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Analysis

Economic valuation of the nitrogen content of urban organic residue by the agricultural sector

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ABSTRACT

Urban organic residues (UOR), often perceived as environmental problems, could be valuable for the environment and agriculture. Spreading of UOR on agricultural lands functions as a disposal solution as well as a source of organic nitrogen, thereby enabling cropping systems to decrease mineral fertilization. The study shows the beneficial effect of two types of UOR on crop yields and the abatement of greenhouse gases. It culminates in an estimate of the economic shadow value of UOR, according to its nitrogen content, while accounting for various farm system characteristics and UOR availability. It is conducted for the densely populated Ile-de-France region, which has large amounts of UOR and agricultural acreage. Per tonne valuation of raw UOR for farming system use ranges from €1.5 to €7. Mineral fertilizer demand decreases by 18% in the case of optimal UOR sharing between regional farming systems, which leads to an 8.7% reduction in agricultural N_2O emissions. Moreover, the per hectare gross marginal output increases by €39 for the region's utilized agricultural area. We use an agricultural supply model, a crop model, and a tool for estimating changes in soil organic matter. The method can be easily extended to other regions of the European Union.

1. Introduction

Urban organic waste and its management are of great concern to the environment. Urban organic residue (UOR) is the biodegradable part of household and yard wastes, including the organic residues in wastewater. The organic waste is a general environmental issue, as it proceeds from human activities through sanitation and waste industry. We propose that agriculture stands to benefit from using these non-agricultural residues as production inputs. Indeed, UOR can be recycled for agricultural spreading because of its nitrogen (N) fertilizing capacity as well as other bio-geochemical characteristics. Organic matter spreading is known for its short- and long-term positive impacts on soil properties and crop yields (Gabrielle et al., 2005).

Utilities companies that manage organic waste face transformation, storage, and transport costs, leading them to seek economically advantageous outlets. For example, in 2007, French sewage sludge production was approximately 1,120,000 tonnes of dry matter, 70% of which was spread in agricultural areas (MEEDDAT, 2009). As a result, UOR is a potentially growing market. This study focuses on two types of UOR, namely urban sewage sludge (USS) and compost of green waste and sludge (GWC). Compost from green waste and sludge is a marketed product, manufactured from waste, whereas sewage sludge is a residual of sewage treatment that is to be disposed of. A national and European regulatory framework exists that insists on this distinction between waste and product. The framework established standards for compost distribution and sewage sludge spreading. UOR management is relevant to several European directives, such as the Nitrates Directive (91/676/EEC), the Waste Directive (2006/12/EC), the Wastewater Directive (91/271/EEC), and the Sewage Sludge Directive (86/278/EEC).

This legal and policy framework is essential, considering the external effects of UOR use in agriculture. Indeed, UOR spreading is a legitimate environmental concern. On one hand, it is a substitute to mineral fertilization and thus a solution to reduce mineral fertilization's environmental damages. On another hand, UOR spreading is an olfactory nuisance, as well as a source of soil pollution and greenhouse gas (GHG) emissions. For those reasons, agricultural recycling of urban organic waste must be apprehended as a solution to an environmental issue that is beyond the agricultural sector.

This study aims to assess the use of UOR as a source of nitrogen in agriculture from an economic stand point. In some parts, the nitrogen content of UOR will be considered like other nitrogen organic amendments, especially nitrogen from livestock effluents (LE). Our approach is composed of four elements: (i) An estimation of the private value of a UOR-sourced nitrogen unit to farmers; (ii) a specific analysis of the long-term effects of organic matter spreading on nitrogen surpluses in soil as well as the short-term effects of fertilization on yields; (iii) a multi-scale analysis at plot, farm and agricultural region scales; (iv) an appraisal of N_2O emissions as an externality of organic matter spreading.

For these purposes, we base the economic valuation of UOR spreading in agriculture on agro-economic modeling, using the European *AROPAj* agriculture supply model (Galko and Jayet, 2011), the *STICS*

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crop model (Brisson et al., 2003; Coucheney et al., 2015), and the *CARBO-PRO* tool for estimating carbon evolution in soil. We use yield-to-nitrogen response functions from *STICS* in *AROPAj* (Godard et al., 2008; Leclère et al., 2013) and enrich the modeling by including both the short- and long-term effect of organic nitrogen spreading with the aid of *CARBO-PRO*. On the agronomic side, field experiment data are available, as many studies have already been carried out on bio-geo-chemical properties and yield (Hargreaves et al., 2008; Houot et al., 2002; Annabi et al., 2011).

Regions that combine large urban areas and significant agricultural activities may benefit from UOR recycling. Urban density and population size generate a large UOR supply, while utilized agricultural areas (UAA) are a non-negligible outlet for this type of waste. The French Ile-de-France region perfectly illustrates such a situation, with a population of almost 12 million and UAA that accounts for 48.7% of its area.[1] As a consequence, this region supplies a relevant test case for our applied modeling analysis.

Results reveal the significant benefits (mostly long-term) of UOR spreading in relation to mineral fertilization substitution. Benefits include increases in gross margin (private benefit) and the abatement of greenhouse gas emissions (external social effect). The beneficial effects regarding greenhouse gases must, however, be weighed against the potentially negative impacts of USS spreading by means of heavy metal leaching, which has not been included in our N-focused analysis. The social shadow cost of USS is also likely to be negatively affected by other negative externalities such as unpleasant odor. Bearing in mind the regional availability of UOR and assuming optimal allocation of UOR among farmers, recycling UOR in agriculture could lead to a reduction of mineral fertilizer consumption of 17.8%, compared to complete non-use of UOR. Moreover, agricultural N_2O emissions could decrease by 8.7% with the replacement of mineral fertilizer by organic fertilizer. Finally, based on UOR recycling benefits for farmers, we assess the value of a UOR unit through its nitrogen content.

In Section 2, we detail the modeling framework for the economic study of UOR at different scales. We include a presentation of the *CARBO-PRO* model and its contribution in the assessment of the long-term effects of organic matter spreading. We present the calculation process and results in Section 3. A discussion of the results and policy implications follows in Section 4. The final section presents our conclusions.

2. Modeling Framework

The analysis uses the *AROPAj* model, which incorporates most of the economic and biophysical aspects related to farming system behavior. This model involves mathematical programming and the bio-economic categories of models (Arfini, 2012; Ciaian et al., 2013). The principles of the model may be found in De Cara and Jayet (2000) and De Cara et al. (2005), and a detailed description in Jayet et al. (2015). The version used in this paper is that which corresponds to the 2002 FADN data (Galko and Jayet, 2011).

The basic linear structure of the model is designed to optimize gross margin of farming systems, which are subject to economic and technical constraints. The model consists of a set of independent, mixed integer and linear-programming models. Each of these describes the annual supply choice of a given “farm-type” and is representative of “real” farmers. The farm-type representation makes it possible to account for the wide diversity of technical constraints faced by European farmers. The crop and nitrogen blocks of the basic model take into account different nitrogen sources, mineral as well as organic. Regarding the nitrogen balance, we base our approach on exponential dose–response function, in which dose corresponds to nitrogen intake, and response to yield (see Ackello-Ogutu et al., 1985 and Frank et al., 1990 for discussion on the functional form selection).

The analysis is presented at three scales:

– plot level, including different sources of organic nitrogen and long-term effect of organic matter spreading on one plot dedicated to a single crop;
– farm level (i.e. the farm group mentioned above), with an agricultural area containing various crops;
– regional level, including different farm groups.

2.1. Plot Level

2.1.1. Integrating Long-term Effects in the Yield-to-N Response Function

At the plot scale, yields used in *AROPAj* come from the linkage with the *STICS* model. The latter model simulates crop growth, yield, and water- and nitrogen- balances. Inputs take into account soil and daily weather data, crop type and management practices, as described by Brisson et al. (2003). The model is partitioned into various modules: three for simulating the aerial portion of plants (leaf area index, biomass and yield), three for soil simulation (water and nitrogen balances, root growth), and one for simulating interactions between cropping practices and the soil–plant system. The *STICS* model therefore can deal with variability in pedo-climatic conditions and nitrogen fertilization methods. The seminal work of Godard et al. (2008) and its extension by Leclère et al. (2013) describe the process leading to nitrogen to yield response functions as the link between *STICS* outputs in terms of yields and endogenized yields in *AROPAj*. Dose–response functions are of the Mitscherlich–Baule's type[2]:

$$Y(N) = B - (B - A)\exp^{-\tau N}, \tag{1}$$

where Y is the crop yield (per area unit), A and B are the minimum and maximum yields respectively, N is the amount of generic mineral nitrogen (per area unit), and τ is the yield-to-nitrogen sensitivity ratio. The higher the value of τ is, the higher the yield, given a requested amount of nitrogen, and for given A and B values. The exponential form enables it to meet both agronomic and economic requirements (i.e., on the economic side, concavity and strict increasing monotonicity). It offers good properties for easily estimating economically optimal fertilization rates.[3]

We use an enhanced form of the response function described by Eq. (1). The function has to include all forms of nitrogen input (mineral fertilizer, livestock effluents and UOR) and the long-term effect of organic nitrogen spreading. Indeed, organic residue shave short-term fertilizing effects by virtue of their nitrogen, phosphorus, and potassium content. UORs also have effects on biological and pH activity in the soil. The long-term effect of urban organic residue and animal effluent depends on to their capacity to increase soil organic matter, which is associated with many soil properties such as water retention, cation exchange capacity, and nitrogen-to-plant availability. On the economic side, we focus on last benefit.

Repeated organic matter application increases soil humus and its slow mineralization process increases long-term N provision in the soil. In short, mineralized organic nitrogen is a double source of nitrogen by virtue of its long- and short-term effects (Gabrielle et al., 2005). Consideration of this additional source may lead to changes in nitrogen inputs and crop production.

Following Godard et al. (2008), an initial distinction is made between nitrogen sources in the response function regarding the short-term effect.

1 http://www.insee.fr/fr/regions/idf/reg-dep.asp?theme=10&suite=1Insee2012

2 We chose to omit indexes related to crops and farm types.

3 Only the main marketed crops, for which the *STICS* model generates the observed yield in accordance with pedo-climatic data, are represented. By default, the function is limited to a couple {N-input; yield}.