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Seedbed preparation for arable crops: Environmental impact of alternative mechanical solutions

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ABSTRACT

This study quantifies, using the Life Cycle Assessment (LCA) method, the environmental impact of sequences of operations for seedbed preparation for arable crops under different soil textures and soil refinement intensities. Comparing the environmental loads of alternative sequences of operations permitted to detect the most environmentally sustainable sequence in each working condition.

To this purpose, 13 alternative sequences of field operations for seedbed preparation were analysed, considering primary and secondary soil tillage and minimum tillage. The study was carried out considering a cradle to farm gate perspective and selecting as functional unit "1 ha tilled with an appropriate soil refinement for sowing and seed germination". Three 60-ha farms in Northern Italy were considered. Inventory data (e.g., farm and field information, machinery fleets, fuel, lubricant and materials consumptions and exhaust gases emissions) were calculated with the model ENVIAM (ENVironmental Inventory of Agricultural Machinery operations).

The impact assessment was completed with the ReCiPe characterisation method. Results showed that seedbed preparation completed with two implements (one for primary and one for secondary soil tillage) instead of three (e.g., one for primary and two for secondary soil tillage) results in a better environmental performance on impact categories (e.g., eutrophication, ecotoxicity and metals depletion) affected by the manufacturing phases and by the consumption of materials along machinery life span. The impact categories affected by fuel consumption and exhaust gases emissions showed the best results with low energy-consumptive operations (e.g., slatted plough, no-Power Take Off harrow and minimum tillage). Coarse textured soils and soils lowly refined (i.e. unrefined soil particles adapt for crops characterized by seeds with a size close to that of winter crops or by high seed density) showed low burdens on all impact categories, whereas fine textured and highly refined soils (i.e. small soil particles adapt for crops with small seeds or by low seed density) were responsible for the highest impacts. This is primarily due to the larger number of harrowing repetitions and of energy and fossil fuel consumption.

The results can be up-scaled to arable crop production systems with similar pedo-climatic and operative features, such as other Mediterranean countries. Farmers associations, stakeholders and politicians could promote policies and define incentives that encourage producers to adapt to more environmentally sustainable crop productions.

1. Introduction

In agriculture, mechanisation represents an essential activity for the cultivation of crops with a marketable value for food and feed purposes. Among mechanical field operations, seedbed preparation is fundamental for achieving an optimal soil condition for seed germination.

Several tillage machines and different sequences of operations for seedbed preparation can be identified (Bacenetti et al., 2015a; Castanheira et al., 2010; Kouwenhoven et al., 2002; Panettieri et al., 2013; Vakali et al., 2011). The reason for this wide range of possibilities (namely primary and secondary soil tillage) is linked to: (i) the specific features characterising the production context (Van Linden and Herman, 2014), (ii) local pedo-climatic variables (e.g., soil texture, soil moisture, field shape and slope, temperature and rainfall) (Lovarelli et al., 2017), (iii) mechanical variables of tractors (e.g., engine power, engine load, working speed, displacement system) (Molari et al., 2012; Perozzi et al., 2016) and implements (e.g., working width, working depth) (Lovarelli and Bacenetti, 2017) and (iv) operating variables (e.g., machinery fleet, working promptness, number of workers, farm-field distance) (Pitla et al., 2016; Šarauskis et al., 2014).

From an environmental perspective, every production system is responsible for an environmental impact. With environmental impact is

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meant the possible adverse effect caused by the subtraction of inputs and release of substances in the environment (i.e. in air, soil and water). The existence of different alternatives in terms of tillage machines and of variables that affect the production context (i.e. pedo-climatic, mechanical and operating variables), determines that different environmental impacts arise. Accordingly, a tractor and an implement, or more in general a sequence of field operations (e.g., primary plus secondary soil tillage), can be adequate for a context, but not for another even spatially close to the first. If more sequences are feasible in the same context, their environmental impact can differ due to this local variability as well as to the availability of machinery options among which to choose (Barthelemy et al., 1992).

Potential adverse effects are quantified with the Life Cycle Assessment (LCA) method. LCA is a worldwide adopted approach (ISO 14040 series, 2006) that aims at investigating with a holistic approach all inputs and outputs of a production system and at transforming these data (i.e. inventory data) in potential environmental impacts. From the several studies performed with LCA approach on the environmental evaluation of agricultural food and feed productions (Notarnicola et al., 2015) it has emerged that field operations are responsible for a relevant share of the environmental load attributed to agriculture (Dace et al., 2015; Hokazono and Hayashi, 2012; IPCC, 2006). Mechanical field operations (e.g., soil tillage, seeding, fertilisation, harvest), are responsible for the consumption of important masses of fuel, of the emission of engine exhaust gases (carbon dioxide CO_2, nitrogen oxides NO_X, carbon monoxide CO, hydrocarbons HC, etc.) and of the consumption of materials (tires abrasion, materials that must be substituted along the machinery life span and those that must be disposed of at the end of the machinery life span, etc.) (Boone et al., 2016; Bacenetti et al., 2015c; Lee et al., 2016; Schmidt Rivera et al., 2017). Each of these substances is responsible for environmental impacts.

The aim of this study is to calculate, using the LCA approach, the environmental load of mechanical field operations for seedbed preparation of arable crops evaluating the effect that the different pedo-climatic, mechanical and operating conditions can have on the environmental point of view. To do this, different seedbed preparation options (primary + secondary soil tillage) were considered. They were defined by taking into account that arable crops can demand for highly or lowly refined soils and for deeper or shallower primary soil tillage.

Several LCA studies have already been performed to quantify the environmental impact of crop production and, although the system boundary often differed, one consistent finding was that mechanisation of seedbed preparation is responsible for a relevant share of the environmental impact of those production systems (Bacenetti et al., 2015a, 2015c; Niero et al., 2015; Noya et al., 2015). Therefore, to identify the operational sequence that present a more environmentally sustainable behaviour, 13 alternative sequences of operations for seedbed preparation of arable cropping systems composed of primary and secondary soil tillage have been assessed focusing on the Italian productive context.

The results of this study can be helpful for farmers' associations, stakeholders and politicians to promote policies and define incentives for the completion of operations with higher environmental benefits, in view of promoting more sustainable productions in the near future. Similarly, the upscaling to other geographic contexts characterised by similar pedo-climatic and operating features such as other Mediterranean countries can be particularly useful and interesting for policies promotion.

2. Materials and methods

The sequences of operations for seedbed preparation selected for this study were analysed with the Life Cycle Assessment (LCA) method (ISO 14040, 2006). LCA is a standardised approach adopted worldwide for quantifying the potential environmental impact of processes for products or services during their whole life cycle using a holistic approach. In LCA, four steps are typically taken:

(i) goal of the study, selection of the functional unit, description of the system and of the system boundary,
(ii) Life Cycle Inventory data collection, aimed to identify and quantify the flow of materials and energy from the studied systems and the environment,
(iii) Life Cycle Impact Assessment, during which inventory data are converted in few numeric indicators of environmental impact thanks to a characterisation method. Several characterisation methods were developed over the years but, for agricultural systems, ReCiPe (Goedkoop et al., 2008) and ILCD (Wolf et al., 2012) are the most applied. Within the characterisation method, for each impact category, different characterisation factors allow the conversion of the inputs (e.g., mass of fuel consumed) and outputs (e.g., emission of pollutant *i* in the atmosphere) in the environmental impact,
(iv) interpretation of the results and identification of the process hotspots.

How these steps were implemented in this study is outlined below.

2.1. Goal and scope

The goal of this study is to quantify the environmental impact of several sequences of field operations for seedbed preparation of arable crops to identify those with a lower environmental burden. With sequence of field operations is meant the set of primary and secondary soil tillage operations to carry out in order to prepare the soil to sowing. Along the manuscript, the term "sequence" will be adopted to identify this set.

The focus is on primary and secondary soil tillage, which represent the most energy-consumptive operations for crop production systems (Gronle et al., 2015; Mileusnić et al., 2010). In this study, field operations were carried out by farmers and not by contractors; therefore, the identified sequences were built upon Italian farm-scale contexts.

2.2. Functional unit and system boundary

During this phase, the Functional Unit (FU) must be defined. The FU describes the function of the system and represents the unit to which all inputs and outputs are referring. Commonly, LCA studies about crop cultivation assess the environmental impact using 1 ha as FU (Nemecek et al., 2015; Solinas et al., 2015) or, alternatively, 1 t. In this study, no specific crop is evaluated; therefore, the selected FU is "1 ha tilled with an appropriate soil refinement for sowing and seed germination".

Additionally, in this phase, also the system boundary must be defined; in the system boundary is stated what is included in the assessment and what is excluded. In this case, it comprises primary (soil overthrow/breaking with no repetition on the same field) and secondary (soil refinement with one or more repetitions on the same field) soil tillage, as illustrated in Fig. 1. Given the recent importance attributed to minimum tillage, sequences of operations characterised by no ploughing were analysed; however, in order to respect the identified FU, interventions on field had to guarantee the appropriate soil refinement and seed germination.

2.3. Description of the system

Scientific literature, experts, farmers' associations and technical journals were queried about the most common sequences of mechanical operations that characterise seedbed preparation of arable crops in Italy. The options disclosed to farmers for field operations were similar to different countries (Bacenetti et al., 2015a; Çarman, 1997; De Vita et al., 2007; Dimanche and Hoogmoed, 2002; Lazzari and Mazzetto,