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Linking water footprint accounting with irrigation management in high value crops

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ABSTRACT

In recent years, irrigated agriculture has been in a critical situation due torising production costs, the stabilization or reduction of product prices, and growing pressure to minimize environmental impacts. These circumstances are forcing farmers to find new ways to use resources more efficiently in their production processes.

The volume of water used during the crop growing season is linked to production; the final goal of all agricultural activity. Water footprint accounting is a suitable procedure to assess the relationship between water use and crop yield. However, it does not provide information about irrigation management. For this reason, information on water excess, deficit irrigation, or water needed for cropping practices must be incorporated into the crop water footprint analysis at farm scale.

In this paper, a joint evaluation of crop water footprint accounting and irrigation management indicators is proposed as a diagnostic tool to identify the hotspots of irrigated agricultural systems. Based on this analysis, specific actions can be defined to improve water use efficiency, reduce water abstractions and polluted water returns, and maintain production rates. The methodology has been applied to intensive strawberry production in Southwest Spain, specifically in the vicinity of Doñana National Park; a highly sensitive environmental area located in the province of Huelva. Actions to ameliorate the current situation are proposed.

1. Introduction

Freshwater is becoming an increasingly large and complex global challenge (Hunt, 2004). Freshwater scarcity has been recognized as one of the most crucial environmental concerns (UNESCO, 2006). Nowadays, one-third of the world's population lives in regions affected by water scarcity (UNESCO, 2009), a figure that is expected to reach over two-thirds by 2025. Freshwater availability is affected by several factors, such as world population growth, climate change, and industrial processes. Improving the management of this resource is therefore a major challenge that affects users, water authorities and business (WBCSD, 2006).

Many companies are concerned about this situation and are undertaking initiatives to gain a better understanding of water-related risks along their value chains. Several tools have been recently developed to facilitate water use accounting, the impact of water consumption, or promote a deeper engagement in resource management (Alliance for Water Stewardship, 2012). A reference to most of these tools can be found on the website of the CEO Water Mandate (CEOWM, 2012). All these initiatives have strengths and weakness (UNEP, 2011) and many are still under development (Bayart et al., 2010) or have been recently approved, such as the ISO international standard to assess water use (ISO, 2013).

At the global scale, most water use occurs in agricultural production, which is strongly related with specific activities such as irrigation. Irrigated agriculture is recognized as a water intensive sector due to the high dependency of agriculture on water resource use and management. It is therefore essential that the farming sector take a responsible approach towards the sustainable use and conservation of freshwater.

One of the most frequently used tools to implement such an approach is water footprint accounting; a concept that was first introduced by Hoekstra (2003), and more recently developed within the life cycle assessment framework (Mazzi et al., 2014; Berger and Finkbeiner, 2010; Bayart et al., 2010) and the ISO international standard (ISO, 2013). As an indicator, the water footprint measures the appropriation of water resources by human

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activity by evaluating water consumption and the impact on water quality. This process is also called "water footprint accounting" or "water footprinting" and forms part of a wider evaluation process known as "water footprint assessment" (Hoekstra et al., 2011).

Water footprint accounting is the phase in which data are collected and accounts are developed. It is a suitable procedure to appraise the water use and crop yield relationship. As such, it is a measure of crop water efficiency and hence crop production efficiency.

Many water footprint case studies have been carried out on water-intensive industrial processes and crops, such as cotton and the textile industry (Chico et al., 2013), grapes and the winemaking industry (Ene et al., 2013), tea and margarine production (Jefferies et al., 2012), the paper industry (Hubacek et al., 2009; van Oel and Hoekstra, 2012; Manzardo et al., 2014) or olive oil production (Salmoral et al., 2010). Many other studies have been performed on horticultural crops. Chapagain and Orr (2009) showed that tomatoes grown in Spain are placing an unsustainable strain on local water resources. Their study found that the annual abstraction rates in the province of Almeria in southern Spain, one of the main horticultural crop growing regions in the European Union, are approximately 4–5 times higher than the annual rainfall.

Strawberries are an example of a water-intensive crop that is highly demanded in both the European fresh market and the food industry. The average water footprint of strawberries produced in Huelva ranges from 173 m^3/t (Adams, 2009) to 140 m^3/t (Aldaya et al., 2010). Adams estimates the strawberry water footprint in Poland at 592 m^3/t (Adams, 2009). The marked difference between the Spanish and Polish values is due to the intensive nature of agricultural methods in Spain, where strawberries are cropped in polytunnels and rainfall does not intervene in the water balance unlike the more traditional Polish techniques that depend mainly on green water and produce lower yields.

However, studies carried out on water footprint accounting of crops grown at farm scale only provide information about the water used per unit of agricultural production but not about the irrigation process or whether the water is used efficiently. Therefore, the water footprint indicator should be accompanied by other indicators to evaluate if the irrigation water is being used in the best way possible.

Relative irrigation supply (RIS) is a widely used indicator to assess irrigation management (Levine, 1982). RIS is the ratio of the total annual volume of water diverted or pumped for irrigation and the total theoretical irrigation needs of the crops calculated per irrigation season. This indicator is clearly defined by the International Programme for Technology and Research in Irrigation and Drainage (IPTRID), which developed a set of simple but effective and universally applicable performance indicators (Malano and Burton, 2001). These indicators have become a powerful tool for assessing irrigation processes in irrigation districts or on farms (Rodríguez Díaz et al., 2008, 2011, 2012), and has also proven to be useful as a reference for guiding sustainable development at the regional level (Geng et al., 2014).

Efficient water use is particularly important in high environmentally sensitive areas where poor irrigation practices may have a large impact on water resource availability and pollution. 73% of total strawberry production in Huelva is located in the vicinity of Doñana National Park (Fundación Doñana 21, 2006). Several water regulations affect the park and its surrounding areas: the Guadalquivir and the Tinto, Odiel, Piedras hydrological basin plans (CHG, 2013; CHGuadiana, 2012). The strictest regulation is the "Special Management Plan of Northern Doñana Irrigated Areas" (Regional Government of Andalusia, 2011), which proposes a water allowance of 4000 m^3/ha. Although the strawberry sector claims that the proposed allowance is clearly insufficient, the water authorities argue that the maximum yield can be achieved with the current allowance. The water administration recognizes that specific studies under local conditions are required to improve farmers' irrigation practices and to introduce new irrigation technologies that promote the efficient use of water by reducing the volume of freshwater withdrawal.

Water footprint accounting does not include water use insofar as this water is returned to where it came from (Hoekstra, 2003). It should be noted that the water accounting method is aimed at freshwater consumptive uses, which assess the consequences of water that is "lost" in a particular region (Berger and Finkbeiner, 2010) assuming that additional water applied to the crop returns to the system. Nevertheless this assumption does not always occur as suggested by Perry (2011). There is a fraction of water that can be evaporated or transpired for other purposes than the intended uses (non-beneficial consumption), and water that is lost to further uses such as saline groundwater sinks or flows to the sea (non-recoverable fraction). Therefore it is important that water footprint accounting take into account all water withdrawals as an important fraction of applied water is not available for further uses in the basin. This particular aspect may be critical in a water scarce catchment with a high pressure on water resources and limited water allowances.

The goal of this paper is to propose a joint evaluation of crop water footprint accounting and the RIS irrigation management performance indicator as a diagnostic tool to identify hotspots of the irrigation process in crop production. In the methodology section, the indicators have been adapted to an intensive, high-value horticultural crop that can be cropped outdoors or inside a greenhouse. In the results section, the proposed methodology is applied to a real case study of strawberry crop production in the surrounding areas of Doñana National Park. In the results and discussion sections, the results have been addressed attending to the main water regulations that affect the strawberry sector. The relationship between the proposed performance indicators, the interaction between the strawberry crop and water availability in the study area, and the main hotspots that have been found in the strawberry irrigation process have also been discussed.

2. Methodology

2.1. The performance indicators (PIs) proposal

As a major water consuming sector, agriculture often has a significant water footprint. For agricultural products it is particularly important to examine the water footprint of the crop growing process (Hoekstra, 2003).

According to the virtual water concept introduced by Allan (1998), water is divided into three categories: green, blue and grey water. Green water consumption is defined as the evapotranspiration of rainwater during plant growth, which is especially relevant for agricultural products. Blue water consumption is the volume of ground and surface water that evaporates during the crop season. Thus, it comprises the amount of water that is not returned into the environmental compartment from which it was initially withdrawn, in other words, it is the water that is "lost" in a particular region (Berger and Finkbeiner, 2010). This concept is also known as freshwater consumptive uses. The grey water footprint is an indicator of pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra, 2003).

Following the terminology of Hoekstra (2003), the water footprint of crop growth (WF_c) is the sum of the green, blue and grey components, and is usually expressed in m^3/t, which is equivalent to l/kg.