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Irrigation with drainage solutions improves the growth and nutrients uptake in *Juncus acutus*

Pedro García-Caparrós[a], Alfonso Llanderal[a], Ahmed El-Tarawy[b], Pedro José Correia[c], Maribela Pestana[c], María Teresa Lao[a,*]

[a] Higher Engineering School, Department of Agronomy of the University of Almeria, Agrifood Campus of International Excellence CeiA3, Ctra. Sacramento s/n, La Cañada de San Urbano, 04120, Almería, Spain
[b] Department of Agriculture, Kafrelsheikh University, Egypt
[c] Universidade do Algarve, MeditBio, FCT, Edifício 8, Campus de Gambelas, 8005-139 Faro, Portugal

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ABSTRACT

The potential contamination of surface and ground water by the nurseries in the Mediterranean area obligates the use of novel systems such as the cascade cropping system. The aim of this work was to evaluate the effects of drainage water derived from an ornamental (*Ruscus aculeatus* L. and *Maytenus senegalensis* (Lam.) Exell.) cascade crop system on the growth and polluting elements uptake (N and P) against a standard nutrient solution in *Juncus acutus* L. plants. The experiment consisted of three treatments: a standard nutrient solution (T_{0J}; EC = 150 mS m^{-1}), 1:2 diluted drainage water (T_{1J}; EC = 245 mS m^{-1}) and the raw drainage water (T_{2J}; EC = 310 mS m^{-1}). Biomass, plant and substrate parameters and total N and P uptake by plants were determined at the beginning and at the end of the experiment. This experiment showed that the irrigation with diluted and raw drainage water (T_{1J} and T_{2J}) with lower concentrations of N and P compared to the control treatment (T_{0J}) supposed an increase of biomass and consequently the increase of N and P uptake, where the plants irrigated with higher EC (raw drainage water) showed the highest biomass and total N and P uptake.

1. Introduction

Nowadays, the continuous growth of the ornamental plant industry over the world and in the southern of Spain has brought about mounting concern over the nutrients (N and P) leached from the containers and its potential contamination of the surface and ground water (Lao, 2005). The drainages are normally rich in nutrients, but they are not balanced; moreover, the levels of Na^+ and Cl^- are high for the sensitive cultures (Carrion et al., 2005). The nitrate is leached from most of the mineral soils and container media (Handreck and Black, 1984) and although the phosphate is considered rather immobile within many soils, it is much more readily leached from the container media composed of pine bark or spaghnum peatmoss (Yeager and Barrett, 1984). Both nutrients are of particular concern because of their capacity to lead to eutrophication in waterways (Kim et al., 2003; Taylor et al., 2005). Therefore, taking into account existing legislation such as the Nitrates Directive (91/676/EEC) and the Drinking Water Directive (98/83/EC) which set a maximum allowable concentration for nitrate (NO_3^-) of 50 mg L^{-1} and European Environmental Agency (EEA) (2005) which established a range of phosphorus (P) of 25–50 μg L^{-1} in water, it would be advisable to reduce the environmental pollution through systems compatible with the environment.

The Integrated Farm Drainage Management (IFDM) systems employ sequential reuse of water with the biomass production to help control saline groundwater, the reduction of the wastewater and chemicals and improving the sustainability of arid land irrigated agriculture (Blunk et al., 2005). One example of these systems can be a Serial Biological Concentration (SBC) or a cascade cropping system where the drainage water collected from beneath one crop is used to irrigate the next more salt tolerant crop in the series trying to reduce almost entirely the drainage volume from the last

Abbreviations: AG, aboveground; BG, belowground; DW, dry weight; EEA, european environmental agency; Tf, final plants; FW, fresh weight; HPLC, high performance liquid cromatography; Ti, initial plants; IFDM, integrated farm drainage management; LSD, least significant difference; PAR, photosynthetically active radiation; RH, relative humidity; SBC, serial biological concentration; ANOVA, standard analysis of variance.

* Corresponding author.
E-mail addresses: pedrogar123@hotmail.com (P. García-Caparrós), alfonsollanderal@hotmail.com (A. Llanderal), tarawy101@yahoo.com (A. El-Tarawy), pcorreia@ualg.pt (P.J. Correia), fpestana@ualg.pt (M. Pestana), mtlao@ual.es (M.T. Lao).

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crop (Incrocci et al., 2003). Under the IFDM systems, an important strategy could be the growth of macrophytes as last crop in the series due to its potential to remove the nitrogenous compounds and phosphorus from the wastewater and incorporate them into the plant biomass (Brix, 1991), as have been reported in previous researches with species within *Juncaceae* such as *J. kraussii*, with a significant potential to remove N from highly saline wastewater (Brown et al., 1999; Lymbery et al., 2006) and *J. amabilis* and *J. flavidus* with a great effectiveness at retention of N and P (Read et al., 2008).

The adaptability of macrophytes to salinity is variable and species-dependent (Mufarrege et al., 2011), so it could be reasonable taking into account the use of a native macrophyte from the Mediterranean area which has a high degree of soils and groundwater salinization (Lambers, 2003). *Juncus acutus* L. is an evergreen halophytic macrophyte perennial herb belonging to the family *Juncaceae* (Balslev, 1996) widely distributed in salt marshes or poorly-drained soils (El-Shamy et al., 2012) and can be found in the Spanish coastal marsh communities and in several estuaries of the Iberian Peninsula (Sainz and Ruiz, 2006). Moreover this specie has a wide ecological range, tolerating the soils with high levels of sulphates and chlorides (Fernández-Carvajal, 1982). Cylindrical leaves and stems (culms) with a sharp point on top emerge from the rhizome in bundles and can reach 1 m in height. During late spring/summer, the flowering panicles occur sub-terminally on stems. The seeds (nuts) are protected within the inflorescence and may stay on the plant for 6 or more months before being dispersed by the wind (Greenwood and MacFarlane, 2009).

Although much has been published about the use of macrophytes to remove N and P in municipal, industrial, agricultural wastewaters and stormwater runoff (Vymazal, 2007), very little is known about their use as an ornamental cascade crop system under greenhouse conditions. Therefore, in the present research, a pot experiment with *J. acutus* under greenhouse conditions was established in order to determine the potential to remove nitrogen and phosphorus in diluted or raw drainage from an ornamental cascade cropping system including *Ruscus aculeatus* L. and *Maytenus senegalensis* (Lam.) Excell.

2. Material and methods

2.1. Site specifications and plant material

The experiment was conducted at the University of Almería (36°49′N, 2°24′W).

Rooted cutting of *J. acutus* L. were acquired in trays with plugs of 0.2 L from a commercial nursery. Each plant was transplanted into 1.5 L polyethylene pots filled with a mixture of sphagnum peatmoss and Perlite 80:20 (v/v) and subjected to nutrient solution treatments for 8 weeks (average time to produce saleable nursery crops in pots of 1.5 L following the advices given by local growers). The pots were placed on plastic trays to collect the drainages and covered with galvanized wire to impede that the pots were in contact with the drainages. On this mesh of wire black/white, smooth plastic sheeting was placed to avoid the evaporation; the black side of the film could avoid the mould fungus and algae growth and the white side reflects the sun and reduces the condensation and heat build-up. During the experiment, plants were grown in a greenhouse of 150 m^2. The microclimatic conditions inside the greenhouse for the experimental period, monitored continuously with HOBO SHUTTLE sensors (model H 08-004-02, Onset Computer Crop., Bourne, MA) showed a daily average temperature of 17.1 °C, relative humidity (RH) of 65.6% and photosynthetically active radiation (PAR) of 71.6 $\mu mol\ m^{-2}\ s^{-1}$.

Table 1
Chemical composition of nutrient solutions of each treatment: T_{0J} – standard nutrient solution, T_{1J} – 1:2 diluted drainage water, and T_{2J} – raw drainage water. EC was expressed in $mS\ m^{-1}$ and nutrient concentration in $mg\ L^{-1}$. In T_{1J} and T_{2J}, the values are the means ± standard deviation in each treatment during all experiment (8 weeks).

Parameters	T_{0J}	T_{1J}	T_{2J}
pH	6.50	7.50 ± 0.24	7.50 ± 0.38
EC	150	245 ± 31	310 ± 28
N	84.00	46.76 ± 9.74 5.50	58.24 ± 8.02
P	21.70	5.86 ± 0.53	9.61 ± 2.10
Cl	122.50	687.40 ± 72.53	789.25 ± 69.76
S	64.00	129.60 ± 10.74	166.08 ± 9.84
Ca	80.00	610.40 ± 83.30	648.80 ± 67.07
Mg	33.60	125.04 ± 11.23	137.52 ± 12.57
K	117.00	202.02 ± 26.83	265.98 ± 29.18
Na	59.80	509.91 ± 74.60	589.72 ± 66.08

2.2. Experimental design and treatments

The experiment consisted of three treatments using different nutrient solutions: T_{0J} (150 $mS\ m^{-1}$; a standard nutrient solution or control) reported by Jiménez and Caballero (1990) for an adequate growth of ornamental plants under Mediterranean conditions and was derived from tap water and H_3PO_4, HNO_3 and KNO_3 supplies), T_{1J} (245 $mS\ m^{-1}$; 1:2 diluted drainage water) and T_{2J} (310 $mS\ m^{-1}$; raw drainage water). The nutrient solutions used to irrigate the plants every day were prepared weekly. The drainage water of *R. aculeatus* irrigated with the standard nutrient solution (the same as T_{0J}) was collected weekly. Then, this drainage water was used to elaborate weekly two different nutrient solutions: T_{1M} (1:2 diluted drainage water with tap water with the following composition: 64, 122.50, 80.00, 33.60 and 59.80 $mg\ L^{-1}$ of S, Cl, Ca, Mg and Na; respectively, and EC of 90 $mS\ m^{-1}$) and T_{2M} (raw drainage water) to irrigate daily each treatment of *M. senegalensis* (Lam.) Excell.; respectively. Finally, the leachates collected weekly from the irrigation of *M. senegalensis* (T_{1M} and T_{2M}) were used to irrigate daily each treatment of *J. acutus*; respectively (T_{1J} and T_{2J}) (Fig. 1). The experimental design consisted of three treatments ($T_{0J,}$ T_{1J} and T_{2J}), four blocks and four plants (one plant per pot) per block giving a total of 48 plants with a planting density of 10 plants m^{-2}.

2.3. Nutrient solutions determinations

Four samples of nutrient solution per treatment were randomly collected weekly.

Each sample was composed by aliquots of 25 mL, filtered through 0.45-μm membrane filters and frozen until nutrient analyses were conducted. From each sample, electrical conductivity and pH values were determined by conductivity meter and pH meter (models Milwaukee C66 and pH52 (Milwaukee Instruments, USA), respectively); and the concentrations of nutrients were determined by HPLC (High Performance Liquid Chromatography; model Metrohm 883 Basic IC Plus, anions ion exchange column model Metrosep A SUPP 4, cations ion exchange column model Metrosep C4 100, IC conductivity detector range (0–15000 μS cm-1), Metrohm AG, Switzerland) as described by Csáky and Martínez-Grau (1998). The chemical composition of each treatment was presented in Table 1. The increase of pH in 1:2 diluted and raw drainage water (T_{1J} and T_{2J}) compared to the control treatment can be can be related with the effect of substrate in leachate pH increasing their value as reported Merhaut et al., 2006. In addition, the 1:2 diluted and raw drainage water (T_{1J} and T_{2J}) showed lower N (1.8 and 1.5-times) and P (3.7 and 2.2-times) concentrations compared to the control treatment (T_{0J}), but higher Na (8.5 and 9.8-times) and Cl (5.6 and 6.5-times) concentrations and consequently higher EC compared to the control treatment (T_{0J}).