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Water and Carbon footprint perspective in Italian *durum wheat* production

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ABSTRACT

Agriculture has a strong influence on water consumption; the scarcity of water in some areas is a problem, which affects the balance of entire production areas. Global water resources are widely used for food production; some areas of the Mediterranean are scarce in water and the water demand is expected to increase in the future due to population growth. In addition, carbon emissions related to agricultural production represent about 35% of total greenhouse gas emissions. Starting from these considerations, this study investigates water and carbon footprint in italian *durum wheat* cultivation, taking into account the production from 2011 to 2015. Results showed an extreme variability of these indicators across the country. The regions below 5000 m^3 ha^{-1} of water consumption (dedicated to *durum wheat* production) are located in the South, whilst the highest values are recorded in the Centre and in the North. With regard to the values of the water surface consumption, the situation is quite the opposite: indeed, these are mainly the Southern and the Adriatic regions that have a high value of the ratio between water footprint (WF) and total agricultural area. carbon footprint (CF) showed a similar trend; its highest value was found in Northern Italy (2462 kg CO_2 ha^{-1}), the ratio between the North and the Centre-North is 1.30. Policy suggestions that address management of water resources and sources of carbon emissions could increase the environmental sustainability of italian *durum wheat* production.

1. Introduction

Ryan et al. (2008) predict that the future challenge for agriculture will be to produce without reducing the capacity of natural resources (soil and water), and to avoid creating a fragile and uncertain environment for production. In the Mediterranean, cereals account for over half of the total area of land that is irrigated (Daccache et al., 2014), and although considerable efforts have been made to develop and disseminate several modern wheat varieties (Shiferaw et al., 2014) to increase productivity, few studies have been carried out on the environmental sustainability of cereals production.

The Mediterranean area contributes to 60% of the global production of *durum wheat* (FAOSTAT, 2013). The production of which is expected to experience an increased variability in yield and quality as a consequence of climate change (Toscano et al., 2015). Italian wheat production during 2015 covered an area of 1327,389 ha and yielded 44,537,266 tonnes of cereals (ISTAT 2016). Water resources are widely used for food production and, consequently, its demand is expected to increase in the future due to population grows (Bocchiola et al., 2013; Curmi et al., 2013; Khan and Hanjra, 2009). Agriculture is the main consumer of freshwater in the world, as pointed out by Rodriguez et al. (2015) and accounts for about 70% of water withdrawals (Chen and Chen, 2013). Some Mediterranean areas are water scarce, particularly in Southern and Eastern countries (García-Ruiz et al., 2011). A failure to manage many water systems optimally results in environmental damage (Xu et al., 2016); this is more evident in the case where activities can cause the degradation of hydrological habitats (Chapagain and Orr, 2009). Ercin and Hoekstra (2014) predict that freshwater scarcity and pollution will be worsened in the future and this will decrease its quality. Moreover, some authors have estimated that human dependency on water resources will increase significantly in the future (Alcamo et al., 2003; Bruinsma, 2009; Rosegrant et al., 2009). Chapagain et al. (2006) point out that the majority of costs and impacts of water use and pollution caused by agriculture and industry is not translated into the price of products. However, it is still possible to remain at sustainable levels even with increasing populations through changes in water management (Ercin and Hoekstra, 2014). In order to limit the unsustainable use of global

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freshwater resources, indicators are needed, which make consumption patterns transparent (Ridoutt and Pfister, 2010).

Global water cycles and carbon energy cycles are inextricably linked (Khan and Hanjra, 2009). Scientific evidence has shown that the climate is rapidly changing mainly due to increasing anthropogenic greenhouse gas emissions (Ruddiman, 2003), which stem from various human activities, including agriculture (Janzen et al., 2003).

An issue closely linked to the greenhouse gas balance is related to the carbon cycle and the ability to store it in carbon sinks (IPCC, 2014). It is known (Pattara et al., 2012) that carbon dioxide is absorbed by plant tissue and it is converted into cellulose and lignin and other compounds. The duration of carbon sequestration outside the atmosphere determines whether the cycle is short or long. Unfortunately, in the case of durum wheat, all carbon stored in plant tissues is released into the atmosphere in the timespan of a season or a few years. This implies that in open field crops no direct benefits can be achieved in terms of carbon sinks. As it is well known (Weidema et al., 2008), carbon footprint (CF) is a very effective tool from a communication point of view, but within the complexity of environmental issues it is only one part of the whole. Environmental impact indicators (fresh water contamination, eutrophication, soil salinisation, etc.) that have developed as result of the use harmful plant protection products and the mismanagement of fertilisers and plant protection products should not be neglected.

Directly associated with the theme of choice of crops, the possibility of changing dietary habits towards low CF products can be raised. The issue has been addressed by several authors (Grebitus et al., 2015; Cerutti et al., 2016; Nijdam et al., 2012); however, it seems clear that the influence generated by environmental components in labelling of food products is still marginal compared to product price. There is still not enough done terms of consumer awareness campaigns to clarify labels relating to environmental issues or performance. Although the European Commission (with the single market for green products) and other nations around the world are making great efforts towards a standardisation of environmental certification procedures for products of the same category and for emission mitigation measures related to food production, consumers are still largely uninformed when it comes to environmental labels (Grebitus et al., 2015). Furthermore, a proliferation of environmental labels have contributed to an increase in consumer confusion have made making product choices even more difficult, needs to be taken into account.

The responsible use of water and the reduction/mitigation of carbon dioxide emissions is important in the context of social responsibility and of the guidelines aimed at sustainable management of natural resources. The water footprint (WF) has been widely used as an indicator that contributes to safe and sustainable of water, and CF for as an indicator for carbon dioxide emissions. Although the various footprint concepts are related, significant differences in origin exist between ecological WF and CF.

Rural Development Plan (RDP) is an extremely important tool to regulate the environmental policy. Depending on the purpose for which the RDP model is used, it can be modulled for specific features, such as the assessment of more complex relations in ecosystems and in environment-economy and environment-society interactions. Since the late 1990s, italian producers have struggled to improve the environmental performance of their production processes, an objective which has now been extended to the entire supply chain (Bevilacqua et al., 2007). Regarding products intended for direct consumption (pasta, rice and bread), the phases of the life cycle considered start from the production of raw materials, and conclude with cooking (as specified in the studies of Espinoza-Orias et al., 2011) and the disposal of packaging.

New policies can make food production more sustainable within the carrying capacity or ecological threshold of land and water resources (Khan and Hanjra, 2008) and with this in mind, the carbon and water footprint concepts complement each other, addressing different environmental issues: climate change and freshwater scarcity. Hoekstra (2008) notes that, undoubtedly, there will be a great market for water offsetting and water neutrality, comparable to the market for carbon offsetting and neutrality, but the extent to which this market will become effective in contributing to a more efficient, sustainable and equitable use of the globe's water resources will depend on the rules of the market.

The aim of this paper is to assess the WF and CF of italian *durum wheat* production, identifying both the location and the character of the impacts.

2. Literature review

2.1. Water use in cereal productions

Allan (1998) introduced the concept of virtual water to describe the total volume of water in agricultural products; he suggested that regions, which are poor in water, should import water intensive agricultural products. The water footprint is one of the most common tools used to analyse water management and the WF of a product is defined as the volume of freshwater used to produce it and should be measured over the full supply chain. This is more frequently expressed in water volume per unit of product ($m^3\ t^{-1}$) (Mekonnen and Hoekstra, 2011).

Hoekstra et al. (2011) define the concept of the Blue, Grey and Green WF. The Blue WF measures the amount of available water consumed in a certain period and therefore not immediately returned to the catchment; Grey WF of a process step is an indicator of the degree of freshwater pollution associated with it and is defined as the volume of freshwater that is required to assimilate the pollant load; Green WF is an indicator of human water use and refers to precipitation that does not run off or recharge the groundwater, but is stored in the soil or temporarily stays on the soil surface or vegetation. The sum of these three components gives the total WF.

In the agriculture, many studies emphasise the importance of a responsible use of water resources (Ababaei and Etedali, 2014). The water footprint is also calculated in products derived from *durum wheat*, such as pasta (Ruini et al., 2013). The water footprint (ISO 14046:2014) indicator is a tool that provides interesting information for policy makers (Steen-Olsen et al., 2012) and economists and is useful for water management. Rodriguez et al. (2015) emphasised the relevance of agricultural practices, such as irrigation and fertilisers on the WF of the crop.

Companies and consumers can be advantaged by finding ways of reducing their environmental impacts, as well (Ridoutt and Pfister, 2010). In the context of social responsibility, the WF has been widely used as an indicator that contributes to safe and sustainable use of water (Marano and Filippi, 2015). Freshwater (adequate in terms of qualities-quantities) is a prerequisite for human societies and natural ecosystems.

Despite the importance of WF as an environmental sustainability indicator, it should be considered as a partial tool that can be used together with other indicators to allow for a more in depth look at integrated policies (Perry, 2014).

2.2. Carbon footprint in agricultural production

The carbon footprint is a versatile tool that can also be used for communication purposes due to its direct correlation with the phenomenon of climate change (Pattara et al., 2012). It is particular useful for communication to stakeholder groups who do not have a high-level scientific knowledge. Its easy use has rendered it