Reuse of pretreated cheese whey wastewater for industrial tomato production (Lycopersicon esculentum Mill.)

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ABSTRACT
Due to the high organic load, suspended solids presence, fats content, salinity, etc., cheese whey wastewater (CWW) disposal/management represents a complex issue from an environmental and engineering point of view. In this work, an alternative wastewater management option is suggested. The process includes the CWW pretreatment by means of a basic precipitation stage followed by neutralization of the supernatant. This pre-stage is capable of reducing the organic, suspended solids and fats content to different levels. In a second step, the pretreated CWW has been used in the irrigation of tomato crops (cv. Roma and cv. Rio Grande). Different salinity levels corresponding to 1.75, 2.22, 3.22, 5.02 and 10.02 dS m^{-1} have been tested. Taking into account the obtained results in control runs (fresh water), the salinity level of the pretreated CWW had no significant effect on the flower clusters number per plant, tomatoes number per plant, tomatoes number per cluster, longitudinal and transversal calipers and epidermis firmness of the fruits. Moreover, an increment of soluble solid content in fruits (16% for cv. Roma and 27% for cv. Rio Grande) was observed in saline treatments. Among the drawbacks experienced after irrigation with high salinity level were some physiological disorders such as blossom-end rot. In this line, epidermis firmness and caliper reductions were observed compared to marketable fruit although cv. Rio Grande was less sensible to the aforementioned disorder. The effects of irrigation with pretreated CWW on the soil properties were also investigated. As expected, soil conductivity linearly increased with the pretreated CWW salinity level. Additionally, soil contents in phosphorus, nitrogen and organic matter were increased after the pretreated CWW irrigation. Under controlled saline conditions, the tomato plants irrigation can be a solution for by-products management from cheese industry with the fruits characteristics improvement and the wastewater inadequate discharge reduction.

Keywords:
Cheese whey wastewater reuse
Fertirrigation
Salinity
Tomato quality
Lycopersicon esculentum Mill.
Soil

1. Introduction

Byproducts of the cheese industry (cheese whey — CW, second cheese whey — SCW and cheese whey wastewater — CWW) represent a serious risk from an environmental point of view due to the high organic load, suspended solids presence, oil and fats contents, acidity, and salt concentration. Being a potential environmental hazard, these effluents can also be a source of proteins and lactose. Proteins recovery is normally carried out by means of physicochemical processes such as thermal and isoelectric precipitation, electrocoagulation, coagulation-flocculation with chitosan; acid precipitation, and membrane technologies (Casal et al., 2006; Janson and Lewis, 1994; Lee et al., 2003; Mukhopadhyay et al., 2003; Sternberg et al., 1975; Suárez et al., 2006). Lactose valorization is mainly conducted through biological processes, namely, enzymatic hydrolysis or fermentation to ethanol, hydrogen or lactic acid. However, lactose can also be recovered by chemical processes, for example, nanofiltration, reverse osmosis and ion exchange.

Under controlled conditions, cheese whey can be used as a fertilizer, improving the physical and chemical characteristics of soils. Hence, cheese whey may promote the aggregation of the soil particles (Lehrsch et al., 2008; Robbins and Lehrsch, 1998), simultaneously acting as a source of carbon, energy and nutrients (N, P, K, Ca, Mg, etc.) to plants and microorganisms. Some soil properties such as porosity, aeration capability, retention and water infiltration (Jones et al., 1993a), etc. can be improved after the controlled application of the cheese industry byproducts for agricultural purposes. However, some drawbacks were associated to the application of these by-products, mainly, due to the potential excess of fat, suspended solids or salt contents. Thus, under uncontrolled application, the high level of salinity can negatively affect the soil structure, decreasing the permeability and aeration of the soil (Prazeres et al., 2012).

Basic precipitation applied to CWW leads to roughly 86-90% of fat elimination and 30-80% of suspended solids removal. However, salinity level cannot be reduced by means of the aforementioned technology. Reuse of saline wastewaters in irrigation systems is limited to species showing moderate to high salinity tolerance. Tomatoes are catalogued as plants with moderate tolerance to salinity environments, presenting a soil salinity tolerance of 2.5 dS m^{-1} and a yields decrease of 9.9% dS^{-1} m^{-1} beyond the threshold (Maas and Hoffman, 1977). Additionally, the tomato is one of the leading horticultural crops in the world (Latef and Chaoxing, 2011; Santa-Cruz et al., 2002). On the other hand, Mediterranean countries, such as Portugal, Spain and Italy have serious imbalances in water quantity, with frequent and long periods of drought (Aiello et al., 2007), low rainfalls and hot summers. Water pollution and scarcity reduce the water availability for the agricultural activities in detriment of priority activities, namely, domestic and industrial use. Thus, the reutilization of pretreated CWW for the tomato irrigation can be an innovative alternative for more sustainable use of water resources.

Tomato crops response to adverse salinity levels depends on various factors, including weather conditions, plant development, salt concentration and exposure time (Maggio et al., 2004; Pérez-Alfocea et al., 1993). Salinity might affect the yield (Katerji et al., 1998) and the weight of fruits (Katerji et al., 1998; Sato et al., 2006). Additionally, reductions of the leaf area (Gao et al., 1998); leaves, stems and/or roots dry matter, (Maggio et al., 2007; Romero-Aranda et al., 2001; Zribi et al., 2009), plant height (Mohammad et al., 1998; Romero-Aranda et al., 2001) and root length (Mohammad et al., 1998) have been reported. Moreover, a decrease of the calcium content and the subsequent increases of the sodium and chloride in leaves (Maggio et al., 2007; Zribi et al., 2009; Alian et al., 2000) have also been observed.

After using saline irrigation water for the tomato plants growth, some benefits have been notified. Therefore, increases in antioxidant species (De

Pascale et al., 2001; Wu and Kubota, 2008; Zushi and Matsuzoe, 2009), soluble solids (Sato et al., 2006; Wu and Kubota, 2008), acidity (De Pascale et al., 2001; Sato et al., 2006), amino acids and organic acids (Sato et al., 2006) can be reported.

The aim of this work was to check the effects of pretreated and diluted CWW as irrigation water in tomato crop, as well as, the possible changes in soil properties. The biometric evaluation and chemical characterization of the leaves, stems and roots of tomato plants when irrigated with pretreated and diluted CWW can be found in previous works (Prazeres et al., 2013a,b).

2. Materials and methods

2.1. Pretreated cheese whey wastewater

Raw CWW has been collected from an industry located in the Serpa cheese region (South of Portugal). This factory produces about 5 L of CWW per liter of processed milk. The effluent is characterized by a high value of organic matter in terms of chemical oxygen demand—COD (9.3-18.5 kg m^{-3}), biological oxygen demand—BOD (6.9-12.9 kg m^{-3}) and BOD_5/COD ratio (0.70-0.77). The high salinity (7.13-10.91 dS m^{-1}) and low pH (3.28-4.78) observed are due to the whey type produced and the anaerobic conditions in the storage ponds, respectively. Basic precipitation has been applied for CWW pretreatment. This pretreatment was capable of removing a high fraction of the fat and suspended solid contents. Accumulation of solids and fats on soil surface might deteriorate its permeation and gas exchange capacity.

Pretreated CWW can still be catalogued as a strong contaminated effluent, showing values of approximately 8 kg m^{-3} of BOD and 10 kg m^{-3} of COD (ratio BOD_5/COD > 0.80). Nevertheless, total suspended solids content was reduced about 84% (compared to raw CWW). After the precipitation stage, CWW maintains a high salinity level (electrical conductivity—EC close to 15dS m^{-1}) and a high total dissolved solids (TDS) content of roughly 13 kg m^{-3}. According to Fipps (2003), the pretreated effluent can be considered as an irrigation water of Class 5 (unsuitable) having a very high risk of soil salinity (Varennes, 2003). Bauder et al. (2011) report the severe limitations in the use of these types of effluents. An adequate drainage of the soil is necessary. Additionally, sensitive plants may have some difficulties in the germination stages. To overcome an excess of salts, in this study, the pretreated CWW was previously diluted with fresh water.

2.2. Experimental design

Six different treatments, T_0-T_5, were completed with four repetitions per treatment. Table 1 presents the main characteristics of the irrigation waters (treatments) used. Treatment levels T_1-T_5 were prepared by diluting of pretreated CWW with fresh water (1:50, 1:22, 1:10, 1:5 and 1:2). Average electrical conductivity values were 1.75, 2.22, 3.22, 5.02 and 10.02 dS m^{-1} with sodium adsorption ratios (SAR) of 3.6, 5.7, 10.2, 17.1 and 40.3, respectively. According to literature, irrigation water salinity values of 1.7, 2.3, 3.4 and 5.0 dS m^{-1} should give the salt tolerances leading to theoretical yield potentials of 100, 90, 75 and 50% for tomato crops (Fipps, 2003).

The control experiment water (T_0) is characterized by a low organic matter content (COD = 30 mg L^{-1}), with an average biodegradability index (BOD_5/COD) close to 0.1. Control irrigation water has a salinity level of 1.44 dS m^{-1} (medium risk of soil salinity according to Varennes, 2003), TDS content of 688 mg L^{-1} (Class 3 water catalogued as permissible according to Fipps, 2003) and SAR of 2.2. Phosphorus, nitrogen and potassium levels are substantially lower than the values corresponding to irrigation waters T_1-T_5.

2.3. Analytical procedures

pH and redox potential were determined in a *WTW InoLab* apparatus (pH electrode *SenTix* 41 and redox electrode *SenTix RP*). Conductivity and turbidity were monitored in a *Jenway* 4510 conductivimeter and *WTW Turb*550 turbidimeter, respectively. COD was quantified by a colorimetric method at 600 nm after hot acid digestion with potassium dichromate (150 °C for 2 h) in the presence of silver and mercury sulfates in a *WPA Hydrocheck HC* 6016 digester (APHA, 1998). BOD was determined by a respirometric method (*WTW OxiTop®*), under controlled conditions of temperature, agitation, light absence, neutral pH and acclimated microorganisms. Solids and Kjeldahl nitrogen were analyzed by standard methods (APHA, 1998). Total phosphorus was evaluated by a colorimetric method at 470 nm after the reaction of orthophosphates with vanadate-molybdate reagent. Sodium and potassium were determined in a *CORNING* 410 photometer after acid digestion and filtration through *Whatman* 40 paper filters. The measurement of calcium and magnesium was conducted by volumetric complexation with EDTA in the presence of eriochrome black T indicator. The calcon indicator was used to determine the calcium content.

The chloride concentration was titrated with silver nitrate in the presence of potassium chromate through Mohr's method.

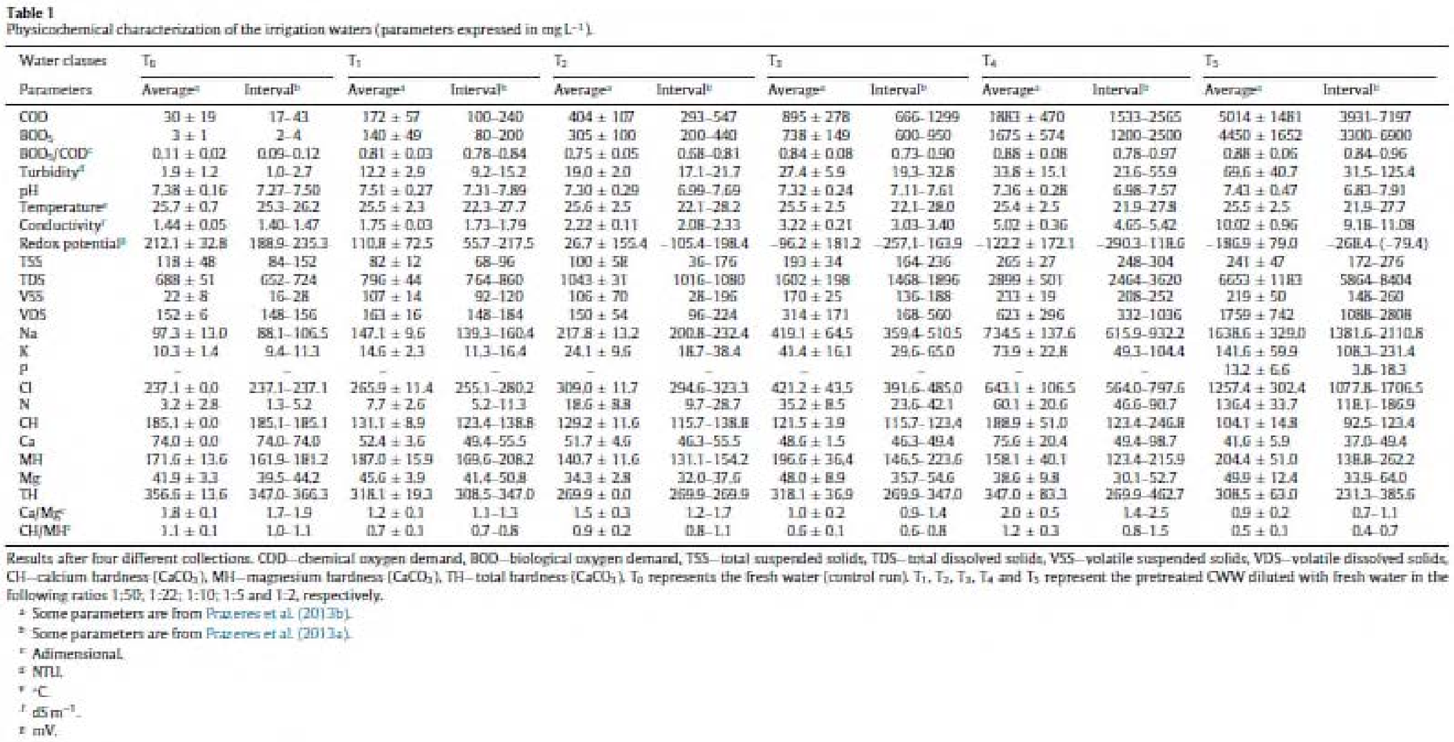

Table 1
Physicochemical characterization of the irrigation waters (parameters expressed in mg L^{-1}).

Water classes	T_0		T_1		T_2		T_3		T_4		T_5	
Parameters	Average[a]	Interval[b]	Average[a]	Interval[b]	Average[a]	Interval[b]	Average[a]	Interval[b]	Average[a]	Interval[b]	Average[a]	Interval[b]
COD	30 ± 19	17–43	172 ± 57	100–240	404 ± 107	293–547	895 ± 278	666–1299	1883 ± 470	1533–2565	5014 ± 1481	3931–7197
BOD_5	3 ± 1	2–4	140 ± 49	80–200	305 ± 100	200–440	738 ± 149	600–950	1675 ± 574	1200–2500	4450 ± 1652	3300–6900
BOD_5/COD[c]	0.11 ± 0.02	0.09–0.12	0.81 ± 0.03	0.78–0.84	0.75 ± 0.05	0.68–0.81	0.84 ± 0.08	0.73–0.90	0.88 ± 0.08	0.78–0.97	0.88 ± 0.06	0.84–0.96
Turbidity[d]	1.9 ± 1.2	1.0–2.7	12.2 ± 2.9	9.2–15.2	19.0 ± 2.0	17.1–21.7	27.4 ± 5.9	19.3–32.8	33.8 ± 15.1	23.6–55.9	69.6 ± 40.7	31.5–125.4
pH	7.38 ± 0.16	7.27–7.50	7.51 ± 0.27	7.31–7.89	7.30 ± 0.29	6.99–7.69	7.32 ± 0.24	7.11–7.61	7.36 ± 0.28	6.98–7.57	7.43 ± 0.47	6.83–7.91
Temperature[e]	25.7 ± 0.7	25.3–26.2	25.5 ± 2.3	22.3–27.7	25.6 ± 2.5	22.1–28.2	25.5 ± 2.5	22.1–28.0	25.4 ± 2.5	21.9–27.8	25.5 ± 2.5	21.9–27.7
Conductivity[f]	1.44 ± 0.05	1.40–1.47	1.75 ± 0.03	1.73–1.79	2.22 ± 0.11	2.08–2.33	3.22 ± 0.21	3.03–3.40	5.02 ± 0.36	4.65–5.42	10.02 ± 0.96	9.18–11.08
Redox potential[g]	212.1 ± 32.8	188.9–235.3	110.8 ± 72.5	55.7–217.5	26.7 ± 155.4	−105.4–198.4	−96.2 ± 181.2	−257.1–163.9	−122.2 ± 172.1	−290.3–118.6	−186.9 ± 79.0	−268.4–(−79.4)
TSS	118 ± 48	84–152	82 ± 12	68–96	100 ± 58	36–176	193 ± 34	164–236	265 ± 27	248–304	241 ± 47	172–276
TDS	688 ± 51	652–724	796 ± 44	764–860	1043 ± 31	1016–1080	1602 ± 198	1468–1896	2899 ± 501	2464–3620	6653 ± 1183	5864–8404
VSS	22 ± 8	16–28	107 ± 14	92–120	106 ± 70	28–196	170 ± 25	136–188	233 ± 19	208–252	219 ± 50	146–260
VDS	152 ± 6	148–156	163 ± 16	148–184	150 ± 54	96–224	314 ± 171	168–560	623 ± 296	332–1036	1759 ± 742	1088–2808
Na	97.3 ± 13.0	88.1–106.5	147.1 ± 9.6	139.3–160.4	217.8 ± 13.2	200.8–232.4	419.1 ± 64.5	359.4–510.5	734.5 ± 137.6	615.9–932.2	1638.6 ± 329.0	1381.6–2110.8
K	10.3 ± 1.4	9.4–11.3	14.6 ± 2.3	11.3–16.4	24.1 ± 9.6	18.7–38.4	41.4 ± 16.1	29.6–65.0	73.9 ± 22.8	49.3–104.4	141.6 ± 59.9	108.3–231.4
P	–	–	–	–	–	–	–	–	–	–	13.2 ± 6.6	3.8–18.3
Cl	237.1 ± 0.0	237.1–237.1	265.9 ± 11.4	255.1–280.2	309.0 ± 11.7	294.6–323.3	421.2 ± 43.5	391.6–485.0	643.1 ± 106.5	564.0–797.6	1257.4 ± 302.4	1077.8–1706.5
N	3.2 ± 2.8	1.3–5.2	7.7 ± 2.6	5.2–11.3	18.6 ± 8.8	9.7–28.7	35.2 ± 8.5	23.6–42.1	60.1 ± 20.6	46.6–90.7	136.4 ± 33.7	118.1–186.9
CH	185.1 ± 0.0	185.1–185.1	131.1 ± 8.9	123.4–138.8	129.2 ± 11.6	115.7–138.8	121.5 ± 3.9	115.7–123.4	188.9 ± 51.0	123.4–246.8	104.1 ± 14.8	92.5–123.4
Ca	74.0 ± 0.0	74.0–74.0	52.4 ± 3.6	49.4–55.5	51.7 ± 4.6	46.3–55.5	48.6 ± 1.5	46.3–49.4	75.6 ± 20.4	49.4–98.7	41.6 ± 5.9	37.0–49.4
MH	171.6 ± 13.6	161.9–181.2	187.0 ± 15.9	169.6–208.2	140.7 ± 11.6	131.1–154.2	196.6 ± 36.4	146.5–223.6	158.1 ± 40.1	123.4–215.9	204.4 ± 51.0	138.8–262.2
Mg	41.9 ± 3.3	39.5–44.2	45.6 ± 3.9	41.4–50.8	34.3 ± 2.8	32.0–37.6	48.0 ± 8.9	35.7–54.6	38.6 ± 9.8	30.1–52.7	49.9 ± 12.4	33.9–64.0
TH	356.6 ± 13.6	347.0–366.3	318.1 ± 19.3	308.5–347.0	269.9 ± 0.0	269.9–269.9	318.1 ± 36.9	269.9–347.0	347.0 ± 83.3	269.9–462.7	308.5 ± 63.0	231.3–385.6
Ca/Mg[c]	1.8 ± 0.1	1.7–1.9	1.2 ± 0.1	1.1–1.3	1.5 ± 0.3	1.2–1.7	1.0 ± 0.2	0.9–1.4	2.0 ± 0.5	1.4–2.5	0.9 ± 0.2	0.7–1.1
CH/MH[c]	1.1 ± 0.1	1.0–1.1	0.7 ± 0.1	0.7–0.8	0.9 ± 0.2	0.8–1.1	0.6 ± 0.1	0.6–0.8	1.2 ± 0.3	0.8–1.5	0.5 ± 0.1	0.4–0.7

Results after four different collections. COD—chemical oxygen demand, BOD—biological oxygen demand, TSS—total suspended solids, TDS—total dissolved solids, VSS—volatile suspended solids, VDS—volatile dissolved solids, CH—calcium hardness ($CaCO_3$), MH—magnesium hardness ($CaCO_3$), TH—total hardness ($CaCO_3$). T_0 represents the fresh water (control run). T_1, T_2, T_3, T_4 and T_5 represent the pretreated CWW diluted with fresh water in the following ratios 1:50; 1:22; 1:10; 1:5 and 1:2, respectively.

[a] Some parameters are from Prazeres et al. (2013b).

[b] Some parameters are from Prazeres et al. (2013a).

[c] Adimensional.

[d] NTU.

[e] °C.

[f] dS m^{-1}.

[g] mV.

2.4. *Agronomy*

Irrigation runs were performed at the Experimental Center of the *Escola Superior Agrária de Beja,* Portugal (38°01′37.28"N and 7°52′10.75"W; altitude of 240 m). The trial was conducted from April 14, 2009 to August 31, 2009. Two tomato cultivars of *Lycopersicon esculentum* Mill. were monitored (Roma and Rio Grande varieties). The plants were transplanted (April 30, 2009) with a distance of 0.20 m and 1 m in the line and between lines, respectively. The experimental design was a bifactorial, having as study factors the cultivar, treatment (salinity level) and interaction cultivar x treatment (cv x treat).

Experiments were carried out in a soil with medium texture (silty clay loam textural class with sand, clay and silt ratio = 67, 21 and 12%), bulk density of 1.2, field capacity of 0.204 m (depth = 0.45 m), low salt content and slightly alkaline nature. Soil conditioning included a first mobilization by disc harrows, mobilization with cultivators, application of fund fertilizer and a final mobilization with a rotary cultivator. Irrigation was conducted by gravity into the furrows. Irrigation was carried out, on average, three times per week for a period of 72 days. The water volume applied was estimated on the basis of the soil matric potential, monitored by "watermark" sensors installed at two depths 20 and 35 cm. Soil samples were collected at depths in the interval of 0-30 cm for characterization. The fruit was weekly harvested.

2.5. *Monitoring the environmental conditions*

The environmental conditions of the experiment were monitored in the weather station of *Quinta da Saúde*, in the city of Beja (*COTR — Centro Operativo e de Tecnologia de Regadio*). Fig. 1 illustrates some operating conditions, such as, average, maximum and minimum temperatures, reference evapotranspiration (ET_0) and global solar radiation (GSR).

2.6. *Analyzed characteristics*

During the experiment, the following crop agronomic information were monitored: flower clusters number per plant, tomato number per plant, tomato number per cluster, longitudinal and transversal calipers, Brix grade (°Brix or TSS_f— total soluble solids or SS_f — soluble solids) and epidermis firmness (or resistance). Twenty fruits were analyzed for each repetition.

The longitudinal and transversal calipers were determined using a *Quantum-Maschinen* digital paquimeter. The epidermis firmness and °Brix were monitored by means of a Vortex penetrometer — *Fruit Pressure Tester* and an *Atagro* refractometer, respectively.

Table 2
Effect of the cultivar, treatment and their interaction (cv × treat) on the flower clusters number per plant, tomatoes number per plant and tomatoes number per cluster.

Characteristics	Flower cluster number plant^{-1}	Tomatoes number plant^{-1}	Tomatoes number cluster^{-1}
Cultivar	n.s.	n.s.	n.s.
Roma	20 ± 3	54 ± 5	3 ± 0
Rio Grande	20 ± 5	54 ± 8	3 ± 0
Treatment	n.s.	n.s.	n.s.
T_0	18 ± 1	53 ± 1	3 ± 0
T_1	27 ± 5	62 ± 8	2 ± 0
T_2	19 ± 1	52 ± 1	3 ± 0
T_3	18 ± 1	48 ± 3	3 ± 0
T_4	19 ± 4	51 ± 10	3 ± 0
T_5	22 ± 2	60 ± 2	3 ± 0
cv × treat	n.s.	n.s.	n.s.
		cv. Roma	
T_0	19 ± 5	54 ± 22	3 ± 0
T_1	23 ± 0	56 ± 6	2 ± 0
T_2	18 ± 4	52 ± 11	3 ± 0
T_3	17 ± 6	46 ± 15	3 ± 0
T_4	22 ± 7	58 ± 25	3 ± 0
T_5	24 ± 8	62 ± 14	3 ± 0
		cv. Rio Grande	
T_0	17 ± 3	52 ± 12	3 ± 0
T_1	30 ± 11	68 ± 31	2 ± 0
T_2	20 ± 11	53 ± 35	3 ± 0
T_3	18 ± 5	51 ± 13	3 ± 0
T_4	16 ± 3	44 ± 11	3 ± 0
T_5	20 ± 7	59 ± 16	3 ± 0
Coeff. variat. (%)	29.20	31.26	14.85

n.s.—Not significant. Coeff. variat.—coefficient of variation. T_0 represents the fresh water (control run). T_1, T_2, T_3, T_4 and T_5 represent the pretreated CWW diluted with fresh water in the following ratios 1:50; 1:22; 1:10; 1:5 and 1:2, respectively.

2.7. *Statistical analysis*

The software program MSTAT-C was used for the statistical analysis of results. Differences among the means were calculated by applying the least significant difference (LSD) test with a confidence range of 95%.

3. **Results and discussion**

3.1. *Production of flower clusters and tomatoes per plant*

The effects of the cultivar, treatment and interaction cv x treat in the production of flower clusters per plant, tomatoes number per plant and tomatoes number per cluster are shown in Table 2.

Each tomato plant produced an average of 17-24 flower clusters in the case of cv. Roma and 16-30 flower clusters in the case of cv. Rio Grande. The tomatoes number per plant was 46-62 and 44-68 corresponding to cv. Roma and cv. Rio Grande, respectively. According to the LSD test, no significant effect of the studied factors (cultivar, treatment, cv x treat) was observed for the flower clusters number per plant, tomatoes number per plant and tomatoes number per cluster.

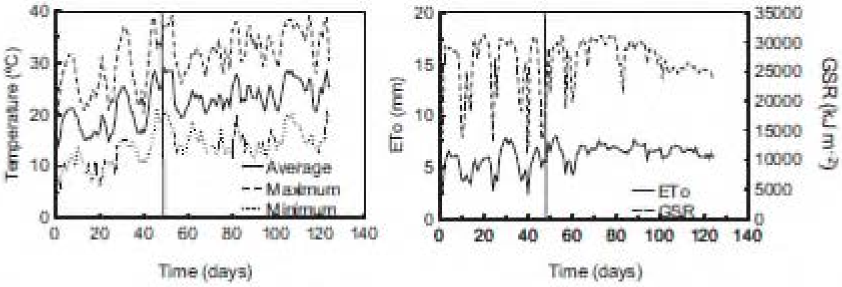

Fig. 1. Temperature, reference evapotranspiration (ETo) and global solar radiation (GSR) during the experiment. Saline irrigation start (|). D= 1 corresponds to day April 30, 2009 (transplantation of the plants).

Frequently, literature reports negative effects of salinity on fruits production. Thus, Katerji et al. (1998), cultivating the variety cv. ELKO 190 that grown in loam, experienced a reduction close to 31% in the tomatoes number per plant when used an irrigation water with a conductivity of 3.6 dS m^{-1} (results compared to the control run = 0.9 dS m^{-1}). Similarly, Tuna et al. (2007) claimed a decrease in fruit number per plant around 11% (cv. Target F1) when using a nutrient solution 75 mM in NaCl (EC = 8.3 dS m^{-1}) if compared to results obtained in the control experiment (EC = 1.9 dS m^{-1}).

3.2. *Marketable fruit quality: Caliper, epidermis firmness and ◦Brix*

The effects of the cultivar, treatment and interaction cv x treat in the marketable fruit characterization are presented in Table 3 in terms of longitudinal caliper (*L*c), transversal caliper (*T*c), *L*c/*T*c ratio, epidermis firmness and ◦Brix. From experimental data, cultivar statistically affected the longitudinal caliper and the *L*c/*T*c ratio ($p \leq 0.05$), while salinity level (treatment) significantly influenced the ◦Brix ($p \leq 0.01$).

Fig. 2 shows the treatment effect (salinity level) on the longitudinal caliper, transversal caliper and *L*c/*T*c ratio for the two studied cultivars. Contrarily to the findings reported in this study for cv. Roma, Yurtseven et al. (2005) observed a significant linear decrease of both tomato caliper (longitudinal and transversal) for increasing of the irrigation water salinity values (from 2.5 to 10.0 dS m^{-1}) if compared to results of the control run (0.25 dS m^{-1}). Depletion of the tomato fruit size under saline conditions can be attributed to inhibition of water absorption by roots and the subsequent reduction of water transport to the fruit. As a result, soluble solids concentration increases in the fruits (Sakamoto et al., 1999; Wu and Kubota, 2008).

The epidermis firmness and °Brix trends for both cultivars are displayed in Fig. 3. According to the statistical analysis, irrigation water salinity level does not affect the epidermis firmness, however, Sato et al. (2006) reported a 24% increase in this parameter (compared to the control run = 1.4 dS m^{-1}) when using a nutrient solution of NaCl with a conductivity of 5 dS m^{-1}. The increase of the tomato epidermis firmness constitutes an advantage not only in the collection, transportation, storage and commercialization processes, but also minimizes the insect, fungus and bacteria attacks.

The °Brix value increased when tomato plants were exposed to saline conditions. This effect was more remarkable in the cv. Rio Grande. The cv. Rio Grande presented a positive linear relationship of the °Brix with the irrigation water salinity level. Thus, maximum values in the °Brix were obtained in treatments T$_2$-T$_3$ and T$_5$ corresponding to cv. Roma and cv. Rio Grande, respectively (16% and 27% increase). Yurtseven et al. (2005) have reported increments in the TSS$_f$ with values of 10.4 and 5.4% when applying irrigation waters with salinity levels of 10 and 0.25 dS m^{-1}, respectively. As stated previously, the tomato growth with saline solutions leads to an increase of the soluble solids content (°Brix) by reducing the water flow to the fruits (Wu and Kubota, 2008). The TSS$_f$ content increase is an important factor at the time of tomato processing (Shao-wei et al., 2010).

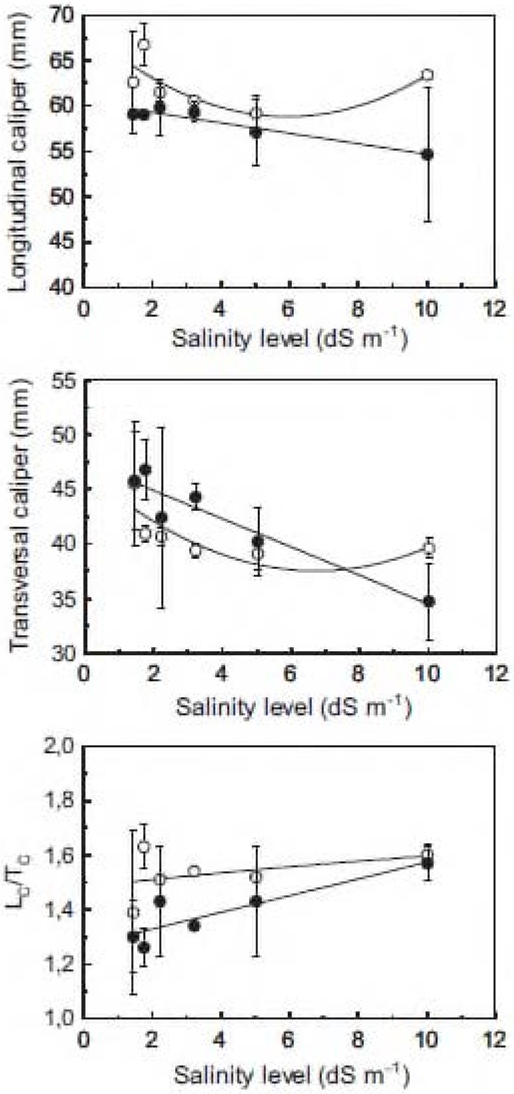

Fig. 2. Effect of the treatment (salinity level of the irrigation water) on the longitudinal caliper (L_C), transversal caliper (T_C) and L_C/T_C ratio for the cv. Roma (○) and cv. Rio Grande (●).

3.3. *Fruit quality in terms of the physiological disorder: Blossom-end rot*

The presence of the physiological disorder of blossom-end rot depends on several factors including irradiation, temperature, water availability, soil physicochemical characterization, soil cationic balance, air humidity, etc. Due to reduced uptake of ca^{2+} (Adams and Ho, 1992), blossom-end rot constitutes one of the main disadvantages of using saline conditions (Martinez et al., 1987). Thus, the site deficiency of Ca^{2+} in the distal placental tissue of the fruit begins with a slight browning symptom in the distal placental tissue, which progressively invades the pericarp (Cuartero and Fernández-Muñoz, 1999). Table 4 shows the effect of the studied factors on the tomato characterization with physiological disorder of blossom-end rot. The stress by high concentration of salts leads to fruit cell membrane deterioration with the subsequent

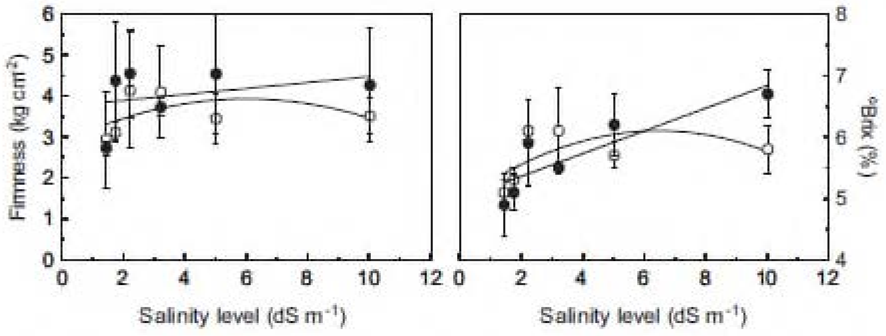

Fig. 3. Effect of the treatment (salinity level of the irrigation water) on the epidermis firmness and °Brix for the cv. Roma (○) and cv. Rio Grande (●).

reduction in epidermis firmness and liquid leakage. In the worst of cases, epidermis firmness reduction of approximately 40% compared to the marketable fruit has been obtained (T3). Besides of the tissue necrosis and firmness reduction, the fruits affected by physiological disorder of blossom-end rot have inhibited growth and maturing more quickly (Cuartero and Fernández-Muñoz, 1999). Fruit caliper reductions (T1-T5) within the ranges of 32-41% and 16-27% for the longitudinal and transversal calipers, respectively, were observed in the cv. Roma compared to the marketable fruits. In this case, the control treatment presented fruit caliper reductions of 30 (for the longitudinal caliper) and 16% (for the transversal caliper), compared to the marketable fruits. Additionally, decreases of 24-38% in longitudinal caliper and 20-35% in transversal caliper were obtained in the case of cv. Rio Grande (compared to the marketable fruits at the same salinity level). For control treatment, declines of 19 (longitudinal caliper) and 39% (transversal caliper) were observed. As a rule of thumb, °Brix increased with the irrigation water salinity level for fruits with disorder of blossom-end rot if compared to the marketable fruits.

3.4. Soil characterization

Fig. 4 displays the soil matric potential at two depths (20 and 35 cm). The irrigation water volume for each treatment is also represented. As inferred from the figure, when the matric potential had a value below -70 kPa, the irrigation water volume increased from 120 m^3 ha^{-1} to a range of 160-200 m^3 ha^{-1}. Consequently, soil matric potential values increased of approximately -90 kPa to values of -59 (depth = 35 cm) and -9 kPa (depth = 20 cm). From this moment, the irrigation water volume was 100 m^3 ha^{-1}. Matric potential varied within the following ranges: -50-(-40) and -37-(-17) kPa to depths of 35 and 20 cm, respectively.

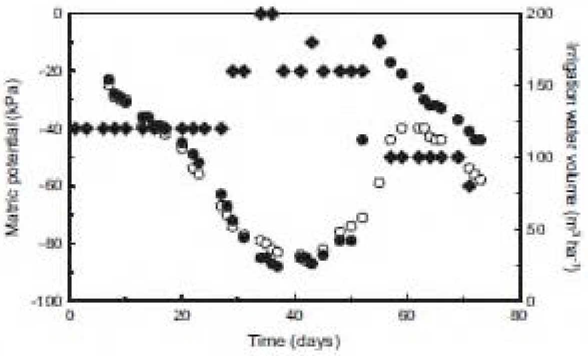

Fig. 4. Irrigation water volume (◆) and soil matric potential (●, depth = 20 cm; ○, depth = 35 cm) evolution along the time. *D* = 1 corresponds to day June 17, 2009.

Soil characterization is shown in Table 5. The analyzed soil was found to be slightly alkaline with pH values in the proximity of 8.0. Broadly speaking, soil conductivity linearly increased with the salinity level of the irrigation water (r^2= 0.91), with a soil conductivity maximum value of 1.647 dS m^{-1} for treatment T5 compared with the control (0.455 dS m^{-1}). Soil salinity increase was primarily due to the sodium and chloride accumulation (see Fig. 5). Hence, sodium increments of 28, 39, 68, 66, and 85% were obtained for the irrigation waters with salinity levels of 1.75, 2.22, 3.22, 5.02 and 10.02 dS m^{-1}, respectively. This condition may affect

Table 3
Effect of the cultivar, treatment and their interaction (cv × treat) on the marketable fruit quality.

Characteristics	Longitudinal caliper (mm)	Transversal caliper (mm)	L_C/T_C	Epidermis firmness (kg cm^{-2})	°Brix (%)
Cultivar	*	n.s.	*	n.s.	n.s.
Roma	62.33 ± 2.62	40.86 ± 2.40	1.53 ± 0.08	3.54 ± 0.50	5.7 ± 0.4
Rio Grande	58.16 ± 1.95	42.37 ± 4.42	1.39 ± 0.11	4.03 ± 0.71	5.7 ± 0.7
Treatment	n.s.	n.s.	n.s.	n.s.	**
LSD value	–	–	–	–	0.6492
T_0	60.83 ± 2.48	45.65 ± 0.17	1.35 ± 0.07	2.83 ± 0.16	5.0 ± 0.1c
T_1	62.88 ± 5.46	43.87 ± 4.16	1.45 ± 0.26	3.74 ± 0.90	5.2 ± 0.1bc
T_2	60.65 ± 1.19	41.54 ± 1.24	1.47 ± 0.06	4.35 ± 0.29	6.0 ± 0.2a
T_3	59.94 ± 0.89	41.84 ± 3.46	1.44 ± 0.14	3.92 ± 0.26	5.8 ± 0.4ab
T_4	58.13 ± 1.50	39.63 ± 0.80	1.47 ± 0.06	4.00 ± 0.77	5.9 ± 0.3a
T_5	59.03 ± 6.19	37.17 ± 3.42	1.59 ± 0.02	3.89 ± 0.54	6.3 ± 0.7a
cv × treat	n.s.	n.s.	n.s.	n.s.	n.s.
Coeff. variat (%)	5.47	8.22	8.44	27.83	7.31

n.s.—Not significant; different lowercase letters indicate significant differences with $p \leq 0.05$, according to the LSD test. Coeff. variat.—coefficient of variation. T_0 represents the fresh water (control run). T_1, T_2, T_3, T_4 and T_5 represent the pretreated CWW diluted with fresh water in the following ratios 1:50; 1:22; 1:10; 1:5 and 1:2, respectively.

[*] Significant for $p \leq 0.05$.

[**] Significant for $p \leq 0.01$.

Table 4
Effect of the cultivar, treatment and their interaction (cv × treat) on the fruit quality with physiological disorder of blossom-end rot.

Characteristics	Longitudinal caliper (mm)	Transversal caliper (mm)	L_C/T_C	Epidermis firmness (kg cm^{-2})	°Brix (%)
Cultivar	n.s.	*	*	n.s.	n.s.
Roma	39.68 ± 3.98	32.41 ± 3.57	1.23 ± 0.09	2.96 ± 0.53	6.1 ± 0.4
Rio Grande	40.96 ± 6.18	29.61 ± 2.97	1.39 ± 0.21	2.97 ± 0.61	6.2 ± 0.8
Treatment	**	*	n.s.	n.s.	*
LSD value	4.819	3.395	–	–	0.8342
T_0	45.93 ± 3.13a	33.18 ± 7.47 a	1.42 ± 0.39	2.66 ± 0.52	5.2 ± 0.2b
T_1	–	–	–	–	–
T_2	42.28 ± 4.32ab	32.46 ± 2.01a	1.30 ± 0.06	3.10 ± 0.90	6.4 ± 0.4a
T_3	39.33 ± 3.85bc	28.94 ± 0.03bc	1.36 ± 0.13	2.52 ± 0.52	6.1 ± 0.2a
T_4	35.18 ± 0.02c	31.67 ± 0.84ab	1.12 ± 0.02	3.17 ± 0.19	6.1 ± 0.2a
T_5	36.11 ± 2.89c	27.81 ± 2.23c	1.30 ± 0.00	3.06 ± 0.60	6.8 ± 0.6a
cv × treat	n.s.	*	n.s.	n.s.	n.s.
LSD value	–	4.801	–	–	–
		cv. Roma			
T_0	43.72 ± 2.29	38.46 ± 5.35a	1.14 ± 0.10	2.30 ± 1.46	5.3 ± 0.4
T_1	45.20 ± 5.08	34.36 ± 1.78	1.32 ± 0.11	3.61 ± 1.42	6.0 ± 0.1
T_2	39.23 ± 6.71	31.05 ± 2.97 bc	1.26 ± 0.10	2.47 ± 0.99	6.2 ± 0.3
T_3	36.61 ± 0.07	28.92 ± 1.91 cd	1.27 ± 0.09	2.89 ± 0.61	6.2 ± 0.5
T_4	35.16 ± 1.29	32.26 ± 4.95bc	1.10 ± 0.13	3.04 ± 0.10	6.3 ± 0.1
T_5	38.15 ± 3.61	29.38 ± 0.41bcd	1.30 ± 0.10	3.48 ± 0.83	6.3 ± 0.5
		cv. Rio Grande			
T_0	48.15 ± 2.76	27.90 ± 1.81 cd	1.70 ± 0.03	3.03 ± 0.45	5.1 ± 0.1
T_1	–	–	–	–	–
T_2	45.34 ± 2.76	33.88 ± 1.81ab	1.35 ± 0.03	3.74 ± 0.49	6.7 ± 0.0
T_3	42.06 ± 8.25	28.97 ± 0.39cd	1.45 ± 0.30	2.16 ± 0.48	5.9 ± 0.1
T_4	35.19 ± 2.20	31.08 ± 0.16bc	1.13 ± 0.06	3.30 ± 2.23	6.0 ± 1.1
T_5	34.06 ± 2.19	26.23 ± 0.89d	1.30 ± 0.04	2.64 ± 0.46	7.2 ± 0.6
Coeff. variat. (%)	7.58	6.89	9.81	31.82	8.51

n.s.—Not significant; different lowercase letters indicate significant differences with $p \leq 0.05$, according to the LSD test. Coeff. variat.—coefficient of variation. T_0 represents the fresh water (control run). T_1, T_2, T_3, T_4 and T_5 represent the pretreated CWW diluted with fresh water in the following ratios 1:50; 1:22; 1:10; 1:5 and 1:2, respectively.

* Significant for $p \leq 0.05$.

** Significant for $p \leq 0.01$.

the soil structure in terms of soil clay dispersion, preventing the infiltration and reducing the permeability (Bauder et al., 2011). Additionally, sodium and chloride may have a toxic effect on plants (Glover, 2001). Katerji et al. (1998) by using irrigation waters with salinity levels of 2.3 and 3.6 dS m^{-1} reported increases in the soil salinity in the ranges of 4.5-6.4 and 4.0-5.4 dSm^{-1}, respectively, for the loam and clay, compared to the control that presented a soil salinity of 0.8 dS m^{-1}. In the present study, soil salinity level presented always a lower value than the soil maximum salinity tolerance for the tomato crops (Fipps, 2003; Maas and Hoffman, 1977), including the maximum irrigation water salinity treatment (T5). However, caution should be adopted when the pretreated CWW application is used in the long-term, since it can affect the structure, permeability and aeration of the soil. When cheese whey was

Table 5
Soil characterization after the irrigation with different saline waters.

Parameter	Expression of results	T_0[a]	T_1	T_2	T_3	T_4	T_5
Phosphorus	P_2O_5 mg kg^{-1}	135	143	132	129	197	164
Potassium	K_2O mg kg^{-1}	>200	>200	>200	>200	>200	>200
Magnesium	Mg mg kg^{-1}	>125	>125	>125	>125	>125	>125
Organic matter	%	1.28	1.35	1.4	1.35	1.2	1.35
Texture	–				Medium		
pH (H_2O)	–	8.3	8	8.1	8.2	8.2	8.1
Lime need	$CaCO_3$ t ha^{-1}	0	0	0	0	0	0
Carbonates	$CaCO_3$%	27	24	25	25	22	27
Active calcareous	$CaCO_3$%	6.88	5.38	6.5	5.5	4.75	6.13
Total nitrogen	N%	0.101	0.102	0.102	0.096	0.105	0.115
C/N	–	7	8	8	8	7	7
			Exchange basis				
Ca	$\text{cmol}_c\ \text{kg}^{-1}$	25.48	18.99	28.41	22.54	18.99	20.85
Mg	$\text{cmol}_c\ \text{kg}^{-1}$	1.6	1.42	1.97	1.67	1.11	1.2
K	$\text{cmol}_c\ \text{kg}^{-1}$	0.32	0.28	0.37	0.34	0.3	0.35
Na	$\text{cmol}_c\ \text{kg}^{-1}$	0.43	0.48	0.9	1.37	1.02	2.29
Exchange acidity	$\text{cmol}_c\ \text{kg}^{-1}$	0.00	0.00	0.00	0.00	0.00	0.00
EBS	$\text{cmol}_c\ \text{kg}^{-1}$	27.83	21.17	31.66	25.92	21.42	24.69
CEC	$\text{cmol}_c\ \text{kg}^{-1}$	27.83	21.17	31.66	25.92	21.42	24.69
SDB	%	100	100	100	100	100	100
			Saturation degree of the exchange complex with				
Ca^{2+}	%	91.6	89.7	89.7	87	88.7	84.4
Mg^{2+}	%	5.7	6.7	6.2	6.4	5.2	4.9
K^+	%	1.1	1.3	1.2	1.3	1.4	1.4

EBS—Exchange basis sum; CEC—cationic exchange capacity; SDB—saturation degree in basis. T_0 represents the fresh water (control run). T_1, T_2, T_3, T_4 and T_5 represent the pretreated CWW diluted with fresh water in the following ratios 1:50; 1:22; 1:10; 1:5 and 1:2, respectively.

[a] Some parameters are from Prazeres et al. (2013b).

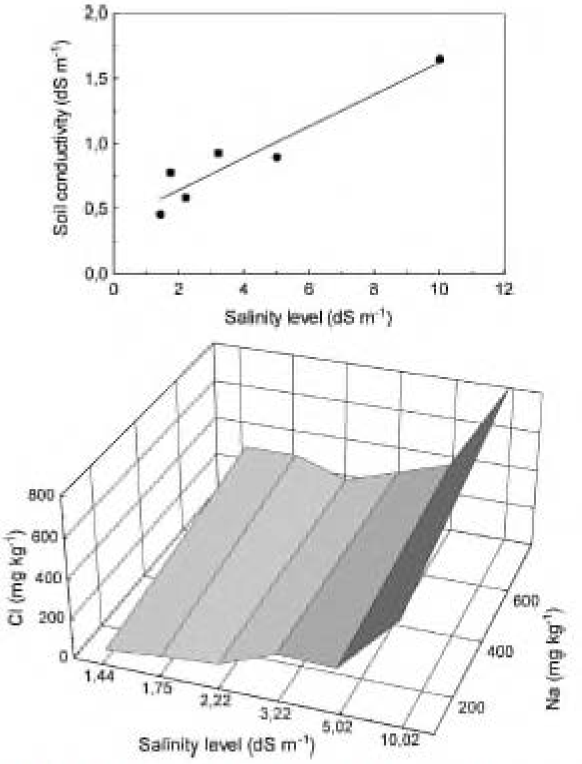

Fig. 5. Conductivity, chloride and sodium contents on the soil at different salinity levels of the irrigation water.

used for land application, some advantages have been observed, namely, by decreasing the clay dispersion and SAR; and increasing the infiltration rate, soil aggregation stability and crop yield (Jones et al., 1993a,b; Kelling and Peterson, 1981; Lehrsch et al., 1993, 1994). Additionally, the acid pH of the cheese whey decreases the pH of the soil, increasing the Ca solubility and leaching of exchangeable Na (Lehrsch et al., 1994). However, an infiltration rate decrease can be observed by using excessive cheese whey applications even at short-term (Watson et al., 1977). According with Jones et al. (1993b), the salts and organic load limit the cheese whey application and should be given rest periods to improve the infiltration rate. On the other hand, the organic/salt overloading can also affect the initial plant growth (Jones et al., 1993a).

In addition, fertirrigation with pretreated CWW (T_1-T_5) improved the phosphorus and total nitrogen levels of the soil, especially in T_4 and T_5 treatments. The exchange basis (Ca, Mg, K, Na) were also affected by the irrigation water salinity level. A positive and linear increase of the Na exchange basis with irrigation water salinity level was experienced. Exchange basis of Ca, Mg and K showed maximum values for the salinity level of 2.22 dS m^{-1}. Similar results were obtained for the exchange basis sum (EBS) and cationic exchange capacity (CEC).

The irrigation water salinity level increase influenced the saturation degree of the exchange complex, with depletion of the calcium percentage (≤8%), and increase of magnesium (T_1-T_3) and potassium (T_1-T_5). Additionally, an increase of exchangeable sodium percentage from 1.6 (T_0) to 9.3 (T_5) was also obtained.

4. Conclusions

Tomato irrigation with pretreated and diluted cheese whey wastewater can be an alternative for small and medium cheese producing factories. The process presents some beneficial effects on fruit quality. Thus, under controlled saline conditions, epidermis firmness and soluble solids content (monitored by °Brix) are improved if compared to control runs. Irrigation water salinity levels between 1.75 and 10.02 dS m^{-1} had no significant effect in fruit caliper. Thus, this study presents a new vision on the marketable tomato production at salinity conditions through the reuse of pretreated and diluted wastewater from the cheese industry. Additionally, soluble solids increment creates an economic benefit toward the producers, once the sweet fresh tomato demand by the consumers is increasingly more pronounced. The main drawback of the proposed alternative is the effect on soil properties. In this sense, precautions must be taken when the pretreated and diluted cheese whey wastewater is used for long-term irrigation. Thus, further research is required to verify the effects on the soil structure, permeability or compaction after using saline pretreated wastewater in long-term.

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