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Sustainable design and life cycle assessment of an innovative multi-functional haymaking agricultural machinery

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ABSTRACT

The reduction in the use of raw materials and the spread of energy efficient processes and components are necessary from both the economic and the environmental viewpoints. This paper presents the design of an innovative multi-functional agricultural machinery able to integrate three separate traditional implements used for hay raking, hay baling and bale wrapping, i.e. hay rake, round baler and bale wrapper machines, with the aim of speeding up the harvesting operations and reducing both the energy consumption and the global environmental impact. A comparative analysis about the adoption of the traditional implements and the new multi-functional machinery is reported. Particularly, the reduction in both the fuel consumption (−32%), the human labor (−66.7%) is discussed together with a differential environmental analysis of the proposed system and the traditional implements. To meet such a last purpose, the study adopts the life cycle assessment methodology carefully quantifying the impact indicators for three different categories, i.e. human health, ecosystem quality and resource depletion. The results highlight a global environmental impact reduction of about 35%. The proposed system represents an effective and competitive improvement to ease and speed the haymaking process and to reduce the environmental impact of such a key farmer activity.

1. Introduction

In these years, the agricultural chain is experiencing a period of significant transformation. The economic crisis affecting the entire agricultural sector led to a greater sensitivity to the production costs, so that greater attention is paid on the development of efficient processes (FAO, 2010). The use of chemical fertilizers, the over-exploitation of the soil and the adoption of intensive pesticides are proving their ineffectiveness, with long-term effects, and they are subject to a negative perception by the market (Mózner et al., 2012; Dorais, 2007). In the recent past, the international community frequently discusses the environmental sustainability of the agricultural products and the effects of pollution on both the public health and the product quality (Millennium Ecosystem Assessment, 2005; Lagerberg and Brown, 1999). In this context, mechanized automation plays a crucial role. If the producer is able to reduce the economic costs and the environmental impact associated to the life cycle of the products offered to the final customers a sustainable source of competitive advantage is possible with benefits for its own sector and for the whole community. As a result, the manufacturers are looking towards the design of effective methods based on both the environmental and mechanical efficiency of automated agriculture.

An Italian manufacturer of haymaking systems is developing an innovative Multi-Functional Machinery (MFM) able to jointly perform three operations that are usually conducted by a same number of standalone devices, i.e. hay rake, round baler, bale wrapper. Such a multi-functional system introduces significant modifications in the haymaking procedures: hay collection, hay baling and bale wrapping are carried out within a single step requiring a single device towed by a tractor. Fig. 1 represents the innovative concept behind the new MFM.

Despite the increase in the efficiency is predictable, the environmental benefit introduced by the use of the MFM compared to the corresponding three standalone machines is not obvious and its evaluation is the aim of the present research. A comparative Life

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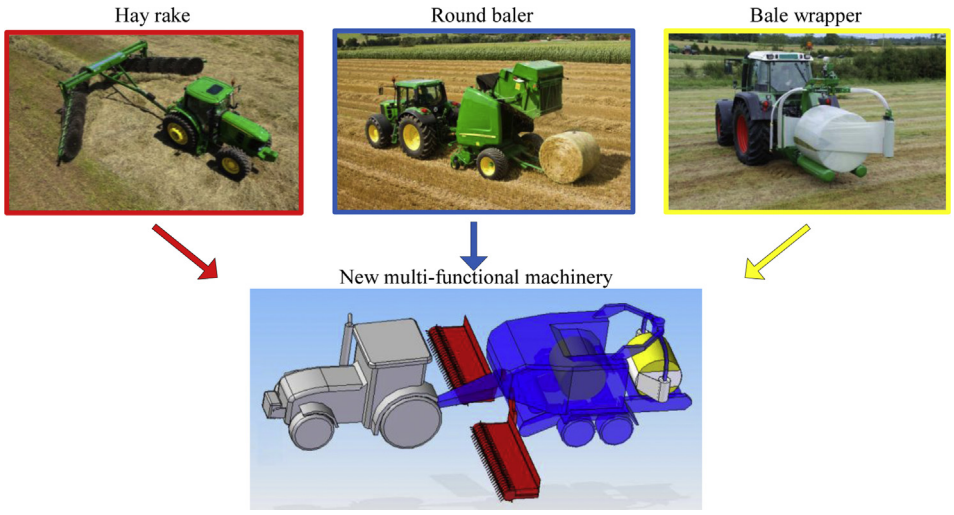

Fig. 1. New multi-functional machinery.

Cycle Assessment (LCA) is proposed: the new MFM is compared to the standalone implements on the basis of the environmental burden introduced by their life cycles. The assumed functional unit is the production of 98,700 wrapped hay bales, which corresponds to 3000 machine working hours. The description of the haymaking process and the MFM features, developed during the machine design phase, are followed by the comparative LCA presentation. The results are, then, shown, both, aggregately and split by machine functional unit stressing their contribution to the global system environmental impact and highlighting the savings coming from the switch to the proposed MFM.

According to the introduced topic, the remainder of this paper is organized as follows: the next Section 2 proposes an introduction to the integration of LCA methodology to the Eco-Design process and a literature review about the most significant scientific contributions on LCA studies applied to the agricultural context. Section 3 presents the functional description of the haymaking process and the agricultural machinery analyzed in this study. The LCA steps are fully described in Section 4, while the key results of the comparative LCA are reported in Section 5 and fully discussed in Section 6. The last Section 7 ends the paper with conclusions about the environmental effects related to the improvement actions on the haymaking procedure redefinition.

2. STATE-OF-THE-ART of LCA in agriculture and farming operations

2.1. LCA and Eco-Design

The systematic consideration of design issues relating to resource preservation, environmental protection and human health over the whole product life cycle is defined as Eco-Design or, synonymously, Design for Environment (Fiksel, 1993; Hauschild et al., 2005). An extended taxonomy of Eco-Design tools based on the most relevant literature contributions on environmental design methodology is in Bovea and Pérez-Belis (2012). They identified twenty main Eco-Design methodologies, more than half of which are based on the use of LCA, or simplified LCA, as the tool for the evaluation of the product environmental profile. The potential benefits associated to the effective integration of LCA within the Eco-Design process are well discussed in the literature (Keoleian, 1993; Robèrt et al., 2002), together with the limits of LCA approach assisting (Millet et al., 2006). Nielsen and Wenzel (2002) proposed a framework for the integration of the environmental performance estimation within the Eco-Design process that involves the application of LCA in different design steps. LCA is a standardized methodology and its application is popular in the agricultural and food production research fields.

2.2. LCA in agriculture

In the recent years, the contributions of the scientific community to the environmental impact assessment of the processes related to the agricultural production grew up significantly. From 2010 to date, more than two hundred articles, which have both “life cycle assessment” and “agriculture” as main issues, are published. Such a popularity is justified by the relevance of the food production to the environmental impact generation. Tukker et al. (2006) assessed that the food and beverage sector involves 20–30% of the total environmental impacts resulting of the European Union citizens' consumption, in which meat and dairy productions account respectively for 4–12% and 2–4% of the equivalent carbon dioxide emissions. Roy et al. (2009) proposed an extended review on LCA studies related to the food production, classifying several contributions on the basis of the food product features. A whole section is dedicated to LCA on dairy and meat production. According to the authors, the agricultural phases are reported to be the main hotspot in the life cycle of milk and semi-hard cheeses. Comparable conclusions on the relevance of the agricultural phase in dairy and meat production impact were drawn by Berlin (2002) and Foster et al. (2006). Hospido et al., 2003 analyzed milk production in Spain and found that the feed production phase is a hotspot of milk life cycle. In particular, the production of silage, representing the 21% by weight of the animal feed, is estimated to be responsible for 29% of global warming and acidification, and 23% of the eutrophication effects of the total milk production process. Some LCA studies adopting extended system boundaries indicate that the agriculture production is the main source of impacts in the life cycle of meat products (Mattsson et al., 2000; Foster et al., 2006;