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Research article

Drip irrigation uptake in traditional irrigated fields: The edaphological impact

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ABSTRACT

Historical and traditional flood-irrigated (FI) schemes are progressively being upgraded by means of drip irrigation (DI) to tackle current water and demographic challenges. This modernization process is likely to foster several changes of environmental relevance at the system level. In this paper we assess the effects derived from DI uptake on soil health and structure in ancient FI systems through the case study of Ricote, SE Spain, first established in the 10-13th centuries CE. We approach the topic by means of physico-chemical analyses (pH, electrical conductivity, available P, carbon analyses, bulk density, soil water content and particle size distribution), Electrical Resistivity Measurements (ERT) and robust statistics. We reach a power of $1\text{-}\beta = 77$ aiming at detecting a large effect size ($f \geq 0.4$). Results indicate that, compared to FI, DI soils present significantly higher water content, a higher proportion of coarse particles relative to fines due to clay translocation, and less dispersion in salt contents. The soils away from the emitters, which were formerly FI and comparatively account for larger extensions, appear significantly depleted in organic matter, available P and N. These results are not affected by departures from statistical model assumptions and suggest that DI uptake in formerly FI systems might have relevant implications in terms of soil degradation and emission of greenhouse gases. A proper assessment of the edaphological trade-offs derived from this modernization process is mandatory in order to tackle undesired environmental consequences.

1. Introduction

The substitution of traditional flood/furrow irrigation (FI) by drip irrigation (DI) is one of the main pathways for the modernization of traditional irrigated systems, which play an important role in regions like Nepal, Indonesia, Morocco, Peru or the Philippines (Pluquellec, 2002). In the Mediterranean, traditional irrigated systems that have been kept steadily operative since ancient times include Andalusi irrigated-terraced fields (Spain, 711–1492 CE), the Ghoutta of Damascus (Syria, c. 2000 BCE), the khettara systems of Tafilalt and the Ziz (Morocco, Middle Ages), or the oases of Timimoun (Algeria, >1000 CE) (Barceló, 1989; Bianquis, 1989; Lightfoot, 1996; Remini et al., 2011). DI uptake is expected to increase water efficiency, crop yields and the attractiveness of irrigated systems in rural areas, ultimately ensuring their sustainability in the current context of water stress, demographic growth and rural depopulation (García-Ruiz et al., 2011; Iglesias et al., 2010; Playán and Mateos, 2006; Wallace, 2000).

From a technological standpoint, DI provides steady amounts of water directly to the root crops through line sources (emitters) on or below the soil surface, mostly at small operating pressures (20–200 kPa) and low discharge rates (1–30 l/h) (Dasberg and Or, 1999). DI and FI are mutually exclusive at the plot level, since DI

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uptake requires discarding the hydraulic infrastructure (e.g. channels, pools) and suspending part of the work related with traditional irrigation (e.g. manuring, levelling, ridge and channel maintenance). This means that large extensions of soils managed and irrigated under FI will be neglected under DI. However, DI in traditional FI schemes is often implemented progressively, with both agro-systems temporarily coexisting within the same irrigation scheme during the upgrading process (see Sese Mínguez, 2012; van der Kooij, 2009). Such situations offer the possibility to assess in coherent settings their contrasting effects in soil health and structure, ultimately gaining an insight into the sustainability of traditional and modern intensive agriculture.

There is a considerable amount of literature on both the particular effects of FI (e.g. Heakal and Al-Awajy, 1989; Hussein et al., 1992; Khokhlova et al., 1997; Ricks Presley et al., 2004) and DI (e.g. Dasberg and Or, 1999; Hannam et al., 2016) in modifying the properties of dry soils. DI and FI have also been compared and their differences assessed in terms of potential water efficiency rates (Maisiri et al., 2005; Playán and Mateos, 2006; van der Kooij et al., 2013), harvest yields (Hussien et al., 2013; Kucukyumuk and Yildiz, 2013; Shrivastava et al., 1995; Yohannes and Tadesse, 1998), emission of greenhouse gases (Kallenbach et al., 2010; Sánchez-Martín et al., 2008; 2010) or social benefits and farmer welfare (Datar and Del Carpio, 2009; Karaa et al., 2009; Narayanamoorthy, 2004; Postel et al., 2001). Much less interest has comparatively been devoted to quantify the impact that DI uptake has on specific physico-chemical features of formerly FI soils (Obbink and Alexander, 1977). To our knowledge, no work has been carried out on assessing the effects derived from withdrawing FI during the modernization process of enduring FI systems.

This paper aims at assessing whether there is a large effect in soils caused by DI uptake in traditional, long-term FI systems. We contribute with quantitative data to the debate on the upgrading of traditional, long-term irrigated systems and its related environmental consequences (FAO, 1999; Lecina et al., 2010a, 2010b; Playán and Mateos, 2006). Unlike former works, which have mostly relied on p-values to test the hypothesis of no effect while overlooking other issues of statistical concern [e.g. sample size, effect size, outliers or compositional data (Aitchison, 1986; Ellis, 2010; Filzmoser et al., 2009a,b,c; Maronna et al., 2006; van den Boogaart and Tolosana-Delgado, 2013; Wilcox, 2005)], our work tackles the topic following a robust statistical approach. We use the case of Ricote (SE Spain), an irrigated-terraced area first built between the 10th-13th centuries CE that reached its current extension (120 ha) shortly before 1614 CE (Puy, 2014; Puy and Balbo, 2013; Puy et al., 2016). The system had fully relied on flood irrigation until 2007, when DI was partially introduced. The case of Ricote illustrates the history of many farmers of traditional Mediterranean irrigated fields, who have opted to progressively implement DI in the face of current environmental, social and economical challenges.

1.1. Study area

The historical irrigated-terraced fields of Ricote (38° 09′ 00.82″N, 1° 22′ 04.14″W) are located in Murcia, SE Spain, and extend over 120 ha in a *hoya*, a flat basin surrounded by mountains (Fig. 1). Since the middle of the 20th century, Ricote specializes in the growing of lemon trees, with the production being sold on national and international markets. The climate of the region is semi arid, with summer and winter temperatures ranging between 31 and 34 °C and 1–5 °C respectively, annual rainfall averaging 200–350 mm and evapotranspiration fluctuating between 750 and 900 mm (López Bermúdez, 1973).

The basin is characterized by limestone, Keuper marls, polygenic sandstone and dolostone formations, with soils being mostly Calcisols, Regosols and Leptosols (IUSS, 2006). Xerophytic vegetation dominates, especially *Cistus ciprus*, *Retama sphaerocarpa* and *Rosmarinus officinalis*.

The irrigated terraces at the lowest reaches of the hoya (~235 m asl) are mostly broad (40–60 m wide) cropping surfaces constructed by fill and sustained by stonewalls, while those along the highest reaches (~375 m asl) are narrower (3–20 m wide) and sustained by earth banks (Puy, 2014; Puy et al., 2016). Since their first construction between the 10th-13th centuries CE, the Ricote irrigated-terraced fields have been flood-irrigated with the water provided by a perennial spring located to the SW of the basin (~390 m asl), which supplies a consistent flow of 12–13 l/s (García Avilés, 2000). Before DI uptake in 2007, the water flowed from the spring to the plots through a network of artificial channels, either excavated in the soil or covered by concrete pipes to minimize water losses and siltation. Irrigators opened the gates of the channels and let the water flood in their plots. FI was traditionally performed at least five times per year, and included cleaning of the channels, tilling, fumigation of the weeds twice a year and of the lemon trees once a year, pruning, manuring with P, K and N-based fertilisers, burning of the branches and ridge construction and maintenance. Irrigators who chose to equip their properties with the DI system filled or discarded the traditional hydraulic infrastructure within their plots. Nearly 90% of the parcels included in the historical hydraulic system (1651 out of 1835) are currently equipped with DI, with just some properties still being flood-irrigated by means of the traditional channel network.

DI was first implemented in 2007 after three previous attempts fostered by the Water Council that were turned down by the irrigators. The system consists of 1) two pools of 18.000 m^3 and 45.000 m^3 located on top of two hills to the N and S of the irrigated area, which respectively store water from the Segura River (pool 1) and from the spring and the Segura River (pool 2) (Fig. 1), 2) the network of pipelines, tubes and emitters, whose function is to distribute the water from these pools to the plots, 3) 105 station cabinets spread across the hydraulic system with consumption meters and mechanical and electronic devices to open and close counters and inform the Water Council on possible system breakdowns, 4) the electrical network, which connects the station cabinets with the Water Council computer, and 5) the Water Council computer, which regulates the functioning of the system, controls the station cabinets and stores all the data. The installation of the system cost 2.160.000€, of which 500.000€ (23%) were funded by the Consejería de Agricultura y Agua de la Región de Múrcia (Agriculture and Water Council of the Region of Murcia), 450.000€ (22%) by the Spanish Ministry of Agriculture, and the remaining 1.210.000€ (54%) being directly covered by the landowners themselves. The benefits earned from trading their produces were so low (e.g. c. 300–400€ per person per year) that irrigators had to use their own personal savings to upgrade the irrigated system (García Avilés, personal communication). Agricultural tasks carried out by drip irrigators include pruning, burning of branches, checking of the emitters, fumigation of the lemon trees and the weeds once and twice a year respectively, and replacement of broken devices from the DI system included within their own properties.

2. Materials and methods

2.1. Sampling

An *a priori* power test on an omnibus, one-way Anova was carried out with G*Power 3.1 (Faul et al., 2009) in order to assess the sample size needed to detect a large effect size ($f \geq 0.4$)