Scientia Horticulturae 243 (2019) 401–410

Contents lists available at ScienceDirect

Scientia Horticulturae

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

Fruit yield and survival of five commercial strawberry cultivars under field cultivation and salinity stress

Jorge F.S. Ferreira*, Xuan Liu, Donald L. Suarez

US Salinity Laboratory (USDA-ARS), 450 West Big Springs Rd., Riverside, CA 92507, United States

ARTICLE INFO

Keywords:
Abiotic stress
Saline irrigation
Salinity stress
Fragaria ananassa

ABSTRACT

Strawberry is one of the most salt-sensitive horticultural crops, and important to the economies of both United States and California, the highest producer country and state, respectively. Thus, the increasing salinity (electrical conductivity) of irrigation water (EC_{iw}) in semiarid areas of the world is a growing concern to strawberry growers. We evaluated five commercial cultivars under the EC_{iw} of 0.7 (control), 1.0, 1.5, and 2.5 dS m^{-1}, under field conditions for 240 days. Increased EC_{iw} increased Cl^- in all tissues, while Na^+ only increased in roots and petioles. Thus, toxic effects of salinity in leaves were attributed to Cl^-, not Na^+. All cultivars maintained sufficient levels of both macro and micronutrients in shoots without competition between Na^+ and K^+, or Ca^{2+} or between Cl^- and NO_3^-. All cultivars had decreased fruit production, even when EC_{iw} increased to 1.0 dS m^{-1}. Although 'Albion' and 'San Andreas' had the least fruit yield at control salinity, 'Albion' was the cultivar with the least mean relative reduction in fruit yield, marketable fruit size, shoot + root biomass, and survival at EC_{iw} = 2.5 dS m^{-1}, and thus the most salt tolerant. Regarding absolute yield, 'Monterey' was the highest fruit producer under salinity. All cultivars maintained fruit total soluble sugars (Brix%) across salinity levels with 'Albion', 'Monterey', and 'Benicia' having the highest values (11–13% Brix) regardless of salinity. 'Albion' and 'San Andreas' were the best at maintaining commercial fruit size under salinity. 'Albion', 'Benicia', and 'Monterey' had higher fruit yields at EC_{iw} = 2.5 dS m^{-1} than 'Ventana' and 'San Andreas' and can enable farmers to produce strawberries with irrigation water EC_{iw} up to 1.5 dS m^{-1}, although with some fruit yield loss. Results indicate that these newer commercial cultivars are more salt-tolerant than cultivars previously tested, and with enough variability in salt tolerance to improve selection for irrigation water salinity with EC_{iw} > 1.0 dS m^{-1}.

1. Introduction

The United States is the largest producer of strawberry in the world with an estimated yield of 1,312,960 metric tons in 2011, which is approximately 30% of all the strawberry produced worldwide (http://faostat.fao.org/site/339/default.aspx). Within the US, California is the major producer, and accounted for over 85% of the fresh and frozen fruits commercialized in 2011 (http://www.californiastrawberries.com/about_strawberries). The crop depends heavily on irrigation in California and other major production regions. The increasing salinization of irrigation waters used by strawberry farmers in southern and central California, and elsewhere, means that growers must either find new water sources or accept significant yield loss and profitability. Alternatively, researchers may identify varieties that can tolerate high salinity levels in irrigation water.

Strawberry is highly sensitive to salinity with a low threshold of 1.0 dS m^{-1} for the electrical conductivity of the soil saturation extract (ECe), after which yield decreases 33% with each increasing ECe unit (Grieve et al., 2012). Salinity tolerance work, previously done under greenhouse conditions, with the *Fragaria ananassa* cultivars Douglas and Toro showed that sodium and sulfate did not cause ion toxicity in strawberries, whereas chloride-based waters (NaCl and KCl) led to leaf scorching after 26 days, or six irrigations, with waters containing 18 mmol L^{-1} (an approximate salinity of EC_{iw} = 1.8 dS m^{-1}) of either salt (Martinez-Barroso and Alvarez, 1997). These authors also determined that leaf Cl^- concentrations of less than 1% and an electrical conductivity of the irrigation water (EC_{iw}) of less than 2.0 dS m^{-1} did not produce toxicity symptoms on the cultivars studied, but that salinities over 5 dS m^{-1}, even with low leaf Cl^- concentrations could cause leaf damage.

Strawberry plants genetically engineered to overproduce osmotin were reported to tolerate salinity close to EC of 20 dS m^{-1} (Husaini and Abdin, 2008). However, no high-osmotin strawberry plants have been released for commercial production so far. Based on the knowledge that

* Corresponding author.
E-mail address: Jorge.Ferreira@ars.usda.gov (J.F.S. Ferreira).

https://doi.org/10.1016/j.scienta.2018.07.016
Received 4 May 2018; Received in revised form 9 July 2018; Accepted 13 July 2018

salinity effects will vary within the same species and among different cultivars, screening of commercial and wild type strawberry cultivars can be a feasible approach to find salinity-tolerant strawberry cultivars and to study the mechanism by which different cultivars can cope with salinity stress. Traditional breeding of strawberries has resulted in varieties with improved fruit yield, size (e.g, 'San Andreas'), appearance (e.g., 'Benicia' and 'Ventana') and sweet taste for fresh fruit in the US and Asian markets (e.g., cv. 'Monterey'), resistance to fungal and bacterial diseases, resilience to transportation, and increased post-harvest shelf life (Capocasa et al., 2008). In 2012, the six most cultivated cultivars bred by the University of California, in decreasing order, were 'Albion', 'San Andreas', Portola, 'Ventana', 'Monterey', and 'Benicia'. Our study involved five commercial strawberry cultivars used in California and elsewhere (the day-neutral cultivars 'Albion', 'Monterey', and 'San Andreas', and short-day cv. 'Benicia', and 'Ventana') and aimed to evaluate the cultivars for salt tolerance based on fruit yield, plant biomass, and plant survival.

2. Materials and methods

2.1. Experiment design

Bare-rooted crowns of five cultivars of strawberry released by the University of California breeding program were freshly dug out and donated by Sierra-Cascade Nursery (Susanville, Calif.) and included the day-neutral cultivars 'Albion' (released 2004), 'Monterey' (released 2008) and 'San Andreas' (released 2008), and short-day (June bearing) cultivars 'Benicia' (released 2010) and 'Ventana' (released 2001). Crown diameters varied among cultivars, but were fairly homogeneous within each cultivar. The plants were at 5 °C for two weeks until planted in a non-fumigated sandy loam soil (Suarez and Grieve, 2009) as a split plot design with salinity as the main plot or block variable, and cultivar as the subplot variable. The experimental site was located at the USDA-ARS, U.S. Salinity Laboratory, Riverside, California (Lat. 33E58′24″N, Long. 117E19′12″W). The area was divided into 12 raised beds (main plot or block) to accommodate four salinity levels (SL) assigned to each of the five cultivars (CV), with three replicates (R). There were 5 subplots (containing five CV each) per bed. Each main plot, or bed, had 12 plants of each cultivar amounting to 60 plants (each bed received a salinity treatment) with a total of 720 plants for the whole experiment (12 beds × 5 CV × 4 SL × 3 R). Each subplot occupied 2.294 m^2 comprising 12 plants of one cultivar (in two rows of six plants), including the space between beds. The spacing between plants in adjacent beds was approximately 1.3 m (including space between beds) and the length of each bed was 9 m (4.2 × 30 feet), evenly divided into 5 subplots longitudinally. There was a trough of 60 cm between salinity treatments within a raised bed to prevent mixing of salinity treatment during drip irrigation. The five cultivars were randomly assigned as subplots into each treatment (plot), according to a random map generated by SAS PLAN procedure. The experimental area was sprinkled with Riverside municipal water (EC_w = 0.6 dS/m) for a week to lixiviate excess salts from soil. Bed soil was homogenized with a rototiller and mounded to prepare new beds (35 cm in height). Then, two soil samples (15 cm deep) were taken per bed and analyzed for salinity at the US Salinity Lab before assigning the treatments, and before adding fertilizer. The planting density was 52,310 plants/ha. Two soil samples per bed were also taken at the termination of the experiment.

The planting was on Oct. 31 and Nov. 1, 2012 with two rows of plants per bed and 6 plants per row for each subplot (12 plants). Two drip lines were installed along the two rows of plants, respectively on each bed. Underneath each drip line, a 12–15 cm deep and 10 cm wide trench was dug and slow-release fertilizer (10-10-10 in N-K-P with micronutrients) was applied at 9.4 g per plant, and subsequently the trench was backfilled with soil.

Table 1
Electrical conductivity of irrigation water (EC_{iw}), osmotic potential, composition of irrigation waters (in dS m^{-1}), and initial soil EC_e. Concentrations of calcium (Ca^{2+}), Na^+, and Cl^- of irrigation waters used to apply salt treatments are also presented. Ratio of Na^+:Ca^{2+} was = 1:1 in $mmol_c$ L^{-1}.

EC_{iw} (dS m^{-1})	Osmotic potential (MPa)	Ca^{2+}	Na^+ ($mmol_c$ L^{-1})	Cl^-	Initial soil EC_e (dS m^{-1})
0.7	−0.029	2.6	2.6	1.2	0.32
1.0	−0.038	4.5	4.5	5.0	0.45
1.5	−0.057	6.8	6.8	9.6	0.68
2.5	−0.093	11.4	11.4	18.8	1.14

Note: The Ca^{2+}, Na^+, and Cl^- concentrations in Riverside municipal water (tap) water were taken into consideration when preparing the solutions to achieve the target EC values. EC_e = Electrical conductivity measured in the extract of the saturated soil paste.

2.2. Salt treatment

Salt treatment composition to achieve target electrical conductivity of irrigation water (EC_{iw}) was constructed using ExtractChem model (Suarez and Taber, 2012) to have four salinity levels, measured as electrical conductivity (EC), and with a ratio of Na^+:Ca^{2+} = 1:1 in $mmol_c$ L^{-1} balanced by Cl^- (Table 1), and applied through the irrigation waters. The water used to prepare saline treatments was Riverside municipal water of EC_w = 0.6 dS m^{-1} and pH = 7.5. This water was analyzed at the US Salinity Lab and contained in average (in $mmol_c$ L^{-1}): 0.45 NO_3-, traces of PO_4^{3-}, 0.1 K^+, 3.2 Ca^{2+}, 0.8 Mg^{2+}, 1.2 SO_4^{2-}, 1.8 Na^+, 0.9 Cl^-, 3.5 HCO_3^-. NaCl and $CaCl_2$ were used as the salinizing salts. Irrigation waters were stored in 1400-L, covered plastic tanks. Plants were irrigated once daily at mid-day during the winter and twice daily, at mid-day and mid-afternoon during the growth period after winter. This system provided roughly irrigation water amounts of 0.24, then 0.48 cm daily. Salt treatment was initiated on Nov. 29, 2012, approximately one month after planting.

2.3. Sampling of fruits, plants, and soil

Fruits that developed more than 75% red color were harvested at each sampling time, immediately brought to the laboratory and weighed for fresh weight. Fruits weighing 10 g or less are of no commercial value and were not considered for fruit production, but were recorded to quantify marketable fruit size percentage of cultivars under salinity.

At the end of the experiment, live plants were collected and separated into leaves, petioles, and roots. These were dried separately and ground to approximately 1 mm particle size and used for the determination of macro and micronutrients, sodium, and chloride, with methodology described elsewhere (Dias et al., 2016). Runners were not analyzed, only the plant parts bearing fruits.

Two soil samples were collected from each of the 12 plots before and after the experiment. After the experiment, samples were taken in the bed to a depth of 15 cm underneath where plants and drippers were located. Samples were dried in the laboratory and saturation pastes were prepared, and solutions extracted and analyzed to determine the electrical composition of the saturated soil paste (EC_e) and major inorganic ions.

2.4. Fruit sugars

Fruit sugar content was measured using a portable Refractometer, MA871 (Milwankee, Romania) as total soluble sugars (Brix %). Freshly harvested fruits were cut into halves, placed in a garlic press lined with two layers of cheese cloth, and squeezed into a test tube. Two samples of 100 µL were measured from six fruits per cultivar and averaged for each of the three replicates of the five sub-plots, with n = 3.