Changes in EC, pH and in the concentrations of nitrate, ammonium, sodium and chlorine in the drainage solution of a crop of roses on substrates with drainage recycling

Cambios en CE, pH y en los contenidos de nitrato, amonio, sodio y cloro en la solución drenada en rosa cultivada en sustratos con recirculación de drenajes

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ABSTRACT

The rose cultivation system has been changing from soil to substrate on the Plateau of Bogota. The objective of this study was the monitoring of the EC, pH, and the levels of nitrate, ammonium, sodium and chlorine in a drainage solution in a crop of roses with substrates based on burnt rice husk and coconut fiber. The Charlotte rose variety grafted onto 'Natal Briar' was planted in a greenhouse located in one of the SENA facilities in Mosquera (Colombia); with a density of 6.5 plants/ m^2. For this experiment, a split plot design was used arranged in randomized blocks with a three-level recirculating system (0, 50 and 100%) on the substrates 100% burnt rice husk; 65% burnt rice husk plus 35% coconut fiber; and 35% burnt rice husk plus 65% coconut fiber, repeated three times. The EC decreased from 2.7 to 1.3 mS cm^{-1} within weeks 2 and 5 which demonstrated an increase of mineral consumption by the plants. The pH levels dropped from 7.46 to 6.27 within weeks 3 to 8 and then increased to 7.39 within weeks 8 to 12. Nitrate concentrations showed a decreasing trend in recirculation treatments within weeks 2 to 12. A lower ammonium concentration was observed at week 4 in treatments with and without recirculation during the vegetative stage. The levels of sodium and chloride increased in treatments with recirculation, without signs of toxicity.

Key words: soilless crops, organic substrates, recirculating drainage, cut flowers.

RESUMEN

El sistema de cultivo de rosa en la Sabana de Bogotá ha venido cambiando de suelo a sustrato. El objetivo del presente estudio fue monitorear la CE, el pH y las concentraciones de nitrato, amonio, sodio y cloro de la solución drenada en un cultivo de rosa sembrado en sustratos a base de cascarilla de arroz quemada y fibra de coco. En el SENA de Mosquera (Colombia) se sembraron en invernadero rosas de la variedad Charlotte injertadas sobre 'Natal briar', a densidad de 6,5 plantas/m^2. Se empleó un diseño de parcela dividida en bloques al azar con 0, 50 y 100% de recirculación en los sustratos cascarilla de arroz quemada, cascarilla de arroz quemada 65% más fibra de coco 35% y cascarilla de arroz quemada 35% más fibra de coco 65%, con tres repeticiones. La CE del drenaje decreció de 2,7 a 1,3 mS cm^{-1} entre las semanas 2 y 5, lo cual indicaría mayor consumo de sales minerales por la planta. El pH disminuyó entre las semanas 3 y 8, de 7,46 a 6,27; con posterior incremento a 7,39 entre las semanas 8 y 12. El nitrato presentó una tendencia decreciente en los tratamientos con recirculación entre las semanas 2 y 12. La menor concentración de amonio se presentó en la semana 4 con y sin recirculación en el estadio vegetativo. Las concentraciones de sodio y cloro aumentaron en los tratamientos con recirculación, no se observaron síntomas de toxicidad.

Palabras clave: cultivo sin suelo, sustratos orgánicos, recirculación de drenajes, flor de corte.

Introduction

From the entire crop of hybrid roses on the Plateau of Bogota, it is expected that no more than 10% is currently using substrates or recycling drainage systems. However, there is an increasing interest which leads to an increasing demand of substrates and techniques to improve productivity and quality of the flower stems. This trend of soilless cultivation is also present in other south-american countries such as Brazil (Furlani *et al*., 2005).

Cabrera (2006 and 2007) reports that commercial cultivation of roses is handled with excess inputs of water and fertilizers, creating losses between 50 and 60% due to nitrogen leaching. These surpluses have an environmental impact on surface and ground water bodies.

The same author reports that nitrogen ions have a salinizing effect because the NO_3^- concentrations found in leachates collected from roses (with different doses of nitrogen) contribute between 21 to 76% of the total electrical conductivity (EC).

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Roses are capable of uptake nitrogen as nitrate and ammonium. When a plant absorbs nitrate, assimilation occurs in the leaves, where it is reduced to ammonium before becoming amino acids and proteins (Lorenzo *et al*., 2000). Moreover, when a plant uptake ammonium, the plant directly converts it into amino acids and proteins and so it saves energy in comparison with the uptake of nitrate. Another important aspect is nitrogen uptake during the phenophase, in this respect, Cabrera (2006) reports that roses uptake more nitrogen when the flower stem is close to harvest, which implies that there are phonological stages in which there is a greater concentration of nitrate in the leachates.

Nevertheless, these soilless techniques are debated as a global concern: pollution of water and soil generated from leachates dropping from open soilless systems because ions such as phosphates and nitrates generate eutrophication in surface water bodies when they are constantly added to the environment as leachates (Bechmann and Øgaard, 2010). Additionally, ground water bodies are contaminated by the presence of nitrates which are harmful to human health, as seen with methemoglobinemia, or blue baby syndrome, which is developed due to the consumption of nitrate concentrations greater than 45 mg L^{-1} (Boink and Speijers, 2001).

To reduce the pollution generated by leaching from open systems, the alternative of recirculating the nutrient solution is used in order to conserve water and minimize the loss of nutrients (Tüzel *et al*., 2001). Although the conversion of open drainage systems to recirculating drainage mitigates impacts to the environment, there are also problems present because changes in the concentration of nutrients and increasing levels of the EC in the nutrient solution through salt accumulation (Ehret *et al*., 2005). On the other hand, the use of waste water accelerates the salinization of the nutrient solution and of the substrate because of the accumulation of, especially, sodium and chlorine (Incrocci *et al*., 2006; Savvas *et al*., 2005).

The management of the nutrient solution quality in closed systems involves tracking some relevant variables such as: 1) EC, 2) pH and 3) some ions that have positive correlations with the EC such as Na^+, Cl^- and NO_3^-, among others. In addition, monitoring variables must be in real time to estimate the quality of the drained solution, and the water and fertilizer volumes required for its supplementation (Savvas, 2002).

Knowing the EC variations of the nutrient solution is important since this by itself does not ensure that there is a good nutrition process, because recirculation causes nutrient imbalances. In closed crops systems, the concentration of ions is constantly adjusted by monitoring the EC, the criteria for adjustment is related to the cultivated species and desired EC (Ling *et al*., 2001; Pardossi *et al*., 2002; Ehret *et al*., 2005). Additionally, there are climatic conditions that affect this variable, for example, high radiation and low relative humidity cause a high EC, and likewise, high relative humidity and cloudy days also increase the EC (Savvas, 2003).

Another important aspect for managing the nutritive solution is pH. Values above 7 induce deficiencies of P, Fe, Mn and Cu and sometimes Zn. pH values below 4 cause root damage because of the effects from H^+, several Mn and Al hydroxides that are soluble at a pH level less than 5; below 5.5 pH levels, the growth of the plant may be affected because it may not absorb Ca, K and Mg; below a 4.5 pH level, one sees increases in the proportion of phosphate content in the nutrient solution in undissociated forms that are not uptaked by the plant. The desired pH range for most crops is between 5.0 and 6.2 (Savvas, 2003).

Among soilless crops, there are often salinity problems that have a detrimental effect on production due to the high osmotic pressure in the root micro environment which reduces growth and plant production. The need for washing the substrates is often determined by the accumulation of sodium and chlorine in the root environment, especially when poor quality irrigation water is used (Massa *et al*., 2008). However, sodium is considered as a beneficial element for three reasons: it is essential for certain plants species like C_4 and CAM, it can replace potassium functions in plants and it has a positive effect on the plant's growth (Marschner, 1998).

In roses cv. Lambada, Lorenzo *et al*. (2000) reported that with 10 meq L^{-1} sodium sulfate in the nutritive solution, the floral stem length increased, thus the nitrogen and potassium contents in the leaf tissue, conversely, the variables values dropped when the salt concentration increased to 30 meq L^{-1}. Additionally, chlorine is an essential element involved in water photolysis in the process of the photosynthesis, in addition, it also plays an important role in stomatal regulation, serving as a companion anion to potassium in and out of the guard cells.

Another less known function has to do with cell division. In many plants, the absence of chlorine is reflected in a reduction in leaf area and therefore dry mass is reduced (Marschner, 1998). On the other hand, in roses, sodium and chloride excesses cause necrosis and defoliation on older leaves and stem cracking, as well as decreasing dry mass content mainly due to sodium (Solis and Cabrera, 2007; Oki and Lieth, 2004).

The objective of this study was monitoring the EC, pH, and the concentrations of nitrate, ammonium, sodium and chlorine in the solution drained into a crop of roses with a recycling drainage system.

Materials and methods

The study was conducted at the Multisectorial Center SENA facilities in Mosquera-Cundinamarca, Colombia, located at 5° N and 75° E and 2,516 m a.s.l., with a 12.6°C average annual temperature and 670 mm in average annual rainfall.

The Charlotte rose variety grafted on Natal Briar was planted in pots filled with substrate at a density of 7 plants/m^2 under greenhouse conditions on raised beds with 12 m^2 (15 x 0.80 m), made out of wood and 1/8" diameter cable chains. The crop was grown in a traditional wood greenhouse with side vents (manual curtains) and a passive zenith, covered with plastic film: Agroclear NXF. The fertigation treatments without recirculation were conducted with computerized equipment: Priva®brand, while recirculating treatments were handled by automatic recycling systems with specialized hardware and software, as described by Cuervo *et al*. (2011).

A split plot design arranged in randomized blocks with three levels of recirculation was used. The main plot had three substrates and was replicated three times, for a total of nine treatments. Recirculating levels were 0, 50 and 100% and the substrates used were: 100% burnt rice husk (100BRH), mixture of burnt rice husk 65 with 35% coconut fiber (65BRH) and a mixture of burnt rice husk 35 with 65% coconut fiber (35BRH). The evaluated treatments are summarized in Tab. 1. The fertilizer formula in mg L^{-1} was 170 of total N with 15% ammonium; 35 P; 150 K; 110 Ca; 60 Mg; 82 S; 1 Mn; 0.5 Zn; 0,5 Cu; 3 Fe; 0.5 to 0.1 B and Mo. This fertilizer solution was developed taking into account the nutrients provided by the irrigation water. The EC of the solution was between 1.5 and 1.8 and the pH up to 5.8.

Variable measurement

The EC and pH in the drainage of nine treatments with different mixtures of rice husk and coconut fiber were recorded daily for 13 weeks. The first week of the evaluation corresponded to the week before pruning, the next 9 weeks corresponded to stem growth and flower budding, plus a three-week harvest period. The EC and pH were measured with a potentiometer brand Orion 150AE with two significant figures.

Ammonium and nitrate monitoring was done three times a week at 2, 4, 7, 8, 9, 11 and 12 weeks after pruning (wap) in treatments without recirculation and at 2, 4, 9, 11 and 12 wap in treatments with recirculation. For the quantification of the ions, a reflectometry method was used with Merck® high range strips (5 to 225 mg L^{-1}). Weekly averages of the information obtained are given.

Sodium and chloride ions were recorded in seven phenological stages in the treatments without recirculation: pruning, a day after pruning (dap), primordium (38 dap), rice (45 dap), pea (51 dap), chickpea (58 dap), streaking color (65 ddp) and harvesting (73 ddp). In the treatments with recirculation, the ions sodium and chloride were recorded starting at 51 d after pruning. Sodium determination was performed by means of atomic absorption spectrophotometry with a Aanalyst 300 spectrophotometer with four significant figures; chloride determination was performed with the argentometric detection method with three significant figures (APHA, 1965). In both cases, the samples were taken from the drainage that was collected weekly in each experimental unit.

TABLE 1. Split plot design arranged in randomized blocks with recirculating levels taken as the main plot and the substrates taken as the subplot, used in the assay of the Charlotte rose variety with automatic recirculating drainage.

Treatment	Subtrate types	Recirculation (%)
100BRH	Burnt rice husk	0
100BRH		50
100BRH		100
65BRH	65% burnt rice husk plus 35 % Coconut fiber	0
65BRH		50
65BRH		100
35BRH	35% burnt rice husk plus 65 % Coconut fiber	0
35BRH		50
35BRH		100

Statistical analysis

In order to carry out the EC and pH analysis, the recorded information was consolidated weekly and the SAS / STAT statistical package software was used, Version [8] for Unix Copyright©. Since the field data did not meet the normality test, the Friedman nonparametric statistical analysis was applied. In those cases in which significant difference between treatments appeared, the Tukey test ($P \leq 0.05$) was applied, considering medians as the central tendency measure.

Results and discussion

EC

Fig. 1 shows the EC changes recorded during the development of flower stalks stage. In general, it was observed that between week 2 and week 5, the values of this variable decreased when the demand for minerals required for plant growth increased, particularly in the floral stems manipulated with pruning; at weeks 5 and 6 the lowest EC values appeared, indicating that the plant uptake more nutrients at this stage, which is characterized by a high cell proliferation rate in the stem and in the bud. Hence, the EC tended to increase from week 6 until harvest, indicating that in this period the plant uptake less nutrients and the ions that would be accumulated in the nutrient solution, as is shown in the EC values of treatments with recirculation (Fig. 1A). Because of recirculation, ions accumulate which may affect flower stem growth, such as sodium, chloride, bicarbonates and even magnesium. Those ions fall upon EC and at high concentrations in the nutrient solution are undesirable for the plant (Solis and Cabrera, 2007). The EC median values in those treatments with recirculation were within 1.35 and 2.7 mS cm^{-1}, while in those treatments without recirculation the median values were within 1.5 and 2.5 mS cm^{-1}. In this regard, Sonneveld (2000) reported that EC values greater than 2 mS cm^{-1} influence production. However, Solis and Cabrera (2007) reported that grafted varieties at rootstock of *R. manetti* showed moderate salt tolerance, which is consistent with the results of this research. In the crop of rose, it is recommended that the EC oscillate between 0.8 and 1.5 mS cm^{-1}, this range ensures that no nutritional deficiencies in cultivated plants occur (Bustillo, 2011).

For the analysis of variance at weeks 5 and 6, no significant difference between treatments for the EC were noticed, which confirms that this is an important phase in the uptake of nutrients. However, at week 12, for the harvest period, significant differences between treatments were noticed. The treatment with the highest EC was 100BRH-R100%, which, among other reasons, possibly derived it from the smaller particle size of this substrate compared with other substrates in the study, including mixtures, which implies greater retention due to a larger water contact surface and therefore more concentrated drainage (Quintero *et al*., 2006). Moreover, treatments 35BRH, 65BRH and 100BRH with zero percent of recirculation had the lowest EC values at the end of the production cycle, the rest of the treatments showed intermediate values among those mentioned above. Finally, although there was an increase of the EC in the recirculating solution, the rose plants showed no symptoms of chlorosis or toxicity.

pH

In general terms, the pH trend was similar in all treatments up until the end of the productive cycle under this study (Fig. 1), when three distinct periods were established. The first was seen from week 1 to week 3, when the pH showed a positive slope. The second period started at week 3 until week 8 with a negative slope, possibly due to the electrochemical potential changes generated by a faster absorption of cations rather than anions, compensated by the release of hydrogen ions through the roots (Savvas, 2003). Between week 8 and 12, the slope was again positive; except for the 100BRH-R100% treatment between week 9 and 10. However, the growing trend was maintained in this treatment.

The analysis of the variance for the evaluation period showed significant differences among treatments in each week. However, treatments 65BHR-R50% and 65BHR-R100% tended to have higher pH values during the development of the floral stems period. On the other hand, treatment 100BRH-R50% kept low values for this variable.

Nitrate

At week 7, in treatments without recirculation, the nitrate concentration in the leachates presented inferior values than with daily fertilizer formula applied to the crop. However, by week 9, some outliers were noticed in treatments 65BRH-R0% and 35BRH-R0% (Fig. 2A), when also high volumes of water were demanded, fact that minimized the drainings. In week 9, treatment 100BRH-R0% presented a lower nitrate concentration compared with treatment 35BRH-R0% and 65BRH-R0%, this is due to the fact that burnt rice husk, over time, becomes fragmented into smaller pieces, allowing greater retention of water in the substrate; therefore, when applies fertilizer irrigation greater water drainage was observed and nitrate concentration decreases compared with the other treatments.

During the evaluated period in treatments with drenage recycling (Fig. 2B), there was a decreasing trend of the nitrate concentration in the drainage, with the highest concentrations at weeks 2, 4 and 9, and in the treatment with the biggest amount of coconut fiber and the highest recirculation rate (35BRH-R100%). In addition, this treatment was always among the highest values until the end of cycle. Furthermore, the leachates from treatment 100BRH-R50% maintained one of the lowest nitrate concentrations during weeks 2, 9, 11 and 12, indicating that BRH could hold this anion. For nitrate demand, at the

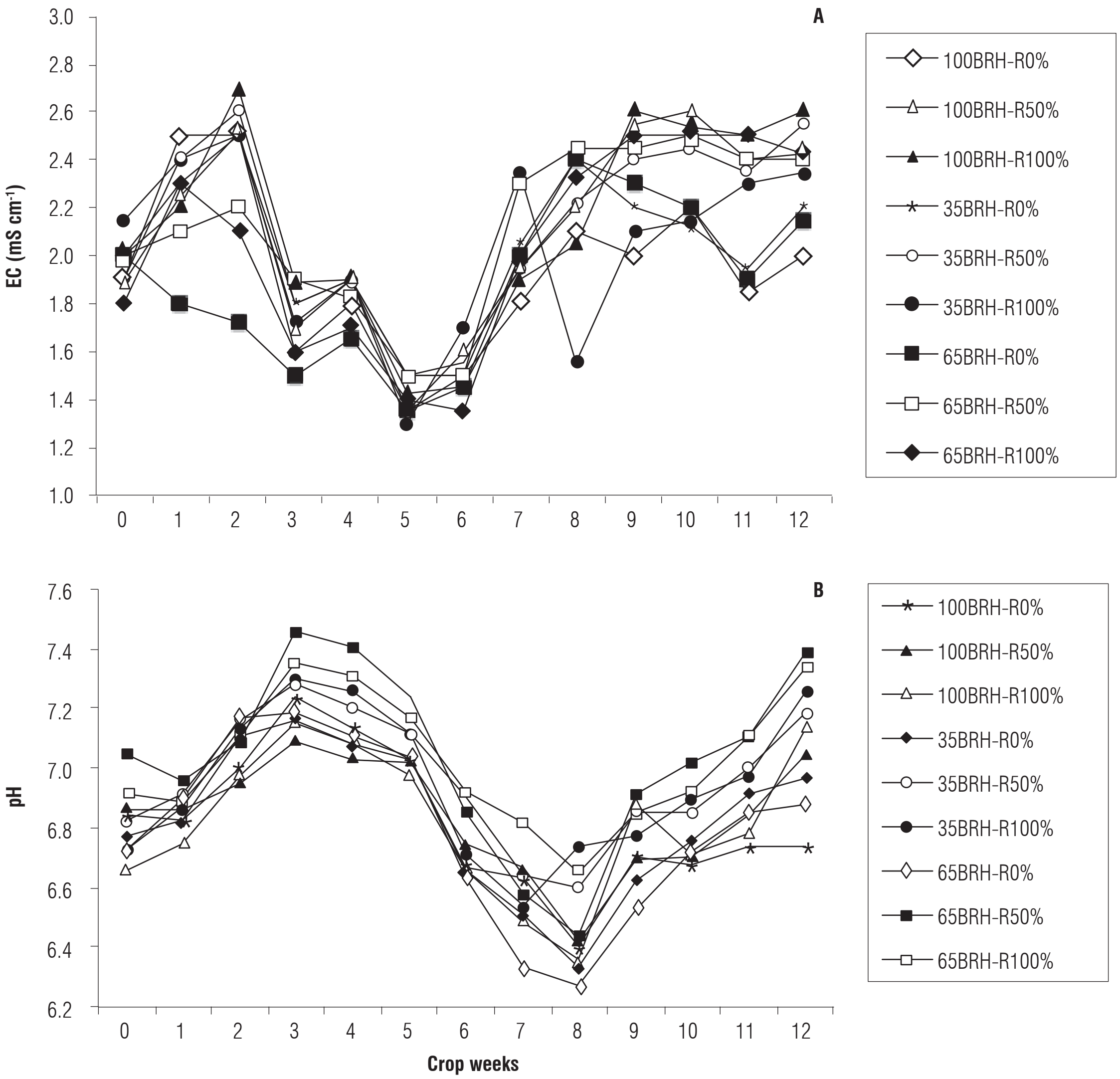

FIGURE 1. Weekly behavior of the EC median(A) and pH (B) during a cycle of development of floral stems from pruning to harvest, working with the Charlotte rose variety grown in substrates with drainage recirculation. For abbreviations of variables see Tab. 1.

crop phenological stage, the treatments with recirculation showed lower values than at the beginning of the floral stem stage. In general, the nitrate contents in the drainage tended to decrease during the development of the flower stalks, which agrees with Cabrera (2006).

Ammonium

The ammonium concentration in the leachates from the treatments with recirculating drainage as well as in those without recirculation did not exceed 2.5 mg L^{-1} (Fig. 3A and 3B), possibly due to the plants' nutritional needs, in addition to the nitrification and ammonium fixation in the organic mass (Navarro and Navarro, 2003). Moreover, at week 4, this cation was not detected in leachates or in drainage, indicating that, during this development of flower stems stage, the plant uptakes efficiently.

Sodium

Tab. 2A shows, that by day 38 after pruning, the lowest sodium concentration in the leachates was related to pruning and rice (45 dap), suggesting the plant uptakes it during this phenophase. Additionally, analysis of variance showed that the sodium concentration in drainage was significantly higher in the stages of rice (45 dap) and pruning compared with the primordium stage (38 dap) (Tab. 2). Subsequently, the sodium accumulated in the drainage of both treatments with and without recirculation.

Cabrera (2008) states that for growing ornamental plants in containers, irrigation water with sodium concentrations below 3 meq L^{-1} cause a minimum degree of problems, concentrations between 3 and 9 meq L^{-1} cuase increasing problems and concentrations greater than 9 meq L^{-1} cause

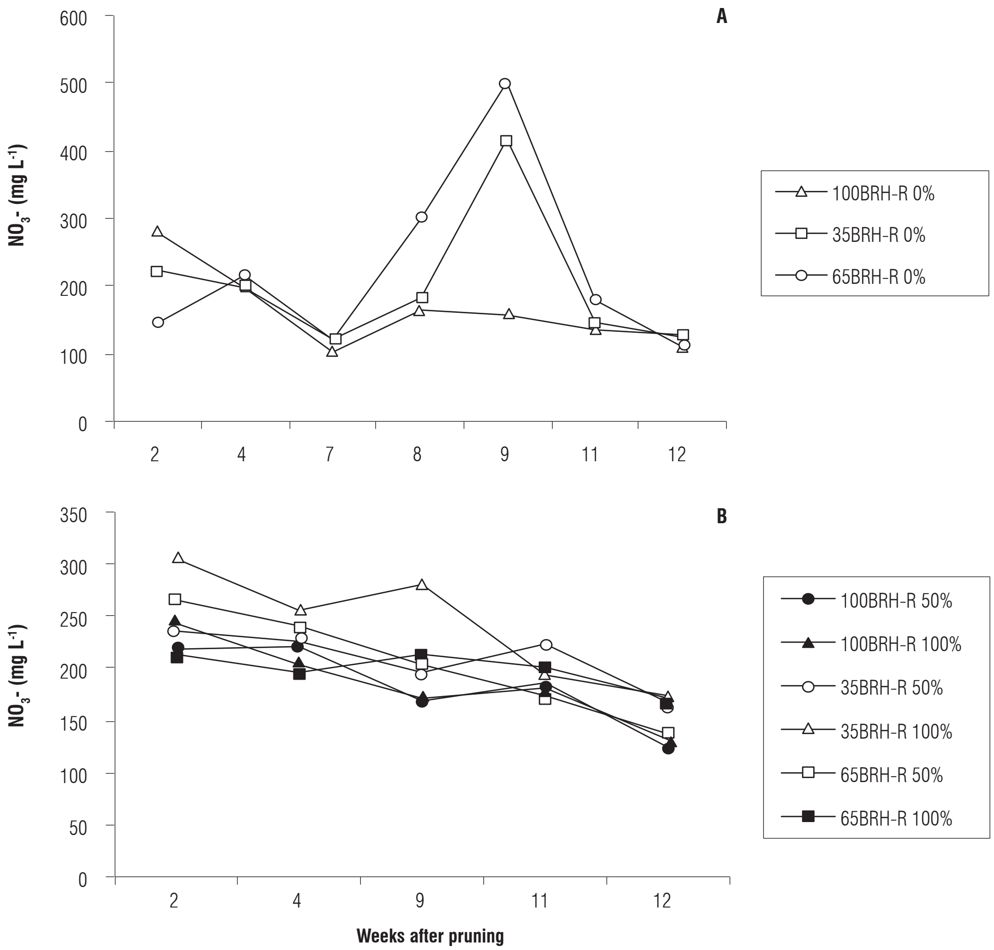

FIGURE 2. Weekly behavior of nitrate ion concentration in the drainage coming from treatments 100BRH, 35BRH and 65BRH without recirculating drainage (A) and with recirculation of 50 and 100% (B), in the Charlotte rose variety grown on substrates. For abbreviations of variables see Tab. 1.

severe problems. According to this criteria, the results of Tab. 3 indicate that the sodium concentration in the fertilizer solution becomes worse with recirculation. However, no signs of toxicity were observed among the roses planted. Furthermore, Lorenzo *et al.* (2000) reported that sodium concentrations of 10 meq L^{-1} stimulate stem growth in the Lambada rose variety, while sodium concentrations of 30 meq L^{-1} negatively affect flower stem growth.

Chloride

Tab. 2B shows this anion with the lowest concentration values on days 1 and 38 for pruning and the primordium phenological stages (38 dap), where it is noticeable that, at these stages, the anion is either retained by the substrate or uptake by the plant. It is important to acknowledge that chlorine, as well as sodium, is not in the fertilizer formula, these ions are incorporated into the crop through irrigation. Tab. 2B shows that chloride tends to accumulate in the leach solution and also that the treatments which had the highest concentration values were: 100BRH-R50% and 100BRH-R100%, confirming that this anion is accumulated by recirculation.

Regarding the handling of chloride, this is an undesirable anion in water for agricultural irrigation. Irrigation water with concentrations under 0-2 meq L^{-1} have minor problems, concentrations between 2 and 10 meq L^{-1} have increasing problems and concentrations higher than 10 meq L^{-1} cause severe problems (Cabrera, 2008). Tab. 2B shows that the chloride concentration in the recirculating solution presented values that indicate that the anion concentration is troublesome for agricultural usage. However, no toxicity due to chlorine was observed. In this regard, for rose plants grafted on *R.manetti*, Cabrera (2006) reassessed the sensitivity of the rose to salinity and found that although the rose is considered sensitive to salinity when planted in soil, it behaves tolerant when exposed to increasing concentrations of chloride

TABLA 2. Sodium (A) and Chloride (B) concentrations in the leacheates and drainage of the Charlote rose variety crop in substrate (meq L^{-1}).

	A – Sodium concentration									
	Treatments whithout recirculation (%)			Treatments whith recirculation (%)						
	100BRH	35BRH	65BRH	100 BRH		35BRH		65BRH		
dap	0	0	0	50	100	50	100	50	100
1	9.14 a	9.00 b	8.97 a	-	-	-	-	-	-
38	7.16 c	7.49 c	6.68 b	-	-	-	-	-	-
45	8.87 b	9.83 a	8.86 a	-	-	-	-	-	-
51	11.23	11.86	10.97	9.94	8.67	10.87	12.67	14.90	12.63
58	11.52	13.41	11.88	13.99	17.49	11.24	9.81	15.67	13.57
65	13.10	13.01	13.86	15.86	19.19	11.32	11.23	15.94	15.07
73	11.87	12.42	12.55	15.97	12.42	15.01	13.81	15.90	15.09
	B – Chloride concentration								
1	7.45 c	7.63 c	7.63 b	-	-	-	-	-	-
38	8.26 b	8.29 b	7.72 b	-	-	-	-	-	-
45	10.61 a	11.21 a	10.05 a	-	-	-	-	-	-
51	10.59	12.23	10.65	11.48	9.15	11.70	12.95	15.56	11.87
58	10.71	11.62	10.58	13.11	17.00	11.09	8.99	13.18	12.09
65	13.38	12.36	13.63	15.02	17.76	10.39	10.99	14.78	13.91
73	11.68	12.12	12.53	16.05	12.12	14.29	13.32	14.86	14.73

For abbreviations of variables see Tab. 1.

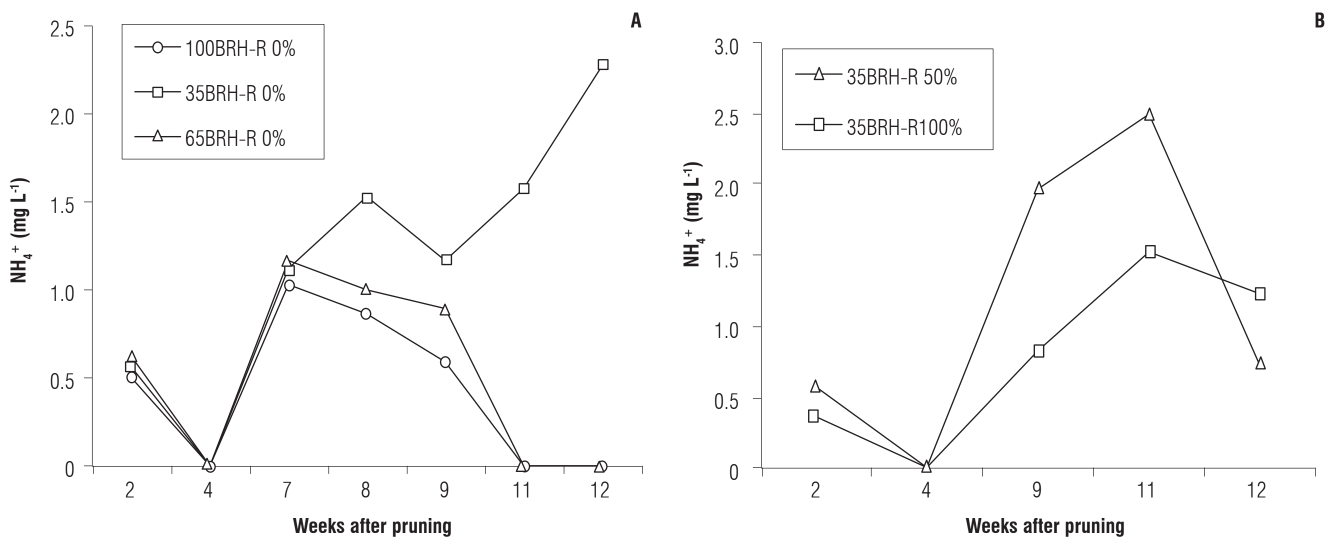

FIGURE 3. Weekly behavior of ammonium ion concentration in the drainage of the treatments 100BRH, 35BRH, 65BRH with 0% of recirculation (A) and treatment 35BHR 50% and 100% with recirculation (B) for the Charlotte rose variety grown in substrates. For abbreviations of variables see Tab. 1.

and sodium in cropping systems with fertigation and hydroponics, especially with the variety Bridal pink grafted on *R. manetti,* which is toleratant to increasing NaCl concentrations up to 30 mM which is equivalent to 30 meq L^{-1} sodium and chlorine (690 and 1065 mg $L^{-1}$of Na and Cl).

Conclusions

The phenological stages of primordium and rice had a higher nutrient demand, including for chlorine and sodium.

Treatments with recirculation have a higher EC than those without recirculation due to the accumulation of nutrients.

Treatments without recirculation showed lower pH values at the end of the cycle, while treatments 65BRH-R50% and 65BRH-R100% had the highest values for this variable, indicating that different proportions of materials used in the substrates have influence over the buffer capacity of the substrate when subjected to recirculation.

Nitrate concentrations in leachates from treatments with and without recirculation are above the values reported as dangerous to human health (45 mg L^{-1}).

In the days before the phonological stage known as primordium, the roses absorbed a higher proportion of ammonium compared to the other stages.

The demand for nitrate increased in the days prior to harvesting of the flowering stem.

The sodium and chloride concentrations in the leachates increased towards the end of the development of the flower stem cycle, so it is assumed that the Charlotte rose variety would be more tolerant to salinity.

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