The role of ecosan in achieving sustainable nutrient cycles

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Abstract

The present flush-and-discharge sewage system introduces a large one-way flow of excreta, containing organic matter, plant nutrients, hormones etc. from terrestrial to aquatic environments. This flow has proven to be a serious impediment to the development of a sustainable society.

End of pipe solutions (sewage treatment works) have so far not been able to make up for this impediment and will probably not be able to do so in the future either. This is shown by the continuously increasing number of problems observed due to this flow of excreta; eutrophication and algae blooms, depletion of arable fields, fish affected by endocrinal disruptions and water polluted by pharmaceutical residues.

EcoSan systems direct the excreta flow in the correct direction, closing the nutrient loop and diverting the hormones to arable land, just as previously during evolution. Furthermore, practical and resource efficient sanitation methods can be employed, since the excreta are collected in a small volume. Therefore, the hygiene standard of EcoSan systems can be higher than that of the present flush-and-discharge system. Furthermore, EcoSan systems also increase the possibility of developing practicable treatments for inactivation of pharmaceutical residues, should this be prioritised by society.

Introduction

We have not inherited this globe from our ancestors, but borrowed it from our children. It is therefore our obligation to strive towards sustainable development. This implies that the use of our two most important sources of food, water and arable soil, must be sustainable. The plant nutrients of the food must be recycled to arable fields, from where they originate. The plant nutrients must flow in closed loops, in the way they have always flowed. With closed nutrient loops, plant production can be sustainable over a very long time perspective. This is illustrated by the African savannah, where plant production has been sustainable for such a long time that the giraffe has had time to evolve its long neck to graze from the trees (Figure 1). This is real sustainability!

This is far from the situation of the present society, where nutrient flows are linear and one-way. Plants take up nutrients from arable soil. We then consume the plant nutrients in the form of food and excrete them in the form of urine and faeces. However, the excreta nutrients are currently not recycled to the fields. If a flush-and-discharge sewage system is used, they are instead flushed away. In some places of the world, the phosphorous and nitrogen in sewage are efficiently reduced before the sewage is emitted to recipient waters. In such cases, most of the phosphorous usually ends up on a landfill (Figure 2). However, in most places, sewage receives no, or very little, treatment before being emitted. The excreta nutrients fertilise algae instead crops. It is quite unavoidable that worldwide eutrophication is increasing.

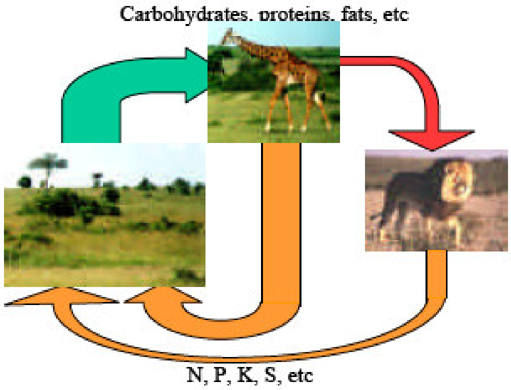

Figure 1: The nutrient loops on a savannah.

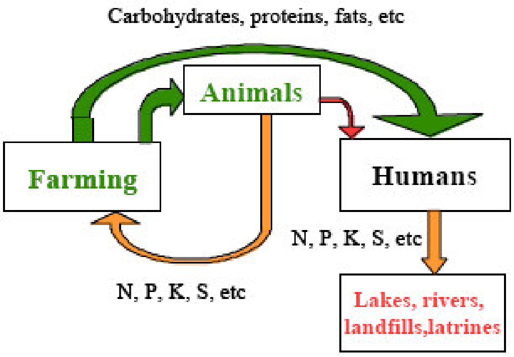

Figure 2: The linear one-way nutrient flow from fields to lakes, rivers and landfills of current human society.

At the other end of the flow, arable fields are being depleted of their nutrients, with decreasing productivity as a result. To remedy this, the fields are supplemented with chemical fertilisers when these can be afforded. Chemical fertilisers are produced by the use of fossil resources, e.g. phosphates and potassium from mines and oil and natural gas to produce plant available nitrogen. In many countries agricultural fields are supplied with doses of plant nutrients that are far larger than any that plants have been exposed to before during their evolution. Naturally, this increases the leakage of nutrients from the fields.

The ample supply of chemical fertilisers also decreases the motivation to recycle excreta nutrients to arable land. This is one factor behind the rapid spread of the conventional water-borne flush-and-discharge sewage system, introduced in Western Europe during the late 19th Century. For city populations, the introduction of the water-borne system led to improvements in health, because it rapidly removed infectious wastes from densely populated areas and because it improved the drainage of the cities. However, excreta may contain pathogens in large concentrations and the flush-and-discharge sewage system normally does not destroy these. Instead the pathogens are partly accumulated in sludge or sediment and partly flushed out with the effluent.

Excreta contain not only plant nutrients and pathogens, but also organic macro and micro substances, e.g. hormones. The flush-and-discharge sewage system drastically increases the flow of excreta, and thus of a large number of different substances, from terrestrial to aquatic environments. This has led to serious eutrophication and oxygen deficiency in the recipient waters. To remedy these negative effects, advanced sewage treatment plants were developed, including processes to remove biodegradable organic substances, nitrogen and phosphorous. However, new negative effects are continually being discovered. One example is the negative effect on aquatic wildlife caused by the female hormone oestrogen in the sewage effluent. Another example is pollution by pharmaceutical residues, which are being discovered in more and more places, even in groundwater resources used for production of drinking water.

The linear flow of excreta substances thus causes eutrophication, depletion of fields and problems with endocrine disruptors in the marine environment. Therefore, it becomes ever more evident that the linear substance flows introduced by the water-borne flush-and-discharge sewage system are major violations of ecology. The sustainable solution to this is not to improve the present end of pipe sewage treatment. It is instead to introduce a sanitation system that supports, instead of violates, the natural cyclic substance flows of nature. It is to introduce EcoSan.

EcoSan - substance flows and hygiene

Ecological Sanitation, EcoSan, is designed to support the natural cycles of plant nutrients and other natural components of excreta, e.g. hormones. When fully implemented, all excreta are returned to arable land in a hygienically and chemically safe way. Thus, the cycles of the plant nutrients contained in food are closed and the other natural constituents of excreta, e.g. natural hormones, also flow to soil, just as previously during evolution.

There is a mass balance in the human body. Excreta contain approximately the same amount of heavy metals as food and therefore there is no risk of heavy metal accumulation in soil due to these fertilisers. They are chemically safe. Of course, this assumes that infrastructure systems are well designed and do not themselves contaminate the excreta.

Pharmaceutical residues are often cited as a new and additional risk when using excreta fertilisers, i.e. in EcoSan systems. This risk has not yet been verified, as far as I know, but risk assessments are underway. Meanwhile, before these studies are reported, my guess is that it actually is the other way around. The risks associated with pharmaceutical residues in EcoSan systems are probably smaller than in the conventional flush-and-discharge system. Downstream from the sewage effluent outlet of big cities, the concentration of many pharmaceutical substances is large enough to be detectable. In some places medical residues have even been detected in the groundwater. These findings are worrying as ground and surface waters are the sources of our drinking water.

Studies have also shown that pharmaceutical compounds degrade to varying degrees in sewage treatment plants and that this degradation increases with the retention time. Since arable soil contains the same types of microorganisms as treatment plants, it is reasonable to assume that the degradation will be high, or essentially total, since the retention time in the soil is very long. However, EcoSan also offers another unique possibility of eliminating the risk of pharmaceutical residues. This possibility is due to the small volumes of excreta collected, which increases the possibility of finding practicable and resource efficient treatments that eliminate or inactivate these substances. For example, incineration of dry faeces will not only sanitise them, but also eliminate pharmaceutical residues.

In EcoSan systems the excreta are source separated, i.e. they are collected and treated in a separate system from the greywater. Since the excreta are collected, stored, treated and transported before being reused as fertilisers, it is very important for practical reasons that they are collected in a minimal volume. The volumes of the excreta themselves are quite small, that of urine being only 1-1.5 litres per person and day and that of faeces only 0.1-0.3 litre. To keep the total volume down, no or very small amounts of flushwater are used in EcoSan systems for collection of excreta.

EcoSan strives towards a sustainable society. The recycling of excreta nutrients for sustainable production of food is a requirement for this society. However, this is not enough. To be sustainable the food produced must also be safe and of high quality. This implies that, while the plant nutrients should be recycled, pathogens should not. This is a very important requirement and at least two barriers against spreading pathogens should be implemented. Several barriers are possible. One is to sanitise the excreta well, another is to handle the excreta in such a way that they do not contaminate food consumed raw. Still another is not to harvest until a long time after fertilising with excreta.

Urine diversion is a component of many EcoSan systems, mainly because urine diversion simplifies the construction of hygienic, no odour, no fly and no water toilets. Therefore, urine diversion toilets with dry collection of faeces can be built inside the house.

Urine diversion also has the additional advantages of simplifying the sanitation of the excreta and of providing two fertilisers with different properties, instead of one, which makes it possible to address the specific nutrient requirements of different crops.

Urine diversion simplifies the sanitation of excreta. This is because the faeces accounts for only a small fraction of the volume but essentially the whole hygiene risk. The small volume of the dry faeces, i.e. without urine or flushwater, makes it easier to contain them and to sanitise them. They can be sanitised already in the toilet, for example by a combination of regular addition of ash or lime and dehydration, which also decreases the risk of flies and odour. The faeces can also be sanitised upon removal from the toilet by a secondary treatment, for example digestion, composting, incineration or by addition of urea or other chemicals. Further studies and developments are needed on these sanitation methods to minimise their need of resources for meeting a specified hygiene standard. Until such studies have been carried out and hygiene guidelines developed, it is important to apply the faeces before planting/sowing, to incorporate them well and not to use them for vegetables eaten raw.

The hygiene risk associated with urine is very small compared to that with faeces. Therefore, provided that the diversion of the urine functions well, the diversion itself can be seen as a hygiene barrier. Urine should also be incorporated well into the soil, to maximise its fertilising effect. In addition, as a hygiene safety measure, until hygiene guidelines have been developed, it is recommended that crops consumed raw are not fertilised with urine closer to harvest than one month (Schönning, 2003). This also ensures that the plant nutrients have time to be taken up and utilised by the crop.

The hygiene risk associated with latrine or blackwater (urine mixed with faeces and in the case of blackwater also with flushwater) is the same as that of faeces. It is therefore important that several hygiene barriers are enforced.

Fertilising effects

Urine is a complete fertiliser that is rich in nitrogen. It can be used in the same way as a nitrogen rich liquid chemical fertiliser. For biological fertilisers, the plant availability of the urine nutrients is uniquely high. In experiments, the phosphorous effect has been as good as that of chemical fertiliser (Kirchmann & Pettersson, 1995) and the nitrogen effect has varied from around 70% to more than 100%, compared to chemical fertiliser. On average the nitrogen effect has been around 90%, after deduction of the nitrogen lost as ammonia (Figure 3; Johansson et al., 2001). In Swedish experiments, the nitrogen loss in the form of ammonia has varied from less than 1% to more than 10%. On average it has been around 5%. To keep the ammonia loss low, it is important to mix the urine into the soil as quickly as possible. The best method is probably to apply it in furrows or holes, which are then covered over immediately after application.

Faecal matter is an organic fertiliser that is rich in phosphorous, potassium and organic matter. Faeces improve soil fertility and increase the buffering capacity of the soil, especially if they have also been mixed with ash or lime. The availability of the nutrients in faeces is slower than of those in urine.

Thus, urine and faeces supplement each other well. Urine is well suited as a fertiliser for nitrogen demanding crops, like maize and spinach, while faeces are well suited as a fertiliser for crops without any large nitrogen demand, like legumes. So far, documented experiments are lacking concerning blackwater. However, since it is a mixture of urine and faeces, and urine contributes most of the nutrients, its fertilising effect should be fairly similar to that of diverted urine.

If plant nutrients are wisely used, introduction of EcoSan will lead to improved production of food. In deprived circumstances and, especially in subsistence farming, this factor can improve both health and economy. EcoSan fertilisers are well balanced complete fertilisers, as they contain the elements in the same ratios as the crops removed them from the fields. Therefore, the risk of unbalanced fertilisation is far less with EcoSan fertilisers than with chemical, which simplifies soil management and decreases the need for chemical soil analyses.

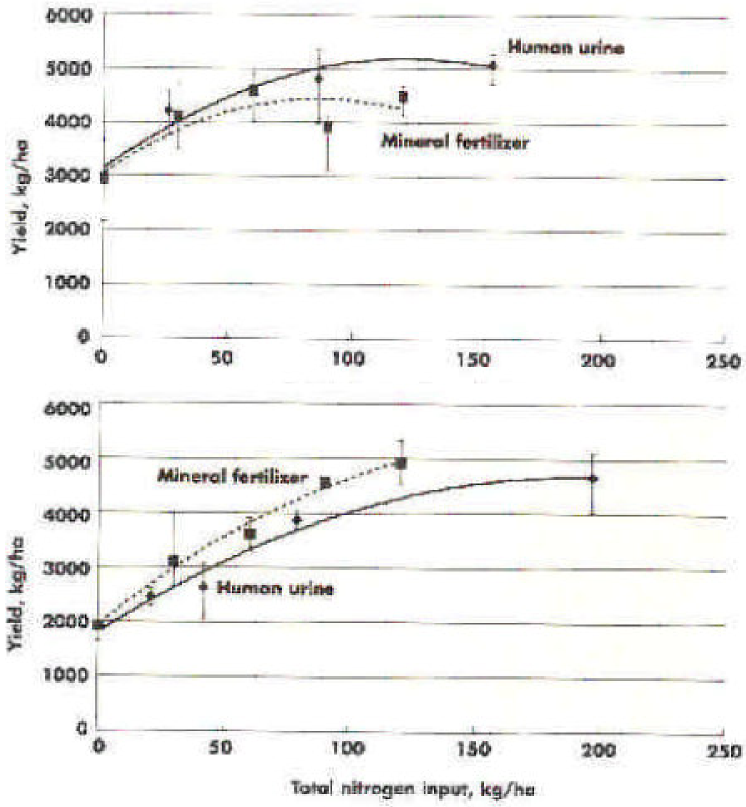

Figure 3: The effect of urine and mineral fertiliser on the yield of barley in an experiment in Sweden 1998 (upper diagram) and 1999 (lower diagram) (Johansson et al., 2001).

Environmental assessments

It is obvious that EcoSan recycles far more nutrients to arable land and emits far less nutrients to water than a conventional flush-and-discharge system, even if the conventional system contains a very effective treatment. For blackwater systems this has also been shown in a number of environmental systems analyses (Bengtsson et al., 1997; Kärrman et. al, 1999; Balmer et al., 2002). These studies also confirmed the low concentrations of heavy metals in excreta, and thus that it is a very pure and unpolluted fertiliser.

However, they also showed that the energy usage of existing blackwater systems is very high. This is due to the large energy usage both by the vacuum system used for collection and by the sanitation process, liquid composting or thermophilic digestion. One conclusion from these studies is that the development of resource efficient sanitation processes should be given the highest priority. Another conclusion is that further development of collection systems is needed, to increase their resource efficiency and decrease their use of water.

Conclusions

The present flush-and-discharge sewage system introduces a large one-way flow of excreta, containing organic matter, plant nutrients, hormones etc., from terrestrial to aquatic environments. This flow is an obstacle to a sustainable environment. End of pipe solutions (sewage treatment plants) can probably never be a sustainable remedy to this imbalance. This is indicated by the continuously increasing number of problems observed, eutrophication, depletion of arable fields, fish affected by endocrinal disruptions, water polluted by pharmaceutical residues.

EcoSan systems make the excreta flow in the natural direction, closing the nutrient loop and directing the hormones to arable land, just as previously during evolution. Since the excreta are collected in a small volume, practicable and resource efficient sanitation methods can be developed. The hygiene standard of these systems can therefore be higher than that of the present flush-and-discharge system. Furthermore, these systems also increase the possibility of developing practicable treatments for the inactivation of pharmaceutical residues, should this be prioritised by society.

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