Human faeces as a resource in agriculture

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Abstract

As much as 60–70% of nutrients discharged from fields end up in toilet waste (Jönsson et al. 1995). Following the principles of sustainable development, nutrients in faeces should be used in plant production, instead of ending up in wastewater treatment plants. In the Nordic countries, less than half of sewage sludge is utilised in agriculture. Negative attitudes and concern about environmental and health hazards caused by sewage sludge have decreased the spreading of sludge on fields. Attempts have been made to improve this situation by enhancing the quality of sewage sludge and finding new treatment methods and functions for it.

Composting toilets and toilets with urine separation make it possible to reclaim and utilise human excreta in the home. Water consumption decreases significantly. Since little or no black water is produced, nutrient releases and intestinal bacteria fail to spread in the environment. Composted toilet waste is suitable for soil conditioner and urine for liquid manure in the yard and garden. Owing to device malfunctions, public prejudice, and lack of information, composting and separating toilets and the recycling of faecal nutrients have not gained enough popularity.

Including

Human faeces is considered a valuable nutrient source in a number of countries. For example in China, in Japan, in Korea, but also in some countries of Africa and South-America nutrients of faeces utilise in agriculture. In the Nordic countries the plant nutrients are collected in waste water treatment plants and a large part pollutes the environment, depending on the system used (Steineck et al. 1999)

Following the principles of the sustainable development recirculation of nutrients of human beings from urban areas to agricultural land is one of the big challenges of our time. The annual amount of toilet waste is about 520 kg/person. This amount includes altogether 7.5 kg of nitrogen, phosphorus, and potassium, and some micro-nutrients in a form useful for plants. If the nutrients in the faeces of one person were used for grain cultivation, it would enable the production of the annual amount of grain consumed by one person (250 kg). (Wolgast 1993)

Composting and separating toilets have enabled the reclamation of human excreta and the use of the nutrients contained in it as fertiliser and soil conditioner. In Sweden, organic farmers have expressed interest in using human urine as liquid manure because of the content of macronutrients and the low heavy metal content (Linden 1997).

If the circulation of human faeces between the urban and rural areas will increase, it must be insured that the quality and fertility of soils are not negatively affected in the long term perspective. This means in the practise that there is a need for research on efficiency and environmental impacts of these organic fetiliser.

Use of sewage sludge in agriculture

Between 30 to 48% of sludge is used in agriculture in the Nordic countries. Rich in organic matter and nutrients, mostly nitrogen and phosphorus, stabilised sludge is used as a fertiliser and soil conditioner in agriculture. Sludge is rather poor in other macro-nutrients, although lime-stabilised sludge contains significant amounts of calcium and magnesium. About a half of the micro-nutrients, copper, zinc, and manganese, are usable for plants. (Mäkelä-Kurtto 1994)

The fertilising value of sludge is weakened by the fact that its nutrient balance does not correspond to the nutrient needs of plants; sludge is poor in nitrogen and rich in phosphorus. The amount of nitrogen in sludge will increase in the future, if the removal of nitrogen from wastewater becomes more efficient. The fertilising effect of the nitrogen contained in the sludge is slow but long-lasting, and the same applies to phosphorus, which takes years to be released into the soil to be used by plants.

Organic matter usually constitutes 50–60% of the dry matter of mechanically dried sludge, which is why the use of sludge in agriculture increases the amount of organic substances in cultivated land. Above all, sludge is most beneficial in mineral soils. An increase in organic matter in the soil improves the structure and water economy of the soil and stimulates microbe activity. It also effectively binds various harmful substances, such as heavy metals, preventing their action on the soil. (Mäkelä-Kurtto 1994)

The disadvantages and limitations of sewage sludge use

The heavy metal content of sewage sludge has been considered the most significant restricting factor in the agricultural use of sludge. The problem is that heavy metals remain in the soil and many of them undergo biomagnification in the food chain. Among the heavy metals in sewage sludge, the most hazardous ones to humans are cadmium, mercury, and lead, while copper, zinc, chromium, and nickel in high concentrations are particularly poisonous to plants. (Levinen 1991)

Industry is the main source of heavy metals in sewage sludge; they also pass into surface waters with rainwater and from corroded piping. The amount of metals in sludge cannot be decreased by sludge treatment; moreover if the amount of organic matter decreases during treatment, the metal concentration is increased.

The heavy metal content of sludge has decreased notably during the past 10 to 15 years. As a result of stricter discharge standards, the quality of waste-

Table 1. Amount of sewage sludge in the Nordic countries, utilisation in agriculture and limiting standards of use (+ = yes, – = no). (Petersen 1999, Malkki 1999, Ugland 1999, Thomsson 1999)

	Amount of sludge tons of DM/year	Utilisation in agriculture	Limiting standards of sludge use Heavy metals	Organic pollutants	Hygiene
Denmark	140 000	–	+	+	+
Finland	150 000	39% (–97)	+	–	–
Norway	92 930	48% (–95)	+	–	+
Sweden	200 000	30% (–98)	+	+	–

water has improved. Industry also monitors the quality of wastewater more thoroughly than before. (Levinen 1990)

In the Nordic countries, the standards and guidelines for sewage sludge use in agriculture are very strict. Maximum content limits have been set for heavy metals both in sludge and in cultivated land, and annual loads are also regulated (table 1).

The organic compounds that end up in wastewater treatment plants come from industry, households, and storm water; some compounds come from landfill sites and agriculture. These compounds can be divided into those indicating general pollution of the environment (PAH, PCB, dioxines, organic stannic compounds and biocides) and those indicating impurities in domestic sewage (e.g. LAS and NPE). Most organic matters bind with sludge, a process enhanced by the fat content and non-polarity of the compounds (Rogers 1996). During the treatment of sludge, the amount and quality of compounds can change considerably.

The organic compounds in sewage sludge have not been researched to the same extent as heavy metals, and research has mainly focused on compounds which occur in high concentrations or are persistent, bioaccumulative, or poisonous. According to current knowledge, organic impurities have not been proved to cause permanent damage to microbe activity in the soil. Furthermore, no negative impact on growth has been observed, as long as the sludge amounts used have corresponded to the nutrient needs of plants (Smith 1996).

In Finland, the organic matter contents of analysed sewage sludge have been so low that it has been considered unnecessary to regulate sludge spreading on the grounds of organic matter (Aalto, 1992). Restrictions on organic impurities in sludge have not been set in Norway either, whereas in Sweden and Denmark, bioaccumulation is prevented by limiting the content of some organic ‘indicator’ matters, and also by setting rules for which grain varieties may be used and the minimum time span between sludge spreading and harvest. (Albihn 1999, Petersen 1999)

Wastewater contains several kinds of pathogens, including microbes, fungi, viruses, protozoa, and parasites. Not all pathogens are destroyed in traditional wastewater treatment, but spread with sludge into surface waters and fields, thus causing contamination risk to people, animals, and cultivated plants. (Lehmann et al. 1983) The contamination risk can be reduced by efficient sludge treatment methods and rules and restrictions concerning sludge use. Composting is the best treatment method with regard to the hygienisation of sludge, since lime-stabilisation does not act on parasite eggs, and decaying and digestion are not very efficient in destroying pathogenic organisms.

According to Smith (1996), the health risk caused by pathogens possibly contained in sludge is relatively low, since the infectious dose is usually quite high and entails swallowing the pathogens. Furthermore, the sludge spreading restrictions in the Nordic countries prevent infection through food. However, the eggs of some parasite worms can survive in the soil for years. It is possible for pasturing cattle to become infected if sludge has been spread on the field before pasturing; however, treated sludge usually contains very few viable parasite eggs (Sekla et al. 1983).

In Sweden and Finland there is no biosecurity-related legislation regulating the use of organic waste as fertiliser. In contrast, such legislation has been passed in several other countries, including Norway and Denmark. If organic waste including sewage sludge is to gain widespread acceptance as fertiliser in agriculture, its hygienic standard will have to be guaranteed. (Albihn 1999)

Sludge use can result in increasing nutrient releases in water bodies. Nitrate is likely to be washed into the groundwater particularly in early and late summer, if there is no growth in the field, whereas phosphorus is not washed into the groundwater even as a result of sewage sludge fertilisation. Instead, bound in soil particles, it can pass into surface waters with overland flow. Sludge is suitable for complementing mineral fertilisation when used according to the rules and regulations on agriculture. (Mäkelä-Kurtto 1994)

If composted sewage sludge is used, one has to be sure it is mature. Immature compost can have harmful effects on plants and soil ecosystems, particularly if the compost is applied before sowing, or if it is used as a growth substrate (Inbar et al. 1990). Today there are no national regulations or standards on testing methods for compost maturity in the Nordic countries.

Urine and its utilisation as a fertiliser

One person produces annually appr. 500 l urine. The urine fraction contains 98% of the nitrogen, 65% of the phosphorus, and 80% of the potassium excreted by a human. Most of the nitrogen in human urine is in a form suitable for plants, for example ammonia nitrogen (Kirchmann and Pettersson 1995, Claesson and Steineck 1996). The nitrogen content in stored human urine depends on the flushing capacity of the toilet water since flushing causes dilution (Jönsson 1997).

Pure urine is microbiologically fairly clean when passed by a healthy person. There is, however, a risk of contamination of the urine by faecal material. Heavy metal contents are much lower in urine than in solid waste but higher than in rain and surface water. The N fertiliser use efficiency of urine is lower than that of ammonium nitrate due the larger gaseous N losses from urine (Kirchmann and Pettersson 1995).

Stored human urine normally has a high pH (8.6–9.2), which increases the risk of ammonia losses during storage and after spreading. Ammonia emissions are both a resource problem and an environmental problem (Löfgren et al. 1998). The high pH in human urine may have a positive effect in killing infectious bacteria and viruses (Höglund et al. 1997).

Diluted with water (5–10% dilution), clean urine is suitable for nitrogen fertiliser for lawn and ornamental plants. Urine can also be used as additive nutrient in yard composts, but its use as fertiliser for edible plants should be investigated.

With separating toilets, the urine is not usually collected and used as fertiliser in the garden, but instead led into grey waters and absorbed into the ground through a septic tank or sand filter (Malkki et al. 1997). With regard to nutrient recycling, more attention should be paid to the utilisation of urine as fertiliser as it contains more nutrients than faeces.

In Sweden, the utilisation of human urine in grain cultivation has been researched. In 1997, an application of human urine, containing 100 kg of total nitrogen per hectare, yielded 68% of the harvest of plots fertilised with the same amount of nitrogen in mineral fertilisers. In 1998, yields from plots fertilised with human urine were at the same level as yields from plots fertilised with an equal amount of nitrogen in mineral fertilisers. (Steineck et al. 1999)

Since most of the nitrogen is lost immediately after urine has been spread, it is recommended that it should be composted deep in the field (Jönsson et al. 1996). For hygiene reasons, urine should be stored in a sealed vessel for six months before spreading.

For the farmer, the spreading of urine in the field makes sense only if the benefit exceeds the costs and the use causes no harm to the environment or health. The financial value of urine is based on the fertilising effect of its nutrients which are suitable for plants: the use of artificial fertilisation can be reduced. Nevertheless, even if the spreading of urine in the field is technically possible and financially profitable, it can still be hindered by public opinion and prejudice. The labour and machinery costs of urine transportation can easily exceed the value of the nutrients. Furthermore, spreading the urine at the wrong time or unevenly on the field can cause considerable crop failures (Malkki et al. 1997)

Faeces and its utilisation as soil conditioner

One person produces appr. 100–200 g of faeces per day, the dry matter content of which is about 20%. Human faeces contain very rich ecosystems of versatile micro-organisms. Bacterial numbers such as 10^{10}/g have been presented (Ketchum 1988). In addition, there are high numbers of viruses, protozoa and fungi. These micro-organisms are strictly or facultatively anaerobic and many of them cannot be cultivated. Thus the numbers presented are not at all accurate and microbiological numbers vary according to diet; moreover the microbial distribution in faeces is very uneven.

Many pathogens that enter the human body orally are enteric. They have been found to be excreted unevenly in faeces and many people without any clinical symptoms can be emitting pathogens. Human faeces are thus very liable to spread enteric micro-organisms to other persons. From the point of view of hygiene, it is extremely important to avoid all circumstances where fresh, unhygienised faeces can contaminate human food, water, or other persons directly.

Raw or partly composted faeces have to be composted before use to avoid the spreading of possible pathogens. They are best composted with bio-waste and garden waste, as this way the carbon/nitrogen relation becomes optimum. The bio-waste causes the microbe population to become varied and the composting process to speed up. Toilet waste has to be composted for at least six months, including summer months, before it is spread on the ground. (Salkinoja-Salonen 1983)

The nutrient content and hygienic quality of composted toilet waste have been studied very little, which makes such waste more difficult to use. The usual way to utilise composted toilet waste is to spread it in the yard under bushes or on wasteland. Owing to biased attitudes towards composted faeces, people rarely use it as soil conditioner or fertiliser for vegetables (Malkki et al. 1997).

At present, composted toilet waste is of little significance as fertiliser or soil conditioner for households (Malkki et al. 1997). This fact is also supported by Hagalund and Olofsson (1997) in their research, according to which utilisation of the nutrients in sludge, urine, and toilet manure still functions poorly in Swedish eco villages.

Conclusions

Human excreta are a valuable source of nutrients. Their use should be promoted in order to replace some of the artificial fertilisers used in agriculture. For the time being, there are many unanswered questions which need to be researched before human excreta can be widely used in plant production.

For agricultural purposes sewage sludge is the most important municipal waste in the Nordic countries. In order to increase the demand for sewage sludge and composted bio-waste, their quality has to be improved to meet the requirements. Quality control has to be strict to assure the consumer that the use of a composted product will not cause problems.

The nutrient content and hygiene of composted faeces and urine should be studied further to enable clear instructions for their use to be drafted. The utilisation of toilet waste is being hindered by prejudice and lack of information – only by efficient information can we influence public opinion.

The development of composting and separating toilets should also be promoted to obtain functional, easy-to-use, and hygienic models to compete with flush toilets. Many of the present models require too much time and trouble from their user, which no doubt reduces their popularity.

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