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Environmental impact of recycling digested food waste as a fertilizer in agriculture—A case study

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ABSTRACT

This study assessed the environmental impacts of recycling the plant nutrients in anaerobically digested food waste as fertilizer in agriculture. This was compared with the impacts of using chemical fertilizer, where the food waste was incinerated, producing heat. The study site was a biogas plant in central Sweden and life cycle assessment methodology was used. The impacts studied were primary energy use, global warming potential (GWP), potential acidification, potential eutrophication, cadmium flow to farmland and use of phosphate rock. Use of digested food waste as fertilizer proved to have larger negative results than use of chemical fertilizer in all categories assessed except use of non-renewable phosphate rock. Sensitivity analyses showed that the scenarios were comparable in terms of primary energy use and better for GWP if some improvements in the anaerobic digestion system were made. However, acidification and eutrophication caused by digestate handling and the cadmium content of digestate should still be considered.

1. Introduction

Food waste contains plant nutrients mainly originating from agriculture. To maintain its fertility, agricultural land needs to be compensated for the loss of these nutrients. One obvious way of doing this is to recycle them back to arable land, in line with both the European Union (EU) waste hierarchy and the principles of ecology in organic farming, as this promotes reuse and recycling (IFOAM, 2013). The need for external plant nutrients is large for farms producing cereals and vegetables for the market (Doltra et al., 2011). In conventional agriculture this need is normally covered by using chemical fertilizers. However, their use is not allowed in organic agriculture, which leads to the use of more expensive fertilizers, e.g. pelletized meat meal.

An alternative fertilizer rapidly becoming more widely used by both conventional and organic farmers in Sweden is anaerobically digested food waste (Avfall Sverige, 2013). Compared with chemical fertilizer, digested food waste fertilizer ought to have several environmental advantages, as high quality energy is gained in the production process and the nutrients are preserved within the effluent, i.e. the digestate. On the other hand, production of chemical fertilizer is energy intensive, contributing about 56% to indirect energy use in Swedish agriculture (Ahlgren, 2009) and fixes nitrogen from the atmosphere, thus increasing the amount of nitrogen in the biosphere. Chemical fertilizer production thus increases the global flows of nitrogen and phosphorus at a time when the levels of nitrogen have already exceeded the safe planetary boundaries and the levels of phosphorus are about to do so (Rockström et al., 2009). Use of pelletized meat meal fertilizer recycles nitrogen and phosphorus and does not increase their global flows, but has the disadvantage that it is relatively energy demanding (Spångberg et al., 2011).

Use of digestate also contributes to carbon sequestration, as digestate organics are incorporated into the soil. The production of biogas is the reason why anaerobic digestion of food waste is rapidly increasing in Sweden, by 25% between 2009 and 2011 (Energimyndigheten, 2012a). Recently, the Swedish parliament set a national goal that by 2018, 40% of all food waste should be treated in such a way that both nutrients and energy are recovered, i.e. that it is digested (Swedish Government, 2012).

The Swedish population is exposed to high levels of cadmium (Cd), resulting in adverse effects on both skeleton and kidney tissues. The main exposure routes are through food and smoking. Food cadmium intake is high, partly due to high levels of cadmium in Swedish agricultural soils. The maximum level in fertilizers in Sweden to prevent this situation deteriorating further has been

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estimated at 12 mg Cd per kg phosphorus (KEMI, 2011). Meeting this level is a challenge for all recycled fertilizers. Manure contains about 8–15 mg Cd per kg phosphorus (KEMI, 2011) and food waste around 35 mg (Jönsson et al., 2005). Chemical fertilizers used in Sweden mostly contain around 3–6 mg Cd per kg phosphorus (KEMI, 2011). However, chemical fertilizers give a net cadmium input to the soil, while recycled fertilizers, such as manure and food waste, largely recycle cadmium previously taken up from the soil and therefore should not increase the level in the long run.

Earlier life cycle assessment (LCA) studies on anaerobic digestion of food waste have mainly focused on assessing different waste treatment alternatives at the level of city (Bernstad and la Cour Jansen, 2011; Kirkeby et al., 2006) or country (Börjesson and Berglund, 2007; Fruergaard and Astrup, 2011; Kim et al., 2013; Khoo et al., 2010). A few LCA studies have shown that incineration of food waste is a better alternative than anaerobic digestion in terms of the environmental impact (Kim et al., 2013; Fruergaard and Astrup, 2011; Börjesson and Berglund, 2007). Other LCA studies have reported that anaerobic digestion of food waste is more beneficial than incineration (Khoo et al., 2010; Bernstad and la Cour Jansen, 2011). However, in those studies infrastructure and digestate handling were not included.

Several studies (Kim et al., 2013; Börjesson and Berglund, 2007) have reported that anaerobic digestion of food waste gives a net contribution to GWP. Other studies have reported a net negative GWP (e.g. Fruergaard and Astrup, 2011; Bernstad and la Cour Jansen, 2011; Poeschl et al., 2012). Incineration of food waste for energy recovery is often reported to avoid GWP (Kim et al., 2013; Fruergaard and Astrup, 2011), but sometimes reported to contribute to GWP (Bernstad and la Cour Jansen, 2011; Börjesson and Berglund, 2007). The results on eutrophication and acidification in some previous studies showed no significant difference between incineration and digestion of food waste (Börjesson and Berglund, 2007; Kirkeby et al., 2006), but these studies seemed not to include digestate handling, which is where the main acidifying and eutrophying emissions occur. Other studies showed that eutrophication (included as nutrient enrichment) was greater for biogas production than for incineration of food waste and results on acidification were greater for incineration than for biogas production (Bernstad and la Cour Jansen, 2011; Fruergaard and Astrup, 2011). The main reasons for these differences in eutrophication and acidification impacts were that digestate storage was not included by either of the studies compared and that nitrogen leaching was included, mainly causing eutrophication. In contrast, the present study included infrastructure and assessed the handling and use of digestate from anaerobic digestion of food waste as a fertilizer for conventional or organic farming. The study was based on data from an organically certified anaerobic digestion plant in central Sweden.

2. Methodology

LCA methodology was used according to ISO 14040 and 14044 (ISO, 2006). System description and data used are provided below.

2.1. Goal and scope

The goal of this study was to assess the impacts on the environment and resources of using digested food waste as fertilizer and to compare these impacts with those of using chemical fertilizer. In the digestate fertilizer (DF) scenario, food waste was digested, the digestion residues spread as fertilizer on arable land and the biogas produced used as vehicle fuel. In the chemical fertilizer (CF) scenario, chemical fertilizer was manufactured and spread on arable land, and the same amount of food waste as was source separated in the DF scenario was incinerated, producing heat.

2.2. Functional unit

The functional unit (FU) assessed was the production, handling and spreading of a fertilizer containing 1 kg plant-available nitrogen and 0.20 kg phosphorus after spreading on arable land. The amount of phosphorus was based on the composition of the digested food waste after spreading. The collection and treatment of 254 kg pure food waste from households was also included in the functional unit. This corresponded to 266 kg food waste (including paper bags and contaminants such as stones, plastic etc.) being collected in the DF scenario and 259 kg in the CF scenario (including contaminants but not paper bags).

2.3. Impact categories

The impact categories of global warming, acidification and eutrophication were evaluated, as these have been shown to be most important for organic fertilizers (Spångberg, 2014; Brentrup et al., 2004). Emissions to air and water affecting these impact categories were estimated, e.g. emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), sulphur oxides (SO_x), ammonia (NH_3)and phosphate ($PO_4{}^{3-}$). Global warming was quantified using a 100-year perspective (IPCC, 2006). Eutrophication and acidification were quantified using the CML 2001 method (Guinée et al., 2002). The primary energy was calculated as the cumulative energy demand (Ecoinvent, 2010) or by multiplying the energy carriers used by their primary energy factor. Use of phosphate rock and the flow of cadmium to arable land were also assessed.

2.4. System boundaries

The processes and activities included are shown in Fig. 1. Data from a biogas plant in central Sweden were used for the DF scenario. The emissions from collection of source-separated food waste from households, production and use of biogas, storage, handling of the liquid and solid digestates, and handling and disposal of reject fractions were included. The biogas produced from food waste was upgraded to vehicle fuel, replacing natural gas. Food waste contaminated with plastic, wood, textiles etc. ended up in the dry and wet reject fractions. The dry reject fraction was incinerated, with recovery of heat, and the wet reject fraction was composted, producing a substrate for soil production. The heavy reject fraction was landfilled. The data used in this scenario were average data for the period 2010–2012. In the CF scenario, the food waste was collected in a mixed household waste fraction and incinerated, producing heat that replaced average Swedish district heating. The fly and bottom ash generated were sent to landfill. In this scenario, chemical fertilizer was used to fertilize arable land and thus fulfil the functional unit. European data were used for the manufacture of chemical fertilizer. The infrastructure of both scenarios was included in the study. Leakage of nitrogen from arable land was neglected, as this was considered to be similar for both scenarios.

3. System description and data used

3.1. Food waste characteristics

Food waste was collected from households and businesses such as restaurants and industries, in approximate proportions of 82% from households and 18% from restaurants and industries (Jönsson et al., 2005). The composition of food waste treated was calculated from the composition of food waste from households, restaurants