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Research Paper

Bridging the gap between reliable data collection and the environmental impact for mechanised field operations

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Mechanisation is related to an important proportion of the environmental impacts associated with agriculture, mainly due to engine fuel consumption and exhaust gas emissions, and materials production, use and disposal. Despite standardised and extensively accepted methods for environmental impact assessment have been developed, their application to mechanical field operations is still limited. In absence of reliable data, the reductions in environmental impact that are achievable cannot be easily evaluated by studying machinery already available on the market and more suitable machinery or by selecting the proper coupling between the implement and the tractor. This study carries out a comparative Life cycle assessment (LCA) of a rotary harrowing operation using different data sources. Data was gathered from: (i) Ecoinvent database, (ii) ENVIAM, a tool developed to support the completion of inventories for agricultural machinery varying the local pedo-climatic, operating and mechanical features, and (iii) primary data directly collected during experimental tests with CAN-bus, GPS and exhaust gases analyser. The analysis showed that using database average data, the resulting environmental load is not always reliable and, in this particular study, it consistently overestimated most outcomes. Moreover, by processing primary data collected using modern technology, the operation could be split in different working phases (effective work, turns, stationary-idling). Thus, specific mechanical features were quantified and this permitted the environmental impact to be evaluated with more detail.

1. Introduction

During recent decades, there has been a marked growth of interest in quantifying and reducing the environmental impact of agricultural production. It is widely known that agriculture plays a role in concerns over air, soil and water quality (Bacenetti, Lovarelli, & Fiala, 2016; IPCC, 2006; Schmidt Rivera, Bacenetti, Fusi, & Niero, 2017) and, in particular, mechanisation has been related to a substantial share of these

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Nomenclature

Variables/nomenclature	Symbol/ abbreviation	Unit
Engine load		%
Engine speed	s	routes s^{-1}
Torque	M	N m
Tractor engine power		kW
Fuel consumption	FC	l h^{-1} kg ha^{-1}
Emission of carbon dioxide	EM CO_2	g [CO_2] h^{-1} kg ha^{-1}
Emission of carbon monoxide	EM CO	g [CO] h^{-1} g ha^{-1}
Emission of nitrous oxides	EM NO_X	g [NO_X] h^{-1} g ha^{-1}
Brake specific fuel consumption	bsfc	g kW h^{-1}
Specific emission of exhaust gases	EMspec	g kW h^{-1}
Climate Change	CC	kg [CO_2 eq]
Ozone Depletion	OD	mg [CFC-11 eq]
Terrestrial Acidification	TA	kg [SO_2 eq]
Freshwater Eutrophication	FE	g [P eq]
Marine Eutrophication	ME	g [N eq]
Photochemical Oxidant Formation	POF	kg [NMVOC]
Particulate Matter Formation	PM	kg [PM10 eq]
Metal Depletion	MD	kg [Fe eq]
Fossil Depletion	FD	kg [oil eq]
Controller Area Network	CAN-bus	
ENVironmental Inventory of Agricultural Machinery operations	ENVIAM	
Exhaust Gas Recirculation	EGR	
Functional Unit	FU	
Global Positioning System	GPS	
Life Cycle Assessment	LCA	
Life Cycle Inventory	LCI	
Life Cycle Impact Assessment	LCIA	
Oxygen	O_2	

negative effects (Niero et al., 2015). The mechanical operations carried out during farming activities have been held responsible for freshwater pollution and greenhouse gas emissions (Notarnicola et al., 2015). Emissions are affected both by fuel consumption and exhaust gases directly emitted into the air, as well as by the consumption of mineral and fossil resources for materials realisation (i.e. the processes of mineral extraction, energy use and production for the materials that compose the tractor and implement) (Boone et al., 2016; Lee, Kim, & Kim, 2016; Mantoam, Romanelli, & Gimenez, 2016). It must be pointed out that not every agricultural field operation is adequate in a particular working context; the variability of working conditions (local pedo-climatic, mechanical and operative variables) and the availability of machinery options (Barthelemy, Boisgontier, & Lajoux, 1992) affects both assessments of mechanical suitability as well as of environmental impact.

Although recently standardised and widely accepted methods for environmental impact assessment have been developed (ISO 14040 series, 2006), their application to mechanical field operations is still somewhat limited (Lovarelli, Bacenetti, & Fiala, 2017). This is due to the difficulties in inventory data collection, since they are site and time dependent, and to the difficulty in getting manufacturing data. With regard to inventory data collection, data can be obtained from both a primary source (i.e. directly collected or measured) and a secondary source (i.e. databases, scientific literature). Certainly, primary data are the most reliable but they are also the most difficult and time consuming to get. For agricultural production, specific geographical, temporal and managerial data are highly relevant (Perozzi, Mattetti, Molari, & Sereni, 2016) and strongly influence the subsequent quantification of environmental impacts. This is mainly because agricultural systems are based on natural variables (e.g., climate and seasonality, temperature and rainfall), on local field-specific variables (soil texture, field shape, etc.) and on the choices made by farmers regarding the machinery adopted and the farm management regimes used, all of which can affect most environmental loads (Bacenetti, Fusi, Negri, & Fiala, 2015; Mantoam et al., 2016).

Reliable data are needed. Although secondary data have the advantage of being more easily available, the pitfall is that they may include simplifications and average values that may not be able to accurately describe the studied system. Specifically, the most important side effects of secondary data are that they can make it impossible to quantify the reduction in environmental loads that are achievable with new machines and innovative technology, since machines may already be available on the market (e.g., minimum and strip tillage, sod-seeding) but not included in databases or, improvements could be made by selecting more suitable machines or performing a proper coupling between the implement and tractor. In fact, in the most used database applied in life cycle assessment (LCA) studies (i.e. Ecoinvent) (Weidema et al., 2013), the impact of the most common field operations is included, but is assessed by considering the average pedo-climatic (e.g., soil texture and moisture), operating conditions (field shape, slope and transfer distance) and mechanical conditions (engine features during transfers, turns and working phases); consequently, the results are not always reliable.

Thanks to the availability on the market of modern tractors and implements, and of new techniques or management strategies, the collection of reliable data is more easily facilitated. In particular, with the modern technologies installed on modern tractors such as CAN-bus (controller area network), a huge amount of contemporaneous information is accessible and constantly measurable during field work (Fellmeth, 2003; Lindgren, 2005; Pitla, Luck, Werner, Lin, & Shearer, 2016). These data can describe how the engine works as well as instant working features and interactions within the tractor. This makes it possible to increase the reliability of data for modern machinery and to optimise and better manage the use of agricultural inputs (Bietresato, Calcante, & Mazzetto, 2015).

The aims of this study were:

- to describe the field experiment of a rotary harrowing operation carried out with typical electronic instrumentation available for modern machinery and use the main