status of South Africans: Links to agriculture and water. WRC: Pretoria

Wilkinson, M., and Crafford, J. 2009 (unpublished) Deliverable G. Discussion document for the use of humanure in subsistence crop production in South Africa. Pretoria: CSIR

Wilkinson, M., Crafford, J. and Moilwa, N. 2008 (unpublished). Deliverable A: Determination of the nutrient content of excreta for South Africans. Pretoria: CSIR

Wilkinson, M., Crafford, J., H. Jönsson** and L. Duncker (undated) Cost-benefit analysis using the ecological and health effects of providing dry sanitation technology to a household in South Africa. Journal Article in Progress.

UNEP (undated). http://www.training.gpa.unep.org/content.html?id=94&ln=6