Agricultural Water Management 152 (2015) 217–221

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Short communication

Yield response of stevia (*Stevia rebaudiana* Bertoni) to the salinity of irrigation water

M. Reis[a,b,*], L. Coelho[a,b], G. Santos[a], U. Kienle[c], J. Beltrão[a,d]

[a] Universidade do Algarve, Faculdade de Ciências e Tecnologia, Campus de Gambelas, 8005-139 Faro, Portugal
[b] ICAAM – Instituto de Ciências Agrárias e Ambientais Mediterrânicas, Universidade de Évora e Universidade do Algarve, Faro, Portugal
[c] Universität Hohenheim Institut für Agrartechnik (440), Garbenstrab, 70599 Stuttgart, Germany
[d] CIEO – Research Centre for Spatial and Organizational Dynamics, Portugal

ARTICLE INFO

Article history:
Received 24 July 2014
Accepted 21 January 2015
Available online 10 February 2015

Keywords:
Electrical conductivity
Saline water
Sugar crop
Salt tolerance
Salt sensitivity

ABSTRACT

Stevia (*Stevia rebaudiana* Bertoni) is a relatively unknown crop in Europe, with great potential as a natural sweeteners source. Stevia has a high content of sweeteners, which are up to 150 times sweeter than sugar, but virtually with no calories. Stevia can be cultivated as an irrigated summer crop in Europe, being suitable to be cultivated in semiarid climates and coastal areas, like the Mediterranean region, which are characterized by the low quality of the irrigation water. Here, we studied the growth development and the yield response of stevia to the salinity of the irrigation water in a Mediterranean region (Algarve, Portugal). It was shown that yield was reduced when electrical conductivity of the irrigation water was higher than 2 dS m^{-1}, during the growth period until the 1st harvest. Later, between the 1st and 2nd harvests, yield reduction began when the electrical conductivity of the irrigation water was greater than 0.3 dS m^{-1}. Hence, it was concluded that stevia is suitable to be grown in semiarid and saline regions, if there is only one harvest; to obtain two or more harvests only fresh water with low electrical conductivity should be used. Moreover, it was shown that stevia crop tolerance to salinity was greater than the one of the sugar cane, and crop sensitivity to salinity was lower in stevia than in the conventional sugar crops.

1. Introduction

Stevia (*Stevia rebaudiana* Bertoni) is a perennial irrigated summer crop, relatively unknown in Europe, where it can be a new promising crop (Tavarini and Angelini, 2013). Stevia is an herb of *Asteraceae* (*Compositae*) family, which grows wild as a small shrub in parts of South America, such as Paraguay and Brazil (Ramesh et al., 2006; Lavinia et al., 2008). Leaves are the economic part of the plant (Ramesh et al., 2006), with a high concentration of steviol glycosides, possible substitutes of synthetic sweeteners (Ahmed et al., 2007; Ramesh et al., 2006; Santos et al., 2000) which gives stevia a great importance as a natural food sweetener supplier crop. Stevia shows an high content of sweeteners, which are up to 150 times sweetener than sugar, but virtually with no calories (Cardello et al., 1999), and its use was already approved by CE regulation in 2011, through regulations that establishes steviol glycosides as food additives, and establishes maximum content levels in foodstuff and beverages (EU Commission Regulation, 2011). Other products from stevia are used for pharmaceutical and cosmetic industries (Ahmed et al., 2007).

Stevia can, apparently, be successfully grown under different conditions regarding climate and soils (Hajar et al., 2014). The plant is adapted to poor soils, with low nutrient requirements, but for an economic production, crop irrigation is required (Ramesh et al., 2006). However, stevia shows some variability in what concerns the sensitivity or tolerance to salt stress (Cony and Trione, 1998).

There is often a tendency for a relation between growth and yield of crops, and salinity, that is well established in the scientific literature: usually, the higher salinity level the less growth and yield of the crop (Ityel et al., 2012; Jamil et al., 2012; Shannon and Grieve, 1999). Growth and yield reduction occurs when salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in a water stress for a significant period of time (Ayers and Westcot, 1985; Munns, 2002).

The effect of salinity on plant yield has been modelled with a piece-wise linear response model (Maas and Hoffman, 1977). Models formulating some physical aspects of the integrated processes of water intake based on transpiration and salinity have

* Corresponding author at: Faculdade de Ciências e Tecnologia, Campus de Gambelas, Edifício 8, 8005-139 Faro, Portugal. Tel.: +351 962654496; fax: +351 289818419.
E-mail address: mreis@ualg.pt (M. Reis).

http://dx.doi.org/10.1016/j.agwat.2015.01.017
0378-3774/

been developed by Hanks and Hill (1980), who have described the effect of osmotic potential on plant root extraction. The simplified diffusion–convection equation to obtain production functions, including the effects of water, salinity and nutrition conditions, was solved by Ben Asher (1988). These models describe the plant as a pipeline of water. Therefore the water uptake and transpiration are synonymous terms such that the yield, which is dependent upon the transpiration rate, given as an unique function of soil water potential or soil osmotic potential (Ben Asher et al., 2012). It was assumed that water uptake depends on matric and water potentials, and on a critical root water potential around −0.3 MPa (Ayers and Westcot, 1985); the assumption that the major effect of soil salinity is a reduction in water uptake in, was supported (Bresler and Hoffman, 1986).

It becomes important to study the influence of saline water irrigation on stevia yield, since around 40% of the world's arable lands have insufficient rainfall to support economically viable agriculture (Tanwar, 2003). Very often, the water for irrigation has a high concentration of salts (Thomas and Middleton, 1993). More than 800 million ha of arable land are estimated to be salt affected (FAO, 2008).

The aim of this study was to determine the effect of irrigation water salinity on stevia yield, namely through the determination of stevia salt tolerance and sensitivity, in a semiarid region.

2. Materials and methods

The trial was carried out in the Campus of Gambelas, University of Algarve, Portugal (37°02′35.45″ N, 7°58′20.64″ W), for 5 months from March to September. The soil is an Haplic Arenosol (ARh) according to the FAO (2006) classification. Algarve's climate can be considered Mediterranean and, in particularly in the southern shore, it is classified as Csa, with semi-arid characteristics, identified by mild rainy winters and by warm and dry summers (Köppen, 1936). Table 1 shows the most important climatic parameters registered during the experimental period.

Stevia seedlings were obtained in a nursery, and grown until plantation in a shaded greenhouse.

Previously to plantation, weeds in the field were eliminated with a systemic herbicide (glyphosate, Montana, Sapec, Portugal). Later, this herbicide was locally applied between cultivation lines, every 2–3 weeks.

Plantation was carried out in March, when the plants showed three pairs of true leaves. Twenty-one days after plantation plants were toped at 0.15 m to homogenize plant height. Fungicide sprayings were applied to prevent mildew (mancozeb) and botrytis (fenehexamid). Plants were fertilized by foliar spraying (Ret-Sul, Eibol, Spain).

Table 1
Main climatic parameters during the experimental time period (the figures during the trial period are indicated in bold).

Month	Temperature (°C)	Relative air humidity (%)	Penman potential evapotranspiration (mm)	Precipitation (mm)
January	10.9	88	52.2	56.4
February	11.5	82	79.1	58.8
March	**13.5**	**80**	**106.8**	**103.8**
April	**17.8**	**75**	**137.9**	**79**
May	**20.4**	**71**	**175.9**	**103.8**
June	**23.5**	**59**	**223.9**	**0.2**
July	**24.4**	**57**	**238.1**	**0.0**
August	**24.6**	**62**	**198.9**	**0.0**
September	**22.4**	**68**	**161.1**	**5.4**
October	**20.4**	**70**	**131.0**	**88.9**
December	10.8	84	63.9	12.6
Year	17.9	73	1632	720

After plantation, all planting spaces were irrigated at field capacity until 0.5 m depth (Lavinia et al., 2008), according to the root system characteristics. The plot was daily irrigated. The daily general water balance equation for the root zone was given by:

$$I + P + \mathrm{CR} = \mathrm{ETa} + \mathrm{Dr} + R + \Delta S \quad (1)$$

where I is the net irrigation, P is the natural precipitation, CR is the capillary rise from groundwater table to the root zone, ETa is the actual seasonal average evapotranspiration (Allen et al., 2005), Dr is the drainage below the root zone, R is the runoff, and ΔS is the change in water storage within the root zone; the units for all these parameters are mm d^{-1}. Capillary rise (CR) and runoff (R) were zero during the experimental period. ΔS, P and Dr were negligible due to the high irrigation frequency and very low or no natural precipitation P after plantation. Hence Eq. (1) was simplified to:

$$I = \mathrm{ETa} \quad (2)$$

The crop evapotranspiration under standard conditions ETc is the evapotranspiration from disease-free, well-fertilized crops, under optimal soil water conditions, producing maximal yield, in specific climatic conditions; it is given by Doorenbos and Pruitt (1981):

$$\mathrm{ETc} = K_c \cdot \mathrm{ET0} \quad (3)$$

where K_c is the crop coefficient under standard conditions (Doorenbos and Pruitt, 1981) and ET0 is the reference evapotranspiration (Penman–Monteith). The applied crop coefficient (K_c) value was 1, according to the average K_c range values obtained by Fronza and Folegatti (2003) and Lavinia et al. (2008) for stevia crops. Hence, for the experimental conditions, Eq. (3) can be simplified by:

$$\mathrm{ETc} = \mathrm{ET0} \quad (4)$$

Irrigation water amounts were daily applied, in order to replenish the soil profile to field capacity up to a depth of 0.50 m. To control soil water along the soil profile, soil water content was monitored periodically during the experiment, gravimetrically measured for a 0.0–0.6 m depth.

Treatments, consisting of six irrigation water salinity levels, were randomly distributed in 12 completely randomized blocks, with 6 treatments each one, in a total of 72 parcels. Each parcel consisted of 10 stevia plants, occupying a plot of 2.55 m^2 (3 m × 0.75 m), with a plant population of approximately 44,500 plants ha^{-1}.

Trickle irrigation and double emitter source (DES) was used for the water application. One irrigation line was connected to a tank with a salt solution (NaCl), and the other irrigation line to fresh water, being these lines coupled together to form a double-joint lateral. Self-compensating emitters (Netafim®, Israel) were used on both laterals, having different and varying discharges (from 2 to 10 L h^{-1}) to obtain various mixings between the two lines while maintaining constant application rates for each trickling point (10 L h^{-1}). Electrical conductivity of the irrigation water varied from 10 to 12 dS m^{-1} in the first lateral (saline water source), from 0.3 to 0.4 dS m^{-1} in the second lateral (fresh water), being the number of treatments six, including control (S1) and five treatments with different salinity levels (from S2 up to S6), as shown in Table 2. This table indicates also the degree of restriction of the use.

The spacing of emitters along the double laterals in the rows was 0.30 m. Uniformity distribution of the water was given by Christiansen (1942) coefficient, often computed along the experimental time period, being its value between 89 and 92%, except once, on the first measurement, where it had decreased to 78%, due to an occasional pressure decrease, becoming this problem solved straight away.

Plants were harvested in June, when their average height reached 0.45 m. After harvesting, plants regrew and one more