Hygienic quality of organic fertilizer products intended for plant production in neighbouring farms

Veijalainen Anna-Maria[1*], Heinonen-Tanski Helvi[1], Tontti Tiina[2]
(1) University of Eastern Finland, Department of Environmental Science, Kuopio campus, PO BOX 1627, FI-70211 Kuopio, Finland
(2) MTT Agrifood Research Finland, Lönnrotinkatu 3, FI-50100 Mikkeli, Finland
*Corresponding author: anna-maria.veijalainen@uef.fi

Abstract
Organic fertilizer products were produced in four Finnish full scale facilities with five different types of treatment processes. The hygienic quality of produced organic fertilizers was evaluated by analysing the concentrations of *Escherichia coli*, enterococci, anaerobic clostridia and *Salmonella* by standard methods. According to Finnish Fertilizer Act (539/2006), the fertilizer product is considered hygienic enough if the number of *E. coli* is below 1000 cfu/g and no *Salmonella* is found in 25 g. The results showed that four of five treatment processes were able to produce hygienic fertilizer product for field application. *E. coli* and *S. typhimurium* were detected in one product due to dewatering of finished product with contaminated centrifuge. In conclusions, full scale treatment processes are effective in hygienization. However, critical points of processes must be evaluated and properly working back-up systems need to be planned for emergence situations.

Introduction
High amount of sewage sludge is formed during the wastewater treatment throughout the world. In Finland this amount is ca. 150 000 dw tons annually, and only ca. 4600 tons (3 %) is re-used in agriculture [1]. Sludge is nutrient-rich organic material, which can be turned into valuable fertilizer or soil conditioner with suitable processing according to the principles of sustainable development.

However, sludge contains pathogens, which may pose hygienic risk to agricultural workers or in food production chain if it is not hygienized before application. Variable treatment processes e.g. composting, digestion and lime stabilisation, have been applied for sludge in Finland. The hygienic quality of sludge products may be variable [2], and all products have not met the regulations given by Finnish Fertilizer Product Act (539/2006). According to the Act the products must contain less than 1000 cfu/g *Escherichia coli* and no *Salmonella* is allowed in 25 g.

We studied the hygienic quality of stored fertilizer products before land application and evaluated methods used for hygienization. This study is part of the project "Organic fertilizer products for plant production in neighbouring farms, LeviLogi"-project, which studies new organic fertilizer products introduced into the market. The project is focused on finding suitable spreading and dosage techniques as well as proper storing approaches not forgetting the hygienic and chemical quality of produced organic fertilizers.

Material and Methods
Treatment processes
Organic fertilizers (products A-E) were produced in Finnish wastewater treatment plants or other full scale facilities and stored in windrows before the application into agricultural land. Five treatment processes included A) digestion in biogas process and stack composting, B) digestion in biogas process with dewatering and C) digestion without dewatering, D) digestion with thermal dewatering and E) chemical treatment in three step process including acidification, oxidation and flocculation with dewatering (Table 1).

Product A was produced from municipal sewage sludge, which was pre-treated with a 3-week's mesophilic digestion at 36-37 °C. After digestion sludge was mixed with sedge peat in 1:1 volumetric ratio and mixture was composted in stacks at least for 6 months. Composting stacks were mixed mechanically three times during composting period to ensure uniform quality of each batch.

Products B and C were produced from municipal sewage sludge, separately collected biowastes and agricultural biomasses. The treatment process included 2-phased continuous digestion. Organic residues were pre-treated (including grinding, mixing and removing inorganic residues) and hydrolyzed before continuous thermophilic digestion (52-60 °C) in 2700 m^3 reactor. After digestion material was moved to hygienization tanks (V= 10 m^3) and treated at 70 ^oC for 1 h. Hygienized material was either centrifuged to 25 % dry matter content (product B) or stored without centrifugation with 5 % dry matter content (product C).

Product D was produced from 3-class animal by-products including municipal sewage sludge, household biowastes, organic residues from food industry and fat separation well sludge. Treatment process included pretreatment, 50 day's mesophilic digestion at 36-37 °C, centrifugation, thermal dewatering and pelleting.

Raw material for product E was municipal sewage sludge, which was treated with continuous chemical process in two reactors. The steps were: acidification with sulphuric acid (pH 3.5-4.5), strong oxidation with hydrogen peroxide (ca. 30 kg/t TS) in the presence of Fe-ions and and 3) polymerization together with pH adjustment and centrifugation.

Table 1. Raw materials, treatment and hygienization processes used for the production of five different types of organic fertilizers (A-E) in Finnish full scale facilities.

Pro-duct	Raw materials	Treatment processes	Hygienization process	Organic fertilizer product
A	Digested municipal sewage sludge	Stack composting with mechanical mixing and grinding	Mesophilic digestion (36-37 °C) and ageing in stack compost	Soil improvement compost (TS 40 %)
B	Municipal sewage sludge, biowastes, agricultural biomass	Pre-treatment, thermophilic digestion, hygienisation and centrifugation	Heat treatment in reactors (V= 10 m^3) ≥70 °C, 1 h	Dewatered digestion residue (TS 25 %)
C	Municipal sewage sludge, biowastes, agricultural biomass	Pre-treatment, thermophilic digestion, hygienization	Heat treatment in reactors (V= 10 m^3) ≥70 °C, 1 h	Digestion residue (TS 5 %)
D	Municipal sewage sludge, biowastes from households and food industry, fat separation well sludge	Pre-treatment, mesophilic digestion, centrifugation, thermal dewatering and pelleting	Thermal dewatering ≥102 °C, ≥10 min	Dry granules (TS 90 %)
E	Municipal sewage sludge	Acidification, oxidation, polymerization, alkalinisation and centrifugation	Oxidation with ca. 30 kg/t TS H_2O_2 together with acid conditions and Fe-ions	Chemically treated soil improvement (TS 28 %)

Sampling

The samples for microbiological analysis were collected from organic fertilizers at the time of field application. Three samples, which all consisted from five subsamples, were collected systematically from each windrow. Total of six samples were analysed from products A-D and nine samples from product E, which had two and three windrows in agricultural land, respectively. If hygienic quality did not meet the limits given by Fertilizer Product Act (539/2006), the concentrations of *E. coli*, enterococci, anaerobic clostridia and *Salmonella* were also analysed from soil 21 days after the application into agricultural land from the depth of 2-12 cm. Ten sub samples were pooled together to form one soil sample for microbiological analysis from each field plot.

Figure 1. Organic fertilizer B, which was produced from municipal sewage sludge, biowastes and agricultural biomass.

Microbiological analyses

All microbiological analyses were started within 24 hours after sampling. The hygienic quality of produced organic fertilizers and soil samples were evaluated by analysing the concentrations of *Escherichia coli*, *Salmonella*, enterococci and anaerobic clostridia. *E. coli* was analysed by applying ISO 16649-2 (2001) [3] and *Salmonella* by using pre-enrichment and Rappaport-Vassiliadis broth according to ISO 6579 (2002) [4]. *Salmonella* strain was serotyped in the laboratory of Finnish Food Safety Authority EVIRA with EVIRA 6004 modified ISO 6579 (2002) method. Intestinal enterococci were determined on Slanetz-Bartley agar (Lab M, UK) and confirmed with catalase as described in [5]. Anaerobic clostridia were analyzed according to NMKL 56 (2008) [6] otherwise but D-cycloserine was added to growth medium to increase the selectivity.

Results

The hygienic quality of stored products was found to be good in most cases (Table 2). Only after the treatment process which was used for the production of organic fertilizer B, the hygienic quality did not meet the limits of Fertilizer Act (539/2006) set for *E. coli* and *Salmonella*. There number of *E. coli* was over 1000 cfu/g in two of the six analysed samples, and *Salmonella* was detected in five of the six analysed samples (Table 2). Therefore the soil samples were analysed after field application. The detected *Salmonella* strain was found to be pathogenic *S. typhimurium.* In spite of the fact that the occurrence of all salmonella serotypes are not usual in Finnish domestic animals or people, *S. typhimurium* belongs to those most common serotypes which can be found in fresh faeces of animals and human beings.

Table 2. The minimum and maximum concentrations of *E. coli*, enterococci, anaerobic clostridia (cfu/g) and *Salmonella* (positive/negative) in products (A-E) before the field application (n=6 in products A-D and n=9 in product E). The detection limit was 1 cfu/25 g for *Salmonella* and 5 cfu/g for other hygiene indicator microbes.

Product	*Escherichia coli* (cfu/g)	Enterococci (cfu/g)	Anaerobic clostridia (cfu/g)	*Salmonella* (positive/negative)
A	not detected	not detected	1300 – 1.7×10^4	negative
B	18 – 1300	2700 – 8.7×10^4	3800 – 2.5×10^4	positive in 5of 6 analysed samples
C	not detected	<5 – 5	8000 – 9300	negative
D	not detected	not detected	<5 – 10	negative
E	5 – 230	860 – 8500	2000 – 1.7×10^4	negative

Microbial concentrations were reduced after the field application due to the dilution effect and deteriorated conditions for intestinal microorganisms under sun and other environmental factors. Neither *E. coli* nor *Salmonella* was detected in soil samples collected from the fields where the product B was spread. The concentration of anaerobic clostridia was 63-630 cfu/g soil, which was 0.2-6.0 % of original concentration detected in fertilizer product B before application.

Conclusion and perspectives

This study showed that different full scale processes, which are used for the hygienization of sewage sludge and other organic waste materials in Finland, can be effective. Only one of the five evaluated processes failed in producing hygienic organic fertilizer product. The reason was found to be the lack of decontamination of sludge dewatering system. In that case, the same centrifuge was used for both untreated and hygienized sludge without cleaning it before centrifugation of hygienized sludge. This kind of critical points should be taken into account while designing treatment processes. Initialization of well-designed back-up systems is needed to avoid the contamination of final fertilizer product. After successful process the sludge can be re-used without hygienic risks in agricultural applications, and the use of organic fertilizer products can be increased.

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