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Use of hydroponics culture to assess nutrient supply by treated wastewater

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ABSTRACT

The use of treated wastewater for irrigation is increasing, especially in those areas where water resources are limited. Treated wastewaters contain nutrients that are useful for plant growth and help to reduce fertilizers needs. Nutrient content of these waters depends on the treatment system. Nutrient supply by a treated wastewater from a conventional treatment plant (CWW) and a lagooned wastewater from the campus of the University of Balearic Islands (LWW) was tested in an experiment in hydroponics conditions. Half-strength *Hoagland* nutrient solution (HNS) was used as a control. Barley (*Hordeum vulgare* L.) seedlings were grown in 4 L containers filled with the three types of water. Four weeks after planting, barley was harvested and root and shoot biomass was measured. N, P, K, Ca, Mg, Na and Fe contents were determined in both tissues and heavy metal concentrations were analysed in shoots. N, P and K concentrations were lower in LWW than in CWW, while HNS had the highest nutrient concentration. Dry weight barley production was reduced in CWW and LWW treatments to 49% and 17%, respectively, comparing to HNS. However, to a lesser extent, reduction was found in shoot and root N content. Treated wastewater increased Na content in shoots and roots of barley and Ca and Cr content in shoots. However, heavy metals content was lower than toxic levels in all the cases. Although treated wastewater is an interesting water resource, additional fertilization is needed to maintain a high productivity in barley seedlings.

1. Introduction

The reuse of treated wastewater for crop irrigation has been widely recommended for their environmental benefits, especially in those areas with problems of water shortage (Pereira et al., 2002; Qadir et al., 2007).

Chemical composition of treated wastewaters depends on their origin and the treatment received. Effluents from non-industrial municipalities that have received at least secondary treatment have generally low concentrations of heavy metals, which do not cause any adverse effects on plant growth and public health (Crook, 1998). However, they contain suspended and dissolved organic and inorganic solids (Pereira et al., 2002). Conventional treatment plants have higher removal efficiency of biological oxygen demand (BOD) but a lower removal efficiency of total nitrogen and total phosphorus than lagooned treatment plants (Muga and Mihelcic, 2007).

Several authors reported that treated wastewaters can be used as a fertilizer for wheat, maize and barley in field conditions (Hussain et al., 1996; Vazquez-Montiel et al., 1996; Rusan et al., 2007). However, soil fertility should be taken into account.

Hydroponic cultures have been widely used in studies of plant nutrition (Alam et al., 2001; Crowley et al., 2002) because the root medium is homogeneous (Le Bot et al., 1998) and deficiencies and toxicities are more evident than in soil cultures (Ma et al., 1997). On the other hand, they can be useful for nutrient removal from wastewaters (Ghaly et al., 2005; Vaillant et al., 2003). Snow and Ghaly (2008) showed that hydroponically grown barley was able to reduce significantly the pollution load of aquaculture wastewater. Moreover, the reuse of treated wastewaters in hydroponic cultures to produce commercially valuable plants has been previously evaluated (Rababah and Ashbolt, 2000; Oyama et al., 2005). Recently, treated wastewater has also been considered a feasible source of water to produce barley fodder under hydroponic system (Al Ajmi et al., 2009; Al-Karaki, 2011).

A hydroponic culture experiment was established in order to compare the growth response and mineral nutrient status of barley supplied with two different treated wastewaters. The effect of treated wastewaters on heavy metal accumulation was also evaluated. This experiment complements a larger research to study the effects of these two types of treated wastewater on three common Mediterranean soil types sown with barley (Adrover et al., 2012).

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2. Material and methods

Seeds of barley (*Hordeum vulgare* L. cv. County) were sown in germination cells filled with vermiculite and kept in a germination chamber untill emergence. Once germinated were watered with half-strength *Hoagland* nutrient solution.

One-week seedlings were transplanted to 4 L polyethylene containers filled with three continuously-aerated types of water: half-strength *Hoagland* nutrient solution (HNS; Hoagland and Arnon, 1950), treated municipal wastewater from a conventional treatment plant (CWW) and treated municipal wastewater from the lagoon system (LWW). The conventional wastewater treatment plant works with the activated sludge system and has a capacity of 5000 equivalent inhabitants with a daily flow of 1000 m^3. The water for the experiment was collected from the secondary settling tank. The lagooned wastewater came from a wastewater stabilization pound located at the campus of the University of Balearic Islands, with a capacity of 225 equivalent inhabitants and a daily flow of 50 m^3, which was thoroughly described by Amengual-Morro et al. (2012). The water for this experiment was collected from the second maturation pond. Water properties are shown in Table 1. Five seedlings were planted in each container and a set of four containers was used for each treatment. Previously, roots were thoroughly washed with distilled water. Seedlinds were supported with a polystyrene disc with the same diameter of the container. These discs also covered the containers to exclude light from the solution and root systems. After two weeks from the transplanting, two plants were removed in each container.

Weekly, both treated wastewaters (CWW and LWW) were collected from the treatment plants, nutrient solution (HNS) was prepared and water of the hydroponic culture was changed for the three treatments. Distilled water was added if the volume of the solution decreased during the week, in order to keep the containers full without adding nutrients.

Plants were grown in a greenhouse. The experiment was repeated twice. In the first time (culture 1), barley seedlings were transplanted on 24th of March of 2006. The repetition of the experiment (culture 2) started on 12th of April of 2006.

Barley plants were harvested after four weeks in both hydroponic cultures. Roots and shoots were separated. Roots were thoroughly washed with distilled water. Plant material was dried in an oven at 60 °C for three days and weighed to measure crop production. Plant samples were milled to <1 mm. Contents of N, P, K, Ca, Mg, Na and Fe in shoots and roots in addition to contents of Cd, Cr, Cu, Mn, Ni, Pb and Zn in shoots were measured. N was analysed by the *Kjeldahl* method (Bremmer and Mulvaney, 1982). To determine the levels of other elements, 1 g of the sample was dry ashed at 550 °C for 3 h and dissolved in 5 ml of 25% nitric acid and 50 ml of double distilled water. After mixing thoroughly and standing for approximately 30 min, the supernatant was filtered through 0.45 μm and analyzed with an inductively coupled plasma spectrophotometer.

Crop production and mineral content were analysed by two-way ANOVA, with water treatment and repetition (culture 1 and 2) as main factors. Means were separated by *Tukey*'s test ($p < 0.05$) for comparisons. All statistical analyses were performed using SPSS 15.0.

3. Results

Both treated wastewaters (CWW and LWW) had low inorganic N contents compared to HNS, which were 15% and 3%, respectively. Ammonia was the predominant form of N in treated wastewaters, in contrast to HNS, where most of N was in nitrate form. Treated wastewaters had also a lower content in P and K than HNS. Concentrations of these two elements were higher in CWW than in LWW. Ca and Mg concentration were lower in treated wastewaters than in HNS but there were less strong differences than in the case of N, P and K. In contrast, Na concentration was higher in CWW, followed by LWW, than in HNS, where the concentration of this element was unappreciable. Another differential characteristic of treated wastewaters, in comparison with HNS, was the presence of suspended solids, which was higher in lagooned wastewater. Moreover, pH was very much higher in treated wastewater, reaching values upper to 9 in LWW (Table 1).

The treatment with CWW produced a 57% of shoots and a 51% of roots in culture 1 and a 39% of shoots and a 55% of roots in the culture 2, comparing to HNS. The production of the treatment with LWW was still lower, 22% of shoots and 26% of roots in culture 1 and 11% of shoots and 17% of roots in culture 2, comparing to the treatment with HNS (Fig. 1). The crop production was statistically different in the three water treatments but not statistically significant differences were found between both cultures (Table 2).

Mineral content in shoots was statistically significantly different ($p < 0.05$) between the three water treatments, although no differences were found between both cultures, except for N and Mg. Shoots of barley grown in HNS had higher N, K and Fe content and lower Ca and Na content than those of barley grown in both treated

Table 1
Chemical composition of irrigation water. Mean values and range between brackets.

	HNS	CWW	LWW
EC 25 °C (dS m^{-1})	1.15	1.54 (1.50–1.60)	1.00 (0.91–1.11)
pH	6.2	8.0 (7.9–8.1)	9.3 (8.9–9.6)
SS (mg l^{-1})	0	46 (28–64)	115 (82–140)
$N-NO_3^-$ (mg l^{-1})	113	3 (0.2–10)	0.2 (0.0–0.6)
$N-NH_4^+$ (mg l^{-1})	14	16 (12–18)	3 (1–6)
Total P (mg l^{-1})	31.0	2.4 (1.9–2.8)	0.9 (0.7–1.2)
K (mg l^{-1})	197	16 (15–18)	12 (11–13)
Ca (mg l^{-1})	60	39 (31–50)	24 (21–29)
Mg (mg l^{-1})	28	12 (11–12)	13 (12–14)
Na (mg l^{-1})	0	90 (85–96)	57 (53–64)
Fe (mg l^{-1})	0.5	bdl	bdl
Cu (mg l^{-1})	0.01	bdl	bdl
Mn (mg l^{-1})	0.25	bdl	bdl
Zn (mg l^{-1})	0.03	bdl	bdl
Cd, Cr, Ni, Pb, (mg l^{-1})	bdl	bdl	bdl

HNS, Hoagland nutrient solution; CWW, treated wastewater from a conventional treatment plant; LWW, treated wastewater from a lagoon; EC, electrical conductivity; SS, suspended solids; bdl, below detection limit. Detection limit: Fe, 0.001 mg l^{-1}; Cu, 0.0004 mg l^{-1}; Mn, 0.018 mg l^{-1}; Zn, 0.001 mg l^{-1}; Cd, 0.0006 mg l^{-1}; Cr, 0.01 mg l^{-1}; Ni, 0.005 mg l^{-1}; Pb, 0.009 mg l^{-1}.

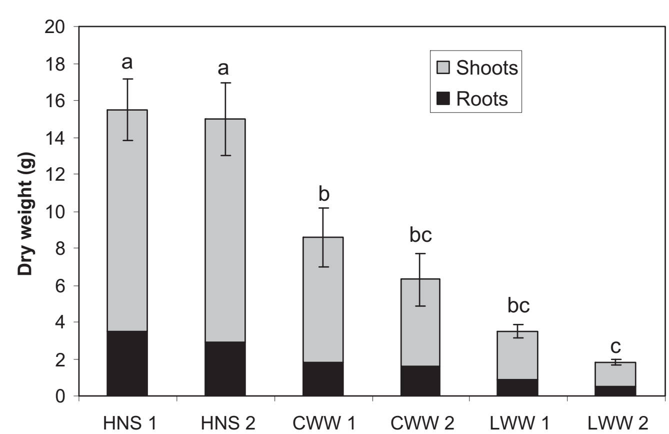

Fig. 1. Aboveground (shoots) and belowground (roots) biomass for each treatment in the cultures 1 and 2 (HNS, Hoagland nutrient solution; CWW, treated wastewater from a conventional treatment plant; LWW, treated wastewater from a lagoon). Error bars represent the standard error of the total dry weight. Treatments with different letters are statistically different according to the *Tukey* test at $P < 0.05$ for total biomass (roots and shoots).