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Rice fertilised with urban sewage sludge and possible mitigation strategies: an environmental assessment

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ABSTRACT

Among the different cereals, rice plays a relevant role in terms of production and dietary intake. Although the highest rice producers are Asian countries, this crop is also cultivated in Europe and, within Europe, Italy is the most relevant country. There are not studies evaluating in detail the environmental load arising from the application of urban sewage sludge in rice fields that, being flooded, are characterized by anaerobic conditions. The goal of this study was to evaluate the environmental performance of rice cultivation fertilised with urban sewage sludge in the Pavia district. Moreover, three mitigation strategies have been proposed and evaluated: the substitution of urban sewage sludge with compost, the introduction of an additional aeration and the collection of straw.

The results suggest that the main contributors to the environmental impact of rice are methane emissions associated with the degradation of the organic matter during the flooding period, nitrogen emissions associated with the application of fertilisers, and diesel used for the field operations. The differences among the proposed alternative scenarios are considerable, suggesting that strategies to improve the environmental performance of rice are possible. In more details, in order to reduce the environmental burdens of rice fertilised with urban sewage sludge, the two most effective possibilities are: the substitution of urban sewage sludge with compost and the implementation of an additional aeration period during the cultivation. The first option determines an improvement in all the categories analysed, and particularly in toxicity-related impact categories, with reductions of 99.6%, 78.8% and 68.7% for human toxicity-cancer effects, human toxicity-non cancer effects and freshwater ecotoxicity, respectively, followed by Climate Change (−25.4%) and Mineral Fossil Resource Depletion (−19.2%). The introduction of an additional aeration is beneficial for the Climate Change and Photochemical Oxidant Formation, with a reduction of 9.7% and 1.6%, respectively.

Concerning the results of the Climate Change impact category, the use of standard emission factors for the estimation of methane emission involves uncertainty; the development of country-specific emission factors would be instrumental in overcoming this point of weakness. Finally, despite the focus on the Italian context, this study proposes different mitigation strategies, which can be applied to other rice systems in order to reduce their environmental impact.

1. Introduction

Among the different cereals, rice plays a relevant role in terms of production and dietary intake (FAO, 2013; Lovarelli et al., 2016b). According to the Rice Outlook 2014, there are around 161.6 million hectares of rice all over the world and an annual global consumption of 488.8 million tons (USDA, 2014). Although the largest production of rice is located in Asia (China, India and Japan), this crop is also cultivated in Europe (425,017 ha in 2013) (Enterisi, 2014). Within Europe, Italy is the most important country in terms of rice production accounting for approximately 55% of the European rice

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area (Enterisi, 2014). In more detail, 227,000 ha were dedicated to rice cultivation in Italy in 2015 (+3.6% respect to 2014) with 4194 farms, mainly located in the districts of Pavia, Vercelli and Novara (Callegarin, 2015). The average yield in 2014 was 6.4 t ha^{-1}, which is considerably higher than the world yield (4.43 t ha^{-1}) (Enterisi, 2014).

Rice cultivation involves different agricultural activities that p a number of environmental impacts. Such impacts are mainly associated with the use of fossil fuels for the mechanization of field operations, the consumption of fertiliser and agrochemicals and to methane emissions arising from the fermentation of organic material in the flooded rice fields. Due to flooding conditions that characterise rice cultivation in many areas, the greenhouse gases (GHG) emissions (mainly methane) associated with the production of rice is usually higher than in other crops (Renzulli et al., 2015). In the last years, the environmental impact related to rice cultivation has been evaluated in several studies; nevertheless these studies were mainly focused on rice cultivation in Japan (Harada et al., 2007; Roy et al., 2009; Yoshikawa et al., 2012; Hokazono and Hayashi, 2012), China (Xu et al., 2013) and Bangladesh (Roy et al., 2007) and only few studies are available for the European context (Fusi et al., 2014; Blengini and Busto, 2009). Large differences were found in the environmental performances, due to differences in the management practices, such as straw management (Fusi et al., 2014), water regime (Kanta Gaihre et al., 2014), sowing type (Romani and Beltarre, 2007) as well as climatic and soil conditions (Hokazono and Hayashi, 2012). Regarding fertilisation activities for rice cultivation and, in particular, its impact on the environmental performance, few studies have been carried out so far. In flooded paddy fields, the application of organic fertilisers can dramatically increase methane emissions due to the anaerobic decomposition of organic matter (Leip, 2007; Leip and Bocchi, 2007). On the other hand, the use of organic fertiliser reduces the consumption of mineral fertilisers, whose production is energy intensive (Renzulli et al., 2015) and represents a significant production cost.

In the Italian rice districts such as Vercelli, Pavia and Novara, there is a limited livestock activity. Therefore, there is little availability of organic fertilisers and rice is mainly fertilised with mineral fertilisers (Fusi et al., 2014). Alternatively, streams such as digestate, compost and urban sewage sludge have interesting potential as sources of nutrient and organic matter.

Urban sewage sludge is the result of the wastewater treatment in anaerobic digestion plants, primarily from household sewage. It can be spread on fields alike other organic fertilizers with the exception of those fields in which heavy metals are already present at high concentrations (Directive 86/278/CEE) (EC, 1986). Urban sewage sludge is available in higher quantity than digestate due to the limited distribution of anaerobic digestion plants in rice districts (González García et al., 2012; Bacenetti et al., 2013; Negri et al., 2014; Lijó et al., 2014a, 2014b). In comparison with compost, urban sewage sludge is cheaper. However, compost, together with green manure, is the main fertiliser used on the Italian organic rice production systems (Bacenetti et al., 2016).

The aim of this study was to assess the environmental performance of rice cultivation in Northern Italy (Pavia district, Lombardy region) under a fertilisation regime based on urban sewage sludge. Derived from the environmental assessment, the *hotspots* of the system were identified. To this purpose, the Life Cycle Assessment (LCA) method (ISO, 2006) was applied from a cradle-to-farm gate perspective.

The novelty of the study is to clearly highlight the environmental consequences of the application of organic fertilisers in paddy rice fields and to identify effective solutions to maintain rice production levels and to ensure reduced environmental load. To this purpose, several alternative scenarios under different schemes for straw management, water regimes and type of organic fertilisers, were also evaluated.

2. Materials and methods

Life Cycle Assessment (LCA) is a holistic method to assess the environmental impacts and resources used throughout the life of a product (process or activity) from raw material acquisition, production and use, to waste disposal (ISO 14040, 2006). This method has been widely considered to determine the environmental profile of numerous agricultural systems (Milà i Canals et al., 2006; Cellura et al., 2012; Bacenetti et al., 2015b; Noya et al., 2015; Renzulli et al., 2015).

2.1. Goal and scope definition

The goal of this study was to evaluate the environmental performance of rice cultivation fertilised with urban sewage sludge in the Pavia district. This study was driven by the following questions:

1. What is the environmental impact for rice grain fertilised with urban sewage sludge?
2. What are the main *hotspots* associated with the rice production system?
3. What environmental benefits can be achieved under different cultivation regimes, considering irrigation, fertilisation and straw management?

The outcomes of such analysis can be useful for the identification of the conditions leading to the lowest environmental impact and accordingly, the study can be helpful to farmers, technicians and local politicians involved in the rice production process.

2.2. Functional unit

The functional unit provides the reference to which all other data in the assessment are normalised. The mass based functional unit is prevalent in LCA studies of agricultural systems (Notarnicola et al., 2015). Accordingly, 1 ton of paddy rice at commercial moisture (14% of moisture) was selected as functional unit.

2.3. Description of the production system (Baseline scenario)

The cultivation system can be divided in different sections:

1. Section I: Field preparation. This section involves soil tillage, carried out by ploughing (depth 35 cm) and harrowing, organic fertilisation performed with a slurry spreader and followed by further harrowings (1 with disc harrow and 1 with rotary harrow) and, finally, ditching. The latter operation is important to allow effective water management during the growing season.
2. Section II – Sowing operations. Sowing takes place in early May in dried paddy field with a seeder: 185 kg ha^{-1} of seed are used. After sowing, rolling is carried out to support seed germination followed by a second ditching.
3. Section III – Crop management: This section involves weed and pest control, carried out by the applications of herbicides (2 times) and fungicides (1 time) and water management. Water management includes one stage of aeration in June; the flooding ends about 20 days before the harvest and, globally, it lasts 95 days.
4. Section IV – Harvesting operations. Harvesting is performed with a self-propelled combine harvester, and the transport of grain to the farm is carried out with two farm trailers. Straw is

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