Pretreated cheese whey wastewater management by agricultural reuse: Chemical characterization and response of tomato plants Lycopersicon esculentum Mill. under salinity conditions

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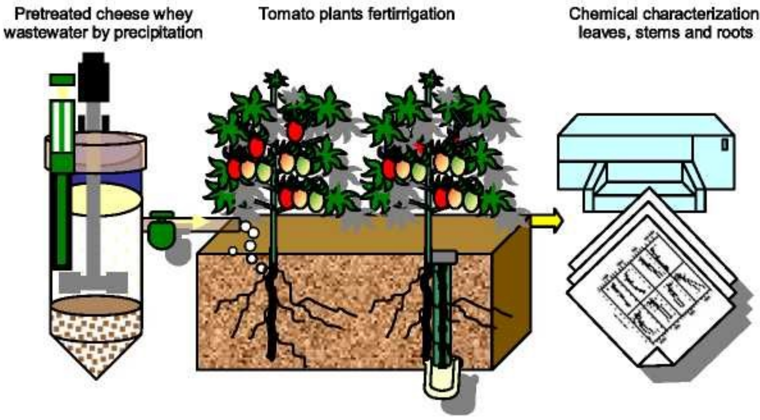
HIGHLIGHTS

- Plant growth with diluted wastewater does not lead to visible negative effects.
- Leaf and stem sodium linearly increases with salinity level.
- No significant differences are obtained in leaf and stem chloride content.
- Sodium accumulation is more pro- nounced in cv. Roma than in cv. Rio Grande.
- Ca and K accumulation seems to act as a saline tolerance mechanism in cv. Rio Grande.

GRAPHICAL ABSTRACT



Keywords:
Dairy effluents
Saline wastewater
Vegetative tissues
Sodium accumulation
Tolerance mechanisms
Nutrient competition

Abstract

The agricultural reuse of pretreated industrial wastewater resulting from cheese manufacture is shown as a suitable option for its disposal and management. This alternative presents attractive advantages from the economic and pollution control viewpoints. Pretreated cheese whey wastewater (CWW) has high contents of biodegradable organic matter, salinity and nutrients, which are essential development factors for plants with moderate to elevated salinity tolerance. Five different pretreated CWW treatments (1.75 to 10.02 dS m^{-1}) have been applied in the tomato plant growth. Fresh water was used as a control run (average salinity level = 1.44 dS m^{-1}). Chemical characterization and indicator ratios of the leaves, stems and roots were monitored. The sodium and potassium leaf concentrations increased linearly with the salinity level in both cultivars, Roma and Rio Grande. Similar results were found in the stem sodium content. However, the toxic sodium accumulations in the cv. Roma exceeded the values obtained in the cv. Rio Grande. In this last situation, K and Ca uptake, absorption, transport and accumulation capacities were presented as tolerance mechanisms for the osmotic potential regulation of the tissues and for the ion neutralization. Consequently, Na/Ca and Na/K ratios presented lower values in the cv. Rio Grande. Na/Ca ratio increased linearly with the salinity level in leaves and stems, regardless of the cultivar. Regarding the Na/K ratio, the values demonstrated competition phenomena between the ions for the cv. Rio Grande. Despite the high chloride content of the CWW, no significant differences were observed for this nutrient in the leaves and stems. Thus, no nitrogen deficiency was demonstrated by the interaction $NO3^{-}/Cl^{-}$. Nitrogen also contributes to maintain the water

potential difference between the tissues and the soil. Na, P, Cl and N radicular concentrations were maximized for high salinity levels (>2.22 dS m^{-1}) of the pretreated CWW.

1. Introduction

Cheese whey wastewater is defined as the greenish-yellow and/or whitish effluent generated in cheese making plants. The characteristics of the CWW may significantly vary depending on the milk type (goat, cow, sheep and buffalo), final products (cheese and/or cottage cheese), volume and quality of the washing water, cleaning agent type (alkaline and/or acidic chemicals) and valued whey volume. The principal contaminant indicators show a relatively high organic load with biodegradability index higher than 0.5, which suggests the suitability of the biological process application. Consequently, organic removal levels higher than 80% have been reported. However, the final effluent still presents an unaffordable organic content with COD (chemical oxygen demand) values close to 11 kg m^{-3} in some cases (Gavala et al., 1999). Additionally, excessive hydraulic retention times between 8 and 13 days are normally required (Kalyuzhnyi et al., 1997; Rivas et al., 2010; Yang et al., 2003), constituting a serious drawback of the biological technology.

Some physicochemical processes have been applied to pretreat the CWW. For instance, calcium hydroxide, sodium hydroxide, iron and aluminum salts have already been employed to deal with raw CWW (Rivas et al., 2010, 2011). Chemical precipitation has been reported to be a very efficient technology to remove total suspended solids, fats, turbidity and some nutrients like phosphorus and nitrogen. Simultaneously, COD removal can reach values close to 50%. Hence, the effluent obtained can still be catalogued as a strong organic pollutant. Recently, the application of technologies based on the use of ozone, Fenton and combination of ozone with hydrogen peroxide or catalysts has been described to treat CWW after the aerobic biodegradation (Martins and Quinta-Ferreira, 2010; Martins et al., 2010). However, due to the high organic load, these technologies fail when dealing with raw CWW.

The utilization of a component of CWW, namely, the cheese whey as a potential fertilizer is a common practice (Lehrsch et al., 2008; Robbins et al., 1996). However, soil application of cheese whey may affect the physicochemical structure of the former (Saddoud et al., 2007). This effect is mainly due to the solids, fat and salt contents (Prazeres et al., 2012). Solids and fats associated problems can be minimized when physicochemical treatments are first applied. Nevertheless, the salinity level remains unchanged. High salt concentrations in the soil can result in a “physiological” drought condition because the roots are unable to absorb water (Fipps, 2003). Thus, salinity management procedures are imperative. The demand for crops with moderate to elevated salinity tolerance can be a solution. Tomato plants have a moderate salt tolerance (Tuna et al., 2007). These plants present irrigation water and soil maximum salinity tolerances of 1.7 and 2.5 dS m^{-1} (Fipps, 2003), respectively.

The tomato crop irrigation with saline water has positive and negative aspects. Several research studies have reported reductions in the yield and in the fruit fresh weight under saline conditions (Sato et al., 2006; Zushi and Matsuzoe, 2009). Additionally, changes in the intracellular concentration of organic and inorganic compounds in the plant tissues are important factors for the osmotic adjustment, specifically, in leaves (Aziz et al., 1999; Tuna et al., 2007). Accumulation of the amino acid proline (Zushi and Matsuzoe, 2009), sodium and chloride (Alian et al., 2000; Maggio et al., 2007; Martinez et al., 1987), calcium and magnesium (Martinez et al., 1987) has been described.

The aim of this experimental work was to assess the effects of the tomato plant irrigation with pretreated and saline CWW under different salinity conditions (1.75-10.02 dS m^{-1})compared to fresh water (1.44 dS m^{-1}). Thus, in the present work, the chemical composition response of the different vegetative tissues (leaves, stems and roots) of the tomato plants was investigated. The biometric evaluation (fresh weight, dry matter, leaf area, stem diameter and length, primary root length, etc.) of the leaves, stems and roots of the tomato plants was studied in a previous work (Prazeres et al., 2013).

2. Materials and methods

2.1. Pretreated cheese whey wastewater characterization

Pretreated CWW by basic precipitation shows a high biodegradable organic matter. The total suspended solids (TSS) content of about 256 ppm also contributes to the contamination. However, most of the solids are sugars and proteins susceptible to biodegradation, improving the soil aggregation (Kelling and Peterson, 1981). Pretreated CWW is also rich in nutrients (ppm), such as, sodium («3400), potassium («270), phosphorus («50), chloride («2200), nitrogen («270), calcium («40) and magnesium («40). As stated previously, the main problem of the pretreated CWW is the salinity level (sodium and chloride). As a consequence, the pretreated CWW was diluted with fresh water.

2.2. Experimental design

Six different treatments were considered and designed as treat- ment levels T0-T5 (Table 1). Treatment levels T1-T5 were obtained after dilution of pretreated CWW with fresh water (1:50; 1:22; 1:10; 1:5 and 1:2). The electrical conductivity of these irrigation waters ranged between 1.75 and 10.02 dS m^{-1}. Fresh water was used as control run (T0). The detailed characterization of the pretreated CWW and irrigation waters can be found in a previous work (Prazeres et al., 2013).

2.3. Irrigation experiments and soil characterization

Irrigation experiments were carried out at the Experimental Center of the Escola Superior Agrária de Beja, Portugal. Two tomato cultivars Lycopersicon esculentum Mill. were used, inscribed in the European Catalog as cv. Roma and cv. Rio Grande. The field experiments were conducted for a saline exposure time of 72 days in a soil with medium texture (silty clay loam textural class with sand, clay and silt ratio = 67, 21 and 12%), scarcely salty and alkaline (Table 2). The reference evapotranspiration, temperature and precipitation presented average values of approximately 6 mm, 23 °C and 0.2 mm, respectively.

2.4. Analytical procedures in plant chemical characterization

Plants were separated into the different vegetative tissues: leaves, stems (including ramifications) and roots. The dry samples were triturated and passed through a sieve with 1 mm of diameter (Nag, 2006).

Table 1
Physicochemical characterization of the irrigation waters.

Parameters	T_0	T_1	T_2	T_3	T_4	T_5
COD	30 ± 19	172 ± 57	404 ± 107	895 ± 278	1883 ± 470	5014 ± 1481
BOD$_5$	3 ± 1	140 ± 49	305 ± 100	738 ± 149	1675 ± 574	4450 ± 1652
BOD$_5$/COD[a]	0.11 ± 0.02	0.81 ± 0.03	0.75 ± 0.05	0.84 ± 0.08	0.88 ± 0.08	0.88 ± 0.06
Turbidity[b]	1.9 ± 1.2	12.2 ± 2.9	19.0 ± 2.0	27.4 ± 5.9	33.8 ± 15.1	69.6 ± 40.7
pH	7.38 ± 0.16	7.51 ± 0.27	7.30 ± 0.29	7.32 ± 0.24	7.36 ± 0.28	7.43 ± 0.47
Temperature[c]	25.7 ± 0.7	25.5 ± 2.3	25.6 ± 2.5	25.5 ± 2.5	25.4 ± 2.5	25.5 ± 2.5
Conductivity[d]	1.44 ± 0.05	1.75 ± 0.03	2.22 ± 0.11	3.22 ± 0.21	5.02 ± 0.36	10.02 ± 0.96
Redox potential[e]	212.1 ± 32.8	110.8 ± 72.5	26.7 ± 155.4	−96.2 ± 181.2	−122.2 ± 172.1	−186.9 ± 79.0
TSS	118 ± 48	82 ± 12	100 ± 58	193 ± 34	265 ± 27	241 ± 47
TDS	688 ± 51	796 ± 44	1043 ± 31	1602 ± 198	2899 ± 501	6653 ± 1183
Na	97.3 ± 13.0	147.1 ± 9.6	217.8 ± 13.2	419.1 ± 64.5	734.5 ± 137.6	1638.6 ± 329.0
K	10.3 ± 1.4	14.6 ± 2.3	24.1 ± 9.6	41.4 ± 16.1	73.9 ± 22.8	141.6 ± 59.9
P	–	–	–	–	–	13.2 ± 6.6
Cl	237.1 ± 0.0	265.9 ± 11.4	309.0 ± 11.7	421.2 ± 43.5	643.1 ± 106.5	1257.4 ± 302.4
N	3.2 ± 2.8	7.7 ± 2.6	18.6 ± 8.8	35.2 ± 8.5	60.1 ± 20.6	136.4 ± 33.7
Ca	74.0 ± 0.0	52.4 ± 3.6	51.7 ± 4.6	48.6 ± 1.5	75.6 ± 20.4	41.6 ± 5.9
Mg	41.9 ± 3.3	45.6 ± 3.9	34.3 ± 2.8	48.0 ± 8.9	38.6 ± 9.8	49.9 ± 12.4

Parameters are expressed in ppm. Results after 4 different collections. 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. COD – chemical oxygen demand; BOD – biological oxygen demand; TSS – total suspended solids; TDS – total dissolved solids.

[a] Adimensional.

[b] NTU.

[c] °C.

[d] dS m^{-1}.

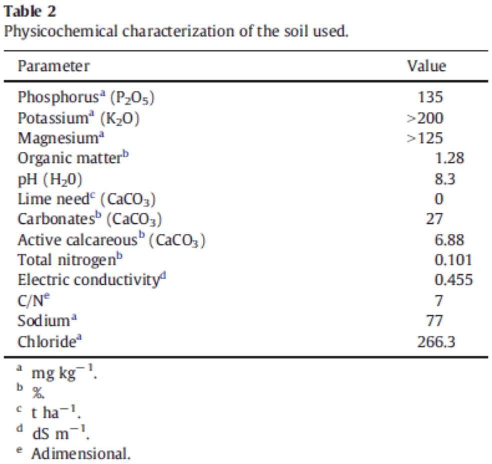
[e] mV.

Organic matter was determined after calcination at 550 °C for 6 h in a P SELECTA-HORN 186331 muffle. The calcined residue was there- after digested in acid medium with a 3 N HCl solution and filtered through Whatman 40 filters. The P, Na, K, Ca, and Mg levels could be analyzed. Total phosphorus was evaluated by a colorimetric method at 430 nm after the reaction of orthophosphates with vanadate- molybdate reagent. Sodium and potassium were determined in a CORNING 410 photometer. Calcium and magnesium determinations were conducted by volumetric complexation with EDTA (0.010 M) in the presence of eriochrome black T indicator and buffer solution. The calcon indicator and triethanolamine (30%) were used to determine the calcium content in basic medium (0.5 N NaOH solution).

Chloride was obtained from the dry samples after extraction with a 0.085 M calcium nitrate solution on a horizontal agitator for 15 min. Once filtrated, the solution was titrated with standardized solution of silver nitrate (0.028 M) in the presence of potassium chromate indicator until the appearance of red color (www.editora.ufla.br).

Kjeldahl nitrogen was obtained after calcination under an acidic (H2SO4) and hot medium in the presence of a metallic catalyst (copper sulfate and potassium sulfate) in a 6 1007 Tecator digester.

Table 2
Physicochemical characterization of the soil used.



Parameter	Value
Phosphorus[a] (P_2O_5)	135
Potassium[a] (K_2O)	>200
Magnesium[a]	>125
Organic matter[b]	1.28
pH (H_20)	8.3
Lime need[c] ($CaCO_3$)	0
Carbonates[b] ($CaCO_3$)	27
Active calcareous[b] ($CaCO_3$)	6.88
Total nitrogen[b]	0.101
Electric conductivity[d]	0.455
C/N[e]	7
Sodium[a]	77
Chloride[a]	266.3

[a] mg kg^{-1}.
[b] %.
[c] t ha^{-1}.
[d] dS m^{-1}.
[e] Adimensional.

The residue was dissolved in a basic medium (32% NaOH solution) and distilled (BUCHI Distillation B-316). Ammoniacal nitrogen was collected into a boric acid solution (4%) and titrated with standardized solution of hydrochloric acid (0.2 M).

2.5. Statistical analysis

MSTAT-C statistical program was used to treat the experimental results. The differences between the means were determined by using the Least Significant Difference (LSD) test for a confidence range of 95%.

3. Results and discussion

The irrigation water quality can severely affect the system soil- water resources-plant. When plants suffer any imbalance of one or more nutrients, their metabolism experiences critical disturbances. These perturbations can be monitored by visible symptoms of deficiency/toxicity (Prazeres et al., 2013) and physicochemical characterization of the plant tissues. Significant visible symptoms of deficiency or excess of nutrients on the plant tissues were not observed during the irrigation tests. Thus, the determination of the chemical characterization of the plant tissues is of paramount importance to detect adverse/positive effects in tomato plant growing under salinity conditions. Effect of the cultivar, treatment (salinity level) and their interaction on the leaf, stem and root chemical characterization was investigated (Supplementary Table 1). The behaviors of the organic matter, nutrients and ratios for the different vegetative tissues are discussed in the following sections.

3.1. Foliar nutrients behavior

The organic matter and nutrients behavior with the salinity level for cv. Roma and cv. Rio Grande is illustrated in Fig. 1. The sodium and potassium leaf concentrations increased linearly with the salinity level in both cultivars. However, the leaf sodium accumulation was more pronounced for cv. Roma. The toxic accumulation of sodium and chloride in leaves has been correlated with the stomata closure and the chlorophyll reduction (Romero-Aranda and Syvertsen, 1996). Never the less, photo synthetic activity reduction by chlorophyll synthesis depletion has not been experienced when diluted and pretreated CWW was used in tomato plants growth. A chlorophyll content increase measured by the SPAD (Soil Plant Analysis Development) index was found in a previous work (Prazeres et al., 2013). The cv. Rio Grande seems to have mechanisms that minimize the sodium accumulation in the leaf tissues. This effect appears to be due to the higher Ca and K ab- sorption capacity of the cv. Rio Grande. Cuartero and Fernández-Munoz (1999) reported that the tomato plants which absorb greater amounts of Ca and K show lower Na/Ca and Na/K ratios in their leaves. This finding occurred in the cv. Rio Grande compared to the cv. Roma. Consequently, plants of the cv. Rio Grande present a nutritional balance closer to the plants grown under non-saline conditions. Additionally, Na/K ratio in the tomato plant leaves is one of the principal indicators of the plant tolerance capacity to select and use K (inclusion and selectivity) in salinity conditions with Na exclusion (Cuartero et al., 1992). An increase on the Na/Ca ratio is connected with the membrane sites competition and the inhibition phenomena of the uptake and transport of calcium under saline conditions (Tuna et al., 2007).

Increasing the nitrogen concentration around 98% in the irrigation water (treatment T5) compared with the control led to an increase of about 44% in the leaf tissues of the cv. Rio Grande. This effect is related with no nitrogen deficiency. The nitrogen deficiency can happen by the interaction $NO3^{-}/Cl^{-}$ (Tuna et al., 2007) under salinity conditions due to the depolarization by Na^{+} of the plasmatic membrane (Suhayda et al., 1990).

The cv. Rio Grande presented a calcium content increase in the range of 10-25% and a magnesium content decrease in the interval of 20-35.0%, if compared to results obtained in the control run. Consequently, the ratio Ca/Mg increased to values within the range of 8.8-10.5 (T1-T5) compared to the value of5.9experienced in treatment T0. When exposed to saline conditions, leaf calcium content in tomato

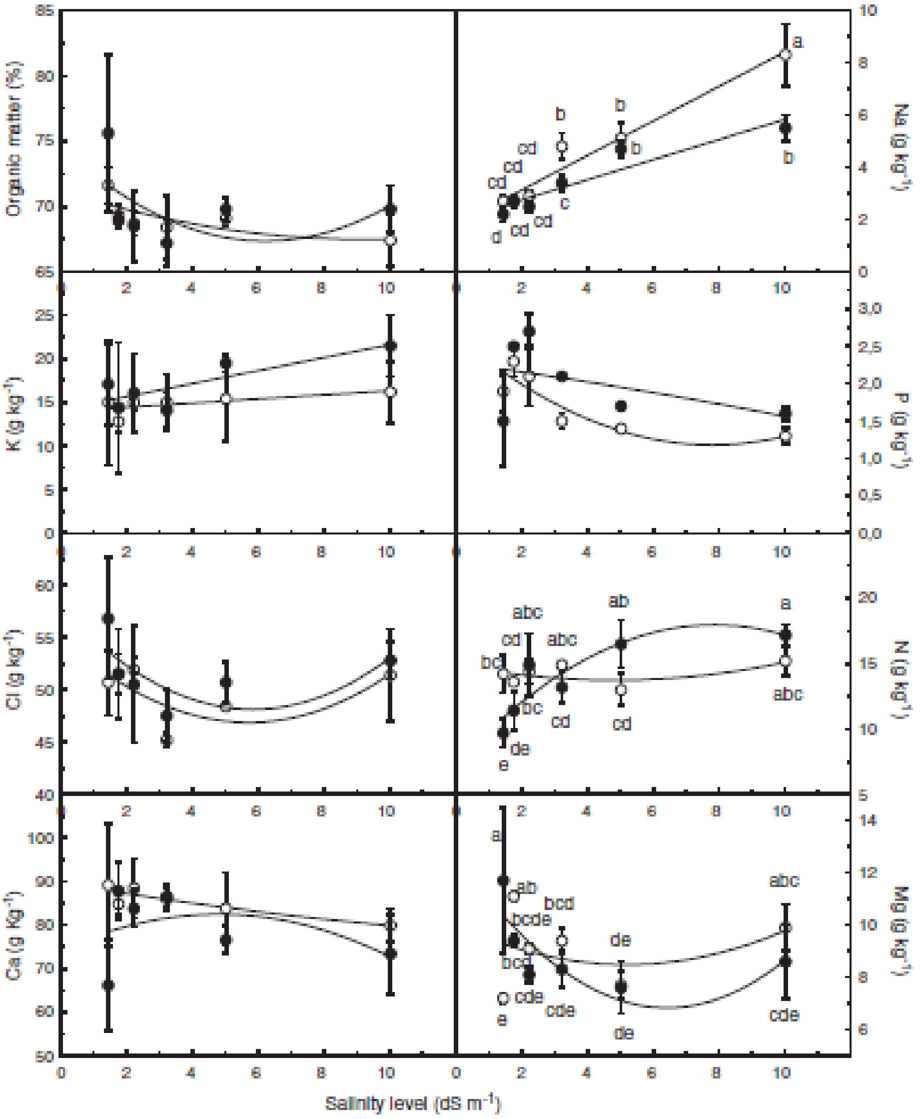
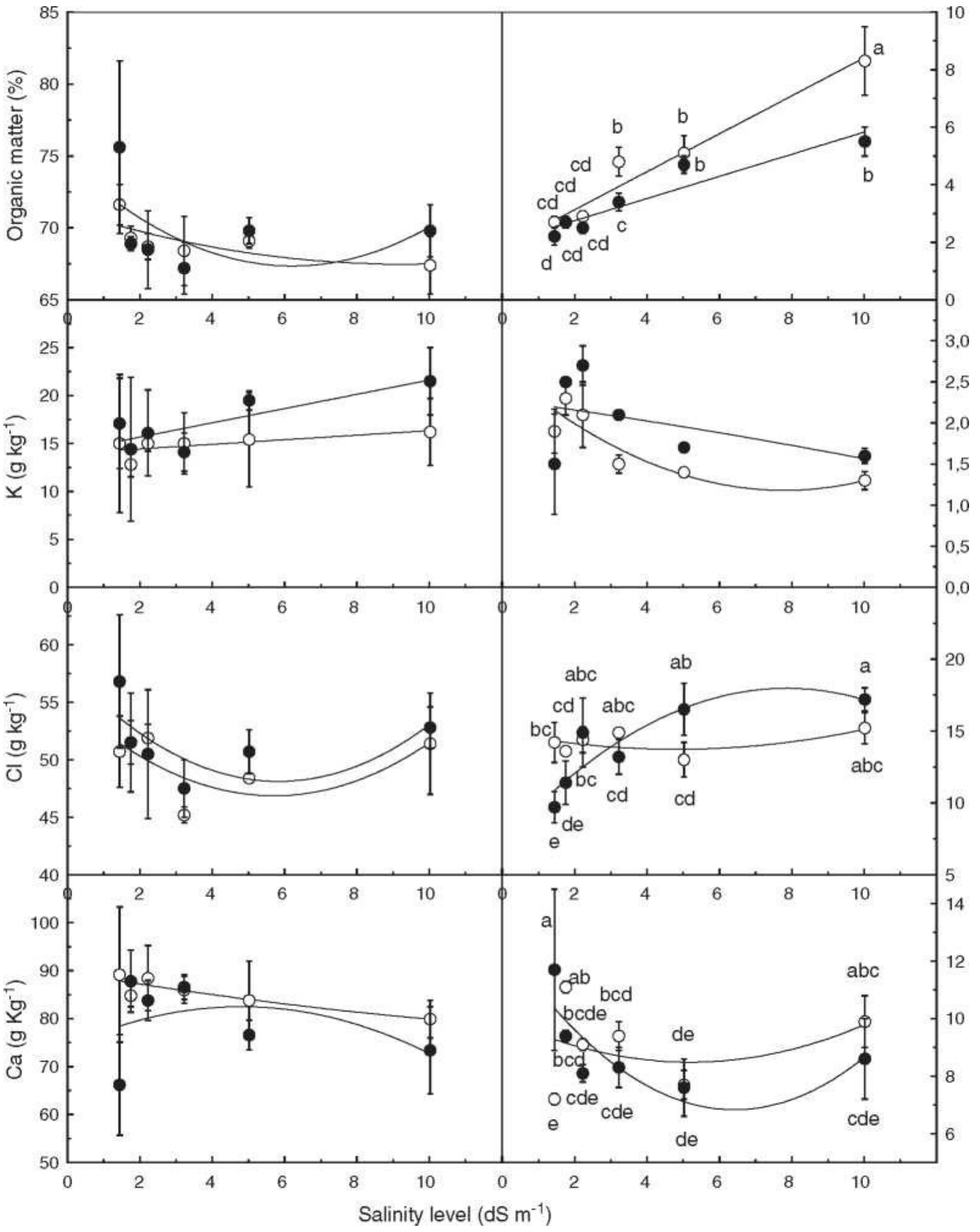


Fig. 1. Effect of the pretreated cheese whey wastewater reuse on the leaf nutrients and organic matter of the two cultivars. ○, cv. Roma; ●, cv. Rio Grande. Different lowercase letters indicate differences with $p \leq 0.05$, according to LSD test.



cultivars has been reported to follow different trends. Maggio et al. (2007) achieved a reduction of the leaf calcium content, identifying a reduction in activity of this ion in the presence of NaCl by competition phenomena in the root surface.

The cv. Roma presented higher leaf concentration in Na, Ca and Mg than the cv. Rio Grande in the salinity level T5. Increasing the leaf Na concentration contributes to maintain the water potential difference between the leaves and the soil, required condition to obtain water from the saline solution (Cuartero and Fernández-Munoz, 1999). The cv. Rio Grande showed higher leaf concentration of K, P, Cl and N than the cv. Roma for the salinity level T5. K absorption is of paramount importance for the osmotic potential regulation of the tissues and for the anion neutralization (Varennes, 2003). Further- more, the K and N nutrients may confer tolerance of the crops to salinity.

3.2. Stem nutrients behavior

The organic matter and nutrients behavior is depicted in Fig. 2, for both cultivars. Similarly to results observed in leaft issues, a linear and positive relationship between the sodium content in the stems of tomato plants and the salinity level for both cultivars ($r^2 = 0.98$) was also found. An analogous result was obtained in the K content for the cv. Rio Grande ($r^2 = 0.93$).

Regarding calcium concentration, a negative linear relationship with the salinity level for the cv. Rio Grande was verified. In this case, the minimum value was achieved in the salinity level of 10.02 dS m^{-1}, with a reduction of approximately 19%. Simultaneously, a positive linear relationship of the magnesium content with the salinity level (T_1-T_5) for the cv. Rio Grande was also revealed (where the maximum magnesium value was obtained with an increase of about 16%). Opposite

Fig. 2. Effect of the pretreated cheese whey wastewater reuse on the stem nutrients and organic matter of the two cultivars. O, cv. Roma; •, cv. Rio Grande. Different lowercase

letters indicate differences with $p < 0.05$, according to LSD test.

behavior showed the cv. Roma in the treatment with salinity level of 2.22 dS m^{-1}, where the calcium increase was negligible («4%). However, a magnesium reduction of 54% was recorded.

3.3. Radicular nutrients behavior

Only few studies have been focused on the salinity effect in the development, growth and chemical composition of the tomato plant roots after prolonged exposure to conditions of salt stress. Moreover, the knowledge of the radicular system response to salinity conditions constitutes an important indicator. Roots constitute the basic system to neutralize the salt stress (Smith et al., 1992), which may be affected in the same way that the leaves (Caines and Shennan, 1999).

The organic matter and nutrients behavior with the salinity level of the irrigation waters is shown in Fig. 3, for both cultivars. Concerning the cv. Roma, the root sodium increase was 41% against 33% recorded for the cv. Rio Grande. Similar result was obtained by Tuna et al. (2007) when used a nutritional solution containing 75 mM NaCl in tomato plants of the cv. Target F1. In this case, a sodium concentration increase around 74% was achieved.

In addition, the maximum radicular concentrations of K, Cl, N, Ca and Mg were achieved in the salinity level T5 for the cv. Rio Grande. For the cv. Roma, the maximum root accumulation of Cl, N and P was found when the salinity level of 3.22 dS m^{-1} was applied. Some investigators have reported a reduction of calcium and potassium, and no significant increase of the nitrogen content in terms of saltiness in the tomato plants. The study of Tuna et al. (2007) reported reductions in calcium and potassium of 14 and 43%, respectively.

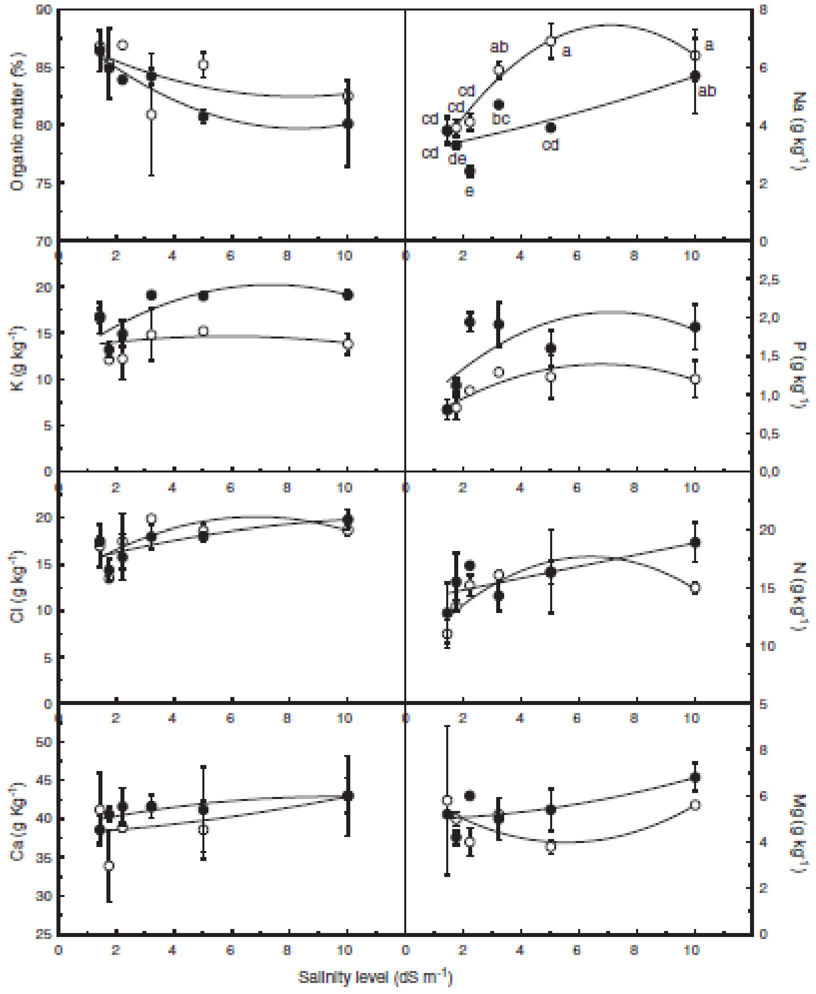


Fig. 3. Effect of the pretreated cheese whey wastewater reuse on the root nutrients and organic matter of the two cultivars. ○, cv. Roma; ●, cv. Rio Grande. Different lowercase letters indicate differences with $p \leq 0.05$, according to LSD test.

3.4. Ratios: Na/Ca, Na/K and Cl/N

3.4.1. Foliar ratios

As stated above, the behavior of some nutrients ratios constitutes an important factor to understand the plant response to adverse conditions. Fig. 4 (top) shows the foliar ratios for the cv. Roma and cv. Rio Grande. The Na/Ca ratio demonstrated a linear and positive relationship with the salinity level of the irrigation water, regardless of the cultivar (r^2 = 0.91-0.97). Similar linear trend was obtained for the Na/K ratio when analyzing the results from the cv. Roma (r^2 = 0.95). However, for the cv. Rio Grande, the Na/K ratio did remam approximately constant for salinity levels > 3.22 dS m^{-1}. In this situation, a sodium concentration increase was accompanied by a potassium concentration rise. This effect indicates a high activity of the potassium nutrient and competition phenomena between Na and K ions that probably share the same transport system on the root surface (Rus et al., 2001). For cv. Rio Grande, the transport through the sodium-potassium pump appears to be more efficient. The active transport, namely, the sodium-potassium pump may ex- plain the competition phenomena between sodium and potassium (see Fig. 5A). The sodium-potassium pumps are transmembrane proteins that act against the concentration gradient with energy expen- diture through ATP (adenosine triphosphate) molecule hydrolysis, with formation of ADP (adenosine diphosphate) and phosphate group. In the work presented by Tuna et al. (2007), the K concentration was about 3 times the leaf sodium concentration (K/ Na = 2.67 and Ca/Na = 4.79) when using a nutrient solution with 75 mM NaCl in the tomato plants cv. Target F1.

The maximum reductions in the ratio Cl/N were observed in the cv. Roma (15%) and cv. Rio Grande (38-47%) for the treatments T3 and T2-T5, respectively. This effect seems to be due to lower absorption or rejection of the chloride ion when applying high nitrogen concentrations (18.6 to 136.4 ppm) compared to the control (3.2 ppm). The irrigation water composition may change the root membrane cationic composition, especially in the lipid composition, which affects the anions absorption (see Fig. 5B). Kafkafietal. (1982) reported similar results in the leaf chloride reduction for the tomato plants when in creasing the nitrogen concentration. Oppositely, in the study conducted by Alian et al. (2000), there was a chloride concentration increment in the leaves under saline conditions.

3.4.2. Stem ratios

The stem response under salinity conditions can be identified in the Na/Ca, Na/K and Cl/N ratios, represented in Fig. 4 (middle), for the cv. Roma and cv. Rio Grande. Unlike the Cl/N ratio, Na/Ca and Na/K ratios increased linearly with the salinity level, regardless of the cultivar (r^2 = 0.90-0.99). This effect seems to be due to the in- creased mobilization of sodium along the stem and its concentration at the level of the leaf tissues. In the cv. Roma, the sodium concentra- tion in the stems achieved a value 66% higher (treatment T5) than the

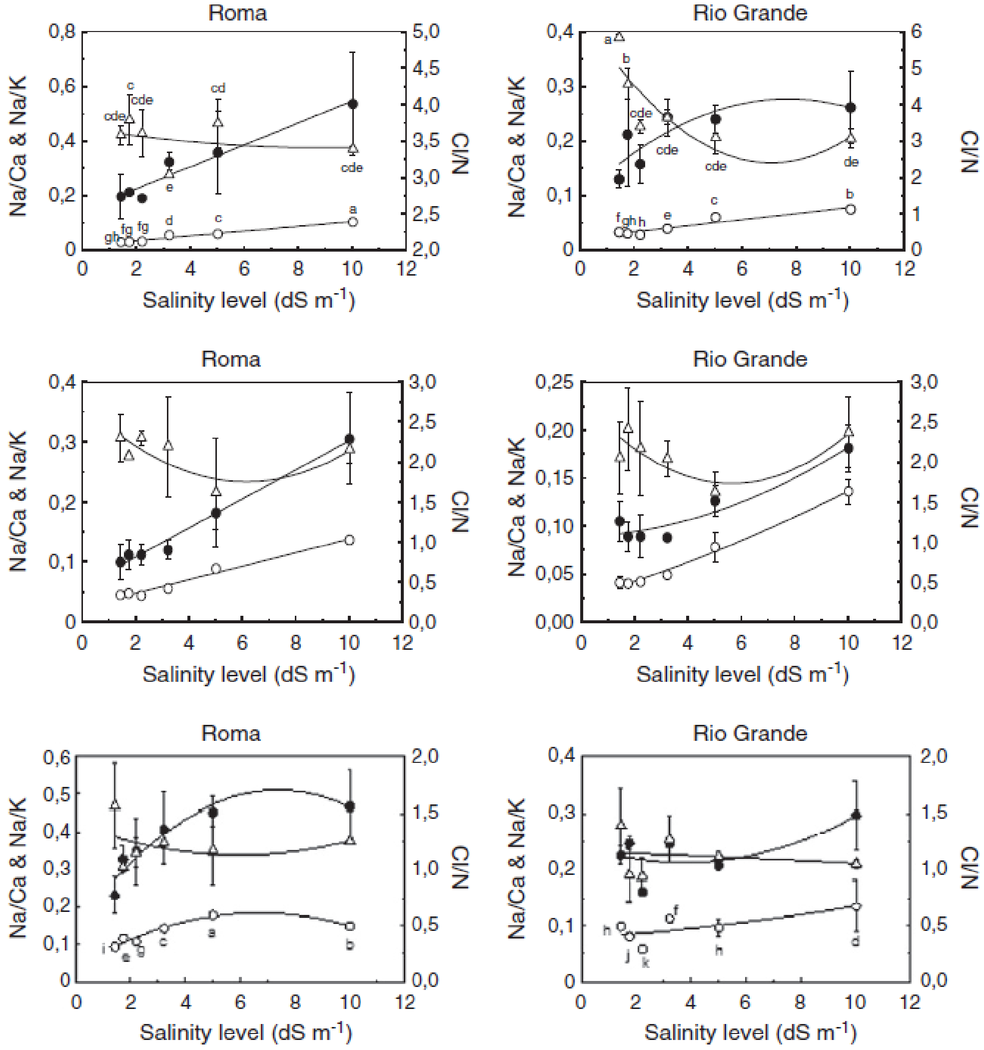


Fig. 4. Effect of the pretreated cheese whey wastewater reuse on the tissue ratios of the two cultivars: leaf ratios (top), stem ratios (middle) and root ratios (bottom). ○, Na/Ca; ●, Na/K; Δ, Cl/N. Different lowercase letters indicate differences with $p \leq 0.05$, according to LSD test.

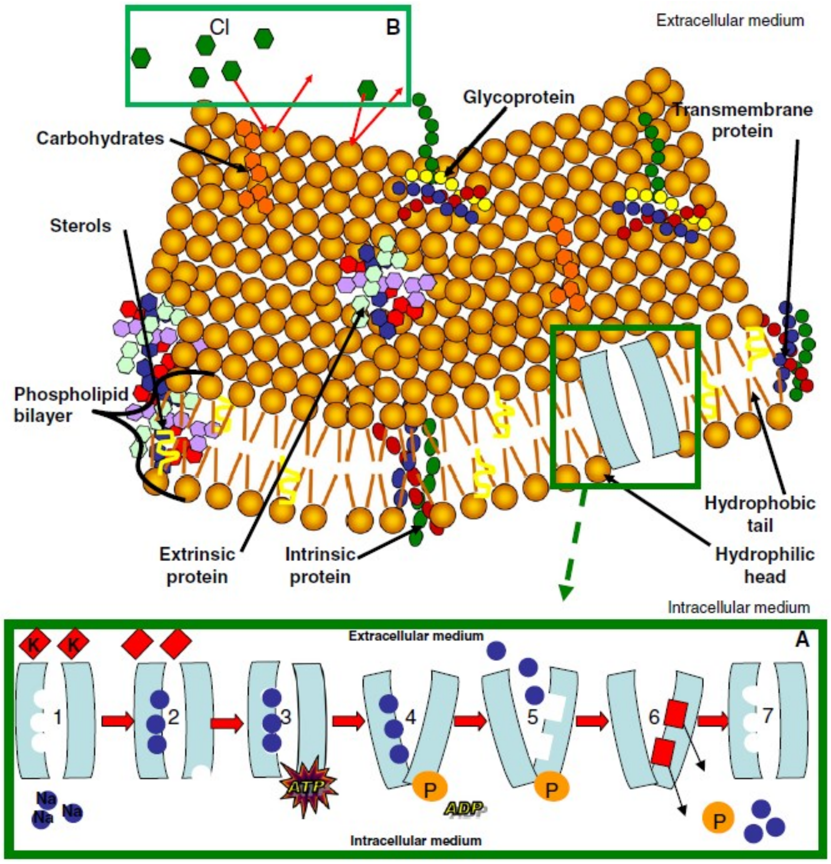


Fig. 5. A — Competition phenomena between Na and K ions that share the same transport system on the root surface. 1 — Sodium–potassium pump with two subunits: α and β. 2 — Three ions of sodium were captured from the intracellular medium and occurs the subunit β transformation that creates an active site for ATP binding. 3 — One phosphate group of the ATP molecule is bound to the active site of the subunit β. 4 — ATP is hydrolyzed with formation of the ADP molecule + phosphate group that remains connected to the subunit β. 5 — Liberation of the three sodium ions for extracellular medium. The pump conformation has high affinity for potassium ions. 6 — Transport of the two potassium ions from the extracellular medium for intracellular medium and phosphate group liberation. 7 — The protein returns to its original conformation and a new cycle can be started. B — Chloride ion rejection through the cationic composition of the root membrane (lipid composition).

one observed in the control, with insignificant reduction of K (5%). Similar value was obtained in the cv. Rio Grande when comparing the treatments T0 and T5. However, a K increase was experienced (33%) in this latter case.

3.4.3. Radicular ratios

The Na/Ca, Na/K and Cl/N ratios of the radicular nutrients with the irrigation water salinity level are represented in Fig. 4 (bottom), for both cultivars. Na/Ca and Na/K ratios showed maximum values for T4-T5 (cv. Roma) and T5 (cv. Rio Grande). This effect may enhance the sodium ion toxicity in the root tissues, and consequently, their transportation to the leaves.

4. Conclusions

The results of this study allow to understand the tomato plant behavior (Lycopersicon esculentum Mill.) when exposed to different saline environments by fertirrigation with pretreated cheese whey wastewater. Under saline conditions, the nutrients P, Cl and Ca were, preferentially, accumulated in leaves, followed by stems and roots. Contrary, potassium and nitrogen were accumulated, on a larger scale, in stem tissues.

Sodium content varied linearly and positively with the salinity for both study factors (treatment and interaction CV x TREAT) and in the different vegetative tissues (with exception for the roots).
Additionally, this parameter was accumulated in roots, subsequently in leaves and stems.

In accordance with the previous statements, organic matter and nutrient contents constitute important indicators to determine the tomato response under irrigation with saline/pretreated cheese whey wastewater. As well as, the nutrient ratios indicate the presence of competition, accumulation, exclusion and/or compartmentalization phenomena of the tomato plant. The diverse behavior of the studied cultivars suggests that present different tolerance mechanisms to maintain the osmotic potential in the vegetative tissues. Accordingly, the optimal cultivar selection should take into account the tolerance capacity under saline conditions.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2013.06.080.

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