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► To cite this version:

Marilys Pradel. Assesssing fertilisation pratices with organic residues in agriculture: A life cycle assessment perspective. 15th International Conference Ramiran, Jun 2013, Versailles, France. 4 p. hal-00947804

HAL Id: hal-00947804

<https://hal.science/hal-00947804>

Submitted on 17 Feb 2014

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Assessing fertilising practices with organic residues in agriculture: a life cycle assessment perspective

Pradel Marilys^{1*}

(1) Irstea, UR TSCF, Domaine des Palaquins, Montoldre, 03150, FR

*Corresponding author: marilys.pradel@irstea.fr

Abstract

A large part of the environmental impacts in agriculture are due to the emissions of chemicals such as nitrous oxide (N₂O), ammonia (NH₃) and nitrate (NO₃). As they generate such substances, sludges are often associated with environmental burdens and contribute to major environmental impacts (acidification, eutrophication and global warming). In this paper, we achieve a LCA study for 45 sewage sludge spreading scenarios. After assessing the system boundaries and the functional unit, inventory data were collected. Two impact assessment methods were chosen: Eco-indicator 99 and the CML baseline 2. An analysis of nitrogenous emission origins according to spreader technological performances was possible according to the first results. LCA results mainly show that pedoclimatic conditions have an influence on the environmental impacts of spreading scenarios especially for acidification, eutrophication, and global warming and that environmental impacts present significant difference between spreading machines.

Introduction

As they generate nitrous oxide (N₂O), ammonia (NH₃) and nitrate (NO₃), manures, sludges and to a lesser extent mineral fertilisers are often associated with environmental burdens and contribute to major environmental impacts (acidification, eutrophication and global warming). Concerns over these emissions have led to the assessment of the environmental impact of fertilisation processes or to the reduction of these emissions through different application techniques, mainly for ammonia volatilisation and, to a lesser extent, for nitrate leaching and nitrous oxide emission.

This paper presents a comparison of the environmental impacts of sewage sludge spreading scenarios involving different types of spreaders in different pedoclimatic conditions using Life Cycle Assessment. Life Cycle Assessment (LCA) is a common tool to assess environmental impacts of a product or a system. The process or product life cycle is assessed from raw material acquisition through production, use and disposal in a "cradle to grave" perspective. Each step of the life cycle consumes energy, depletes non renewable resources and produces air, soil and water emissions at different scales (local, regional or global scale). According to ISO14040 standards [3], Life Cycle Assessment is conducted through a four step procedure including (i) goal and scope definition, (ii) life cycle inventory, (iii) life cycle impact assessment and (iv) interpretation..

Material and Methods

System boundaries

The system boundaries are quite difficult to evaluate because spreading operations may be considered part of both the crop management and the sewage sludge disposal route. As our study is focused on the spreader environmental performances, the system boundaries are limited to the spreading operation as shown in Figure 1.

The system takes into account the logistic phase and the spreading operation itself. The inputs include the environmental impact of the agricultural machinery used for spreading operations, in both logistic and spreading phases (manufacture and transport of agricultural machinery and shed, lorry transport operation), and the energy used for the agricultural machinery (fuel production). The outputs include emissions from the fuel combustion, for both tractor and lorry, the tyre abrasion of the agricultural machinery and the nitrogenous emissions related to the sewage sludge application in the soil. Emissions during the storage (at waste water treatment plant and intermediate storage) are left out of the system. All the sewage sludge production processes, such as the metallic trace elements (MTE) contained in the sludge and the energy used for the sludge treatment (thickening, dehydration...), are not taken into account in the system.

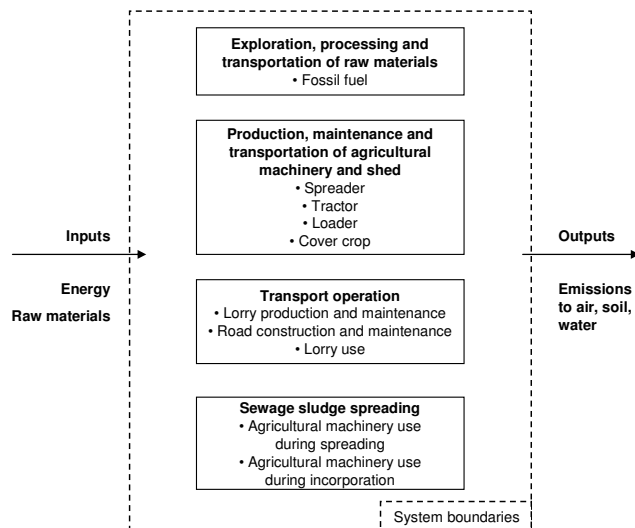


Figure 1: Description of the sewage sludge spreading operation boundaries

If sludge is considered as a fertiliser, the most suitable functional unit will be the quantity of nutritive element spread (N, P or K). However, spreading sludge is subject to legislation and should respect a fertilisation plan. Agronomic value of sewage sludge should be known to best fit the crop needs. The most relevant functional unit for our system will, thereby, be the dry matter ton of sewage sludge spread in the field, taking into consideration both the respect of legislation and an application rate calculated on the basis of the nutrient, which first fits the plant requirements.

Inventory data

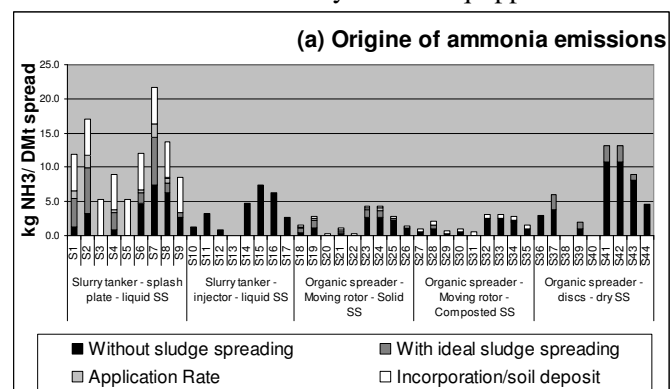
Inventory data and scenarios construction are developed in [1, 2].

Results

Nitrogenous emission origins according to spreader technological performances

According to the method proposed by [1], we calculated the nitrogenous emissions produced by the different studied spreading operations (Figure 2). Results show that spreading liquid SS¹ with a splash plate produces more ammonia emissions than the other spreading techniques. While ammonia emissions are not linked with the spreader performances for other application techniques, the soil deposit and, to a lesser extent, the application rate measured for the slurry tanker equipped with a splash plate have an effect on ammonia emissions for liquid SS spreading (Figure 2a). In addition, using an injection technique reduces ammonia emission in comparison with splash plate technique.

Nitrous oxide emissions are only produced in a pedoclimatic condition, where denitrification potential seems to be high and sensitive to soil compaction (Figure 2b). Finally, nitrate emissions are barely linked with spreader technological performances and depend mostly on soil and climatic conditions (Figure 2c).



¹ SS = sewage sludge

These assumptions have been made because spreading operation has absolutely no interaction with a possible reduction of the MTE environmental impacts and the sludge production process. Nevertheless, the MTE significantly impact the ecotoxicity and toxicity categories and remain the main environmental problem of sewage sludge production.

Functional unit

Sewage sludge can be considered as a waste, as well as a fertiliser. If sludge is considered as a waste, the best functional unit will be the ton of sludge spread (dry or fresh matter).

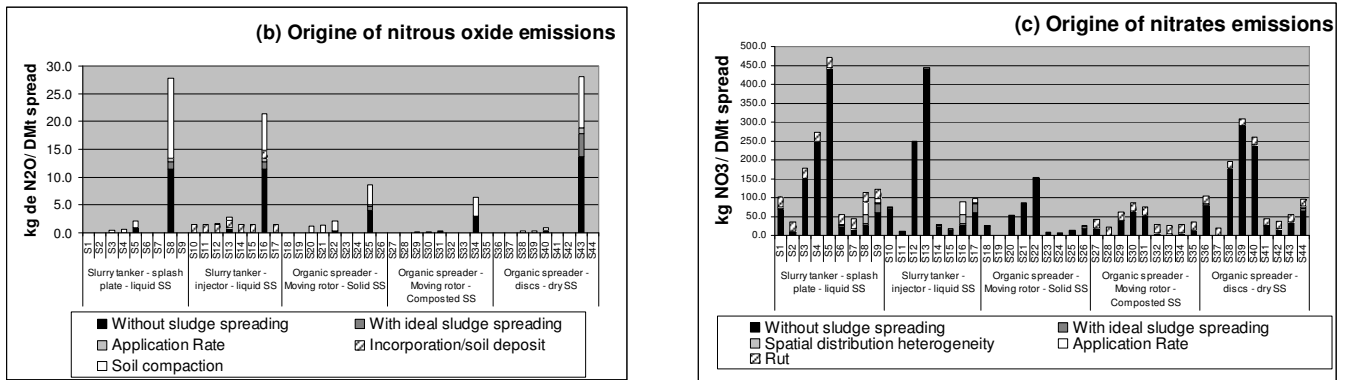


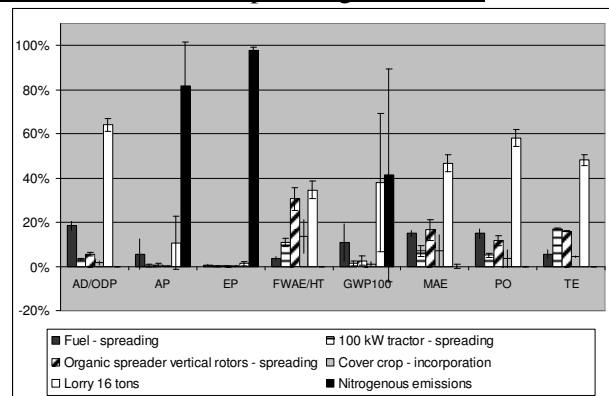
Figure 2 (a, b, c). Nitrogenous emissions according to spreader technological performances

Spreading scenario environmental impact analysis

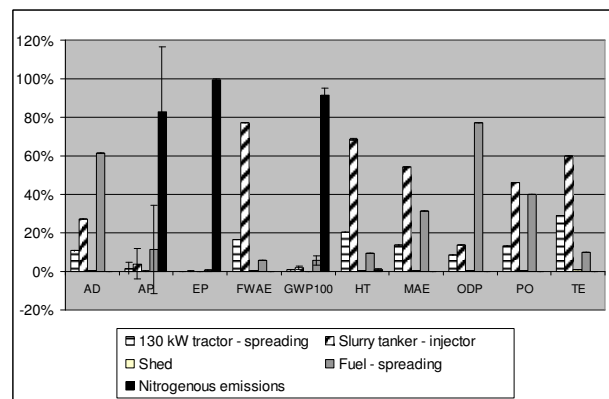
Do environmental impacts present significant differences between the spreading machines?

Figure 3 presents the LCA results for spreading operation involving two pairs of "sewage sludge-spreading machine": (a) solid sewage sludge spread using an organic spreader with vertical rotors and (b) liquid sewage sludge injection. Mean and standard deviation values result from the impacts related to the different pedoclimatic conditions. Only spreading phases representing more than 5% for each impact are shown. Nitrogenous emissions mainly impact on eutrophication (almost 99%), acidification (between 75 to 95%) regardless of the spreading scenarios. Nitrogenous emissions contribute to around 35% of the GWP100 impact categories for all the scenarios, except for injection as it represents 90%. Solid and composted sludge transport from the storage place after treatment to an intermediate storage by a 16 ton lorry on 35 km is the most impacting element for almost all categories. However, sludge transport and organic spreader production equally impact on fresh water aquatic and human toxicity categories. In the same manner, transport equally impacts with nitrogenous emissions on GWP100. Pelleted sludge transport from the storage place after treatment to an intermediate storage by a 28 ton lorry on 100 km equally impacts on each category (except AP and EP). Spreader and tractor production and fuel emissions (during both production and combustion) have the same impact contribution (results not shown). As a conclusion, pelleted sludge transport (89% of dry matter per ton)

on great distances with a high volume lorry (28 tons) has fewer impacts than solid and composted sludge transport (respectively 64 and 33% of dry matter par ton) on average distances with a low volume lorry (16 tons). Without sludge transport by lorry, agricultural material, spreader and tractor manufacturing affects most of the toxicity impact categories and, to a lesser extent, abiotic depletion. Fuel production and combustion in the tractor engine mainly impact on ozone layer depletion and



(a) Organic spreader – vertical rotors – solid SS



(b) Slurry tanker – injection – liquid SS

Figure 3: Environmental impacts of sewage sludge spreading for two technologies using mean and standard deviation values from the impacts of the nine pedoclimatic conditions (CML 2 baseline 2000 V2.04 / characterisation)

abiotic depletion. Photochemical oxidation is equally produced by spreader manufacturing and fuel production, as well as by combustion in the tractor engine. Cover crop transport and use for incorporation has a low impact for all sludge spreading scenarios. We also observed a high variability in GWP100 and acidification LCA results caused by a high variability in nitrous oxide and ammonia emissions, respectively. This high variability is strongly connected to the pedoclimatic conditions as reported by [1] and illustrated in the previous section.

Do the pedoclimatic conditions have an influence on the environmental impact of spreading scenarios?

Figure 4 represents a comparative LCA result between liquid sewage sludge spread with a splash plate and with injectors using Ecoindicator 99 method. Unlike Figure 3, which presents the mean and standard deviation values from the impacts of the nine pedoclimatic conditions, Figure 4 presents LCA results for each pedoclimatic conditions using Ecoindicator single score. These single scores are dimensionless and then can be summed up to present the total environmental burden of the studied scenarios. Generally, single scores are more important for liquid sludge spreading using splash plate regardless of the pedoclimatic conditions, as we

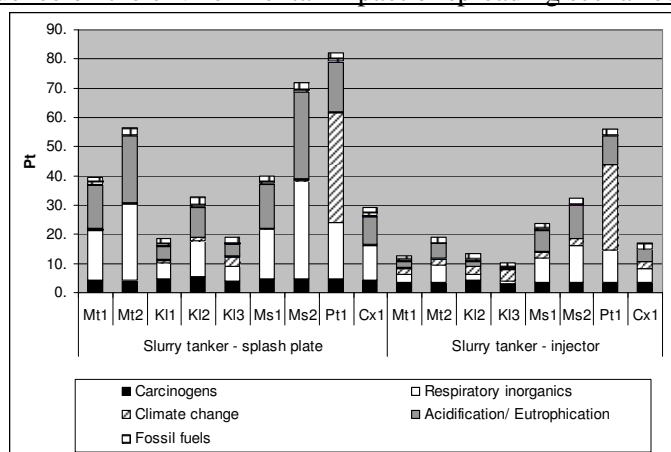


Figure 4: Comparison of liquid sewage sludge spreading using slurry tanker equipped with splash plate or injectors (Eco-indicator 99 (E) V2.06 / single score)

considered an incorporation with cover crop while this step is not taken into account in liquid sludge spreading through injection. So, we observe that spreading liquid sewage sludge, whether using splash plate or injectors, is more impacting in Poitou Charentes pedoclimatic context than in other sites. This can be explained by the high denitrification potential of the local pedoclimatic conditions affecting climate change. According to the pedoclimatic conditions, spreading sludge using injector devices reduces impacts between 10 and 30 single scores (Pt) compared with spreading using splash plate devices.

Conclusion and perspectives

Our LCA study highlights that it is possible to accurately discriminate environmental performances integrating spreaders technological performances for several spreading operations. We also show the importance of the spreading operation phases (loading, transport, spreading) in terms of environmental impacts leading to a better understanding of the spreading operations and to a possible reduction of the main identified environmental impacts.

The proposed method links nitrogenous emissions to the spreader technological performances so that the main spreader technological characteristics can be improved. This step is included within a bigger approach on the spreaders ecodesign.

However, LCA results cannot be generalised to all the spreading operations because of both, the high variability in nitrogenous emissions strongly linked to the spreader performances and the specific conditions and assumptions established for scenarios construction, especially regarding sludge transport by lorry.

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