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Fuel consumption and exhaust emissions during on-field tractor activity: A possible improving strategy for the environmental load of agricultural mechanisation

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ABSTRACT

Agricultural machinery plays an important role on the environmental sustainability assessments of the agricultural sector and, in particular, a prominent part of its impact is due to fuel consumption and engine exhaust gases emissions.

In order to adopt trustworthy data on agricultural machinery operations for fulfilling reliable local inventories in Life Cycle Assessment (LCA) studies, field tests were performed. During the trials several operations were monitored (i.e. ploughing, spike harrowing, rotary harrowing, sowing and rolling) and the measured data with CAN-bus (among which the fuel consumption) and with the engine exhaust gases emissions analyser (CO_2, CO and NO_X) were attributed to the field working states of effective work, turns at headlands and stops that were identified thanks to GPS. Moreover, data during the farm-field transfers were also collected.

In addition to data processing from the field trials, a model for predicting fuel consumption and engine exhaust gases emissions was adopted and its reliability was studied for further future uses.

From the results, specific considerations about the tested tractor (Valtra N101, 82 kW maximum power, IIIA emission stage) and the studied working conditions (e.g., engine speed, torque, working speed and depth) can be performed to get information valid for the engine and the operations.

1. Introduction

Thanks to the application of recent technology to agricultural machinery, and to tractors in particular, a great potentiality for the enhancement of efficiency and for the monitoring of engine variables has been proven (Pitla et al., 2016; Shadidi et al., 2014). Specifically, the use of CAN-bus (Controller Area Network), data logging software, GPS (Global Positioning System) and exhaust gases emission analysers allows collecting a huge amount of data directly related to in-field activity (Hameed et al., 2012; Yahya et al., 2009). In this context, the interest in quantifying and reducing the environmental load of agricultural productions (Renzulli et al., 2015) must be considered as well, and its reliability can be improved with the adoption of the abovementioned technology for both improving the machinery engineering and knowledge (Bishop et al., 2016) as well as the related environmental sustainability (Lovarelli and Bacenetti, 2017).

Regarding the environmental point of view, agricultural mechanisation is responsible for a substantial share of impacts, mainly due to fuel consumption and engine exhaust gases emissions and to the materials wear. The quantification of these impacts, at least for the mechanical field operations, still shows shortcomings (Lovarelli et al., 2017), but also room for improvement (Gabel et al., 2016). In fact, collecting data and monitoring tractors' activity permits to improve the efficiency of tractors, the machinery fleet and their use. This certainly presents advantages on the construction and management perspectives, but also on the environmental one (Lovarelli et al., 2016). Commonly, one of the most limiting factors to inventory data collection for environmental assessments of agricultural machinery is the unfeasibility to collect or measure some inventory data (i.e. primary source) because they can be time consuming and site and time dependent. Although primary data are the most reliable, collecting difficulties and site-specificity cause the widespread use of secondary data (i.e. databases, scientific literature) that, on the other side, can be simplified and not fully reliable (Sala et al., 2017), especially if uncritically used (Lovarelli and Bacenetti, 2017). Nevertheless, particularly for agricultural productions, the geographical (Perozzi et al., 2016), temporal and managerial characteristics (e.g., soil texture, field shape and slope, climate and seasonality, machinery fleet and management choices) deeply

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affect most environmental loads (Bacenetti et al., 2015; Lovarelli et al., 2017).

Collecting primary data is getting more possible thanks to the availability on the market of tractors and implements equipped with new technology and of new techniques or management strategies (Marx et al., 2015). In particular, technology such as CAN-bus, GPS, electronic devices and exhaust gases analysers, allow access to a huge amount of data measurable constantly and simultaneously to the work on field (Fellmeth, 2003; Pitla et al., 2016). These data describe how the engine works, the fuel consumed and exhaust gases emitted and the working features and interactions in the tractor (Janulevičius et al., 2016). Thus, it is possible to monitor and map variables (Bietresato et al., 2015), to increase the reliability of analyses on modern machinery, optimise inputs use and management (Larsson and Hansson, 2011; Lindgren and Hansson, 2004) and identify the optimal combination of work conditions to reduce inputs use (Hameed et al., 2013). In particular, primary data give information on the specific working context and the specific variability of the field operation, therefore accurate processing and robust prediction models for engine-related variables are achievable. Manufacturers can use such information to improve the construction and maintenance of tractors as well as to identify failures.

The general aim of the study is to make advances on the data and model availability related to the modern technology present on tractors, which results helpful for several scopes among which the improvement of data reliability for sustainability evaluations completed by means of Life Cycle Assessment (LCA). The possibility of having trustworthy and specific data permits to calculate the environmental load of agricultural machinery operations in a reliable way, allowing playing a management role for the environmental sustainability and for introducing effective sustainability measures in the manufacturing field and in the farmers' perspective. For reaching this goal, the specific aims of this study are to:

(i) identify the most important data for the filling of reliable inventories of agricultural machinery field operations, thus showing what happens along the different working states of a single operation,
(ii) design and execute experimental field trials, carried out to collect primary data on field operations for cereal crops cultivation, as well as the methodology that was adopted for the data processing and its possible future repeatability,
(iii) apply a reliable quantification model for the prevision of fuel consumption and exhaust gases emissions that takes into account the engine behaviour during the field operations,
(iv) show the discrepancies that can emerge in terms of description of field activities among measured data on field, data related to single working states respect to the whole field work as such and data from test benches, these last with regard mainly to engine exhaust emissions. Lastly, all these differences affect the environmental sustainability of the field operations which is highlighted by several impact categories (e.g., Climate Change, Ozone Depletion, Acidification, Particulate Matter Formation, Photochemical Oxidant Formation and Fossil Depletion; Wolf et al., 2012) (Lovarelli and Bacenetti, 2017).

2. Materials and methods

2.1. Goal of the field trials

The aim of the field experiments is to collect data from CAN-bus and gases analyser in order to have information about the engine working features, fuel consumption and exhausts emissions while directly working on field in order to realise detailed and reliable Life Cycle Assessment (LCA) studies on agricultural machinery operations. In fact, the final goal is the inventory fulfilment for LCA studies on agricultural machines aggregated with this tractor.

LCA is an internationally recognised method that permits to quantify the environmental impact of processes (ISO Series 14040), for which inventory data concerning fuel consumption, engine exhaust gases emissions and the consumption of materials composing machinery represent essential information.

Thanks to the GPS present on the tractor used for the field trials were built maps of the fields. Maps were built on a Microsoft Office Excel spreadsheet using the GPS coordinates and translating them into X-axis and Y-axis data. Every map was characterised by CAN-bus and exhaust gases emissions data grouped in the following working states:

(i) effective work: condition in which the tractor is driving on the stretch effectively carrying out the operation;
(ii) turn at headland: condition in which the driver is manoeuvring at the headlands, including when the implement is lifted/lowered and/or turned before or after the turn;
(iii) stop: when the tractor is not moving, therefore its GPS position along time does not change. In this condition, often, the engine is idling, but this is not a compulsory condition;
(iv) transfer: the whole condition of transport from the farm to the field and vice versa.

To better study the role of the working states, the trials can be distinguished in two main parts:

(i) completion of field operations (such as ploughing, sowing) with defined engine and field working features to study the behaviour of the tractor in those conditions;
(ii) comparison of turning strategies at the headlands during an operation to study the behaviour of the engine within different conditions during the turns at the headlands.

In both cases the aim is to identify the most relevant differences in terms of fuel consumed and exhaust gases released, what working conditions show the best outcomes on the environmental perspective and how can vary the fuel consumption and engine exhaust gases emissions by changing only few work conditions.

2.2. Instrumentation used

Among the instrumentation developed to map, understand and study the activity of the tractor engine and of the related devices employable during on-field activity, the most widely used system is the CAN-bus. It is a serial high-speed wired data network connection that permits to electronic devices to communicate with each other and that, coupled with storing instrumentation, permits to collect huge amounts of data with high frequency (Speckmann and Jahns, 1999). CAN-bus is normed with SAE J1939 for the connections of electronic devices on agricultural machinery and with the standard protocol ISO 11898. It is commonly available on modern medium-high power tractors and has permitted to use and take advantage of electronics on agricultural machinery, in particular with the improvement in data monitoring and collection and in sustainability evaluations.

The data logger that was used for the acquisition and storage of CAN-bus data is Dewesoft® software that is equipped with the translation key from CAN-bus and uses more than 100 communication channels to be selected. Already on-board it was possible to check how variables were changing over time, by means of the interface available with an on-board-mounted laptop that allowed selecting the variables to be shown. The data collection and saving in Microsoft Office Excel format was performed for the subsequent processing phase.

The portable instrument for the measurement of engine exhaust gases is Testo® 350; it analyses the flux of gases from the exhaust pipe of the tractor and results the values in ppm (or in % for CO_2). The measured gases are NO_X, NO, NO_2, CO and O_2; CO_2 (vol%) is obtained from calculations deriving from O_2 concentration. In addition, the sample