ARTICLE IN PRESS

Journal of Cleaner Production xxx (2015) 1–16

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Comparative life cycle assessment of three representative feed cereals production in the Po Valley (Italy)

Isabel Noya [a], Sara González-García [a, b, *], Jacopo Bacenetti [c], Luís Arroja [b], Maria Teresa Moreira [a]

[a] Department of Chemical Engineering, School of Engineering, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain
[b] CESAM, Department of Environment and Planning, University of Aveiro, 3810-193 Aveiro, Portugal
[c] Department of Agricultural Engineering, University of Milan, Milan, Italy

ARTICLE INFO

Article history:
Received 1 August 2014
Received in revised form
24 February 2015
Accepted 1 March 2015
Available online xxx

Keywords:
Wheat (*Triticum* spp. L.)
Triticale (*x Triticosecale* Wittmack)
Maize (*Zea mays* L.)
Cereal crops
Digestate

ABSTRACT

The cultivation of three different cereals – wheat, triticale and maize (five classes: 300, 400, 500, 600 and 700) – dedicated to grain production for feed purposes was assessed to quantify their environmental profiles and identify the most sustainable crop from an environmental perspective. The most critical processes throughout the life cycle of the cropping systems were also identified. These cereals were chosen because they are the most widespread cereal crops in the Po Valley (Lombardy region), the most important agricultural area in Italy.

The standard framework of the Life Cycle Assessment (LCA) was followed to assess the environmental performance of the different cropping systems. Several impact categories were evaluated, including climate change (CC), ozone depletion (OD), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), human toxicity (HT), photochemical oxidant formation (POF), terrestrial ecotoxicity (TEC), freshwater ecotoxicity (FEC), marine ecotoxicity (MEC), water depletion (WD), fossil depletion (FD) as well as land use as an indicator.

The results showed that the maize class 300 was the cereal with the worst environmental profile in the base case, considering economic allocation and no environmental burdens related with digestate production. This scenario presented the most intensive agricultural practices and the lowest biomass yield in comparison with the other crops. In contrast, the maize classes 600 and 700 were the cereal crops with the best environmental profiles in most impact categories. The lower requirements of fertiliser (and thus, fertilisation activities) as well as the higher biomass yield were responsible of these favourable results.

However, according to the environmental results, the selection of the best biomass source depends on several methodological assumptions such as the functional unit and the allocation criteria considered (between the grain and the straw) as base for the calculations. Thus, the results of a sensitivity analysis showed that the choice of a mass allocation instead of economic one caused lower environmental impacts in all the categories. Moreover, the consideration or not of the environmental burdens related to the digestate production (the main organic fertiliser used) was also a critical step in the environmental evaluations. The inclusion of environmental loads related to digestate production caused a notable increase in the impact of all the cropping systems regardless the cereal and the impact category. This conclusion could be extrapolated to other systems that exclude the additional burdens allocated to the production of organic fertilisers.

1. Introduction

The favourable soil and climatic conditions as well as water availability make Northern Italy a good region to produce agricultural crops with high potential yields (MATTM & MIPAAF, 2010). For this reason, it is recognised as a leading area for the development of cropping systems (MATTM & MIPAAF, 2010). Likewise, agricultural

* Corresponding author. Department of Chemical Engineering, School of Engineering, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain. Tel.: +351 234370349.

E-mail address: sara.gonzalez@usc.es (S. González-García).

http://dx.doi.org/10.1016/j.jclepro.2015.03.001
0959-6526/

Please cite this article in press as: Noya, I., et al., Comparative life cycle assessment of three representative feed cereals production in the Po Valley (Italy), Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.03.001

activities are remarkably linked to livestock production. In this sense, Northern Italy accounts for 68%, 85% and 80% of total dairy cattle, pigs and poultry reared in Italy, respectively (MATTM & MIPAAF, 2010).

The main crops in Northern Italy are cereals and forages, among which maize grain (21%) and winter cereals (17%) stand out (MATTM & MIPAAF, 2010). Cereals can be harvested under two different regimes depending on the final purpose: a) energy crops (mainly for biogas production), where the biomass is harvested, ensiled at the waxy-ripeness stage, when it is rich in easily degradable carbohydrates and has optimal dry content (El Bassam, 1996; Heiermann et al., 2009), and b) animal feed production, where the grain is harvested as late as possible (soft-dough stage) and separated from the remaining biomass (straw). The harvesting of cereal at this stage of maturity leads to high values of dry content, fibre and protein (Khorasani et al., 1997).

Cereals have been traditionally cultivated under extensive agriculture, following farming directives that aim at optimising the use of internal inputs while reducing external inputs such as fertilisers and pesticides (Nemecek et al., 2011). Conversely, the lower yields per unit of land associated to these systems imply larger requirements of arable land (Mózner et al., 2012). Considering that the global demand for agricultural products is expected to double in the next decades (Baudron and Giller, 2014), farming systems based on intensive agriculture philosophy are particularly important (Mózner et al., 2012). These intensive farms achieve higher yields in comparison with conventional or extensive agriculture, but they require higher degree of mechanisation and a wide range of chemicals (Mózner et al., 2012).

Consequently, current agricultural production systems have been identified as the major contributor to greenhouse gases (GHG) emissions on a global scale, accounting for 14% of global net CO_2 emissions (Cooper et al., 2011). In addition, agricultural practices affect ecosystems by the use of limiting resources (e.g. fossil fuels and water) and the emission of polluting substances other than GHG such as nitrate, phosphate, sulphur oxides or ammonia associated to agrochemicals application and machinery use (Tilman et al., 2001; Bellarby et al., 2008; Biswas et al., 2010; Reay et al., 2012; Reckmann et al., 2012). In fact, nitrates and phosphates leakage in surface and groundwater cause major environmental problems such as eutrophication with an increase of phytoplankton in water (Tilman et al., 2001).

For all these reasons, the perception of the relationship between agriculture and environment has considerably changed and concerns have been raised about the sustainability of agricultural production systems (Bechini and Castoldi, 2009). Thus, it is becoming more relevant to exactly determine the environmental impacts of farming activities and the alternatives to mitigate these impacts (Bell et al., 2014).

The available literature distinguishes between procedural and analytical tools in order to assess the environmental impacts derived from agri-food/feed production systems. Life Cycle Assessment (LCA) is a methodology useful to assess the environmental impacts and resources used throughout the life of a product (process or activity) from raw material acquisition, production, use to waste disposal (Finnveden and Moberg, 2005). In particular, this methodology has been widely considered in numerous agricultural systems (Charles and Nemecek, 2002; Charles et al., 2006; Milà i Canals et al., 2006; Benglini and Busto, 2009; González-García et al., 2010; Gallego et al., 2011; Cellura et al., 2012; Goglio et al., 2012; Roer et al., 2012; González-García et al., 2013; Khoshnevisan et al., 2013; Wang et al., 2014) and its application has identified the critical environmental stages in various production processes. For example, Cellura et al. (2012) conducted an LCA study of vegetable production (peppers, melons, tomatoes, cherry tomatoes and zucchini) in Italy and reported that the packaging step and the greenhouse structure accounted for a substantial share in the environmental impact distribution. Gallego et al. (2011) concluded that the major contributing processes to the environmental impact in the production of dried alfalfa were the dehydration process, production and use of agrochemicals, water consumption and road transport. Wang et al. (2014) focused on a wheat – maize rotation system with high yields and resource use efficiency and reported reduced environmental burdens in comparison with conventional production, due to the lower demand of non-renewable energy and water, increased grain production and more efficient land use.

The main purpose of this study was to estimate the "cradle-to-gate" environmental effects caused by the cultivation of the three most important cereal crops in Europe used for feed production (MATTM & MIPAAF, 2010; FAO, 2004): maize, wheat and triticale. The plantations under study were located in the Po Valley (Lombardy region, Northern Italy), considered the most important agricultural area in Italy with a large number of livestock farms and agro-industries (Carrosio, 2013).

2. Materials and methods

Life Cycle Assessment (LCA) is a technique for assessing the potential environmental impacts and resources consumption associated with a production system (ISO 14040, 2006; Finnveden et al., 2009). LCA methodology was chosen to perform the environmental analysis according to the principles described in ISO standards (ISO 14040, 2006).

2.1. Goal and scope definition

The goal of this study was to evaluate and compare the environmental burdens associated with the cultivation of three of the most widespread cereal crops in Europe, destined to the production of animal feed: maize, wheat and triticale. Since the cereals under assessment are complementary, a comparative assessment was carried out with the aim of determining which one would present the highest and the lowest contributions to the environmental impact. Likewise, the most critical stages (commonly named *hot-spots*) throughout the life cycle were identified. The study was performed from a cradle-to-gate perspective. Thus, further stages such as grain conversion into feed, consumption and final disposal of waste were excluded from the assessment.

Seven agricultural systems were considered: one for wheat, one for triticale and five for maize taking into account different cropping classes (300, 400, 500, 600 and 700). In all these crops, the main product is the grain harvested, which is entirely dedicated for feed. The remaining biomass (that is, straw) has other applications, mainly energy generation in boilers and animal bedding. The further processing of cereal straw was excluded from the assessment since it is not an objective of feed production and it is out of the scope of this study.

2.2. Functional unit

According to ISO standards, the functional unit (FU) is defined as a quantified performance of a product system to be used as a reference unit in an LCA (ISO 14040, 2006). Since the main function of the systems under study is the grain production for animal consumption, the FU for each agricultural system was defined as "one tonne of grain (dry basis) for feed production". The selection of a mass-based FU is in agreement with other LCA studies on cereal crops (Charles and Nemecek, 2002; Benglini and Busto, 2009; Khoshnevisan et al., 2013).

Please cite this article in press as: Noya, I., et al., Comparative life cycle assessment of three representative feed cereals production in the Po Valley (Italy), Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.03.001