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# Toward precision irrigation for intensive strawberry cultivation

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ABSTRACT

The Doñana area in Southwestern Spain has the largest concentration of strawberry producers in Europe. The annual yield, close to 300,000 t, is mainly devoted to the international markets (more than 90%). Due to the high water demand of strawberries and to the environmental concerns of the destination countries, the maximization of water use efficiency is critical for the strawberry sector.

Aiming at the efficient water use in the strawberry production, a comprehensive drip irrigation system has been designed, according to precision irrigation principles. The system has been developed based on a three stages methodology. First, the irrigation process carried out by farmers has been assessed to identify inefficiencies in the irrigation system and management. Their performances have been evaluated using indicators such as the Relative Irrigation Supply (RIS), Strawberry Irrigation Water Applied (SWA) and Strawberry Water Footprint Applied (SWFA). The second phase is focused in an accurate irrigation scheduling based in precise crop water requirements estimation and the optimum irrigation pulse design. Finally, the irrigation system has been designed with the prevailing wisdom of meets the needs of the crop in a timely manner and as efficiently and as spatially uniformly as possible. The most appropriate drip irrigation emitters for the particular conditions of the strawberry production in the study area have been selected. The rest of the on-farm irrigation technologies required to control the system have been integrated, including soil water sensors, smart water meters, programmers, electrovalves and weather station. This precision irrigation system has been installed in a commercial strawberry farm during the irrigation season 2013–2014.

Also, an application for PC, mobiles and tablets has been developed to provide farmers practical information (e.g. irrigation times) for optimal irrigation scheduling.



## 1. Introduction

In many European basins where irrigated agriculture is concentrated, there is an increasing competition for water (Knox et al., 2012). Climate change threatens to exacerbate the situation with a reduction in water resources availability (Fallon and Betts, 2010), and an increase in agricultural water demand (Rodríguez Díaz et al., 2007). Despite its economic importance, the sustainability of irrigated agriculture is under threat due to increasing water scarcity (Fereres et al., 2011) and concerns regarding the impact of over-abstraction on the environment (EEA, 2009).

Under a scenario of reduced water availability, increasing drought frequency and uncertainties associated with a changing climate, the European' irrigation sector needs to do more with less, increasing water productivity (t/ha) by improving water efficiency and producing more "crop per drop" (Monaghan et al., 2013).

Strawberries are a good example of water intensive crop that is highly demanded by both the European fresh market and the food industry. The largest concentration of strawberry production in Europe and the second in the world is located in the Southwestern region of Spain (Huelva). The destination of more than 90% of the Spanish strawberry production is the international market which demands high quality strawberries, produced under sustainable conditions (Fundación Doñana 21, 2006).

The intensive cultivation of strawberries, carried out on beds covered by black plastic underneath polytunnels, demands large amounts of freshwater to satisfy the crop water requirement as well as other agronomic practices such as soil preparation and plantation.

The strawberry cultivation returns huge economic and social benefits to the region becoming in a strategic sector that generates more than 700 work days per ha and year and the annual creation of more than 55,000 jobs (Fundación Doñana 21, 2006). Despite the strawberry farming generates wealth in the region, it is identified

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as a water intensive activity due to its high dependency on water resources. Therefore there is a concern regarding the environmental sustainability of the crop production in the area. This concern is aggravated further by the circumstance that about 73% of the total strawberry production in Huelva is located in the vicinity of the Doñana National Park (Fundación Doñana 21, 2006), a high environmentally sensitive area. The Doñana National Park wetland is a valued wildlife refuge that belongs to the UNESCO World Heritage list and it is also a Ramsar site, a Biosphere Reserve and a European Community Special Protection Area (Regional Government of Andalusia, 2009). Therefore the ecological sensitivity of Doñana is recognized worldwide, and in this case, water is the most affected resource by the interaction between the irrigated agriculture and the environment, where water dynamics play a crucial role.

According to WWF (2012), there is an alarming decrease of the groundwater flow in certain wetland areas. The Geological and Mining Institute (IGME) highlights that during the last 30 years, the average summer flows recorded in the main streams that flow into the Doñana marshes in Doñana has suffered a 50% reduction.

Several water regulations affect the Park and its surroundings: the Guadalquivir and the Tinto, Odiel, Piedras hydrological basin plans (CHG, 2013; CHGuadiana, 2012). The most restricted 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 allowance proposed is clearly insufficient, the different water authorities assure 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 the farmers' irrigation practices and to introduce new irrigation technologies that promote the efficient use of water by reducing the volume of freshwater withdrawal.

Based on the precision irrigation principles, irrigation should be a precision activity that involves both the accurate assessment of the crop water requirements and the precise application of the exact amount of water at the right time, using hydraulic elements with high volumetric efficiencies and that allow spatially uniform applications (Smith et al., 2010).

Micro-irrigation systems are able to apply small amounts of water at short time intervals. These systems are typically designed to wet only the zone occupied by plant roots and to maintain this zone at or near an optimum moisture level. Micro-irrigation systems have a greater potential for precision irrigation than other systems. They are easily controlled and are commonly automated (Phene and Howell, 1984; Meron et al., 1996; Dukes and Scholberg, 2004; Wanjura et al., 2004; Evett et al., 2006). Research for micro-irrigation systems has been undertaken primarily in horticultural crops including viticulture (Capraro et al., 2008a,b) and fruit tree orchards (Coates et al., 2004; Adhikari et al., 2008).

The potential efficiency of micro-irrigation, mainly drip irrigation, is often quoted as greater than 90%. However, like in other irrigation systems, the ability to achieve high level of efficiency is more a function of the management rather than an inherent property of the system (Smith et al., 2010). For example, Shannon et al. (1996) found that drip irrigation application efficiencies under commercial conditions in sugar cane ranged from 30 to 90%, mainly due to over irrigation and deep percolation.

Dominant causes of non-uniform applications form drip irrigation systems are: pressure variations along the lateral pipelines, emitter clogging and a non-appropriate irrigation management zones (IMZ). Hanson et al. (1995) have developed extensive evaluation of the uniformities of applications of micro-irrigation systems in USA. Results have shown that uniformities are less than desirable, usually below 80%. This fact is supported by other authors who reported distribution uniformities of 32% in the case of drip irrigated vineyards (McClymont et al., 2009; Hornbuckle et al., 2009a).

The most common irrigation emitters used in the strawberry production area in Huelva are one-year low density polyethylene tapes. This type of hydraulic element is cheap and easy to setup. Despite these advantages plastic tapes are not the most suitable system to irrigate crops by pulses as it is required in the typical sandy soils presented in the study area. Based on the uniformity evaluations on field during seasons 2011–2012 and 2012–2013, the distribution uniformity dropped dramatically around 50% at the medium-end period of the season. One of the reasons to reach that low values is the increasing emitter clogging probability during the season due to the suction phenomena that occurs when the system drains between each irrigation event (García Morillo et al., 2012). All the types of emitters reduce drastically their water application efficiency even with only the 5% of emitter clogging. Another reason is related to the fact that the plastic tapes are not pressure compensating emitters what make them very sensitive to pressure variations that provoke flows out of the manufacturer's design range (García Morillo et al., 2012; González Perea et al., 2014). In cases of pressure excess in emitters, the flow rates are significantly higher than the nominal flow. On the contrary, in beds longer than 50 m, pressure drops dramatically in the end on the plastic tapes causing low flow rates. This is common in the region as farmers do not check their working pressure and therefore, they do not know how much water they are applying.

To exacerbate the drawbacks of the irrigation process carried out by farmers, the management of the irrigation systems is based on the farmer's experience instead of rational basis (use of agroclimatic and soil data). The farmer's general rule is to use inputs as much as possible (e.g. water, fertilizers, pesticides, etc) if there is no economic of regulation limitations to avoid yield losses. Strawberry is a very profitable crop despite of its high costs. The inefficiencies detected in the irrigation process have motivated the necessity to develop a comprehensive irrigation system for the strawberries production.

The main target of this paper is to design a comprehensive irrigation system for the strawberry crop in the particular conditions of the study area. This system, that will be designed taking into account precision irrigation principles, must be able to supply the required amount of water at the right time with very high efficiencies. The system is supported by tools and technologies currently available that provide valuable information in the decision making process.

The designed precision irrigation system is a three-stage process. In the first one the irrigation process is assessed by a set of performance indicators ($PI_s$) to detect possible inefficiencies in the irrigation system and its management. The second one is focused in an accurate irrigation scheduling based in (i) the accurate estimation of crop irrigation needs and (ii) the design of the optimum irrigation pulse. In the third stage, a comprehensive irrigation system supported by new technologies is developed (Fig. 1).

The different control elements and calculation procedures cited above can be controlled by a specific application that finally provides the operation variable (irrigation time) for each day of the cropping season.

## 2. Methodology

Precision irrigation involves not only the installation of new electronic devices but it must be considered as an holistic approach where the current inefficiencies are detected and the best irrigation management strategies are designed and applied in the field using the appropriate irrigation technology.