The Quality of Compost
from dry toilets

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The quality of compost from biolitter (BLT) dry toilets – compared to source-separating dry toilets

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Astonishing assertions

To justify their stand, proponents of source-separating dry toilets sometimes cite a Japanese study [1], which asserts that when composting combined urine/faeces in « conventional style » dry toilets (as in Joseph Országh's BioLitter Toilet (BLT) [2] or in Joseph Jenkins' Humanure Toilet [3]), all of the nitrogen originally present in human dejecta is supposedly lost. Conversely, when faeces and urine are separated at the source, only 65% of the nitrogen would be lost. In other words, this study suggests that the amount of nitrogen recovered (for agriculture) from a source-separating dry toilet is greater than that of a BLT (or Humanure toilet), and even that BLT-derived compost is a poor fertilizer.

Despite the fact that many thousands of households use a BLT/Humanure toilet at home, and subsequently use the composted dejecta/humanure (these often being called « human waste ») in their garden, the Japanese study's observations do not truly resolve, quantitatively speaking, the question of compost quality derived from a particular type of dry toilet. The experimental approach used by source-separating dry toilet followers is usually based on the retention or loss of nutrients (nitrogen, phosphorus) found in human dejecta during composting. That is one way of addressing the problem, but we will show that for a proper comparison, test results must accurately reflect the processes and transformations that occur in both types of toilets. Moreover, other criteria must be considered, besides the question of nutrients.

Because of the different processes involved in these respective dry toilets, we find that nothing in this study allows an objective comparison between a source-separating dry toilet and a BLT/Humanure toilet, nor an adequate value judgment.

[1] HOTTA, S. & FUNAMIZU, N. (2006). Nitrogen recovery from feces and urine in urine diverting composting toilet system Presented at the 2nd International Dry Toilet Conference, August 16-19, 2006, Tampere, Finland. Department of Environmental Engineering, Graduate School of Engineering, Hokkaido University, Kita-13, Nishi-8, Kita-ku, Sapporo, Japan, 10 pages. Link: https://www.researchgate.net/publication/260404553_Nitrogen_recovery_from_feces_and_urine_in_urine_diverting_composting_toilet_system.
Pointed out by «Pierre l'écoleau» (Pierre Guillaume), author of website éc'eau-logis (link : http://www.ec-eau-logis.info/).

[2] Link : http://www.youtube.com/watch?v=zUTaiFItH58 .

[3] JENKINS, J (2005). The Humanure Handbook : A Guide to Composting Human Manure. Link : http://humanurehandbook.com/contents.html.

A dubious methodology

We must emphasize that the Japanese study does not provide any evidence to prove the environmental benefits of source-separating dry toilets, nor to question the positive impacts of BLT/Humanure toilets, given the study's methodology.

Despite the weakness of the translation (presumably from Japanese), the document's structure does not appear to present the rigorous scientific qualities necessary to provide conclusive evidence. In addition, the experimental methodology is incompletely documented.
The study is limited to assessing the amount of nitrogen that can be recovered from composted faeces and stored urine derived from source-separating dry toilets, disregarding the processes that lead to the finality, namely agricultural use. In this sense, the study presents an incomplete analysis that seems to advocate in favour of source-separating dry toilets.

That being said, let's now consider the study's experimental methodology.

First: « composting » faeces

Faeces were accumulated for 6 months in a container called a « bioreactor ». Sawdust was mixed in at the end of the sixth month. (The sawdust had been frozen up to that point to ensure uniformity in the quality of the litter from one test to another!) Distilled water was added to the mixture to set the initial moisture content at 60%. The fact that this mixture was left to cure for an undefined period (presumably 6 to 12 months) in an enclosed container is qualified as « composting »! Ammonia volatilization was measured throughout that period, and after a year, the study reports that 65% of the nitrogen had been lost in the « composted » faeces.

Frozen sawdust? Distilled water? Enclosed container? How does this relate to true composting that occurs in direct contact with the earth, in the presence of essential soil life? Not to mention that when using a BLT/Humanure toilet, carbonaceous litter is added immediately after toilet use to initiate the composting process, not 6 months later. (Again, one can perceive the will to space out the emptying of the dry toilet receptacle, consistent with source-separating dry toilet use.) The crux of the problem lies precisely in knowing what happens between the production of dejecta/humanure and the addition of carbonaceous litter. Unfortunately, this has not been thoroughly analysed in the study.

The methodology used for faeces reveals certain similarities to the processes inherent in the use of source-separating dry toilets. On the other hand, in a BLT/Humanure toilet, the processes are quite different. Immediately after excreta are produced, they are put in contact with carbon-based cellulosic litter. Composting of human manure (or « humanure ») is initiated soon thereafter. This is done outdoors – in aerobic conditions – and in direct contact with the soil.

The purpose of the exercise should have been to compare the environmental impacts of the two types of processes. But to do that, it would have been necessary to transpose experimentally the respective processes involved in both types of dry toilets. This has obviously not been done.

In fact, if no cellulosic materials are added immediately after production of faeces, complex deconstruction processes start up, along with mineralization processes that are responsible for the nitrogen losses linked to the evaporation of ammonia. This process occurs especially in enclosed tanks, even when some aeration is provided. During this stage in the « bioreactor », proteinaceous molecular structures – essential to the formation of humus – are destroyed. This phenomenon is irreversible. The addition of cellulosic litter, previously frozen or not, actually comes too late because the protein structures that could react with the litter's cellulosic polymers have by that time been destroyed. Although some compensation occurs after ammonia nitrogen reacts with the cellulose's carbohydrate content, this unfortunately does not replace what should have occurred: the graft of -NH_2 amine functions found in faeces' amino acids, on the litter's cellulosic chains, to bind the two types of macromolecules: proteins and celluloses; thus a missed opportunity of spatially cross-linking these polymers [4] to form humic acid, the first step towards the formation of stabilized humus in the soil. This process cannot take place in the bioreactor (in the absence of cellulose), nor during composting (in the absence of decomposed proteins in the bioreactor).

Therefore, it is not possible to effectively compare maturation of faeces in a tank followed by composting in a tank, to composting of freshly mixed faeces/cellulosic litter directly on the soil.

Second: urine storage

In the Japanese experiment, urine was stored for 35 days, all the while measuring its degree of conversion to ammonia. The study reports that as urine was stored in an airtight container (i.e. in strict anaerobic conditions), the ammonia transformation process halted after 28 days. At this point the remaining quantity of aqueous nitrogen was measured: no cellulosic litter at stake, no composting, nor any explanation of how the urine could be effectively reused for agricultural purposes without harming the environment. The study strictly addresses the theoretical amount of nitrogen available, regardless of its form or the feasibility of its reuse. Thus, the report states that 100% of urine's initial nitrogen content remains available, regardless of the fact that a third of this is already mineralized into ammonia due to airtight anaerobic storage conditions. As a result, organic nitrogen has undergone extensive mineralization.

An important fact about urine is that it contains three-quarters of the nitrogen produced in human dejecta. During storage, an ever-present enzyme called urease hydrolyses carbamide (also called « urea », represented by the simplest molecule [$(NH_2)_2CO$]), to form two ammonia molecules (HN_3) and one carbon dioxide molecule (CO_2) [5]. The interruption of enzymatic hydrolysis is predictable in

[4] Cellulose is a natural polymer with flexible linear molecular chains (http://en.wikipedia.org/wiki/Cellulose). The structure of these chains is similar to that of a mixed set of strings with few knots. These «strings» are more or less parallel, forming clusters. The fibrous structure of wood, woody plants, and even paper is a result of these. The large protein molecules contained in faeces, with amino acid functions ($H_2N–CHR–COOH$) (http://en.wikipedia.org/wiki/Amino_acid) that also polymerise due to peptide bonds (-CO-NH-), are smaller than cellulosic polymers. But the amines (-NH_2) from amino acids are the ones that graft on carbohydrate polymers. In fact, nitrogenous molecules (amino acids) penetrate and weave themselves into cellulose's fibrous structure to cling to and interconnect the fibres. In so doing, the cellulosic fibres become laterally affixed to protein molecules. The linear fibrous structure transforms into a spatial array resembling a network that is distorted in all directions. The two-dimensional linear structure becomes a three-dimensional spatial structure, which already constitutes humic acid. Through the action of enzymes secreted by aerobic bacteria, a cellulose-amino acid bond is obtained. From a chemical standpoint, the new bond is formed between protein's amine (-NH_2) functions and cellulose's (-OH) functions thanks to some sort of condensation reaction, with the elimination of a water molecule, to form the bonded graft between the two. One can describe the process as follows: [cellulose]-OH + H_2N-[amino acid] → [cellulose]-O-NH-[amino acid]. The aggregate thus formed is already humic acid. Note that ammonia (NH_3), inevitably formed during the decomposition of proteins, grafts well on cellulose molecules, but does not give rise to the spatial structure that characterizes humic acids. Therefore, composting plant-derived biogas digestate or composting faeces derived from source-separating dry toilets will not form humic acids that are necessary for the formation of stabilized humus in soil.

[5] During storage of urine or faeces, carbamides (or ureas : http://en.wikipedia.org/wiki/Category:Ureas) are hydrolysed by an enzyme called urease (http://en.wikipedia.org/wiki/Urease). Besides ammonia (NH_3) and carbon dioxide (CO_2), secondary amines (R_1-NH-R_2) are formed, which may eventually bind to the cellulose, without the capacity to bind two cellulose molecules. This reaction – quite marginal for urine –misleads tenants of source-separating dry toilets and proponents of biogas production into asserting that the composting of plant waste mixed with stored faeces or the

a closed container, as the end-products, NH_3 and CO_2, remain in solution instead of leaving the container in gaseous form. Thus, hydrolysis stops. At the end of the storage phase, almost all of the nitrogen is found dissolved as ammonium ions (NH_4^+). When opening the container at this point, since a portion of the nitrogen is oxidized, a more or less concentrated solution of ammonium nitrate (NH_4NO_3) is formed. This is a fertilizer that is commonly used in « modern » agriculture. One can then measure the nitrogen: indeed there is little loss, if any. The problem lies in the fact that this nitrogen is a chemical fertilizer. It increases crop yields at the expense of soil humus reserves.

Thus during storage of faeces and urine, deconstruction of the organic material occurs, along with a large increase in entropy (the degree of disorder). On the other hand, when composting of a mixture of faeces, urine and cellulose (derived from the usage of a BLT/Humanure toilet), the graft of amine functions on cellulose dramatically decreases the system's entropy. Instead of a series of decomposition [6] reactions, a synthesis [7] of humic macromolecules occurs. This absolutely crucial thermodynamic aspect is not taken into account in chemical agriculture [11], leading to errors of assessment.

Ammonium nitrate is a strong electrolyte that increases the ionic strength of soil's retained (interstitial) water. This accelerates the natural decomposition of any remaining humus (if any!). The acceleration is dramatic, since it is an electrochemical reaction producing ions (nitrate, potassium nitrite, etc.). The speed of this reaction increases exponentially as the ionic strength of retained water increases. The phenomenon is well detected, observed as a dramatic decrease in farmland's humus content, where synthetic fertilizers (all strong electrolytes) are used. It is nonetheless true that the release of inorganic nutrients also increases crop yields. Thus, resorting to source-separating dry toilets is fully consistent with chemical agriculture: maximum yields obtained from the use of inorganic nutrients.

Conclusions of the Japanese study

The study's findings (including results on nitrogen content) lead its author to compare source-separating dry toilets to « conventional style » dry toilets (for example, the BLT and Humanure toilet): for this, results of an earlier study on « conventional style » toilets by the same author are cited, (presumably using the same dubious methodology described above). From this earlier study, the author mentions that 80% of the initial nitrogen content in the dejecta (combined faeces and urine) mixed with a sawdust matrix had evaporated into ammonia gas after 28 days. From this, the study concludes, by simple extrapolation (!), that after one year, the compost derived from « conventional style » dry toilets would contain between 0 and 3% of the initial nitrogen.

Well of course, this methodology applied to dejecta leads to huge nitrogen loss. The « nitrogen volatilization » mentioned in the earlier experiment on faeces is consistent with the fact that the dejecta had been stored in a tank that was not airtight. In an airtight tank, all of the nitrogen would have been conserved, just like the methodology applied to urine storage described earlier. By letting the ammonia evaporate, the losses are obviously enormous. Nevertheless, a proper experimental comparison between the two types of dry toilets would have required a different

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composting of biogas digestate «produces humus». Some fibrous humus is effectively formed, binding to soil particles, but ephemerally. In addition, this humus simply cannot hold water or even plant nutrients, as proven by conventional soil analyses, precisely because of the lack of a spatial structure. Such humus decomposes very quickly into water and carbon dioxide, releasing nitrate ions that obviously increase agricultural yields. Observing such returns obscures the real problem: the depletion of organic humic matter in soil. This «false humus» absolutely does not prevent erosion, nor does it increase the soil's water- and nutrient-holding capacity.

6 Link : http://en.wikipedia.org/wiki/Chemical_decomposition .

7 Link : http://en.wikipedia.org/wiki/Chemical_synthesis .

approach for the BLT/Humanure toilet, such as mixing « fresh » dejecta with the proper quantity of cellulosic litter, then placing it on the soil for proper composting (windrow/heap composting, or ground-surface composting [8]) Under such conditions, the release of ammonia is totally negligible (and completely odourless) and nitrogen loss associated with evaporation of ammonia is a non issue.

By treating (in fact, mineralizing) a mixture of faeces and urine in-tank, the comparison between source-separating toilets and BLT/Humanure toilets has been deliberately distorted. The way BLT/Humanure toilets are used, dejecta derived from their use come in direct contact with cellulosic litter. By composting the resulting mixture directly on the soil (in aerobic conditions), a process of synthesis instead of decomposition [9] occurs. Nitrogen proteins and amines penetrate macromolecular structures where they remain mostly organic and non-leachable. The « nitrogen loss » announced in the study is based on an incorrect methodology that has no relation with a BLT/Humanure toilet.

Even then, the main problem lies in the fact that the assessment of nitrogen losses is only a very minor aspect of the actual environmental impacts of the two types of toilets. The true value of an organic agricultural amendment lies in the presence of humic structures containing organic non-leachable (non-ionic) nitrogen and phosphorus. Conserving nitrogen in an enclosed tank and releasing it as ammonia, in a nitric or even a nitrous state (NO_2 formed under anaerobic conditions, quite toxic) is pointless. Indeed, composting of a mixture of litter and ammonia solution certainly forms a bit of humus [4], but much less so and of lesser quality than that which is formed during the composting of BLT/Humanure toilet effluent.

In light of the above, incomplete findings and a dubious methodology that has no bearing on realities in the field, we come to conclude that the study constitutes an implausible essay.

Alternative method : assessing the regenerating value of compost

A comparison could however be made between the two types of toilets, but using a different methodology.

What should be done is to compare compost obtained after the addition of cellulosic litter to faeces and urine stored in-tank (under anaerobic conditions), to that obtained from composting of BLT/Humanure toilet effluent on the soil (under aerobic conditions). Besides determining the quantity of nutrients (total nitrogen, organic and inorganic), one must also determine the proportion of ionic (inorganic) nitrogen contained in both composts. The experiment would consist in weighing a given sample of dried compost and placing it in a beaker with a quantity of distilled water. After stirring (with a magnetic stirrer) for a predetermined time and at a controlled temperature, one would proceed to the filtration of the mixture. The electrical conductivity of the liquid would then be measured, as well as the quantity of NO_3^- and NH_4^+ ions in solution. Thus, one could verify the remaining quantity of non-leachable nitrogen in each compost.

One could also attempt to develop an analytical method to determine and quantify the true regenerating value of humus obtained by composting. The degree of polymerisation of humic acids formed would appear to be an objective measure. The greater the polymerisation, the better the compost's water- and nutrient-retaining capacity (after adsorption to a mineral support) and

[8] Link: http://www.eautarcie.org/en/05f.html#c .
[9] This decomposition is inhibited, thanks to the graft of amine functions on cellulose.

the better its capacity to harbour soil life [10]. An increased degree of polymerisation leads to « weaker » acid functions (R-COO-). In other words, the acidity constant K_a becomes increasingly low. One should therefore try to quantify the relative value of this constant to form a comparison scale between different samples of compost.

Before measuring humic acid's apparent acidity constant, you need to remove the sample's free inorganic ions, for example by extraction with distilled water. Then return the residue into water to activate the organic acid functions. The liquid obtained after filtration and maturation will serve to prepare (by means of dilution) a series of samples showing decreasing electrolyte concentrations. Then measure the electrical conductivity k (pronounced « kappa ») with respect to the degree of dilution. Express the solute concentration C in arbitrary terms, by assigning the value 1 to the original undiluted solution. Then graphically represent k/C as a function of 1/k . The slope of the resulting curve will be representative of the degree of polymerisation of humic acids present. Here we measure a weak acid's apparent acidity constant K_a, i.e. that of humic acid obtained from composting [11]. The smaller this constant (arbitrary value), the greater the degree of polymerisation [12]. Then one can compare the apparent pK_a constants measured in both types of compost.

This quite conventional electrochemical method is used to measure the acidity constant of very weak acids but has never been applied to humic acids. Unlike what happens with pure acids, in the case of a mixture of similar-type acids presenting a certain range of molecular weights, which is the case of compost's humic acid, a graph showing k/C as a function of to 1/k may not be linear. The slope of the curve should therefore be measured at – for example – a dilution level set by convention. The acidity constant thus determined will only be a relative value, yet will be relevant for comparing different compost samples.

Measuring the organic matter in the two composts is also relevant. The balance-sheet of total nitrogen and phosphorus should also be drawn up. The starting point of reference is the quantity of nitrogen and phosphorus contained in human dejecta [13], representing 100%. Then determine their distribution, for example, ionic nitrogen, organic (non-leachable) nitrogen and nitrogen losses.

Conclusion

Notwithstanding the study's aforementioned weaknesses, its analyses are based on the concept of chemical agriculture: reducing the concepts of soil fertility and soil quality to its mere nutrient content (N-P-K). Soil's pedological, thermodynamic and electrochemical aspects are superbly ignored! As for the experimental methodology, it does not take into account the differences between anaerobic and aerobic treatment of dry toilet effluent in the period between the initial production of faeces and urine, and the eventual agricultural use of the composted material.

In reality the nutrients are far less important in terms of quantity than their position in the proteinaceous molecular structures present in human and animal dejecta. It is precisely these

[10] The spatial structure described in Note 4 on humic acids is exactly what we are attempting to measure here. As the degree of polymerisation increases, the -COOH functions lose part of their acidity. The measured acidity constant K_a decreases as the molecular weight increases.

[11] Here you draw a tangent to the curve obtained at an arbitrary concentration that is by convention. The ordinate of the tangent being a, the slope being b, the acidity constant is calculated by the relationship $K_a = a2/b$. In presenting the results, it is not the numerical value of K_a that is placed in the tables of results, but rather the value of $pK_a = - \log K_a$. The higher the numerical value of pK_a, the better the water-holding capacity of the compost's nutrients.

[12] In fact, the weaker the K_a value, the greater the pK_a value.

[13] Link : http://www.eautarcie.org/en/05e.html .

structures that are destroyed in a wastewater treatment plant, during anaerobic storage of dejecta and also during the methanization of organic waste, not to mention the senseless burning of biomass [14] for purposes of alternative or « green » energy production. EAUTARCIE's ecological sanitation principle n°3 [15] sets a stand on this.

One need not worry about the legitimacy of the Biolitter toilet (BLT) / Humanure toilet. Nevertheless, this simple, rigorous and common-sense concept continues to face opposition that words, however rational and convincible, do not seem to temper, when confronted to incomplete knowledge that is sometimes detached from certain realities.

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[14] Link: http://www.eautarcie.org/en/07a.html .
[15] Link: http://www.eautarcie.org/en/02c.html .