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Research Paper

Environmental assessment of underdrain designs for a sand media filter

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Increasing energy demand is the main problem linked with the adoption of more efficient irrigation techniques, particularly microirrigation. In microirrigation systems, important pressure losses and therefore energy consumption, occur at the filters, which are a key component in preventing emitter clogging. Previous studies have shown that the main pressure drop across sand media filters, which are widely used in microirrigation, occurs in the underdrain elements. To minimise this problem, new underdrains should be designed but an issue is how their environmental impact can be reduced. Two alternative design strategies were found: firstly, keeping the original filter dimensions and reducing energy consumption during operation by 30%; and, secondly, reducing filter size and reducing construction material by 25% but keeping the original pressure losses. A life cycle assessment transforming environmental effects into monetary values was carried out comparing a commercial sand filter with the two filters designed following the two aforementioned strategies. Results show that both alternatives reduce the environmental impact of the sand commercial filter. Reduction of filter size is the optimum strategy if filtered volumes are below 63,000 m^3 along the filter life, while reduction of energy consumption was the best alternative for higher filtered volumes. This work shows the usefulness of life cycle assessment for assessing design strategies that could improve the sustainability of microirrigation equipment.

1. Introduction

Over the last 50 years, world agricultural production has grown to between 2.5 and 3 times, while the cultivated area has grown only by 12%. More than 40% of the increase in food production has come from irrigated areas, which have doubled in area. Over the same period, the cultivated area per person has gradually declined to less than 0.25 ha, a clear indicator of agricultural intensification. Irrigated agriculture currently uses 2.2% of the world's land surface and accounts for 70% of all water withdrawn from aquifers, streams and lakes (FAO, 2011). Within this context, irrigation sustainability assessment is important, especially in areas where rainfall is scarce and/or irregular. For example, Costa et al. (2016) noted that water is considered the most important and valuable resource in the Mediterranean basin. With the objective of increasing water use efficiency, a common strategy has been

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Nomenclature

CO_2	carbon dioxide
CPD	computational fluid dynamics
E	energy consumed by the filter, MJ
HDPE	high density polyethylene
LCA	life cycle assessment
NBR	nitrile butadiene rubber
PO_4	phosphate
SO_2	sulphur dioxide
V	filtered volume, m^3
Δp	pressure drop produced by the filter, MPa
η	efficiency of pumping system, dimensionless

to replace surface irrigation with microirrigation; this approach has been prioritised by irrigation modernisation policies adopted in different countries (Tarjuelo et al., 2015). For example, the area using microirrigation in Spain increased by 14.0% from 2006 to 2016, reaching 50.6% of the irrigated surface in 2016 (MAPAMA, 2017). This achieved a 9.5% reduction of irrigation water consumption from 2005 to 2015 (INE, 2017). Together with water consumption, energy consumption must be considered because irrigation is the major energy consumer in agricultural systems (Pelletier et al., 2011). In this regard, energy accounts for approximately 40% of the costs of managing operating and maintaining the irrigation equipment (Rodríguez-Díaz, Pérez-Urrestarazu, Camacho-Poyato, & Montesinos, 2011). Therefore, improving both water and energy use efficiency in microirrigation systems should be considered.

Filtration is a key operation for the successful operation of a microirrigation system since it prevents one of the main problems of this irrigation method, emitter clogging. Sand media filters offer the best performance (Capra & Scicolone, 2007; Duran-Ros, Puig-Bargués, Arbat, Barragán, & Ramírez de Cartagena, 2009). However, the pressure drop, and therefore the energy requirements, produced by sand filters are not negligible. The filter underdrain has an important effect on the pressure drop and different studies have analysed the performance of different underdrain designs (Arbat et al., 2011, 2013; Bové, Arbat, Pujol et al., 2015; Bové et al., 2017; Mesquita, Testezlaf, & Ramirez, 2012; Pujol et al., 2016). Although the environmental impact of sand filters has to be computed for a complete assessment of its performance, this aspect not has not been considered in previous studies because the focus was on reducing pressure drop across the filter.

The global environmental impact of the filter includes the impact from its construction and functional life until its disposal or recycling. Since different filter designs for reducing the overall environmental impact are possible, thus a method should be used to calculate and compare the impact of design alternatives. In this regard, Life cycle assessment (LCA) is a standard method used to analyse environmental sustainability of a process or system along its whole life cycle (ISO, 2006) and has been shown to play an important role in the environmental assessment of water use efficiency measures (Notarnicola et al., 2017).

Several recent works have carried out LCAs focussing on irrigation systems. When replacing sprinkler irrigation, microirrigation usually increases the eco-efficiency in different irrigation areas by improving water use efficiency (Maia, Silva, & Costa, 2016) and reducing energy consumption (Mehmeti, Todorovic, & Scardigno, 2016). Romero-Gámez, Audsley, and Suárez-Rey (2014), using LCA to analyse the sustainability of leafy crops, concluded that the reduction of the environmental impact of irrigation equipment should be a priority. However, most of the LCAs used in irrigation (e.g. Eranki, El-Shikha, Hunsaker, Bronson, & Landis, 2017; Foteinis & Chatzisymeonb, 2016; Pradeleix et al., 2014) only consider pumps and driplines without including the filters. This is a crucial omission since filters assure the long term performance of microirrigation systems (Duran-Ros et al., 2009) and, thus, increase its sustainability.

To our knowledge, LCA has not been used for considering sustainability issues when designing filters for microirrigation systems. Thus, in this study the main goal is to assess alternatives for the design of microirrigation sand filters from an environmental perspective following LCA methodology.

2. Materials and methods

2.1. *Description of alternatives*

Several types of sand filter underdrains are found in the market. The aim of the underdrain is to evacuate, as fast as possible, the water from the filter. Significant pressure drop takes place in the drainage zone (Arbat et al., 2013; Bové, Arbat, Pujol, et al., 2015). An underdrain design associated with reduced pressure loss includes a nozzle inserted into a plate (Burt, 2010; Mesquita et al., 2012). To improve the hydraulic behaviour of these filters, a new concept of drainage, formed by a low height cylinder filled with a granular confined coarse medium, was designed and shown to reduce the total pressure drop over the filter by 30% (Bové et al., 2017). The new filter was constructed as a prototype, but for comparison, a new design that could allow it to be commercial produced without modification to its hydraulic performance was considered.

Three designs were considered, all with the same flowrate (3 l s^{-1}). This flowrate is frequently recommended by manufacturers for these types of filters. Alternative 0 was a commercial design with 500 mm internal diameter and 12 nozzles inserted in plate as a drainage element; with this geometry, the superficial filtration velocity at the design flow was 0.015 m s^{-1}. Alternative 1 was the same filter but the nozzle plate substituted with the new underdrain design and kept the same diameter; the velocity filtration at the design flow was 0.015 m s^{-1}, but the pressure drop was reduced. Alternative 2 reduced the filter diameter to 400 mm, so the filtration velocity at the design flow was increased to 0.024 m s^{-1}, drainage was improved and the pressure drop was close to alternative 0.

All designs had a steel housing, where the inlet and outlet water connections were inserted, and two access ports, one vertical located at the top of the filter and the other horizontal located at the bottom of the filter column. Access ports were