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Carbon footprint assessment on a mature vineyard

Serena Marras[a,b,*], Sara Masia[a], Pierpaolo Duce[c], Donatella Spano[a,b], Costantino Sirca[a,b]

[a] DipNET, Dipartimento di Scienze della Natura e del Territorio, University of Sassari, Italy
[b] CMCC, Euro-Mediterranean Centre on Climate Change, IAFES Division, Sassari, Italy
[c] CNR-IBIMET, Consiglio Nazionale delle Ricerche, Istituto di Biometeorologia, Sassari, Italy

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ABSTRACT

It is recognized that agriculture is the fourth largest contributor to global greenhouse gases (GHGs) emissions by sector (14%) and the wine industry is one of the most important economic sectors in terms of production and distribution worldwide. However, agriculture can also contribute to sequester carbon, so it is important to understand the double role of such systems.

Even if the agricultural phase is recognized by several authors to have a strong environmental impact during the wine production, only a few studies estimate GHG emissions related to this stage. In addition, the determination of the carbon footprint (CF) (i.e. the amount of direct and indirect CO_2 emissions caused by a production process) of the agricultural phase is not a simple task due to the large uncertainty related to local characteristics, climate, land, agricultural practices, grape type, and to a general lack of experimental data.

The main goal of this work was to determine the CF of a mature vineyard during the grape production process. The CF analysis was conducted in a typical Mediterranean vineyard located in the South of Sardinia (Italy) using 1 kg of grape yield as functional unit. The system boundary was "from cradle to gate" excluding winemaking processes, distribution, and consumption. In addition, the study was addressed to assess the role of the vineyard to offset carbon emissions at the end of the productive year. The Eddy Covariance technique was used to directly measure the CO_2 exchange over the vineyard and the net CO_2 budget was computed by combining the measured fluxes and the GHG emissions estimated by the CF analysis.

Results showed that the production of 1 kg of grape determined a total amount of GHG emissions of 0.39 kg CO_2-eq and most of them derived from external inputs such as fossil fuel combustion and soil management.

In addition, ecophysiological processes could contribute to offset the CO_2 emissions released during the agronomic practices.

1. Introduction

In recent years, there has been a growing concern related to the eco-sustainability of production processes, and consumers are becoming more interested in environmentally friendly practices, products, and services. The widespread adoption of intensive production systems in agriculture leads to increase soil degradation, loss of biodiversity, reduction in soil organic matter and water, and increase in air and soil pollution (Zabini, 2008). Measures are then needed to promote sustainable production processes.

The fourth largest contribution to global greenhouse gases (GHGs) emissions is given by agriculture (14%) (Metz et al., 2007), and the wine industry is one of the most important economic sectors in terms of production and distribution worldwide. The International Organisation of Vine and Wine (OIV) states that, in 2014, 270 million hectoliters of wine have been produced on a total vineyard area of more than 7.5 million hectares. The major producing Countries in the Mediterranean Basin (Italy, France, and Spain) reached a total area of approximately 2.6 million hectares and a production of almost 130 million hectoliters (OIV, 2015). The noteworthy economic impact of these data makes necessary the development of methodologies aiming to estimate greenhouse gases (GHGs) emitted in the atmosphere from everyday products and services, and to search for useful strategies to reduce them.

Life Cycle Thinking (LCT) is a quantitative approach which aims at taking into account all life cycle phases of a product

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* Corresponding author at: DipNET, Dipartimento di Scienze della Natura e del Territorio, Università di Sassari, Via de Nicola 9, 07100 Sassari, Italy.
E-mail address: serenam@uniss.it (S. Marras).

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(e.g. extraction of the raw materials, pre-production processes, production, consumption, end-of-life) in a broad range of methodologies and instruments for sustainability assessment and management. Several LCT-based methods have already been produced so far, and the Life Cycle Assessment (LCA) is one of the most known to account for the environmental burdens associated with the different life cycle stages of wine (Neto et al., 2013; Vázquez-Rowe et al., 2013), and providing multiple impact categories to be analyzed (e.g. global warming, human and environmental toxicity, natural resource depletion, ozone layer depletion, summer smog) However, LCA also presents disadvantages due to its holistic and comprehensive principles. Consequently, LCA studies developed a number of indicators, such as water footprint or carbon footprint (CF) (Čuček et al., 2012; Laurent et al., 2012; Scipioni et al., 2012).

CF analysis, as a part of the LCA approach, quantifies CO_2 emissions directly and indirectly caused by an activity or accumulated during the lifecycle of a product or service (Wiedmann and Minx, 2007). This approach enables to identify the contribution of a production process to climate change considering emissions of the GHGs covered by the Kyoto Protocol (Bosco et al., 2011). It is typically expressed in kg CO_2-equivalent (CO_2-eq), i.e. a measure of the greenhouse effect of a gas considering its Global Warming Potential (GWP).

Recently, several approaches and guidelines have been developed for accounting GHG emissions, including (1) methodologies at territorial scale developed by the IPCC, (2) the Publicly Available Specification 2050 (PAS 2050) developed by the British Standard Institute and the Carbon Trust (BSI, 2011), and the (3) Greenhouse Gas Protocol (GHG-Protocol) developed by the World Resources Institute and the World Business Council for Sustainable Development (WBCSD/WRI, 2004). In the wine sector, the most used protocols are the International Wine Carbon Protocol (IWCP), the French Bilan Carbone (ADEME, 2010), and the OIV-GreenHouse Gas Accounting Protocol (OIV-GHGAP).

Winemaking process can be subdivided into two main phases: agricultural and industrial. Agricultural phase accounts for GHG emissions related to practices for vineyard planting, pre-production and grape production sub-phases, while the industrial phase includes vinification, bottling, packaging, distribution, and waste management processes (Bosco et al., 2011).

Several studies applied the LCA methodology to evaluate the environmental performance of the wine sector (Notarnicola et al., 2003; Aranda et al., 2005; Ardente et al., 2006; Petti et al., 2006; Pizzigallo et al., 2008; Gazulla et al., 2010; Point et al., 2012; Vázquez-Rowe et al., 2012a,b; Benedetto, 2013; Neto et al., 2013), and the CF analysis (Colman and Päster, 2007; Smyth and Russell, 2009; Cholette and Venkat, 2009; CSWA, 2009; Smart et al., 2009; Bosco et al., 2011; Pattara et al., 2012; Rugani et al., 2013; Vázquez-Rowe et al., 2013). However, only a few studies analyzed the CF for a single stage of the production process by addressing specific aspects related to it as, for example, the agricultural phase (Kavargiris et al., 2009; Venkat, 2012), the wine distribution and the end-of-life (Cholette and Venkat, 2009; Reich-Weiser et al., 2010).

In the winemaking process, the agricultural phase has been recognized to contribute from 17% (Rugani et al., 2013) up to 40% (Benedetto, 2013; Neto et al., 2013) to GHG emissions. Studies reported that the use of pesticides, fertilizers, and diesel consumption for vineyard practices are the main sources of GHG emissions in the wine chain (Niccolucci et al., 2008; Pizzigallo et al., 2008; Bosco et al., 2011; Point et al., 2012; Benedetto, 2013; Rugani et al., 2013; Fusi et al., 2014). However, the determination of the CF in the agricultural phase is not a simple task because of various issues. Large uncertainty in the estimation derives from differences in the local ecosystems, climate conditions, land texture, agricultural practices, and grape varieties (Rugani et al., 2013). In addition, a general lack of experimental data and information makes difficult the CF quantification of this stage.

Apart from the production system complexity, a critical point is to include, in the net carbon budget estimation, the carbon sequestered by the different components (soil and grass cover, woody biomass, etc.) of the vineyard system (OIV, 2011) that can offset the emissions from fossil fuel, usually representing the larger source of GHG in the agricultural systems. Most of studies assume balance between the biogenic CO_2 sequestered and released back to the atmosphere. As a result, CF analysis usually omits biogenic carbon issues. In addition, studies are largely based on carbon estimates and only part of them uses experimental data.

Micrometeorological methods are commonly applied to directly measure CO_2 exchanges between a system and the lower atmosphere, and the Eddy Covariance (EC) technique is the standard methodology used in the Fluxnet International Monitoring Network (Baldocchi, 2003). It is commonly used to obtain long-term measurements of CO_2 exchanges and helps in understanding and quantifying ecosystems capacity to absorb atmospheric carbon.

Even if the EC method is widely used over different ecosystems around the globe, so far little is known about the vineyard ability to sequester carbon and offset GHG emissions. CO_2 flux measurements over vineyards were usually reported for short measurement periods (a few weeks up to one month) (Spano et al., 2004, 2008), apart the three-year period analyzed by Guo et al. (2014).

The general aim of this work was to investigate the vineyard capability to offset GHG emitted during the agricultural phase of the production process. In addition, the research tried to identify the agronomic practices that mainly contributed to emissions, affecting the global carbon budget, and to include the biogenic contribution (quantified through direct measurements) in the calculation of the net carbon budget. The analysis was conducted in a typical Mediterranean vineyard. The IWCP Protocol was used to perform the CF analysis, while an Eddy Covariance tower was set up over the studied vineyard to directly measure the CO_2 flux in the soil-vegetation-atmosphere continuum.

2. Materials and methods

2.1. Carbon footprint methodology

The CF analysis was carried out in an experimental site located in the South of Sardinia (Italy). It was performed using one kg of grape yield as functional unit, and identifying a system boundary "from cradle to gate", excluding winemaking processes, distribution, and consumption. The analysis focused on the main agricultural practices conducted in the period October 2009–September 2010: fertilization application, soil management tillage, pruning, and harvesting.

The CF was computed following the International Wine Carbon Protocol (IWCP), and adopting its related calculator named International Wine Carbon Calculator (IWCC). In this work, only emissions related to Scope 1 or "primary footprint" (i.e. all emissions under the direct control of the farm) were considered and limited to the agricultural phase. Specifically, these are emissions related to the use of fossil fuel, both for agronomic practices and for traveling from the farm center to the field, and emissions from activities affecting the short-term carbon cycle (e.g. pruning, harvesting, and human metabolism of workers). All GHG emissions are expressed as CO_2 amount (kg) when carbon was directly released by the analyzed process or as CO_2-eq (kg) when Nitrogen (N) emissions were included, as requested by the CF guidelines.

Emissions from stationary fuel use (water heaters and frost fighting equipment), and fugitive emissions are not considered since heaters or boilers are not used in the investigated farm. Also,