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Biosecurity and arable use of manure and biowaste — Treatment alternatives

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Abstract

The potential negative environmental impact of manure and biological waste (BW) can be minimised at a profit by recycling plant nutrients in the food chain. Current large-scale livestock production, epizootic diseases and increasing globalisation increase the need for biosecurity, to minimise the risk of disease transmission to the food chain. Arable use of manure and BW can inadvertently spread infectious diseases; opinion differs concerning the risk levels. To obtain general acceptance for arable use, a hygienically safe end-product is needed. This paper provides a detailed discussion of treatment alternatives for co-treatment, i.e., mixture before treatment of manure and BW. Composting, anaerobic digestion and ammonia treatment are the three options given. A decision support tool is also presented and discussed. Suitable treatment methods must combine biosecurity aspects with environmental, economic and nutrient recycling aspects to create a beneficial whole-farm approach.

Keywords: Biosecurity; Biological waste; Hygiene; Pathogens; Manure; Nutrient recycling

1. Introduction

Recycling of plant nutrients from manure and biological waste (BW from households, the food industry, restaurants, toilets etc.) in the food chain is important for a sustainable agriculture. However, besides the desired plant nutrients also undesired pollutants, including pathogenic microorganisms, antibiotic-resistant bacteria and organic pollutants such as pharmaceutical residues and hormones, may be present in the material.

To obtain general acceptance for arable use of manure and BW, a hygienically safe end-product is needed. The structure of today's animal production and the global trade of its products rely on an advanced level of biosecurity to minimise the risk for spread of epizootic and zoonotic diseases. A set of different barriers, e.g., treatment of manure or BW, or selection of what crops to fertilise, can help decrease the risk for disease transmission and prevent the pollutant from affecting the end product.

Methods for manure treatment differ according to type and size of animal productions, tradition and local conditions. If BW from the society can be co-treated and recycled together with manure, this can benefit both the farmer and society. A general use of more effective treatment methods for manure and BW may prevent ecosystem contamination and introduction of pathogens and organic pollutants into the food chain while reducing the need for artificial fertilisers.

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2. Pathogens and organic pollutants in manure and biowaste

2.1. Pathogens

Numerous species and subtypes of bacteria, viruses and parasites are found in manure and BW. Some are disease transmitters (pathogens), such as classical swine fever virus, and many of these also pass between animals and humans (zoonoses), e.g., *Salmonella* and VTEC (verotoxin-producing *Escherichia coli*), causing severe enterohaemorrhagic infections in humans. In Sweden, VTEC is present in 10% of cattle herds overall, and in the south-east of the country in as many as 23% of herds (Eriksson et al., 2005). The situation in other Western countries is comparable. When manure is not properly sanitised, it can be an important cause of spread of this infection. Pathogens that cause epizootic diseases, e.g., classical swine fever, can also be transmitted via manure and BW. Such disease outbreaks are often handled very strictly, with slaughter and destruction of the carcases in all infected and suspected infected herds. This can have enormous economic consequences for both the farmer and society.

In developing countries, infectious diseases of both animals and man are more frequent than elsewhere, causing a heavy load of pathogens in manure and BW. Pathogens that are exotic in the developed world may be commonly seen here. A successful elimination of such microorganisms may need a modified or more advanced treatment process. Parasitic diseases are of special interest here, as in some areas almost 90% of school children carry intestinal parasites (Holland et al., 1989; Gabrielli et al., 2005).

2.2. Organic pollutants

Organic pollutants such as hormones and antibiotics may be present in manure and BW. Antibiotic-resistant bacteria can thus end up in the environment, where their resistance genes can spread to better-adapted indigenous bacteria, increasing the resistance reservoir (Kühn et al., 2005). Despite the decreased use of antibiotics in animal husbandry since the ban on antimicrobial feed additives in the EU, group treatment of animals is frequently carried out, especially in pig and poultry herds, during severe outbreaks of certain infectious diseases. The manure from herds treated with antibiotics contains residues and/or metabolites of the antibiotic used, as well as resistant bacteria and/or resistant genes (Acar and Moulin, 2006). A favourable environment for resistance development and transmission to other microbes may be present in manure or in soil. Besides a prudent use of antibiotics, manure management strategies can therefore help to retain powerful antibiotics in human and veterinary medicine for future generations.

Adequate treatment of manure can minimise the risk of spreading antibiotic-resistant bacteria, and can also be a means to degrade active compounds. However, some drugs can cause problems during biological treatment, since they have the ability to inhibit natural biological processes at relatively low concentrations (Loftin et al., 2005). In addition, some pharmaceutical compounds are very stable in the environment. For example, no degradation was observed for tiamulin (included in the pleuromutilin group) during 180 days of manure storage (Schlusener et al., 2006), or for tetracycline during 152 days in a soil microcosm (Jensen et al., 2002). However, the main effects of organic pollution on the environment are observed in aquatic life, e.g., reproductive disorders in fish (Sumpter and Johnsson, 2005).

3. Dissemination of pathogens

On-farm spread can occur via storage, transport and use of manure (Himathongkham et al., 1999; Cools et al., 2001). Further spread can occur from manured land via surface run-off, leakage to groundwater, dust particles and harvested crops. Animals kept outdoors on frozen land in winter, e.g., horses or livestock on organic farms, increase surface run-off of manure-based pathogens. Grazing animals can transmit pathogens directly to other animals and to the environment. Inadequate management of the manure can result in a fully infected herd and also spread to neighbouring herds.

To-farm spread occurs by the pathways described above from neighbouring farms, or via vector animal such as birds, rodents or insects. Infections can also be introduced via incoming live animals, feedstuff, equipment, manure and BW, etc. Humans can introduce pathogens, i.e., if toilet waste is added to slurry tanks. In high-density livestock areas, excess manure may have to be transported to other regions, a practice involving a considerable increase in biosecurity risk as diseases not indigenous to a region may be introduced. In addition, use of BW from society creates new routes of disease transmission between animals, humans and the environment. When such material is introduced on a farm, zoonotic diseases are of major interest, but epizootic diseases can also be introduced, for example by food scraps originating from other countries (EC legislation 1774/2002).

4. Treatment of manure and BW

Manure treatment differs according to tradition and local conditions. In general, larger farms have more opportunities. Farms located close to urban areas may be forced to treat manure, mainly to decrease the smell. If available farmland is not already heavily loaded with manure, BW from society can be recycled as a fertiliser, a solution that can profit both the farmer and society. Three different treatment methods for producing hygienically safe end-products are further described below (Table 1). These methods offer opportunities to co-treat manure with BW.

In Europe, more than 65% of livestock manure is handled as slurry, a mixture of urine, faeces, water and bedding material (Menzi, 2002). A common manure management practice is storage, which is therefore mentioned as a reference to the three treatments described below. The degree of sanitation that occurs during storage is not sufficient (Gibbs et al., 1995; Himathongkham et al., 1999). Some pathogens, e.g. VTEC, can persist in slurry for up to several months, the lower the temperature the longer the survival (Kudva et al., 1998). Some bacteria (e.g., *Salmonella*, VTEC) can proliferate significantly if conditions are favourable, e.g., as regards nutrient availability, and so the regular transfer of fresh manure from livestock buildings may help sustain populations of these pathogens during storage (Gibbs et al., 1995; Wang and Doyle, 1996). Levels of indicator organisms, such as coliforms and *Enterococcus*, vary over time during storage, and pathogen levels are likely to follow a similar pattern (Gibbs et al., 1997). A long storage period without inputs of fresh material is generally impossible, since storage capacity at farm level is largely determined by the need to contain nutrients until disposed of/used for crop production. Long-term storage of manure also has a negative impact on the environment, as emissions of the greenhouse gas methane and of ammonia continue throughout the storage period.

4.1. Legislation

EC legislation (1774/2002) strictly regulates the treatment of BW if it includes animal by-products (ABP) or manure. For category 1 ABP, including, e.g., material from ruminants which may be suspected to be infected with prions, incineration is compulsory. Category 2 ABP, including, e.g., carcases from other animals than ruminants, may be recycled as plant nutrients in the food chain, if pressure cooked (133 °C/20 min/3bar) in combination with other treatment. Manure for sale has to be sterilised, although several exceptions exist.

Category 3 ABP (such as low-risk slaughterhouse waste) may also be recycled, if separate pasteurisation at 70 °C for 60 min. is combined with other treatment. Additional EC legislation 208/2006, implemented in January 2007, permits alternative treatments to pasteurisation. However, individual member states have to validate that such treatments have a hygiene effect equivalent to pasteurisation at 70 °C for one hour, but hygiene validation of new, alternative treatment methods in a scientifically based, generally accepted way is not yet available.

4.2. Sanitation

The effectiveness of a sanitation treatment depends on its temperature, duration, pH, volatile fatty acids, oxygen availability and other factors. Treatment goals can also vary depending on the origin of the manure and BW, and on the potential use of the end-product. Use of a risk assessment tool enables treatment requirements to be evaluated according to the planned use of the product. For example, more or less hygiene-sensitive crops such as vegetables to be consumed raw require a high level of hygiene, whereas for energy crops a more basic level of hygiene may be accepted. Pasteurisation at 70 °C for one hour gives a sufficient reduction in pathogens (Mitscherlich and Marth, 1984). However, the reduction in heat-resistant viruses is limited, and spore-forming bacteria and prions are not reduced at all. So if problems are being experienced with a disease caused by one of these agents, another treatment has to be chosen.

Table 1
Comparison of composting (C), anaerobic digestion (AD) and ammonia treatment (AT) for co-treatment of manure and biowaste

Method	Effect	Advantages	Disadvantages	Comments
C	May give good hygienic quality	Low-tech equipment possible	Labour-intensive painstaking	Skilful handling necessary to achieve good hygienic quality
	Temperature/time dependent	May degrade organic pollutants	Eutrophying emissions	Risk for re-growth
AD	May give good hygienic quality	Valuable energy produced	High-tech equipment needed	Risk for re-growth and methane emissions
	Temperature/time dependent	Mesophilic treatment degrades organic pollutants	Much transport needed to a full-scale centralised plant	
AT	Gives good hygienic quality	Low-tech equipment needed	Covering needed to avoid ammonia emissions	Ammonia recycled as a fertiliser
	pH and uncharged NH3 (aq.) dependent			Low risk for re-growth

The treatment effect has to be continuously monitored by checking the process (i.e., temperature, pH-value, treatment time) and the end-product (i.e., indicator organisms or pathogens). The types of checks performed, and the frequency and number of analyses of the end-product, vary for different kinds of BW and processes. Sampling of non-homogeneous material is complicated, and sample distribution and sampling technique are essential in obtaining representative samples to perform an accurate hygiene assessment. However, such sampling procedures have not yet been standardised. As an extra safety precaution, the use of a particular end-product on farmland may be restricted, or there may be a quarantine period between spread of the end-product and crop harvest or grazing of animals.

Another consideration is that, despite adequate treatment of manure or BW, a risk for multiplication by post-treatment re-growth exists for some bacteria. Such re-growth may follow when complete elimination of some bacteria is not achieved during treatment, or when reintroduction occurs while nutrients are still available.

4.3. Composting

In the UK, France and Eastern Europe, more than 50% of manure is handled in solid form, including faeces and bedding with or without excreta in liquid form (Menzi, 2002), making composting convenient. Slurry may also be successfully composted by forced aeration, or following liquid–solid separation using mechanical methods and/or polymer flocculation. Composting can give acceptable hygiene quality in the end-product, if most of the material achieves sufficiently high temperature (Kjellberg Christensen et al., 2002; EFSA, 2007). Sanitation is achieved if >50 °C is reached and this temperature is maintained for a sufficient time, varying from hours to days depending on the organism and the structure of the material (Feachem et al., 1983). The higher the temperature, the shorter the time needed for treatment. WHO gives a recommendation of a minimum one week of treatment above 50 °C for composting of faecal matter (WHO, 2006). At lower temperatures *Ascaris* spp. generally have the highest survival rate, while at temperatures above 50 °C the survival rate of enteroviruses (ssRNA) is higher (Feachem et al., 1983; Vinnerås et al., 2003). However, neither parasites nor viruses have the capacity for re-growth.

An efficient sanitation requires the compost to be repeatedly turned and/or thoroughly mixed. Incorporation of structural material may be needed, plus an insulation layer above and below the compost. More technically advanced practices, such as preheating of incoming air, can also decrease the sub-volumes within compost heaps maintaining temperatures below 50 °C. Growth of pathogenic bacteria may be possible in such cold zones, at least as long as sufficient nutrients are available. Stabilisation of the treated material, whereby easily degradable organics are degraded, minimises the risk of pathogen re-growth (Sidhu et al., 2001). The main environmental concern is that most of the ammonia released during degradation of organic material will be lost as an acidifying and eutrophying emission during composting. The high target treatment temperature increases this effect. Stabilisation, biological or chemical, also decreases the risk of methane emission from the end-product.

Controlled reactor composting offers possibilities to minimise gaseous emissions via condensing or bio-filter treatment of the outgoing gas. Reactor composting in most cases also decreases the total volume maintaining a low temperature compared to open composting, as the reactor walls have some insulation. The smaller the volume maintaining a low temperature, the more efficient the degree of sanitation, and thus the fewer turnings of the material needed to reach the sanitation goals.

4.4. Anaerobic digestion

Anaerobic digestion at farm-scale has a long history in Asia, whereas in Europe fuel shortages during World War II and thereafter were the main driving force (Köttner, 1999). Manure is used as the main substrate. The interest in farm-scale biogas plants (BGP) is growing in some EU countries, e.g., Denmark and Germany (Al Seadi and Holm-Nielsen, 1999; Köttner, 1999), and also in several developing countries. Co-digesting with BW is an integrated part of large-scale centralised BGP, but is also practised by some farm-scale BGP. Large-scale BGP are increasing in numbers in many countries (15 in Sweden at present). If a pasteurisation step is not used, BGP have to rely on sanitation in the digestion chamber (Sahlström, 2002). Most large-scale BGP use a continuous process, which is less reliable regarding sanitation. The real retention time in the digester may be very short (EFSA, 2007). During mesophilic anaerobic digestion many pathogenic and indicator bacteria, as well as some viruses, need more than 2 days for a 1 $\log^{10}$ reduction (EFSA, 2007). Thermophilic digestion (50–58 °C) of sewage sludge in a large-scale continuous process reduces indicator bacteria and *Salmonella* sufficiently, while mesophilic digestion (30–38 °C) is unreliable (Sahlström et al., 2004; EFSA, 2007). On the other hand, mesophilic digestion has proven to be more efficient in degrading organic pollutants such as benzoic acid, phthalic acid, m- and p-cresol compared with thermophilic digestion (Leven and Schnürer, 2005). Pasteurisation of substrate in a separate, batch-wise step prior to digestion is a reliable treatment.

Recontamination of digested residues can occur during post-digestion storage; this has been reported as a problem during storage and transport in Sweden (Bagge et al., 2005). That study showed that the substrate from the four BGP investigated was properly sanitised by pasteurisation. However, with increasing time since the sanitation, the occurrence and density of unwanted bacteria, such as indicators (i.e., enterococci and coliforms) (Fig. 1) and pathogens (i.e., *Salmonella* or VTEC), also increased.

By using a process adapted for high ammonia content (8 g L^{-1}) at a pH close to 8, it is possible to have a sanitising mesophilic process (unpublished data). Maintaining high ammonia levels requires restricted feeding of the reactor with a high protein diet, e.g., pig manure. Since biogas can also be used as fuel for kitchen stoves, a hygiene evaluation of biogas has been performed, with microorganisms corresponding to the levels in natural gas being detected (10–100 cfu/m^3). The evaluation of this use of biogas indicated a low risk regarding disease transmission (Vinnerås et al., 2006).

Anaerobic digestion is a complex system with environmental benefits, as valuable energy in the form of biogas is produced. However, depending on the system design, large amounts of methane can escape to the atmosphere during digestion and subsequent storage and handling.

4.5. Ammonia treatment

Ammonia treatment both stabilises and sanitises manure and BW. The sanitation effect is achieved at considerably lower pH (9–10) than regular treatment with bases (Allievi et al., 1994). The ammonia treatment requires uncharged ammonia for inactivation of microorganisms (Warren, 1962), and a reduction in the viability of bacteria has been noted from 5mM NH_3 (Park and Diez-Gonzalez, 2003). The total ammonia concentration, pH and the temperature regulate the concentration of uncharged ammonia. By controlling these three parameters, it is possible to optimise the treatment according to the crop to be fertilised. Sanitation requires a closed treatment system, e.g., roofed slurry tanks, otherwise the ammonia is lost as gaseous emissions.

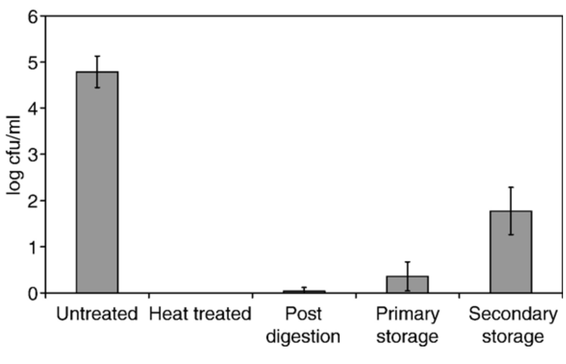

Fig. 1. Density of coliform bacteria (37 °C) in biowaste treated by pasteurisation at 70 °C for 60 min followed by anaerobic digestion. The bars indicate standard deviations. Modified from Bagge et al. (2005).

Ammonia is added either as aqueous ammonia solution or as granulated urea. This treatment is efficient for inactivation of bacteria, parasites and some viruses. No VTEC could be found after 5 days of treatment above 10 °C (according to recommended additives and treatment time described below) (Nordin, 2006). The reduction of single-stranded RNA viruses such as enteroviruses is effective (Ward, 1978), but double-stranded viruses (e.g., rotavirus) are relatively resistant to ammonia, as to most other treatments. Recommended treatment of manure is either 0.5% NH_3 for one week, or 2% urea for two weeks at temperatures above 10 °C, or for one month at temperatures below 10 °C (Ottoson et al., in press). The environmental and economic cost of ammonia treatment is low, as the ammonia used can be recycled as a fertiliser.

Based on the time for decimal reduction of a set of indicator organisms for intestinal pathogens including bacteria, viruses and parasites when exposed to uncharged ammonia, a decision support tool is under development. The tool will be developed for support in deciding upon treatment depending on the external limitations (Fig. 2). Empirical studies have given the required time of treatment for reduction, corresponding to a 5 $\log_{10}$ reduction, for a set of pathogens at different NH_3 concentrations. This is then used in an iterative process for developing treatment recommendations based on:

1. The crop to be fertilised according to its nutrient requirements and hygiene risk
2. Ambient temperature
3. Storage capacity and/or time available before fertiliser is needed
4. Concentration of uncharged ammonia, which is regulated by the total ammonia concentration, pH and the temperature.

A treatment recommendation is produced, recommending concentrations of chemicals to add and required time of treatment before use. This decision support tool is intended to assist in the selection of treatment alternatives for recycling manure and BW in a safe way.

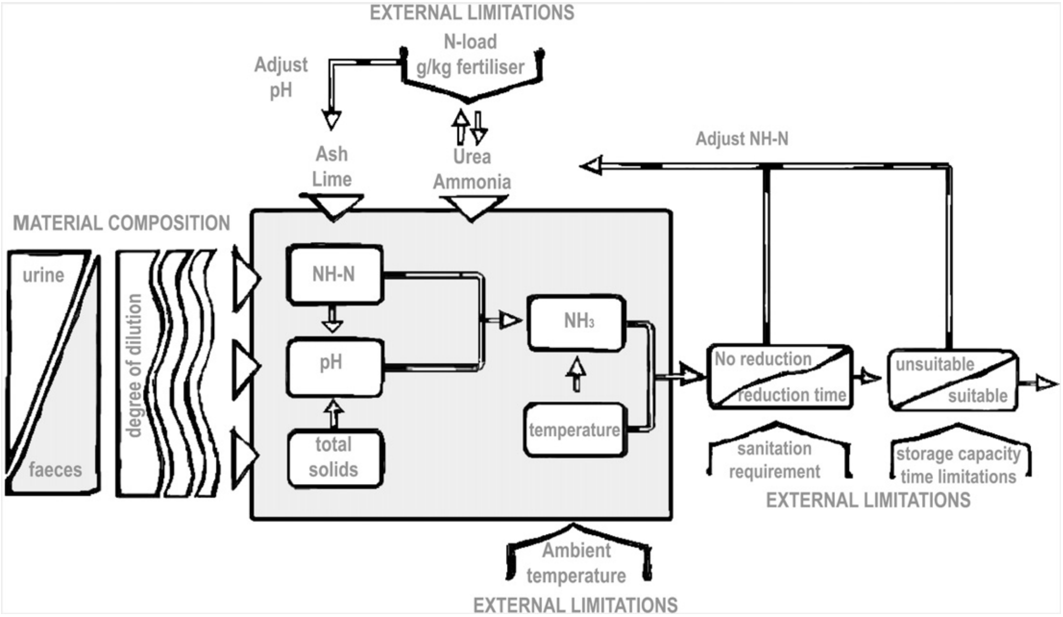

Fig. 2. Schematic representation of a treatment model for biowaste used in the proposed decision support tool.

Following the treatment recommendations, the validated decision support tool will not require any microbial analysis for ensuring hygienically safe fertilisers. Only simple testing of ammonia, pH and dry matter content will be needed.

5. Survival of pathogens after land application

Both the survival and growth potential of pathogens vary considerably between different species and subtypes of microorganisms (Mitscherlich and Marth, 1984). Parasites, spore-forming bacteria, and some types of viruses generally persist for the longest periods of time in the environment. Natural inactivation factors also vary considerably due to climate, season, vegetation, soil type, etc. (Cools et al., 2001; Nicholson et al., 2004). In general, survival is prolonged in a cold climate, a fact that must be taken into consideration if a quarantine period is to be set up as a safety precaution between spread of the end-product and crop harvest/grazing.

Method of application to land is important too, as ploughing-in or injection reduces pathogen spread and animal exposure, but persistence may be prolonged within soil compared to surface application. Furthermore, vegetation may provide a protective environment and enhance survival of pathogens (Ogden et al., 2002). The reliability of natural inactivation factors on plant surfaces, in soil and in feed and foodstuffs should not be overestimated. Bacterial pathogens may in some cases increase in numbers due to changes in the environmental conditions, such as after rainfall (Gibbs et al., 1997). Pathogens may persist in the environment for very long periods, several decades for spore-forming bacteria (Mitscherlich and Marth, 1984). Survival of pathogens in soil, grass and silage for close to 2 months has been shown under laboratory conditions (Fig. 3) (Johansson et al., 2005) and survival in soil and biosolids for over one year has been proven by Gibbs et al. (1995, 1997). Other studies have shown a more rapid reduction in the soil, in general enteroviruses seem to be reduced faster than indicator bacteria (Gibbs et al., 1995; Pourcher et al., 2007). Wild animals may acquire a pathogen and then act as a disease reservoir without displaying clinical symptoms. For example, wild boars in Eastern Europe

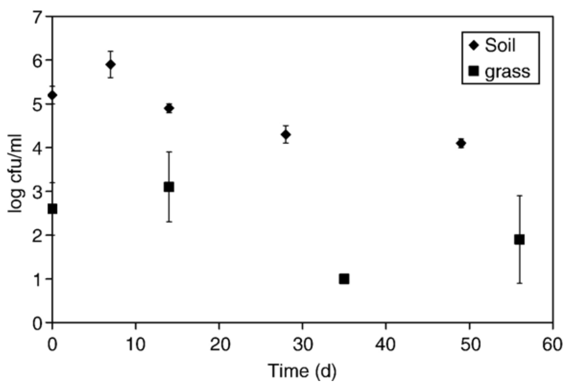

Fig. 3. Concentrations of *E. coli* in soil and on grass during 49 and 56 days of monitoring, respectively. The bars indicate standard deviations. Modified from Johansson et al. (2005).

have transmitted swine fever back to domestic pigs. On the other hand, pathogen pollution may cause infection of immunologically naive wildlife and markedly reduce whole populations.

6. Conclusions

The potential health risks associated with plant nutrient recycling in the food chain must not be ignored. More effective manure and BW management can prevent ecosystem contamination and dissemination of pathogens, while the use of artificial fertilisers may be reduced. Two main factors regulating the inactivation of pathogens have been identified, namely the temperature and the concentration of free ammonia as a function of the time of treatment/exposure. The treatment alternatives presented here (composting, anaerobic digestion and ammonia treatment) all have their advantages and disadvantages depending on local conditions, the material to be treated, and the intended use of the end-product. Therefore, prior to selection of treatment method it is necessary to evaluate the specific local conditions, and to define how the end-product is to be used as a fertiliser, according to hygiene risk of the crop.

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