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An assessment of the effect of human faeces and urine on maize production and water productivity

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Abstract

The key challenge facing many catchment authorities in Zimbabwe and elsewhere is the challenge of feeding the growing populations within their catchment boundaries. Modern agricultural practices continue to mine valuable crop nutrients through increased food production to satisfy ever-increasing food demand. In recent diagnostic survey of smallholder agricultural sector in the Manyame catchments of Zimbabwe it was revealed that exhausted soils depleted of their natural mineral and organic constituents by many years of cropping with little fertilization or manuring were the major factors contributing to low yields and poor food security in this sector in Zimbabwe. The objective of the study was to assess the effect of using sanitized human excreta on maize production and water productivity. The study involved six volunteer farmers with four 10 m × 10 m trial plots each with the following treatments the control, commercial fertilizer treatment urine only plot, and the feacal matter and urine plot. Harvest determination was carried by weighing the yield from each of the treatment plots and comparisons done. Water productivity was computed by calculating the amount of water used to produce a tone of maize per ha. The study showed that human excreta improves maize crop production and water productivity in rain-fed agriculture. The study recommends that the ecological sanitation concept and the reuse of human excreta both humanure and (ecofert) urine can be considered as alternative excreta management options in catchment areas.
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1. Introduction

The challenge of feeding tomorrow's world population is largely dependent on improved water productivity and making optimal use of the available land. This could be achieved by improving soil fertility management by using readily available nutrients from ecological sanitation toilets. Rain-fed agriculture plays an important role in this respect because 80% of agricultural land world-wide is under rain-fed agriculture (Rockstrom et al., 2003). It is anticipated that water productivity enhancement in rain-fed agriculture could be achieved by integrating nutrient recycling through human excreta use.

Global crop nutrient sources, especially potassium (K) and phosphorus (P), continue to be depleted as the demand for food to satisfy growing world population increase. It is estimated that the current world phosphorous reserves will only last for 100–150 years (Otterpohl et al., 1996). The known reserves of currently exploitable phosphate rock are estimated at about 40 billion tons. At the peak rate of consumption (150 million tons per year) these reserves will last more than 250 years. In addition there are vast phosphate resources present in the earth crust which, with today's technology, are not yet commercially exploitable. Although nitrogen is the earth's most abundant element (the atmosphere is 78% nitrogen gas) and an essential

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component of all life, plants can only use nitrogen fixed with hydrogen and oxygen in the form of inorganic compounds. The current over-exploitation of nitrogen from the atmosphere in the production of artificial fertilizers is going to upset the nitrogen balance (Gijzen and Mulder, 2001). The global fertilizer consumption has generally risen over the past years (Fig. 1) and if this trend is not reversed soon, will lead to an unsustainable food production situation. It is therefore important that humankind aim at efficiently utilizing the available resources so that they would also be available to future generations. Some schools of thought suggest the use of short, closed cycles in water and waste management. They argue that the logical path/way of disposing human waste is in agriculture as this makes use of valuable nutrients, whilst at the same time avoiding environmental pollution associated with excreta disposal into water bodies.

The cost of commercial fertilizers cannot be afforded by most poor societies and this is also the sector that does not have access to cattle manure, thereby forcing these people to do without these fertilizers. To ensure sustainable food security is achieved through increased food production, it is essential that cheap and readily available nutrient sources are considered. It is for this reason that ecological sanitation, *ecosan*, is now being promoted, offering an alternative to artificial fertilizers, with the added benefit of soil conditioning. In fact, each person is capable of producing enough fertilizer for his food needs (Table 1).

This paper is based on a study on the potential for utilizing human waste (faeces and urine) for the production of maize conducted from November 2003 to May 2004 in the Marondera district of Zimbabwe. The study was based on pilot scale plots aiming at assessing the potential production based on the yield (production per unit area) and effect on water productivity (harvested weight per unit volume of water).

Table 1
Potential for nutrient production from human waste in Zimbabwe

Annual maize needs in Zimbabwe	1,800,000 tonnes
Maize needs per capita/yr for 11,600,000 people in Zimbabwe	155 kg/cap yr
Assuming 1 ha produces 7 t of maize. 1 ha produces maize for	45 people
Therefore, fertilizer requirements at 175 kg/ha per person for N	3.9 kg N/cap yr
Therefore, fertilizer requirements at 30 kg/ha per person for P	0.7 kg N/cap yr
Compare with sewage	
N production at 10 g N/cap d	3.7 kg N/cap yr
P production at 2 g P/cap d	0.7 kg P/cap yr

2. Methodology

2.1. Study area

The study was conducted in the Marondera District Ward 14, in the Chihota Communal Lands (Fig. 2). The district has a population of 155,000 according to the 2002 national census figures (CSO, 2002). The soils are predominantly well-drained sand soils which are generally not suitable for intensive crop production. The water table is shallow at about 3 m. As a result, Mvuramanzi Trust, a local non-governmental organization, has been promoting the use of ecosan toilets of the Urine Diversion type which are constructed above-ground to avoid encountering the water table. The study area falls under natural region 2 and 3 characterized by average to moderate rainfall ranging between 430 mm and 630 mm. The rainfall comes around the middle of October to the end of March, but is highly variable. The cropping season faces high rainfall variability with mid-season dry spells extending to as long as three weeks. In some bad seasons the mid-season dry spell causes complete crop failure.

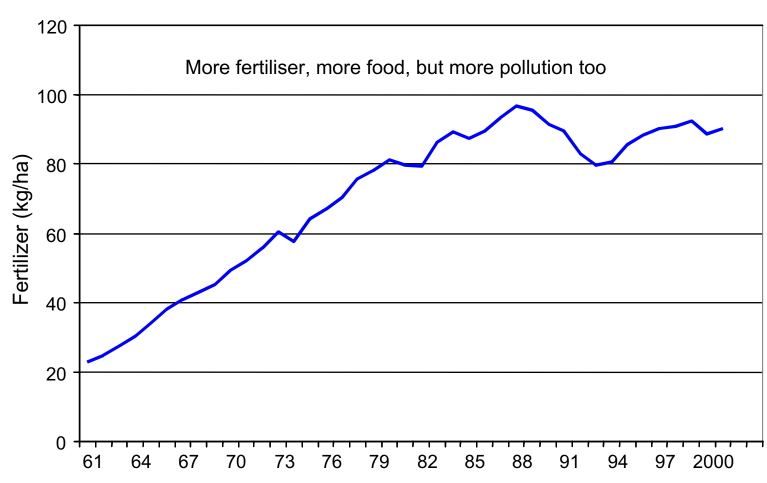

Fig. 1. Global fertilizer use from 1961 (source FAO).

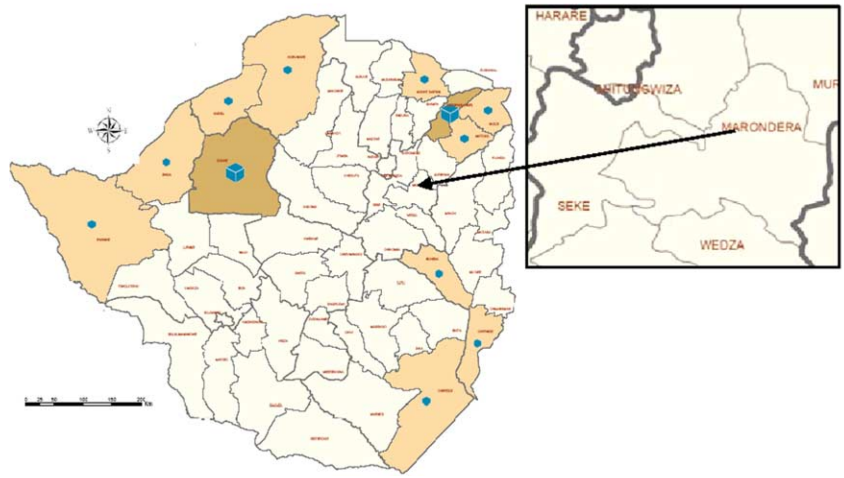

Fig. 2. Location map of Marondera district in Zimbabwe.

2.2. Experimental setup

The study was designed as a two factor experimental design consisting of 10 m by 10 m randomized blocks with three (3) repetitions to ensure statistical validity. The major factor investigated was nutrients. The nutrient factor was assessed on (4) four levels of treatments consisting of the following:

(i) Plot 1: Control plot where maize was planted and allowed to grow without any crop nutrients applied.
(ii) Plot 2: Normal artificial fertilizer treatments of compound D (NPK 7:18:7) as basal fertilizer treatment and ammonium nitrate (34.5%) as top dressing were both applied at the rate of 6 g per crop, as per manufacturer's recommendations.
(iii) Plot 3: Urine (ecofert) was applied at the rate of 100 ml per crop as the basal treatment and 100 ml as the top dressing treatment after 4 weeks and when the crop was at knee level, in line with normal fertilizer application practices in the area.
(iv) Plot 4: Faecal matter (humanure) was applied as basal fertilizer at the rate of 80 g per planting station, whilst urine was applied at 100 ml per plant.

The plots were randomly arranged in the sense that no particular treatment had a fixed position in all the fields. Numbers 1–4 were assigned to these treatments as described above for easy computation and presentation. Plant growth in terms of leaf area stem thickness were monitored at 8 weeks and recorded for each plot. Measurement of the harvest was done by weighing the maize stalk, the maize cobs and the maize seed or cereal (Fig. 3).

2.3. Determination of water use efficiency

Water use efficiency was determined by adding the total amount of rainfall recorded throughout the cropping season and calculating the average rainfall using the following formula:

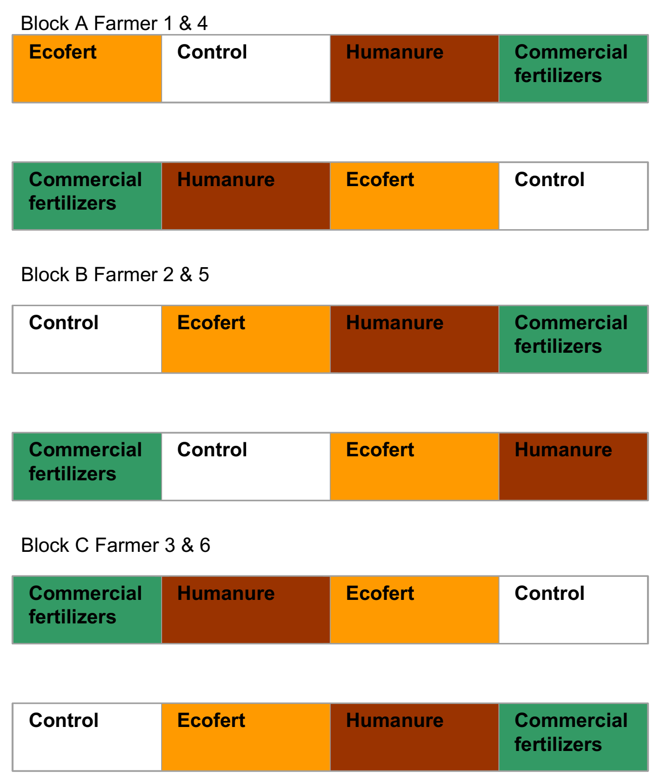

Fig. 3. Layout of the experimental fields used for growing maize with four treatments in each case.

$$\text{Average rainfall} = \text{Total precipitation (mm)} / \text{No. of rainfall events} \tag{1}$$

Daily rainfall records were made using a "farmer's raingauge", graduated conical flask type. The actual amount of water available to the plant was determined from the following water balance equation:

$$P = E + T + D + R + \delta S \tag{2}$$

where

P = rainfall, mm, determined from rain gauge measurements,
E = evaporation, mm,
T = transpiration, mm,
D = drainage, mm,
R = runoff, mm,
δS = change in storage, mm.

It was assumed that there would be no runoff considering the daily rainfalls recorded, and the soil characteristics that affect infiltration and porosity were considered to be the same in all the experimental plots.

2.4. Determination of water productivity

Eq. (2) was used in Microsoft Excel computations to generate water balance and respective water use efficiencies of different treatments. In the calculation of water productivity, the following collected data were entered into excel spread sheet treatments: total and average rainfall, supplementary irrigation (where applicable), average weight of stalk, average weight of cobs and total weight of grain. All the data was expressed in kg per hectare. Eq. (3) was used to calculate the water productivity.

$$W_{\text{pet}} = (W_{\text{P}})T/(1 - e(by)^5) \quad (3)$$

where

W_{pet} = green water productivity (m^3/ton),
$(W_{\text{P}})T$ = productive green water productivity (m^3/ton),
$(1 - e)(by)^5 = b$ is a constant and
y = grain yield (t/ha)

(after Rockstrom and Falkenmark, 2000).

The water use efficiency (WUE) or W_{pet} parameter is defined in this study as the volume of transpiration (m^3) needed to produce 1 tonne of dry matter grain yield (m^3/ton).

3. Results and analyses

3.1. Growth monitoring

Plant growth was assessed in terms of plant height, leaf height, and leaf length (Fig. 4).

A summary of the growth monitoring measurements revealed that humanure + ecofert treated plots had the tallest crop with the longest leaf length followed by the ecofert only treatment which has the widest leaf length and the same stem thickness. Growth monitoring graphs (Fig. 4) show that the maize crop treated with humanure had better plants in terms of height, stem thickness, leaf length and width.

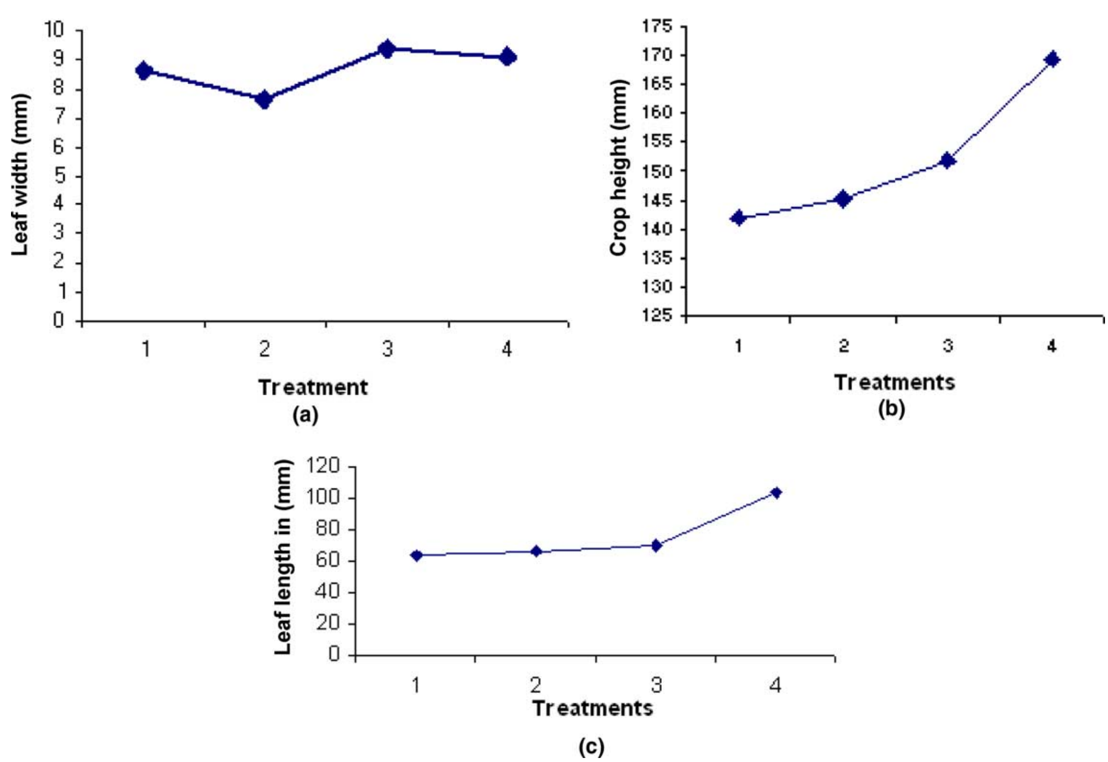

Fig. 4. Crop growth analysis based on (a) height, (b) leaf width, and (c) leaf length.

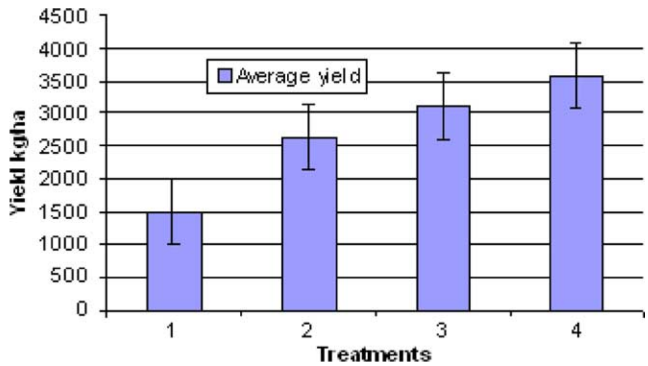

Fig. 5. Average grain yields/ha harvested from the four treatments.

3.2. Maize yield

Maize from different 10 m × 10 m plots were harvested, shelled, dried and weighed, with the data expressed as yield per hectare (kg/ha) (Fig. 5). These results also showed that the ecofert + humanure treatment was the best followed by ecofert only.

3.3. Statistical analysis

The statistical analysis of variance of the treatment effect was analyzed using the Student–Newman Kenls (SNK) method and it showed that yield from humanure + urine (ecofert) treatment (Plot 4) was significantly larger than the control treatment (Plot 1) at $p = 0.05$. There was no significant statistical difference between humanure + ecofert treatment and commercial fertilizer or ecofert treatment alone. The study showed that a much higher yield is obtained if a farmer uses both humanure and ecofert. For example, in the above figure the harvest from humanure plots is above 3.5 tons/ha and the yield for ecofert treated crop is slightly above 3 tons/ha. Yield from commercial fertilizer plots is around 2.5 tons/ha and that of the control is shown to be 1.5 ton/ha. In real practice, however, the yield from a field where no nutrient was applied could be as bad as zero.

3.4. Water productivity

Fig. 6 shows that treatment 4 (humanure + ecofert) used less water per unit weight of maize produced. This shows that ecosan has a potential to enhance water productivity.

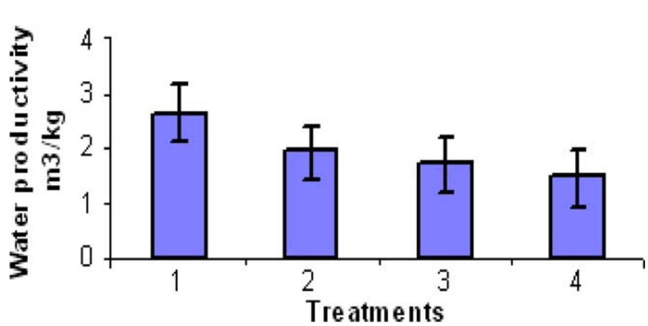

Fig. 6. Water productivity from different treatment sites.

Water use efficiency ranged from 2000 m^3/ton to 2300 m^3/ton for a non-fertilized crop in the control plot (1). The WUE_{et} for crops fertilized with chemical fertilizers compound D and ammonium nitrate (2) and ecofert (3) alone ranged between 1650 m^3/ton and 1700 m^3/ton. The highest water productivity or efficiencies was found on Plot (4), the crops fertilized by a combination of humanure and ecofert, with WUE_{et} of about 1300 m^3/ton from different treatments. The study suggests that humanure plus ecofert has the highest water use efficiency followed by ecofert only, followed by commercial fertilizer. Cultivating without any nutrient is an inefficient use of scarce water resources.

3.5. Field water balance

Eq. (2) was used to compute the water balance. Computation of data was used in order to generate evapo-transpiration (ET) and drainage (*D*). Table 2 shows the estimated water balance of the experimental plots. Using the data from the water balance, the percentage of water used by the crop as evapo-transpiration (ET) and the one being lost as drainage (*D*) was calculated. Table 2 shows the water balance at the experimental plots, the assumption here is being that the *R* is zero.

The total water supplied to each experimental plot was calculated and an average worked out. Fig. 7 is an attempt to show the water balance in the control experimental plot.

The total water supplied to the humanure plot was calculated and an average worked out. Using the data from the water balance Table 2, percentage of water used by

Table 2
Water balance at the experimental plots

Treatment	*P* (mm)	SI (mm)	ET (mm)	*R* (mm)	*D* (mm)
C (1)	631	3	411	0	222
CF (2)	631	3	439	0	194
E (3)	631	3	447	0	186
H (4)	631	3	481	0	152

Note: *P* is precipitation, SI is supplementary irrigation, ET is productive evapo-transpiration, *R* is runoff, and *D* is drainage.

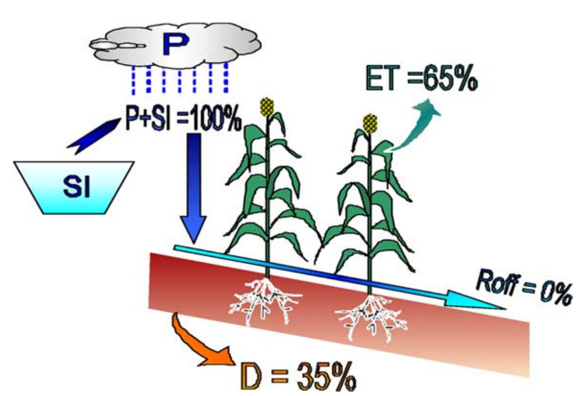

Fig. 7. Water balance in a control plot.

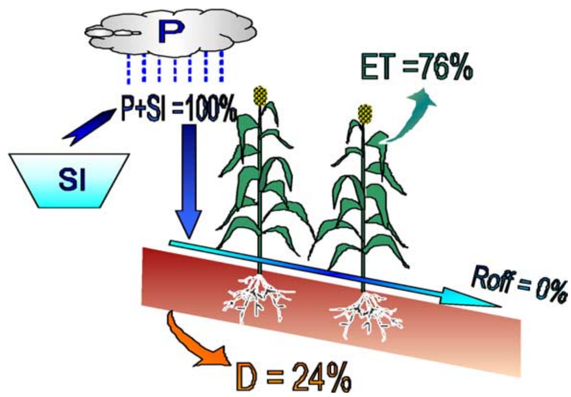

Fig. 8. Water balance humanure + ecofert plots.

the crop as evapo-transpiration (ET) and the one being lost as drainage (D) was calculated. Fig. 8 shows the water balance in the humanure + ecofert plot.

The above diagrams show the different water partitioning of supplementary irrigation (SI) + rainfall (P) at the experimental field level. Fig. 7 shows water partitioning on a field where the farmer is not applying any form of nutrient amendment. On such a plot the study suggests that 65% of the total water supplied is used for productive evapo-transpiration (ET) while 35% is lost as underground drainage (D) and also to contribute to underground water recharge.

On the other hand, Fig. 8 shows a scenario where a farm chooses to embark on a humanure + ecofert maize production strategy. The study reveals that 76% of the total amount of water supplied to a field is taken up by plants as total evapo-transpiration (ET), 11% above the water uptake in field where no nutrients have been used. Consequently a relatively low flow 24% is lost as drainage D. Whilst there is much gain to the farmer in terms of productive (ET) and corresponding grain yield, there is also loss to the underground water recharge from an integrated water resources management (IWRM) perspective.

Measurement of harvest from different treatment showed that a combination of humanure and ecofert assures a farmer of a good return from his capital investment because of good yields. Taking the control as the baseline, yield increases of about 250% are achieved by using such a combination and increases of above 200% is achieved by adopting an ecofert only strategy. This is still higher than the commercial fertilizer strategy which gives 166% increases in yields. Statistical analysis of the data using the SNK variance of effect analysis tool showed that there was a major statistical difference in harvest between humanure + ecofert plots compared with the control but there was an insignificant statistical difference between commercial fertilizer, ecofert, and humanure + ecofert treatments, confirming the hypothesis that human excreta works as good if not better that commercial fertilizers. The analyses also indicated that using humanure + ecofert considerably improves the water productivity in maize production under rain-fed agriculture.

4. Conclusions

Taking into cognisance research limitations such as planting dates, different farming practices, uniformity in fertilizer application rates, and sample sizes, it could reasonably be concluded that humanure + ecofert treatment improve the water productivity by above 10% in rain-fed maize production, ensuring more crop yield per drop of water. Water productivity for a crop where humanure + ecofert is used ranges around 1300 m^3/ton compared to a situation where nothing was used which is about 2300 m^3/ton.

5. Recommendations

Governments should revisit legislation and polices that concerns human excreta management and disposal with a view of defining human excreta as a resource and not a waste. Ecological sanitation toilets should be added on to the list of approved sanitation systems and technologies in the country so that it becomes an alternative system for people interested in reusing human excreta as fertilizer and also in areas where it is impossible to dig pit to construct Blair latrine.

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