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Impact of cropping system and soil tillage on environmental performance of cereal silage productions

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ABSTRACT

In this study the environmental performances of the two most widespread cropping systems for cereal silage production in Northern Italy were analysed. Three different technical solutions for the seedbed preparation (conventional tillage, minimum tillage, and no tillage) were considered too. The Life Cycle Assessment method was chosen for the environmental analysis. The following impact potentials were evaluated: abiotic depletion, climate change, ozone depletion, acidification, eutrophication, and photochemical oxidant formation. One ton of dry matter was chosen as the functional unit. Taking into account that the functional unit selection can affect the environmental results, a sensitivity analysis was performed considering three other different functional units (area, biomethane production, and nutritive value).

For both the crop systems, the emissions due to fertiliser application, diesel fuel consumption and production are the hotspots process with the greater influences on the overall environmental burden. Compared to single crop, the double crop system shows the worst environmental performance for all the evaluated impact categories except for euthrophication and acidification (−21% and −14%, respectively). Among the different technical solutions for seedbed preparations, the minimum tillage and the sod seeding achieve better results than the conventional tillage. For impact categories such as abiotic depletion, photochemical oxidation, climate change and ozone layer depletion there are impact reductions ranging from −2.5% to −11.5% for single crop and from −9.4% to −11.7% for double crop. For acidification and eutrophication the impact reduction is minimal for single crop while, for minimum tillage in double crops a slight increase is observed.

1. Introduction

The food system, including agricultural steps as well as transport, processing, and disposal, is one of the main industries responsible for anthropogenic greenhouse gases (GHG) emissions. In 2008, the GHG emissions from this sector were 9800–16,900 Mt of carbon dioxide equivalent ($MtCO_2eq$) (Gerber et al., 2013).

Among the different subsystems of the food system, agriculture has had the greatest impacts, contributing 7300 to 12,700 $MtCO_2eq$/year (including indirect emissions associated with land-cover change), which is equivalent to 80–86% of total food systems' emissions. Inside the agriculture sector, the main source of GHG emissions are deforestation and land use change (30–50% of agricultural emissions) while other activities like soil tillage, crops cultivation, and livestock represent about 70–50% of agricultural emissions (Gerber et al., 2013). Therefore, over the years, the need to assess the environmental impacts of agriculture has become increasingly important (González-García et al., 2012a; Poeschl et al., 2012b; Lijó et al., 2014a).

Among the different crops, annual and perennial, the cereals have an important role in terms of the cultivated area, and they constitute a very important component of the economy as well (FAO, 2013). In Italy, the cereals cultivation covered 3.59 millions of ha, about 28% of the total agricultural area (ISTAT, 2010). Nevertheless, the production of cereal crops involves environmental, social, and economic issues (Poeschl et al., 2012a; Cherubini et al., 2009; Lijó et al., 2014b). Over the years several studies highlighted that the environmental impact of cereal crops can be remarkable (Iriarte et al., 2010; Uchida and Hayashi, 2012; Bacenetti et al., 2012).

Environmental effects due to cereals cultivation (e.g., climate change, acidification, eutrophication, etc.) stem not only from field

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operations (Deytieux et al., 2012) but also from materials (fuels, fertilisers, and pesticides) extraction, processing, and transport (Capponi et al., 2012; Bacenetti et al., 2013). In more details, soil tillage operations, primary (with plough, ripper) and secondary (with harrows, hoe), involve high fuel consumption and consequently have a deep impact on environmental burdens of agricultural processes (in particular, in impact categories such as global warming potential and abiotic resources depletion) (Castanheira and Freire, 2013; Kustermann et al., 2013; Bacenetti et al., 2013b). Alternative solutions for seedbed preparation such as minimum tillage and no tillage have been evaluated in several studies (Santilocchi and Bianchelli, 2006; Basso et al., 2011; Kennedy et al., 2013). Nevertheless, the performances of these solutions have been addressed mainly from an economic and energetic point of view (Basso et al., 2011; Zhang et al., 2013; Santin-Montanya et al., 2013). Carozzi et al. (2013a) assessed the productive, economic and environmental performances of the maize cropping system in conventional agriculture, minimum tillage and no tillage in the Po Valley area.

Nowadays, in Northern Italy, the most widespread cropping systems to produce silages are:

i) The single crop (SC) system, in which only one crop is cultivated season after season. In this type of cropping system, sorghum and (mainly) maize (hybrids with cultivation cycles longer than 105 days, e.g., FAO's classes 600 and 700) are the most cultivated crops.
ii) The double crop (DC) system, in which two crops grow in the same field in sequence. Usually, in this cropping system, a winter cereal (wheat or triticale) is followed by maize (hybrids with cultivation cycles shorter than 105 days, e.g., FAO class 300–400–500). Between wheat and triticale, this second cereal is the most used for silage production in northern Italy due to higher biomass yield (Giunta and Motzo, 2004; Bechini and Castoldi, 2009) its higher specific biogas production (Negri et al., 2014a);

In regards to the environmental impact, although with the DC system a moderately higher dry matter production per hectare can be obtained (Carrosio, 2013; Negri et al., 2014b), the choice between SC and DC must be carefully evaluated. In the DC system, despite a moderated increase of yields, the field operations and the input consumption (fertilisers, seeds, pesticides, water, fuels) are approximately twice that of the SC system.

In the last decade, in order to evaluate the environmental performances of agricultural processes, the Life Cycle Assessment (LCA) has become more and more employed. LCA is a methodology that aims to analyse products, processes, or services from an environmental perspective (Guinée, 2002; ISO, 2006), providing a useful and valuable tool for agricultural system evaluation (Audsley, 1997; IPCC, 2006; Mangena and Brent, 2006)).

Therefore, the aim of this paper was to analyse the environmental performances of the most widespread cropping systems for silage production in Northern Italy, taking into account different technical solutions for seedbed preparation. Although the environmental impact of cereal crops has been already evaluated (Gonzalez et al., 2012b), in this study the attention is not paid to the crop but the cropping system (understood as a sequence of crops grown in the same field during the year). In more detail, the environmental performances of the SC system (only maize 700) were compared with those of the DC system (winter cereals followed by maize). Regarding the seedbed preparation, two alternative scenarios were analysed: minimum tillage and no tillage.

2. Materials and methods

2.1. Goal and scope definition

The goal of this study is to assess the environmental performances of two cropping systems of cereal crops for silage production. The selected cereal crops are the most cultivated in the Po Valley (one of the most important Italian areas for cereal production) (ISTAT, 2012). The silages produced from these cereal crops are utilized mainly for animal feeding (mainly cattle and pigs) but the cereals can also be used for starch production as well as for as human food or for biogas production (Carrosio, 2013; Lijó et al., 2014a, 2014b).

The target audience of this study are the farmers' associations and local politicians.

In this study, maize FAO 700, maize FAO 500, and triticale cultivations were evaluated using the LCA methodology considering two different cropping systems (SC and DC) as well as different practices for seedbed preparation. In more details, SC was cultivated in 2012 while the DC took place in 2011 and 2012. In regards to soil tillage and sowing, three different technical solutions were analysed:

1. The baseline scenario (BS) represents the situation as it was recorded and described within Tables 1 and 2. Ploughing is carried out at 35 cm depth for maize and at 30 cm depth for triticale while harrowing is performed at 15 cm depth for both the crops. Sowing takes place using a traditional seed drill.
2. Minimum Tillage (MT) is an alternative scenario in which soil tillage is different from the BS: the ploughing is replaced by soil tillage (with ripper of 20 cm depth) and the harrowing is carried out with a disc harrow (10 cm depth). Sowing is similar to the BS.
3. Sod seeding (SS) (also called no tillage) is another alternative scenario in which

sowing directly takes place on not-tilled soil. The no tillage technique requires specialized seeding equipment designed to sow into soil covered with crop residues; a double-disk, no-till seed-drill was considered for sowing.

As for the biomass production values and the mechanization of field operations for seedbed preparation, the results obtained by Basso et al. (2011) and by Santilocchi and Bianchelli (2006) were used in this study since they analysed different soil tillage managements in the same geographic area and for soils having similar characteristics.

2.2. Functional unit

The functional unit is an important step of any life cycle assessment since it provides the reference to which all other data in the assessment are normalized. With LCA's application to agricultural processes, different functional units (FUs) can be selected. In many LCA studies of agricultural production systems, the FU is the area (e.g., 1 ha) (Mila i Canalis et al., 2006; Negri et al., 2014). Nevertheless, the mass-based functional unit is prevalent in LCA studies of agricultural systems (Van der Werf et al., 2007; Gonzalez et al., 2012a). Therefore, in this study, 1 t of dry matter produced in each cropping systems has been considered as the FU.

2.3. System boundaries and cropping system description

Cultivations are carried out in the Po Valley area, the Lombardy region (Italy), the District of Pavia, and, more precisely, on the