The multi-functionality of using cultivated mussels as fertiliser – a scenario study

Spångberg Johanna[1*], Jönsson Håkan[1], Tidåker Pernilla[2]
(1) Swedish University of Agricultural Sciences, Department of Energy and Technology, 75007, Uppsala, Sweden
(2) Swedish University of Agricultural Sciences, Department of Crop Production Ecology, 75007, Uppsala, Sweden
*Corresponding author: johanna.spangberg@slu.se

Abstract
This LCA study assessed the environmental impact of mussel farming on the Swedish coast of the Baltic Sea for subsequent use as agricultural fertiliser. The functional unit was related to the agronomic value of the mussels, including plant-available nitrogen, phosphorus and liming effect and also including the reduction of nutrients reaching the sea. Flow of cadmium to soil was also assessed. In one scenario the mussels were composted and in another they were inertly stored to avoid nitrogen losses and other emissions from storage. Due to significant nitrogen losses from the composting process, the compost scenario resulted in a higher use of energy than the inert storage scenario. Reducing eutrophication by cultivating mussels for fertiliser use proved more energy-efficient than reducing eutrophication in a wastewater treatment plant. Using mussels as fertiliser often supply less cadmium to the field than the chemical fertiliser and liming products it replace.

Introduction
Eutrophication of coastal waters is a serious environmental problem due to increased loads of nutrients, with the Baltic Sea being seriously affected. Nitrogen and phosphorus derive mainly from agriculture, wastewater, industry and, in the case of nitrogen, also from deposition from the atmosphere. To achieve the goal of good ecological status of the Baltic Sea by 2021, the surrounding countries have devised the Baltic Sea Action Plan (BSAP), which requires extensive decreases in nutrient loads, particularly diffuse emissions [1]. Mussels are filter feeders, collecting nutrients bound in e.g. phytoplankton, and if the mussels are harvested and used onshore, their accumulated nutrients are removed from the water and water quality is improved [2]. The mussels commercially cultivated in Sweden, of species *mytilus edilus*, are mainly grown in the Skagerrak Sea for use as human food. Due to the lower salinity of the water in the Baltic Proper, the fully grown mussels are too small there to be used for food with present technology, as the meat is difficult to separate from the shell. Potential mussel cultivation on the east coast would thus be for use as feed or fertiliser. If the potential area of good sites for mussel cultivation of about 800 ha [3] in the Baltic Proper would be used, mussel cultivation would give a total potential reduction of about 480 tonnes of nitrogen and about 32 tonnes of phosphorus per year from the Baltic Proper [4]. Mussels could thus be a significant source of nutrients in organic farming, where especially stockless farms are in need of external nutrients. Mussel harvesting would simultaneously help to combat eutrophication.
Cadmium levels are an important aspect to consider for fertiliser products. There is currently no EU regulation on cadmium in fertilisers, but there are proposals to set a limit of 46 mg cadmium per kg phosphorus [5]. The goal of the study was to assess the environmental impact of using mussels cultivated in the Baltic Sea as fertiliser on agricultural land. Two mussel scenarios were studied; one where the mussels were composted and one where they were stored inertly, to reduce nutrient losses. Also these two scenarios were compared with the use of chemical fertiliser.

Methods and data
Methods
Methodology of Life Cycle Assessment was used in the study [6,7]. Functional unit (FU) was production of 1.00 kg of plant available nitrogen, 0.88 kg of phosphorus and a liming effect of 225 kg calcium oxide (CaO) on arable land (the relation between these agricultural values based on the content of ready mussel compost). To include the function of decreased eutrophication of the sea the reduction of nitrogen and phosphorus at a conventional waste water treatment plant was included in

the chemical fertiliser scenario. Impact categories studied were eutrophication (expressed in PO_4^{3-}-equivalents) and energy use (expressed in MJ). Characterisation method used to calculate the potential eutrophication was CML 2001 (European averages) and for energy balances the cumulative energy demand. Also the flow of cadmium to soil was assessed. The scenarios included all processes from extraction of the raw materials through the production of the fertilisers, e.g. treatment of the mussels, to final disposal of the materials and spreading of the fertilisers on the field. Additional data and references are found in Spångberg et al. [8].

Compost scenario
At present mussels cultivated on the east coast of Sweden seem to grow best on nets. Mussel larvae settle on these nets in June (Fig. 1). After 28-30 months, around 150 tonnes of mussels can be harvested per hectare of sea containing five units of two linked nets, each 125 m long and 4 m deep [4]. The nets float at a predetermined depth and position with the help of plastic tubes on the surface, chains to buoys and steel anchors. The mussel harvesting season is long (2-3 months), and it is not always possible to use the mussels as fertiliser directly and therefore they are composted to reduce the release of strong odour during storage. The mussels were assumed to be harvested in the period October-December.

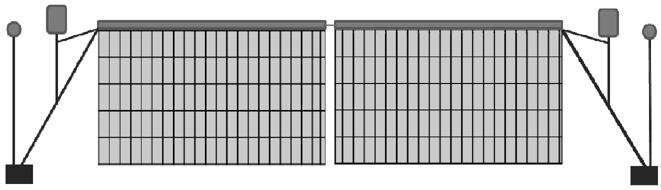

Figure 1. Conceptual sketch of the mussel cultivation net used in this study.

To fulfil the functional unit (FU) in the compost material after spreading, this corresponded to harvesting 1097 kg Baltic Sea mussels. The harvested mussels were loaded onto a fishing vessel, brought to harbour and transported by lorry 50 km to the farm. The mussels were assumed to be mixed with straw from the farm. Nitrogen losses from the compost were estimated to be 58% of total nitrogen content, based on mussel compost trials in Western Sweden [10]. In spring, after about 5-7 months of storage, the compost was assumed to be spread on fields with the spreading technique used for solid manure. Emissions from spreading were assumed to be the same as for solid manure incorporated after 4 hours.

Inert scenario
Cultivation of mussels was done in the same manner as in the compost scenario. To fulfil the FU this scenario corresponded to only 149 kg of harvested mussels. These harvested mussels were crushed on arrival at the farm and stored under anaerobic conditions in a storage tank topped up with water and covered with a PVC lining. Their storage in anaerobic conditions was done to prevent aerobic degradation, and thereby losses of nitrogen and emission of odour. The mussel biomass together with the top-up water was assumed to be pumped from the storage tank and spread using ordinary equipment for liquid manure. To make the Inert scenario fulfil the functional unit and thus comparable with the Compost scenario, an additional 196 kg CaO equivalents and 0.76 kg phosphorus were needed. The liming effect needed corresponded to 393 kg crushed limestone (50% CaO effect per kg dry weight) and the phosphorus to 1.74 kg ground phosphate rock. The average cadmium level in lime products sold in Sweden is about 0.4 mg per kg CaO equivalent [11] and for phosphorus used in this study about 3 mg per kg phosphorus [12].

Chemical fertiliser scenario
In this scenario, the chemical NP fertiliser was calculated as being composed of triple superphosphate (TSP) and ammonium nitrate (AN) with an N:P ratio of 1:0.88. In addition 225 kg of CaO equivalents of crushed limestone were added in order to fulfil the FU. In this scenario an alternative nutrient reduction was included that decreased the emissions to the Baltic Sea by the same amounts of nitrogen and phosphorus as were removed in the Compost scenario and the Inert scenario.

The data used were based on the capacity of the WWTP in Kalmar including use of precipitation chemicals, energy use and use of carbon source for removing nitrogen and phosphorus at the plant.

Results

Potential eutrophication

The mussel scenarios gave large negative values for potential eutrophication due to the mussels taking up nitrogen and phosphorus as they grow (Fig. 2). Storage in the Inert scenario caused significantly lower emissions than the Compost scenario due to the smaller nitrogen losses in this scenario, which resulted in it needing about 86% less mussels per FU than the Compost scenario. The reason the Chemical fertiliser scenarios caused less eutrophication was due to less eutrophying emissions in the production phase. It should be noted that a maximum eutrophication scenario was used, assuming that both nitrogen and phosphorus contributed to eutrophication.

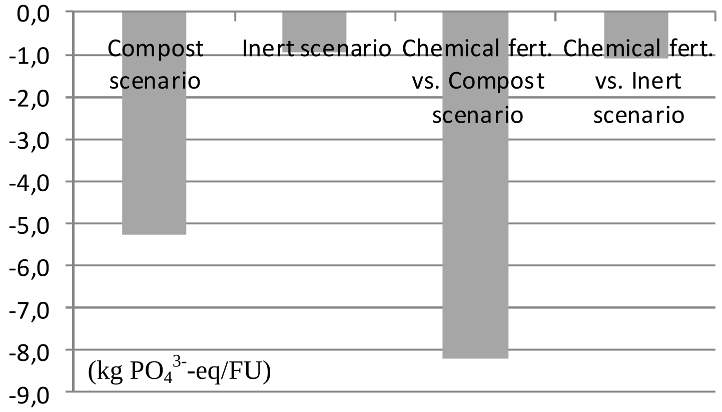

Figure 2. Potential eutrophication for all scenarios.

Energy use

Energy use in the Inert scenario was about 29% of that in the Compost scenario (Fig. 3). Energy use was strongly related to production of materials for mussel cultivation, which accounted for 77 and 36% of the total energy use in the Compost and Inert scenario, respectively. About 85% of the energy used in the Chemical fertiliser vs. Compost scenario and about 50% of the energy used in the Chemical fertiliser vs. Inert scenario derived from the energy demanding process of removing nitrogen at the waste water treatment plant.

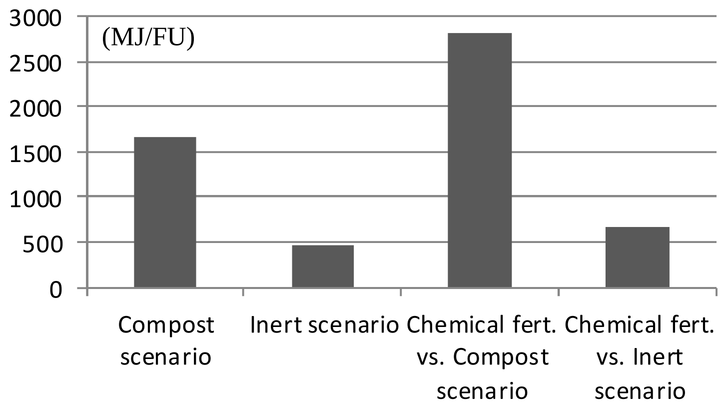

Figure 3. Total energy use for all scenarios.

Cadmium to soil

The results on flow of cadmium to soil showed that even though the mussels had a relatively high cadmium content, when including the agricultural functions of nitrogen content, phosphorus content and liming effect of the mussels, the total amount of cadmium to soil was lower for the Compost scenario than for the other two scenarios (Fig. 4). About 86 and 97% respectively in the Inert scenario and the Chemical fertiliser scenario derived from the lime product.

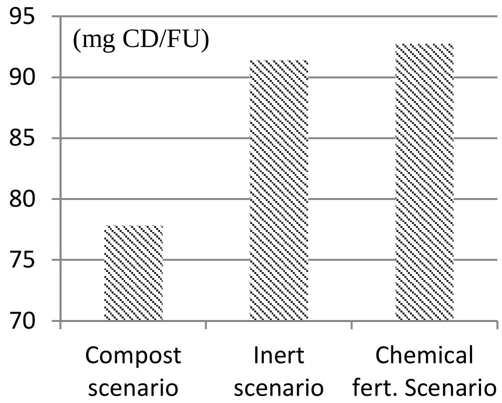

Figure 4. Flow of cadmium to arable soil for all scenarios.

Conclusion and perspectives

The results of this study clearly show the importance of considering the multiple functions provided by mussels applied to agricultural land, i.e. their fertiliser value, their liming effect and their reduction of eutrophication. Cultivating mussels and bringing them to arable land could be a way to mitigate eutrophication, but one should consider the treatment of the mussels so the emissions from the treatment are minimised. Thus smaller amount mussels would be needed and the environmental impact from treatment would be reduced. Also it is interesting to note that when including all three agricultural functions considered in this study of the mussels, the total flow of cadmium to soil is lowest for the scenario with only mussels added to arable land. As most chemical phosphorus fertilisers in Europe also have higher cadmium content than the one used in this study this difference would be even greater in a European perspective.

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