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Potential and constraints of different seawater and freshwater blends as growing media for three vegetable crops

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ABSTRACT

Alternative water sources for irrigation are needed to be found, as agriculture is currently using the 70% of total freshwater. Seawater use for growing crops has long been studied; while an agriculture based on pure seawater is currently impossible, seawater hydroponics may be viable, not aggravating salinization problems in soils. This work aimed at assessing the possibility of growing lettuce, chard and chicory with 3 seawater and freshwater blends (i.e. 5%–10%–15% of seawater). We investigated: i) crops growth, water consumptions, water use efficiency (WUE), water productivity (WP); ii) photosynthetic parameters; iii) principal mineral elements, soluble sugars and phenolics concentration. Lettuce productivity was negatively affected by 10% and 15% of seawater, whereas chard and chicory's growth were not affected by any blend. Interestingly, water consumptions dropped and WUE significantly upturned in every tested crop accordingly with increased seawater concentrations. Leaf concentration of Na^+ and of some other ions increased. We concluded that certain amounts of seawater can be practically used in hydroponics, allowing freshwater saving and increasing certain mineral nutrients concentrations.

1. Introduction

Water scarcity is a major constraint to food production required to meet the quantitative and qualitative change of the global demand in the twenty first century (FAO, 2011). According to several international organizations, the current demographic growth rate will lead to a world population of 9.6 billion people by 2050 (FAO, 2009) and up to 10.9 billion people by the end of the century (UN, 2013). Thus, the human pressure on water resources will tremendously escalate. In particular, irrigation is crucial to food production and its role is expected to increase further, especially in developing countries (FAO, 2002). Nevertheless, water availability is already problematic in many regions, the agricultural sector at present using around 70% of all water from aquifers, streams and lakes. Therefore, it seems necessary to augment food production without a proportional increase of freshwater use.

An additional problem about food security is malnutrition, the diets of over two-thirds of the world population nowadays lacking one or more essential mineral elements (White and Broadley, 2009). In fact, humans require at least 49 nutrients to meet their metabolic needs, 22 of which are mineral elements, and the inadequate consumption of even one of those will result in adverse metabolic disturbances (Welch and Graham, 2004). At present, over three billion people are afflicted with mineral element malnutrition, and the numbers are increasing. Those deficiencies are linked not only to an inadequate quantity of food, but also to its quality: calcium, magnesium and copper deficiencies, for example, are common in both developed and developing countries (Frossard et al., 2000). Among the other important nutrients, vitamins and phytochemicals (such as ascorbic acid, carotenoids, polyphenols and fibers) have beneficial effects in protecting key biological constituents, such as proteins, phospholipids and DNA (Szeto et al., 2004). Since the primary source of nutrients for people comes from agricultural products, those considerations should be taken into account when increasing, or optimizing, food production.

Looking for freshwater alternatives, the most freely abundant source of water on the Earth is represented by seawater. This resource is increasingly emerging as a feasible option in the agricultural sector, either desalinized or blended with other water sources (Yermiyahu et al., 2007). In fact, seawater is rich in most plant

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nutrients (Eyster, 1968), which are often the same nutrients representing limitations in human diets. Furthermore, it is found where around 40% of the world population currently resides. Thus, seawater use in agriculture could represent a strategy to decrease the freshwater demand of the agricultural sector, exploiting, at the same time, the seawater nutrient content.

It is since the early sixties of the last century that seawater use in agriculture has been studied (Boyko, 1996). While a sustainable agriculture relying on pure seawater on a large scale is still utopian, in other cases (e.g. horticulture) small-scale seawater irrigation may be economically viable (Breckle, 2009). Overall, the substitution of a certain amount of freshwater with seawater can be an interesting option in soil-less growing systems, where there are no risks of creating or aggravating salinization problems in soils. Among the many soil-less growing systems, hydroponic culture is characterized by an expanding worldwide vegetable production of about 35000 ha (Hickman, 2011). Of course, the use of high salinity water might affect plants in many ways, as for example causing water stress, ion toxicity, nutritional disorders, oxidative stress, alteration of metabolic processes, membrane disorganization and genotoxicity (Munns, 2002). Hence, this option should be carefully tested before being adopted.

Previous studies on many crops tested at different seawater concentrations generally concluded that the use of seawater in the growing media does not negatively affect the productivity up to certain concentrations (Sakamoto et al., 2014; Turhan et al., 2014; Sgherri et al., 2008, 2007), with maximum thresholds changing according to the species. In addition, specific studies have shown that saline-water treatments may enhance the production of secondary metabolites with high-nutritional value and acknowledged properties in the prevention of important human diseases (De Pascale et al., 2001), increasing also the organoleptic value of some crops (Mitchell et al., 1991). Thus, the possibility of administering certain salt concentrations to increase the content of useful components has been considered (Sgherri et al., 2008). For example, in tomato crop an augmentation of endogenous antioxidant (Sgherri et al., 2007) and carotenoid (De Pascale et al., 2001) concentration was observed under salt stress conditions. Similar results, at least up to certain seawater concentrations, were obtained also on species generally considered less tolerant, such as lettuce (Turhan et al., 2014). Nevertheless, regarding this latter species, controversial results reporting a salinity-induced increase (Unlukara et al., 2008) or reduction (Bartha et al., 2015; Turhan et al., 2014; Kim et al., 2008) of plants dry matter may indicate possible diversities even among cultivars.

All these results suggest that the use of seawater has the potential to achieve horticultural crop biofortification, meaning the endogenous nutrients fortification of food (Ding et al., 2016). In any case, despite scientific literature offers a variety of information on salt effects for over 130 crop species, there are still missing data about many others (Shannon and Grieve, 1998), especially considering their production of nutritional compounds as a response to salinity stress.

The present study aims at investigating the effect of different seawater and freshwater blends on three of the most cultivated horticultural crops: lettuce (Lactuca sativa L. var. Canasta), Swiss chard (Beta vulgaris L.) and chicory (Cichorium intybus L.). Lettuce was chosen because of its cultivar-dependent salinity response, thus the largely diffused variety Canasta is here studied for the first time; chard and chicory because they have scarcely been investigated, despite their spread cultivation and consumption area. In addition, the choice of those species, grown according to their particular seasonality, enabled the experiment to cover a 6-month period, thus keeping the closed-cycle hydroponic system active for a long productive phase. On the basis of these considerations, and to achieve information about the salinity effect on plant growth, water use efficiency (WUE) and the concentration of some important nutritional compounds under the same experimental conditions, the present work specifically explore the possibility of: i) growing lettuce, chard and chicory, using a share of seawater, and ii) assessing if seawater in the growing media affected photosynthesis and the concentration of some important nutritional compounds, particularly mineral elements, pigments, soluble sugars and phenolics.

2. Materials and methods

2.1. Experimental design, plant material and growth conditions

The experiment was carried out in 2014 at the greenhouse facilities of the Department of Agrifood Production and Environmental Sciences at the University of Florence, Italy. A closed-cycle NFT (Nutrient Film Technique) hydroponic system was set up allowing a pump to deliver a continuous flow of nutrients through the plant roots, thereby maximizing the irrigation efficiency. Three common commercial crops were selected for the current trial: lettuce (Lactuca sativa L. var. Canasta), Swiss chard (Beta vulgaris L.) and chicory (Cichorium intybus L.). Such crops were chosen according to their different seasonality (i.e. lettuce and chard are summer crops and chicory is an autumnal crop) with the aim of keeping the NFT hydroponic system active for a continuous productive period, thus covering with the selected crops a 6-month period. The crops were grown according to the following schedule: May 16th to June 19th (lettuce); June 27th to July 31st (Swiss chard) and September 17th to October 30th (chicory), respecting their cycle length as in traditional soil cultivation, thus planning the final harvest at the commercial maturity time.

For each crop, 150 ten-day-old seedlings were bought at a nursery and transplanted into 5 cm mesh pots filled with expanded clay. Plantlets were grown for an additional 10 days in hydroponics supplied with a nutrient solution made of tap water – analyzed, found constant in time and the values fell within the world average values of tap water WSSC (2014) – and liquid fertilizer Flora Series^{TM} (General Hydroponics Europe Inc). Throughout the trial, plants were maintained in normal humidity (relative humidity ranged from 40 to 55%) and without artificial light, light intensity reaching 700 μmol m^{-2} s^{-1} during sunny days, at 28 °C/18 °C day/night temperature for lettuce and chard and at 23 °C/13 °C day/night temperature for chicory cultivation. The experimental setup consisted of 12 independent hydroponic lines, bearing 9 plants each, for a total of 3 randomly distributed hydroponic lines (27 plants) for each treatment. The nutrient solution flow was regulated by a timer that switched the system on 15 min per hour throughout the whole crop cycle. Seawater used in this trial was collected at Marina di Pisa (Italy) one week before the beginning of each experiment and stored in 20 l sterile tanks at 4° C. Characteristics of the collected seawater are reported in Table 1: Na^+ and K^+ values were measured with Flame Photometer Digiflame2000 (Lab Services SAS, Rome, Italy); NO_2, silicates, PO_4, NO_3 were measured with an automatic analyzer AA3 (Bran-Luebbe) according to Grashoff et al. (1983), pH and EC were measured with a portable pH meter (Hanna Instruments^{TM}).

Four different growing media (treatments) were used in the NFT system, corresponding to increased seawater concentrations added to the nutrient solution showing the following electrical conductivity (EC) values: control (tap water and nutritive solution) EC = 0.3 dS m^{-1}; A: 5% seawater EC = 3.4 dS m^{-1}; B: 10% seawater EC = 6.1 dS m^{-1}; C: 15% seawater EC = 9.2 dS m^{-1}. In addition, pH and EC were measured twice a week by using a portable pH meter (Hanna Instruments^{TM}). The growing media were replaced every two weeks and their chemical and physical characteristics are reported in Table 2.