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Review

Producing lettuce in soil-based or in soilless outdoor systems. Which is more economically profitable?

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ABSTRACT

This manuscript presents an economic assessment of two lettuce production systems, soil cultivation (SC) and nutrient film technique (NFT), under three supply scenarios considering increasing desalinated seawater (DSW) availability.

In the NFT system, the yield, the water productivity, the total cost, the revenue and the profit were 5.5, 3.5, 5.9, 5.7 and 3.5 times higher than in the SC system, respectively. The financial assessment showed a net present value (NPV) in the NFT system 3.1 times higher than in the SC system, which indicated that the NFT system could be a more interesting strategy than SC. However, the internal rate of return in the SC system was 4 times higher than in the NFT system, which showed the significantly higher economic profitability of SC investments and the higher profitability risk of the NFT system. In this sense, the higher investment and operational costs in the NFT system led to a lower ratio of profit/total costs (0.079 versus 0.134), which, under non-limiting conditions, positioned the latter above the NFT system. The sensitivity analysis to the price of DSW showed a negative NPV in the SC cultivation under 100% of irrigation with DSW from a water price of 1.1 €/m^3. Such a negative NPV was reached from 1.6 €/m^3 in the NFT system. Regarding the sensitivity analysis for lettuce yield, the NPV became negative in the SC system at a yield of 36,000 kg/ha and in the NFT system under 100% of irrigation with DSW when yield was less than 215,000 kg/ha/year. In short, the results indicated that the NFT system should only be positioned above the SC system under an expected scenario of limited water and land and/or the need to preserve environmentally vulnerable areas.

1. Introduction

The world population is expected to exceed 9 billion people by 2050; this will require extending the land equipped for irrigation by some 32 million hectares, to guarantee an increase in overall food production of some 70% (Faures et al., 2013). Feeding this increasing population will only be possible under an intensive irrigated-agriculture based scenario. However, in arid and semiarid regions, water is generally becoming scarce and the pressure on water resources is becoming more severe. This usually leads to imbalances between renewable resources and total demands, jeopardizing the sustainability of irrigated agriculture, its resilience and hence food production. This is the case of the Segura River Basin (SRB), located in southeastern Spain, where irrigated agriculture is one of the basic pillars of the regional economic growth. In the SRB, feeding this increasing population confronts, on the one hand, the current and expected limitation of the conventional water resources availability. It is of note that the SRB, with an annual structural water deficit above 400 hm^3 (CHS, 2015), is one of the regions with the largest water deficits in Europe (EU) and the first in Spain. On the other hand, conventional practices currently carried out in irrigated lands have led to serious environmental consequences such as: (i) limited control in the use of water and fertilisers; (ii) high concentrations of nutrients and pesticides in runoff; (iii) severe underground water pollution; and (iv) soil degradation accompanied by erosion, among others (Killebrew and Wolff, 2010; Lages et al., 2015). Under this panorama, the continuity of irrigated agriculture in arid and semiarid regions must obligatorily explore other options. Clear candidates are (i) the use of non-conventional water resources such as desalinated seawater (DSW) (Martínez-Alvarez et al., 2017), and (ii) the use of other irrigation system alternatives such as soilless systems (i.e. hydroponic systems), and even, nutrient film technique systems (NFT) (Martinez-Mate et al., 2018). In the latter, water and nutrients flow

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through channels where plants have their root systems in direct contact with the nutrient solution (Albright and Langhans, 1996).

Desalinated seawater represents an abundant coastal and steady water source which effectively removes the climatological and hydrological constraints. However, the high energy requirements associated to its production (≈4.45 kW h/m^3) seem to be its main limitation as compared to other conventional water resources; i.e. from 0.06 kW h/m^3 for surface water to 1.21 kW h/m^3 for desalinated brackish water, which is obviously transferred to the water cost (≈0.70 €/m^3 of DSW in the SRB; Martin-Gorriz et al., 2014; Martínez-Alvarez et al., 2017).

References on evaluating the agronomic and economic implications of using DSW for irrigation are few and far between. For instance, Ben-Gal et al. (2009), on the border between Israel and Jordan, just south of the Black Sea, adjusted the nutritional quality (mainly Ca, Mg and S) of DSW (with an initial electrical conductivity, EC = 0.4 dS/m), and used it to irrigate a greenhouse pepper crop. In their experiment, the yield was increased by almost 50% while the water applied for irrigation was reduced by half. However, the associated cost of fertilizing with Ca, Mg, and S minerals was high (around 0.43 €/m^3; i.e. 3017 €/ha). compared two tomato production systems in southwest Iran, one under irrigation with underground water with an EC = 5.8 dS/m and the other under irrigation with a mix of underground water (42%; EC = 5.8 dS/m) and DSW (58%; EC = 0.21 dS/m). Their results showed that the cost of the system irrigated with DSW (6244 €/ha) was higher than that of the conventional system (5099 €/ha). However, the specific cost per kg of tomato produced was lower in the desalinated water irrigation system (0.077 €/kg) than in the conventional irrigation system (0.088 €/kg) as yield was notably increased, due to the better water quality.

Additionally, hydroponic systems and NFT systems may support continuous production almost throughout the whole year and allow a better management of the nutrient solution, increasing the efficiency in water and fertiliser use, and obtaining higher yields as compared to conventional soil cultivation (SC) (ICARDA-APRP, 2000; Brechner and Both 2014).

Based on the advantages and drawbacks mentioned, as well as on others, farmers should be provided with valuable information concerning environmental and economic implications in order to have criteria that allow them to decide on the most feasible option under a water scarcity situation. Without these analyses, farmers may be reluctant to change to other more productive and efficient irrigation systems and water resources (Alcon et al., 2013a). In this sense, while energy and greenhouse gas emissions associated to the use of DSW and NFT systems have recently been analysed in Martinez-Mate et al. (2018), positioning the NFT system over soil cultivation, their economic viability is largely unknown. Such an economic analysis would rapidly enable the associated inflows and outflows associated to each system to be identified and immediate and decisive action be taken. This criteria-based decision will clearly help growers to manage and use the available resources more efficiently, favouring their maximisation and increasing the level of the production systems while simultaneously reducing costs (Santos and Junqueira, 2004).

In this context, the specific aims of this study were: (i) to evaluate the economic feasibility of implementing NFT systems as compared to SC, and (ii) to quantify the effect of incorporating DSW for irrigation into the outflows, the inflows, and a financial assessment. For this purpose, lettuce was the crop selected since it is the winter vegetable with the highest production and surface area in the region and is one of the most important leafy vegetable crops, with a global production of 38.6 million tons in 2014 (FAOSTAT, 2014). Additionally, it can be readily grown in both soil cultivation and in soilless culture.

2. Materials and methods

2.1. Study area and water supply scenarios

The study was performed in the semiarid Segura River Basin (SRB) located in south-eastern Spain. In the basin, the latest official estimation is that available water resources amount to 1602 Mm^3/y, which includes surface water, groundwater water and water transferred from central Spain through the inter-basin Tagus-Segura (T-S) aqueduct as conventional resources, and reclaimed water and desalinated seawater as non-conventional water resources (CHS, 2015). The SRB is characterised by a marked structural water deficit of about 400 Mm^3/y, which easily exceeds 600 Mm^3/y when dry years occur in the SRB and/or in central Spain. The water shortage situation mentioned and its effects on agriculture's sustainability are being partially compensated by the DSW currently supplied for agricultural use in the basin (158 Mm^3/y) (Martínez-Alvarez et al., 2017).

To carry out the analyses, the Campo de Cartagena Irrigation District, within the SRB, has been selected as the target area for the present study since it: (i) is representative of the intensive export-oriented horticulture in the basin; (ii) is frequently subjected to water supply shortages; (iii) uses a wide range of water sources; and (iv) is the largest irrigation district in the SRB (Soto-García et al., 2013). The selected irrigation district provides farmers with water by means of a collective pressurised network on rotational scheduling, and the allocated water is then stored in on-farm artificial ponds. Under these conditions, farmers need to re-pressurise the irrigation system with their own pumping systems for drip irrigation.

Focusing on the water scarcity circumstances outlined above, the following three desalinated seawater (DSW) supply scenarios have been considered in this study (Martinez-Mate et al., 2018). They are based on the water availability forecasts estimated by CEDEX (2011) report and considering the SRB water balance (Martínez-Alvarez et al., 2017):

1. 9% DSW. This represents the baseline scenario in which the use of DSW is marginal, only accounting for 9% of the water demand, and hence we assume that all water resources for irrigation come from surface and ground water resources (854 Mm^3/y), irrigation returns (124 Mm^3/y), reclaimed water (144 Mm^3/y), desalination (158 Mm^3/y), inter-basin Tagus-Segura water transfer (322 Mm^3/y) and overexploitation of aquifers and deficit irrigation (400 Mm^3/y).
2. 50% DSW. We assume 0 Mm^3/y of water transfer from the Tagus basin, no overexploitation of underground water resources and no deficit irrigation; i.e. 722 Mm^3/y of irrigation supply should be DSW (about 50% of the water demand).
3. 100% DSW. We assume 0 Mm^3/y of water transfer from the Tagus basin, no overexploitation of underground water resources and no deficit irrigation and 0 Mm^3/y from surface and ground water; i.e. 1576 Mm^3/y of irrigation supply should be DSW (100% of the water demand).

2.2. Description of the production systems

Production systems were inventoried according to the following categories: raw materials, labour and machinery (Table 1). For SC production, the data for the analysis were provided by farm managers in the Campo de Cartagena Irrigation District and AMOPA (2006). Data for the NFT production were collected on two existing commercial farms currently using NFT systems for lettuce in the SRB.

It should be noted that values are presented per year; i.e. for the SC system we considered 2 cycles per year and for the NFT system 9 cycles per year.

2.2.1. Raw materials

Raw materials involved the plantlets, the irrigation water, the electric energy, the diesel, the fertilisers, the manure and the plant protection products (Table 1).

For SC cultivation, two cycles of lettuce were carried out which represented 310,000 plantlets/ha. In the case of NFT, a total of nine cycles with 1,485,000 plantlets/ha were considered.

Lettuce cultivated in SC consumed 3700 m^3/ha/year of water for