Modelling management options of organic waste for the evaluation of synergies and trade-offs between climate change mitigation and ecosystem services

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Abstract
Treatment technologies can play a key role aiming to reduce the environmental burdens associated to agricultural waste. Simultaneously they can help to improve production efficiency and convert by-products into valuable resources while enhancing land functions linked to the role of soil in closing substance cycles. In the current study, a modelling framework is presented for evaluating the effects of different strategies for the management of organic waste in terms of GHG emissions, nutrient balance and their relationship with a range of selected ecosystem services, providing a more holistic approach for the analysis of scenarios and decision making process.

Introduction
In the last decades management of manure and other by-products from agriculture has been identified as a major source of environmental impact, especially in those areas with greater concentration of livestock. Degradation of animal manure, for example, leads to the emission of GHG emissions and other N losses thus contributing to regional (eutrophication, acidification) and global scale (climate change) issues. Although poorly understood, farm management (e.g. manure) is expected to affect the interactions between the environmental losses and the level of farm ecosystem services (ES) attained (e.g. biodiversity) [1]. Several treatment alternatives such as composting and anaerobic digestion (AD) have been found to be useful alternatives to decrease GHG emissions (e.g. AD) or to improve soil structure (e.g. composting). To date, however, to our knowledge, there are no tools that are able to investigate the effect of such treatments on environmental losses and ecosystem services together. The aim of this study is to develop an integrated modelling framework that enables us to assess the effects of different organic agri-food waste management options on GHG emissions, other losses, nutrient recovery and influence on a range of selected land functions or ES.

Material and Methods
Model overview
A modelling framework has been proposed to link different sub-models involved in the farm system following a mass balance principle of the considered substances (C, N, P, K). In order to reflect the interactions between the activities and services of the system under study, together with the associated externalities involved, a life cycle assessment (LCA) methodology was applied at every stage, accounting for impacts related to fuel and energy production as well as potential benefits, such as biogas production and compost or digestate application.

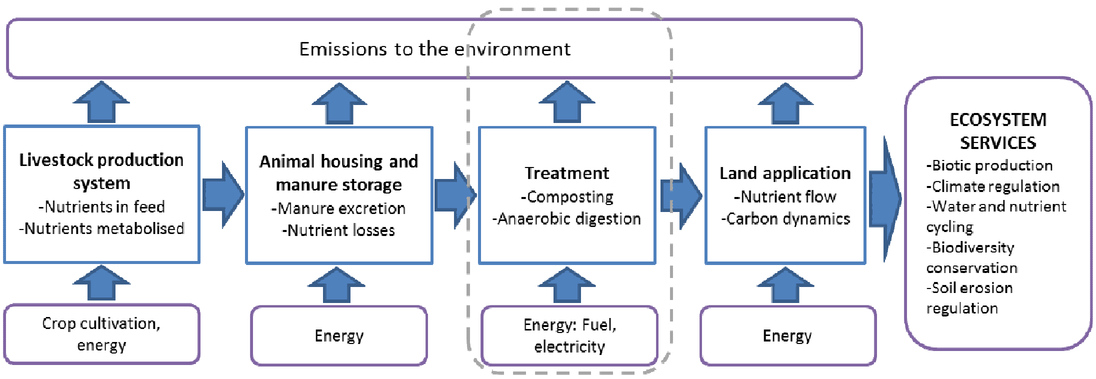

Figure 1. Modelling framework for livestock production system

As indicated in figure 1, present study is focused on the description of the approaches developed for the modelling of the waste management stage. Three main scenarios are considered to build the sub-models. Anaerobic digestion (AD) and composting (CM) were selected as the most probable treatment options for livestock manure together with additional amounts of organic wastes, whereas storage of untreated manure previously to application on the field was considered as the conventional management scenario. AD and CM sub-models were developed from an approach based on the combination of emission factors (EFs) and variation factors (VF), as previously proposed for other authors [2].

Results

Composting model

Composting model was developed from based on a literature review of manure composting experiments. Average emission factors (EFs) for gaseous emissions were calculated and weighted by the product of different variation coefficients related with a selection of characteristics of the input materials (Moisture content, C/N ratio, lignin) and the operational conditions of the process (technology used, ambient temperature, time). Additionally, nutrient (N,P,K) losses by run-off were accounted according previous studies [3], [4].

The main factors influencing the composting process were considered to be moisture content, C/N ratio and lignin fraction. Dry conditions restrict microbial activity, reducing biodegradation process, while an excess of moisture could affect the oxygen supply, leading to anoxic or anaerobic conditions, where emission of methane (CH_4) and nitrous oxide (N_2O) may be enhanced. In well aerated systems, the influence of free air space may be less relevant.[5].

The C/N ratio of the feedstock can also be an important variable. In feedstocks with a high C/N ratio, N is limiting and is more likely to be immobilized than denitrified. Numerous authors have studied the effects of C/N ratio on gaseous emission during the composting of manure. According to the literature reviewed, general trend indicated that a lower C/N ratio leads to higher ammonia (NH_3) and CH_4 emissions, whereas less clear influence was observed for the N_2O.

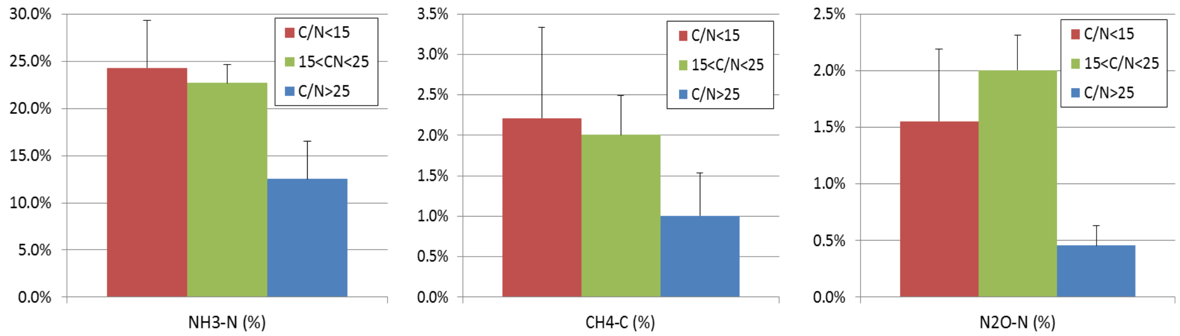

Figure 2. Influence of feedstock C/N ratio on gas emissions from composting

Different studies have also pointed out the relationship between C biodegradability and lignin content, and its influence on nitrogen immobilisation [6], [7]. Hence, a parameter considering lignin fraction of total C is included in the model. Four technological options are considered in the model (static windrow, passive windrow, intensive windrow, forced aeration) which are related with respective factors of energy and fuel consumption. Additionally, the effect of climatic conditions (temperature) and process duration is also accounted through correspondent variation coefficients.

Anaerobic digestion model

Performance of the AD process is considered to be influenced by two principal aspects: substrate characteristics and operational conditions. A theoretical method, Buswell Formula, [8] is applied to calculate CH_4 yield based on chemical composition. Result is corrected according to substrate biodegradability, which is estimated based on the lignin content, according to Chandler's equation [9].

Several variation factors have been considered, involving temperature range, N content, hydraulic retention time and reaction phases (single or two-stages technology). Currently, most of the biogas plants are operated under two optimal temperature ranges: mesophilic (around 35ºC) and thermophilic (around 55ºC). Thermophilic range can reach higher degradation rates and consequently better biogas yields in shorter retention times. However the energy demand for heating is also increased and the system becomes more vulnerable to inhibition issues due to ammonia concentration [10], [11]. Additionally, AD technology applied is also considered. Although most of the industrial scale facilities operate in a conventional single stage process, two-stage AD has shown several advantages, increasing process stability and biogas production under shorter hydraulic retention times (HRT) [12].

Biogas is assumed to be utilised for electricity production in a combined heat and power (CHP) unit, with a thermal and electrical efficiency of 36% and 50% respectively. For digestate management different options are considered: depending on the phase separation technology used (decanter centrifuge, screw-press) and post-treatment applied (composting, drying).

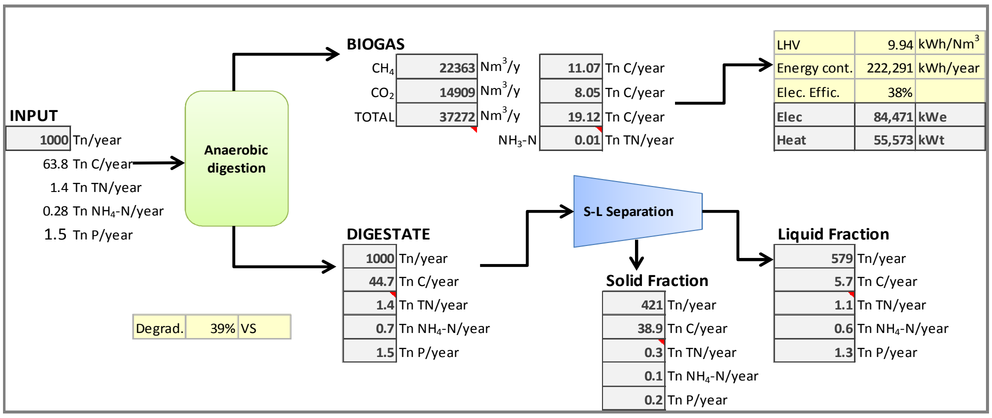

Figure 3. Flow diagram for the AD sub-model

Impact assessment and ecosystem services

Specific emissions and outputs derived from the treatment of manure are estimated according to the described sub-models, thus allowing to link results with other modules for the analysis of the whole farm system from a holistic perspective. Conventional categories such as global warming, eutrophication and acidification potential are considered for impact assessment following LCA methodology. Furthermore, model results involves composition details of the waste management products (compost, digestate), in terms of C and nutrient quantity and quality. This provides the information to explore approaches for C dynamics and nutrients evolution prediction once material is applied into the soil, allowing investigating strategies for the holistic assessment of the system, involving its relationship with land functions. Although not shown here, both AD and composting sub-models can for example be linked to the existing $LAND_{DAIRY}$ modelling approach [13] to produce the whole-farm emissions (including those from the house and fields) and to produce estimations of potential pollution swapping effects (e.g. NH_3 and GHG emissions).

Manure management has a strong influence on soil organic carbon (SOC) which is often recognised as a good indicator for soil quality, This parameter has been related to the so-called life support functions [14], which concern the role that an ecosystem plays in maintaining life processes, such as the closing of substance cycles, climate regulation or biotic production.

Other relevant aspects, such as biodiversity, can also be affected by the waste treatment selected. We are currently selecting existing proposed algorithms [15] linking management with ES. We intend to propose a set of ES linked with by-products management, which to our knowledge is quite novel. For example, relating how plant species diversity generally declines in response to nutrient enrichment, generating changes in ecosystem composition and functioning [15]. Hence, it is expected that different waste management strategies can lead to variations on the nutrient amount and availability of the product applied in the field, so playing an important role for maintaining biodiversity in agricultural systems.

Conclusion and perspectives

In the present study, special focus has been made on the description of the waste treatment sub-models within a modelling framework proposed for agricultural systems, as an attempt to reflect the different interactions between the activities and services involved. This would provide a most holistic view when defining the most adequate waste management strategy for a specific situation, in relation to the capacities of the environment, effects on land ES and possible synergies and trade-offs within the whole farm system.

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