Evaluation of an automatic drainage recirculation system in rose crop in terms of S, Na^+, and Cl^-

Evaluación de un sistema de recirculación automática de drenajes en el cultivo de rosa, en términos de S, Na^+ y Cl^-

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ABSTRACT

In Colombia, mixtures of substrates such as burned rice husk (BRH) and coconut fiber (CF) are used for the cultivation of cut flowers. Fertigation is applied to ensure 30% drainage, which can contaminate water and soil. In a drainage recycling system, there is a tendency for ions that are poorly absorbed by plants, such as sodium and chloride, to accumulate, which can create an ionic imbalance in the solution or salinize the substrate. An automatic drainage recycling system was built in rose cv. 'Charlotte' established in mixtures 100BRH, 65BRH:35CF, and 35BRH:65CF with 0%, 50%, and 100% drainage recycling. The contents of S, Na^+, and Cl^- were evaluated in drainages, substrates, and plant tissue at 0, 5, and 8 weeks after pruning (WAP). The SO_4^{2-} and Na^+ ions presented a similar behavior over time, with contents significantly higher in the substrates with higher CF contents at 0 WAP and the opposite at 8 WAP. In addition, the higher the BRH content and the recycling percentage, the higher the SO_4^{2-} in the drains. There was no significant difference in the S contents in substrates and plant tissue. Drainage recycling (50% and 100%) significantly increased Na^+ contents in the substrate. The Cl^- concentrations were significantly different at 8 WAP, being higher in treatments with recycling (50% and 100%), regardless of the type of substrate mixture.

Keywords: intensive horticulture, cut flowers, organic substrates.

RESUMEN

En Colombia se utilizan mezclas de sustratos como la cascarilla de arroz quemada (CAQ) y la fibra de coco (FC) para el cultivo de flores de corte. Se aplican volúmenes de fertirriego que aseguran drenajes de cerca del 30% que pueden contaminar aguas y suelos. En un sistema de reciclaje de drenajes, hay tendencia a la acumulación de iones que son poco absorbidos por las plantas como el sodio y el cloruro, los cuales pueden crear un desbalance iónico en la solución o salinizar el sustrato. Se construyó un sistema automático para el reciclaje de drenajes en un cultivo de rosa cv. 'Charlotte' establecido en los sustratos 100CAQ, 65CAQ:35FC y 35CAQ:65FC con 0, 50 y 100% de reciclaje de drenaje y se evaluaron los contenidos de S, Na^+ y Cl^- en drenaje, sustrato y tejido vegetal a las 0, 5 y 8 semanas después de poda (SDP). Los iones SO_4^{2-} y Na^+ presentaron un comportamiento similar en el tiempo, con contenidos significativamente mayores en los sustratos con mayor porcentaje de FC en la 0 SDP y lo contrario en la 8 SDP. Además, a mayores porcentajes de CAQ y de reciclaje mayor contenido de SO_4^{2-} en la solución drenada; entre tanto, no se constató diferencia significativa en los contenidos de S en sustrato y tejido. El reciclaje del drenaje (50 y 100%) incrementó significativamente el contenido de Na^+ en el sustrato. Las concentraciones de Cl^- fueron significativamente diferentes en la 8 SDP, con mayores concentraciones en los tratamientos con reciclaje (50 y 100%), independiente del tipo de mezcla de sustratos.

Palabras clave: horticultura intensiva, flores de corte, sustratos orgánicos.

Introduction

In intensive soilless horticulture, drainage recirculation systems are required for the proper collection, evaluation, recompositing, and recycling of the generated effluents. This type of system requires an approximate programming model to recycle the nutrient solution according to the most influential variables affecting quality of fertigation. Under the conditions of cultivation in the Bogotá plateau, the development of technologies that are within the reach of farmers and that allow the management and control of procedures such as fertigation, solution recycling, and climate control in greenhouse crops is needed. These technologies must be characterized by low cost and by a level

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of complexity that allows their use and management by personnel with basic knowledge of systems and cultivation conditions. In some cut flower crops in the Bogotá plateau, drainage is directed towards a reservoir to later use the irrigation water to prepare a new fertigation solution. This is not considered recycling, since the chemical composition of the reservoir water is altered by ions that are poorly absorbed by plants (Cuervo *et al*., 2011).

In soilless culture systems, ions that are not absorbed by plants are drained and tend to accumulate in the recirculating nutrient solution, therefore, they must be discharged from the system. Frequently, in high-temperature environments, ion accumulation can lead to an increase in electric conductivity (EC) of the substrate up to 2.0 dS m^{-1} (Carmassi *et al*., 2013). Roy *et al.* (2014) and Sonneveld *et al.* (1999) concluded that depending on the species, the absorption of sodium and chloride by the plant increases with the increases in their concentrations in the root environment, which is advantageous in counteracting their accumulation in the rhizosphere (Dotaniya & Meena, 2015). However, excess salts in the irrigation solution can negatively affect the vase life of harvested flowers (Atta-Aly *et al*., 1998; Fujimoto *et al*., 2000; Metwally *et al*., 2018; Riley, 1987).

The composition of a nutrient solution is defined by total salt concentration, pH, micronutrient concentrations, macronutrient ratios, and irrigation water composition (Savvas & Adamidis, 1999). When using a drainage recycling system, the physiological response of the cultivated species must be considered. It has been established that nutrient uptake by the plant is specific to each solute and follows Michaelis-Menten dynamics (Claassen & Barber, 1974). Bugbee (2004) categorizes essential nutrients based on their absorption rate in the solution as: i) active absorption and rapid removal (NO_3^-, NH_4^+, P, K, Mn); ii) intermediate absorption (Mg, S, Fe, Zn, Cu, Mo, Cl); and iii) passive absorption and slow removal (Ca, B), as is the case of the efficient absorption of monovalent ions (Schippers, 1980). The mechanism of ion absorption differs for each ion and for each plant species; therefore, the terms "passive" and "active" absorption are general concepts, since plant-specific characteristics play an important role (Coskun & White, 2023), including the stoichiometry of some elements (Ågren & Weih, 2020).

The total nutrient content in the solution determines the EC. However, because of the differential removal rates from nutrient uptake, EC mainly reflects the concentrations of calcium, magnesium, and sulfate remaining in the solution, while micronutrients contribute less than 0.1% to this variable (Bugbee, 2004).

In species such as chrysanthemum, slightly saline waters (1 g L^{-1} NaCl) can be used (Lee & Van Iersel, 2008); meanwhile, when low-quality irrigation water is used, EC normally increases rapidly due to the accumulation of ions such as sodium, chloride, and sulfate and, in the case of hard water, calcium and magnesium. Bicarbonate ions commonly present in groundwater are neutralized by the application of acid. In contrast, micronutrients such as boron or metals could accumulate to toxic levels (Metwally *et al*., 2018); however, their concentrations are on the order of µmol L^{-1}, and unlike other ions that can be determined indirectly by measuring EC, these ions must be monitored by expensive laboratory analysis (Carmassi *et al*., 2013; Olympios, 1999).

Savvas (2003) reports that, especially in the case of actively absorbed macronutrients, such as N, P, and K, keeping their concentrations low could result in good yields. The best results are obtained when the concentrations of elements in the solution correspond approximately to the nutrient: water uptake ratio (Domingues *et al*., 2012; Trejo-Téllez & Gómez-Merino, 2012). Under these conditions, plants do not consume energy to actively take up or exclude ions (Alaoui *et al*., 2022); however, nutrient:water uptake ratios fluctuate in response to climatic conditions, making it difficult to prepare a solution that is consistent with that ratio (Savvas, 2003).

In practice, in systems based on organic substrates, it is difficult to track variations in the concentrations of micronutrients (Cu, Fe, Mn, Zn, and B), possibly due to changes in the physical, chemical, and microbiological characteristics of the substrates. In systems based on coconut fiber, excesses of Na^+ and Cl^- can occur due to the high contents of these ions in the substrate (Abad *et al*., 2002). In addition to the essential ions, it is necessary to consider the absorption of other ions, such as sodium and chloride, to avoid accumulations in the root environment. The ratios and amounts of nutrients absorbed change with the stage and development conditions of the plants. Unexpected changes in the composition of the nutrient solution occur frequently in commercial systems, making it necessary to perform analyses in the root environment (Sonneveld, 2000). Similarly, the composition and volume of the drained nutrient solution vary over time and influence the number of reuse cycles.

Sulfur is an essential element for plants, playing roles in the formation of amino acids and the synthesis of proteins and chlorophyll. In soil, sulfate is the form accessible to plants, but it is susceptible to leaching. Sulfur contents in soils are related to the contents of organic matter, and its chemical transformations are mostly catalyzed by microorganisms (Kertesz & Mirleau, 2004); a similar process occurs in organic substrates, where microorganisms oxidize sulfur into sulfuric acid (Handreck & Black, 2010); in addition, this acid contributes to a high EC (Kämpf *et al.*, 2009).

Chloride is recognized as a component of the photolysis system in photosystem II, as a stomatal regulator in several species, and as a counter anion. Chloride originates from soil, water irrigation, rain, traces of fertilizers, or atmospheric pollution, so no physiological problems are expected due to its deficiency, and the concentration of chloride at toxic levels is the main concern (Wen *et al.*, 2017; Zhang *et al.*, 2021). While average Cl^- content in plants ranges from 2.0 to 20.0 mg g^{-1} dry weight (DW), the critical tissue Cl^- content for toxicity is about 4-7 and 15-35 mg g^{-1} DW for Cl^--sensitive glycophytes and Cl^--tolerant glycophytes, respectively (Colmenero-Flores *et al.*, 2019). One of the reasons for the rapid accumulation of chloride is its weak retention in soils and subsequent leaching due to its high mobility (Cakmak *et al.*, 2023). Although chloride is an essential element for plants, its contents in the plant dry mass is relatively low and the addition of this ion to the solution can be a strategy to decrease nitrate contents in crops, due to the antagonistic effects between these two ions (Chapagain *et al.*, 2003). On average, chloride concentrations in the external solution greater than 20 mM can produce toxic effects in sensitive species, while for tolerant species, concentrations can be up to five times higher without affecting growth (Cakmak *et al.*, 2023).

The concentration of Na^+ in plant tissue is generally high, typical of a macroelement. As a charged ion, the lipid bilayer exhibits very low permeability for Na^+, but it can be transported across the plasma membrane by both low- and high-affinity transport systems, many of which normally transport K^+ into root cells (Taiz *et al.*, 2015). This is possibly related to the role of Na^+ as a partial replacement for K^+ in functions such as osmoregulation (Cakmak *et al.*, 2023). Salt-sensitive plants depend mainly on the exclusion of Na^+ through plasma membrane (Blumwald *et al.*, 2000) and have the ability to compartmentalize and accumulate Na^+ in root cells (Cakmak *et al.*, 2023), thereby reducing its transport to the aerial parts. However, in some ornamental species continuously exposed to high concentrations of Na^+, this capacity can be lost (Cabrera *et al.*, 2009; Cabrera & Perdomo, 2003; Farnham *et al.*, 1985).

In general, roses are classified as sensitive to salinity, tolerating NaCl concentrations between 15 and 30 mM with proper management of irrigation and fertilization. Tolerance depends on the type and concentration of salts, the cultivation system, the type of substrate, the irrigation system and the cultivar and the rootstock (Cabrera, 2003; Cabrera *et al.*, 2009; Cabrera & Perdomo, 2003; Lorenzo *et al.*, 2000; Niu & Rodriguez, 2008).

The objective of this research was to determine the effect of the drainage recycling percentage at three levels (0, 50, and 100%) and the type of mixture of the substrates: 100% burned rice husk (100BRH); 65% burned rice husk, 35% coconut fiber (65BRH); and 35% burned rice husk, 65% coconut fiber (35BRH) on the concentrations of sulfur (S in plant tissue and substrates, and SO_4^{2-} in drainage water), Na^+, and Cl^- during the stages of flowering stem development corresponding to 0, 5 and 8 weeks after pruning (WAP) in rose plants cv. 'Charlotte'.

Materials and methods

Plant material and growth conditions

The research was carried out at the Center for Agricultural Biotechnology of SENA, located in the municipality of Mosquera (4°41' N, 74°13' W; 2,516 m a.s.l.), with annual average temperature and precipitation of 12.6°C and 670 mm, respectively, and with characteristics of the lower montane dry forest (bs-MB) life zone (Guzmán González, 1996). A traditional wooden greenhouse covered with Agroclear® plastic (Andean Chemical Products, Colombia) was used, with five spans of 65 x 6.8 m each, planted with rose cv. 'Charlotte' grafted onto 'Natal Briar'. The crop consisted of 33 raised beds of 15 x 0.8 m, in which 8 L pots were placed, for a planting density of 7 plants m^{-2}.

The fertilizer formula, in mg L^{-1}, was 170 total N (15% NH_4^+), 35 P, 150 K, 110 Ca, 60 Mg, 82 S, 1 Mn, 0.5 Zn, 0.5 Cu, 3 Fe, 0.5 B, and 0.1 Mo. The formula was developed based on commercial formulas commonly used in the region and was further adjusted to reflect the specific characteristics of the available irrigation water. Standard phytosanitary management protocols for this crop were consistently applied throughout the study.

Treatment application and experimental design

For the establishment of the plants, mixtures of the substrates burned rice husk (BRH), with a degree of burning between 70% and 100%, and coconut fiber (CF) (Tab. 1) were used, as follows: 100% burned rice husk (100BRH); 65% burned rice husk, 35% coconut fiber (65BRH); and 35% burned rice husk, 65% coconut fiber (35BRH). The mixing ratios corresponded to the levels of the substrate experimental factor. An automatic drainage recycling system (ADRS) was used, which recycled the drainage at three levels —0, 50, and 100%— and served as the recycling percentage factor. The ADRS methodology is described in Cuervo *et al.* (2011) and Cuervo *et al.* (2012).

The treatments were established as a combination of the levels of the recycling percentage factor and types of substrates, for a total of nine treatments with three replicates each (Tab. 2). The experimental unit was a culture bed. This bifactorial arrangement was carried out under a design of plots divided into completely randomized blocks, where the main plot corresponded to the recycling percentage factor and the subplot to the substrate factor.

$$Y_{ijk} = \mu + \alpha_i + \delta_k + \eta_{ik} + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (1)$$

with $i = 1, 2, 3$; $j = 1, 2, 3$; $k = 1, 2, 3$;

where:

μ is the effect of the overall mean;

α_i is the effect of the *i-th* level of the recycling percentage factor;

δ_k is the effect of the *k-th* block;

η_{ik} is the effect of random error on the parent plot (recycle percentage per block);

β_j is the effect of the *j-th* level of the substrate factor;

$(\alpha\beta)_{ij}$ is the effect of the *ij-th* interaction between the two factors (recycling percentage per substrate);

ε_{ijk} is the effect of random error in the subplot;

Y_{ijk} is the observation in the *k-th* block of the *i-th* level of the percentage recycling factor and the *j-th* level of the substrate factor.

TABLE 2. Treatments evaluated in rose cv. 'Charlotte' grown in substrates with automatic drainage recycling system.

Treatment code	Treatments	Substrates	Recycling (%)
T1	100BRH-0R*	100BRH	
T7	65BRH-0R*	65BRH	0
T4	35BRH-0R*	35BRH	
T2	100BRH-50R	100BRH	
T8	65BRH-50R	65BRH	50
T5	35BRH-50R	35BRH	
T3	100BRH-100R	100BRH	
T9	65BRH-100R	65BRH	100
T6	35BRH-100R	35BRH	

100BRH = 100% burned rice husk; 65BRH = 65% burned rice husk, 35% coconut fiber; 35BRH = 35% burned rice husk, 65% coconut fiber.

*Treatments that do not enter the ADRS.

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Response variables and statistical analysis

In each replicate (bed), sampling of drainage water, substrates, and complete plants was carried out at the stages of development of the flowering stem corresponding to 0, 5, and 8 weeks after pruning (WAP). The samples were sent to the Soil and Water Laboratory at the Faculty of Agricultural Sciences, Universidad Nacional de Colombia, Bogotá campus, to determine the contents of S, Na^+, and Cl^-. The protocols used for the chemical analyses were the following: the chemical characterization of the plant tissue and substrates for Na, S and Cl^- was carried by calcination at 475°C and measured by atomic absorption spectrophotometry. The drainages were chemically characterized by the following methods. Sulfate (SO_4^{2-}): valuation by turbidimetry (precipitation with barium chloride); sodium: atomic absorption spectrophotometry; and chloride (Cl^-): titration with $AgNO_3$ 0.0141 N (Vélez Carvajal, 2012).

TABLE 1. Chemical properties of the substrates used in the experiment.

Substrate	pH	EC	OC	N	P	Ca	K	Mg	Na	Cu	Fe	Mn	Zn	B	S
		(dS m^{-1})				(%)						(mg kg^{-1})			
100BRH	5.53	6.82	27.2	0.51	0.06	0.11	0.01	0.04	0.03	4.4	225	136	54	28	481
65BRH	5.31	6.52	23.6	0.39	0.08	0.4	0.01	0.06	0.08	13.4	433	87	50	34	470
35BRH	5.18	5.18	6.04	26.6	0.5	0.06	0.16	0.01	0.17	19.1	704	66	47	-	548

EC – electric conductivity, OC – organic carbon.

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Statistical analysis

The statistical software R was used to perform the analysis of variance (ANOVA) and the subsequent Tukey comparison test ($P<0.05$) for each evaluation week (Mendiburu, 2023). Scientific visualizations were created using ggplot2 package v3.4.2. (Wickham, 2016).

Results and discussion

Sulfur concentrations in drainage, substrates, and plant tissue

Coconut fiber is a material with high contents of lignin and cellulose (Abad *et al.*, 2002), carbon sources required for the metabolism of S-oxidizing microorganisms, such as bacteria of the genus *Thiobacillus* (Lucheta & Lambais, 2012; Tourna *et al.*, 2014), which can increase the temporary immobilization of S in organo-sulfur compounds (Kertesz & Mirleau, 2004). The oxidation of S to H_2SO_4 or to SO_4^{2-} in organic substrates requires the activity of microorganisms in the presence of a medium with low water saturation, which makes substrates with a higher content of BRH an appropriate medium for this reaction. In addition, the acidity of the medium and the EC are increased (Cabrera *et al.*, 2017), which was also described by Roig *et al.* (2004) for mixtures of CF and expanded clays.

The behavior of the concentrations of S and Na^+ (Tabs. 3-4) shows a positive relationship, as mentioned by Cakmak *et al.* (2023), who noted that when analyzing the ions in the nutrient solution, counter-ions must be considered: if an anion is absorbed at a low rate, the same occurs with its counter-ion.

For Na^+, Cl^-, and SO_4^{2-} contents, a positive relationship between them and the EC is observed; these results are consistent with those referenced by Cabrera *et al.* (2017).

Sodium concentrations in drainage, substrates, and plant tissue

At 0 WAP, significantly higher concentrations of Na^+ were obtained for CF substrates, independent of the recycling percentage of the solution (Tab. 4). At 5 WAP, there was no difference in the concentrations of the ion in the drainage. At 8 WAP, significantly higher Na^+ contents were recorded for the substrates with the highest BRH content and in treatments where drainage recycling was carried out; the opposite was observed in 0 WAP. At the substrate level, for 0 and 5 WAP stages, there was no significant difference between the Na^+ contents; while at 8 WAP, at higher CF contents, significantly higher ion contents were observed, regardless of the recycling percentage. In plant tissue, no statistical differences were found for Na^+.

In general, a growing trend in Na^+ concentrations in the drainage can be observed over time, which may be related to the fact that CF materials, which contain high concentrations of Na^+, underwent washing and leaching of this ion, which accumulated as the solution was recycled. Additionally, the CF-based substrates may have adsorbed Na^+, due to their high capacity for cation retention, which increased over time, possibly due to the activation by acids, such as sulfuric, from microbial activity (Hettiarachchi *et al.*, 2016). With respect to the concentration of the contents within the tissue, there was no evidence of increased uptake of Na^+ into plant tissue associated with the concentrations present in the drainage solution, which contrasts with the findings reported by Solís-Pérez and Cabrera (2007).

Chloride concentrations in drainage water

Chloride concentrations were only significantly different at 8 WAP. At this stage, ion concentrations were significantly higher in recycling treatments independent of the substrate mixture, a typical occurrence in recycling systems (Tab. 5). This behavior may result from Cl^- competing with NO_3^- for absorption (Sambo *et al.*, 2019). During 8 WAP, plants can enhance NO_3^- uptake (Rodríguez & Flórez, 2012), which promotes Cl^- exclusion and reduces inhibition of NO_3^- absorption (Griffiths & York, 2020; Massa *et al.*, 2009). In addition, the concentrations of NO_3^- were approximately twice those of Cl^- (data not shown).

TABLE 3. Mean values ± SD of sulfur contents in drainage water (expressed as SO_4^{2-} mg L^{-1}); substrate (expressed as S mg kg^{-1}); and plant tissue (expressed as S mg kg^{-1}), in rose cv. 'Charlotte' grown in organic substrates with an automatic drainage recycling system (ADRS). Measurements were taken at 0, 5, and 8 weeks after pruning (WAP). Means followed by different letters indicate significant differences at P<0.05 according to Tukey's multiple comparison test.

Week	Treatment																	
	100BRH0R		100BRH50R		100BRH100R		35BRH0R		35BRH50R		35BRH100R		65BRH0R		65BRH50R		65BRH100R	
	SO_4^{2-} in drainage (mg L^{-1})																	
0	341.3±12.1	c	458±90.4	abc	339.3±55.8	c	433.3±51.3	bc	584.3±146.9	ab	560±138.4	abc	457±13.1	abc	483.3±196.9	b	671±51.4	a
5	413.2±122.9	a	520.2±151.7	a	485.8±252.1	a	510.1±108.5	a	425.4±63.4	a	586.9±237.1	a	431.3±75.3	a	671.8±62.9	a	450.8±79.9	a
8	451.33±84.33	d	1203.57±296.07	ab	1528.32±270.26	a	528.79±123.19	d	806.82±192.44	cd	1125.02±59.19	bc	560.86±57.31	d	1059.71±284.1	bc	1238.41±65.17	ab
	S in substrates (mg kg^{-1})																	
0	1626.5±666.3	a	2500.1±799.4	a	4058.8±4317.9	a	8065.2±1841.2	a	5133.2±672.6	a	6843.2±598.5	a	5133.4±1588.6	a	4821.9±4055.5	a	3540.8±1205.2	a
5	4781.75±1737.15	a	8061.26±6597.34	a	5354.27±2832.08	a	6234.9±2964.4	a	8393.9±2882.7	a	6651.99±1850.1	a	7918.8±508.8	a	8062.6±5786.3	a	6970.8±2474.1	a
8	2661.22±422.66	a	5600.04±1519.26	a	7304.4±1676.15	a	7277.3±1286.6	a	11765.7±8911.0	a	15471.99±11314.4	a	4794.5±1073.1	a	10611.2±6806.8	a	10558.6±8019.3	a
	S in plant tissue (mg kg^{-1})																	
0	2484.3±212.2	a	2646.7±225.9	a	2520.3±616.7	a	2653.7±31.9	a	2393.7±327.9	a	2704±175.1	a	2472.7±124.0	a	2561.7±111.3	a	2456.7±461.4	a
5	1801.7±96.8	a	1892.3±164.2	a	2027.3±81.7	a	1857.3±98.1	a	2043.3±137	a	2058.67±367.5	a	1845.3±40.1	a	1828.7±223.5	a	2075±92.6	a
8	1948.7±384.5	a	1893.7±129.5	a	1845±51.0	a	1952.3±28.5	a	1845±84.9	a	1882±355.8	a	1879±153.5	a	1723.3±103.5	a	1803±165	a

TABLE 4. Mean values ± SD of sodium contents in drainage water, expressed as Na^+ (mg L^{-1}); substrate, expressed as a percentage; and plant tissue, expressed as a percentage, in crop rose cv. 'Charlotte' grown in organic substrates with an automatic drainage recycling system (ADRS) at 0, 5, and 8 weeks after pruning (WAP). Means followed by different letters indicate significant differences at P<0.05 according to Tukey's multiple comparison test.

Week	Treatment																	
	100BRH0R		100BRH50R		100BRH100R		35BRH0R		35BRH50R		35BRH100R		65BRH0R		65BRH50R		65BRH100R	
	Na^+ in drainage (mg L^{-1})																	
0	150±6.93	c	230.33±42.12	ab	191.67±30.01	bc	186.33±18.01	bc	273±61.02	a	289.33±51.5	a	186.33±4,16	bc	247±78	ab	303.67±15.04	a
5	298.98±147.65	a	358.58±91.84	a	373.5±112.44	a	319.36±114.37	a	317.65±106.78	a	418.97±173.58	a	265.52±51.19	a	391.88±136.95	a	312.63±42.16	a
8	187.76±21.38	e	405.98±100.78	abc	551.8±120.07	a	233.39±63.05	de	267.82±68.6	cde	388.06±26.72	bcd	223.72±19.42	e	385.65±100.39	bcd	438.8±38.54	ab
	Na^+ in substrates (%)																	
0	0.12±0.05	a	0.15±0.01	a	0.25±0.15	a	0.48±0.18	a	0.28±0.02	a	0.36±0.11	a	0.3±0.09	a	0.32±0.26	a	0.23±0.09	a
5	0.19±0.09	a	0.23±0.06	a	0.23±0.08	a	0.56±0.54	a	0.32±0.14	a	0.25±0.04	a	0.28±0.04	a	0.38±0.37	a	0.28±0.04	a
8	0.08±0.06	b	0.24±0.08	ab	0.25±0.11	ab	0.21±0.08	ab	0.36±0.2	ab	0.4±0.11	a	0.1±0	b	0.25±0.05	ab	0.26±0.14	ab
	Na^+ in plant tissue (%)																	
5	0.05±0.03	a	0.09±0.07	a	0.04±0.02	a	0.05±0.01	a	0.07±0.04	a	0,06±0,04	a	0.06±0.05	a	0.06±0.03	a	0.06±0.04	a
8	0.05±0.01	a	0.06±0	a	0.05±0.02	a	0.06±0.03	a	0.05±0.01	a	0.04±0.01	a	0.05±0.01	a	0.05±0.03	a	0.04±0	a

TABLE 5. Mean values ± SD of chloride contents in drainage water (expressed as Cl^- mg L^{-1}) in crop rose cv. 'Charlotte' grown in organic substrates with an automatic drainage recycling system (ADRS). Measurements were taken at 0, 5, and 8 weeks after pruning (WAP). Means followed by different letters indicate significant differences at $P<0.05$ according to Tukey's multiple comparison test.

Week	Treatment								
	100 BRH0R	100BRH50R	100BRH100R	35BRH0R	35BRH50R	35BRH100R	65BRH0R	65BRH50R	65BRH100R
	Cl^- in drainage (mg L^{-1})								
0	159.3±6 a	162±11.3 a	172.7±28.7 a	154.3±11.0 a	244.3±58.7 a	214.7±59.7 a	167±25.2 a	207.3±57.7 a	264±17.4 a
5	258.9±135.2 a	309.7±88.3 a	328.8±115.7 a	271.4±93.9 a	273.9±109.0 a	362.1±156.2 a	218.1±36.4 a	329.7±134.1 a	258.1±42.7 a
8	179.0±33.7 b	303.0±80.7 ab	417.9±108.4 a	215.6±53.9 b	204.0±40.6 b	295.5±25.0 ab	209.8±22.2 b	271.4±63.9 b	319.7±38.8 ab

Conclusions

The implementation of automatic drainage recirculation systems in rose crops can reduce effluent discharge and minimize environmental impact. However, it is essential to monitor and regulate the accumulation of ions such as Na^+ and Cl^-, since their increase during advanced growth stages may affect stem quality and vase life. This implies that growers must adjust recirculation frequency and substrate composition according to the phenological stage to maintain ionic balance and prevent salinization issues. In addition, the proportion between burned rice husk and coconut fiber directly influences nutrient and salt absorption dynamics and accumulation. Mixtures with higher coconut fiber content promote retention of Na^+ and SO_4^{2-} as time progresses toward the flowering stage of the floral stem under 100% recirculation, while those with higher burned rice husk content tend to accumulate more sulfates under prolonged recirculation. At 8 WAP, the Cl^- concentrations were significantly higher in the treatments with recycling (50 and 100%), regardless of the type of mixture of substrates. For the floriculture sector, a strategy based on substrate mixture rotation or adjustment could optimize nutrient uptake, extend substrate lifespan, and maintain rose quality in intensive production systems.

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Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

WJCB and VJFR: conceptualization, funding acquisition, research, writing – original draft, visualization, and editing. WJCB, YAGC, and VJFR: writing the final version of the article. YAGC contributed to the translation of the article. All authors have read and approved the final version of the manuscript.

Literature cited

Abad, M., Noguera, P., Puchades, R., Maquieira, A., & Noguera, V. (2002). Physico-chemical and chemical properties of some coconut coir dusts for use as a peat substitute for containerised ornamental plants. *Bioresource Technology*, *82*(3), 241–245. https://doi.org/10.1016/S0960-8524(01)00189-4

Ågren, G. I., & Weih, M. (2020). Corrigendum: Multi-dimensional plant element stoichiometry – looking beyond carbon, nitrogen, and phosphorus. *Frontiers in Plant Science*, *11*, Article 915. https://doi.org/10.3389/fpls.2020.00915

Alaoui, I., El Ghadraoui, O., Serbouti, S., Ahmed, H., Mansouri, I., El Kamari, F., Taroq, A., Ousaaid, D., Squalli, W., & Farah, A. (2022). The mechanisms of absorption and nutrients transport in plants: A review. *Tropical Journal of Natural Product Research*, *6*(1), 8–14. https://scispace.com/papers/the-mechanisms-of-absorption-and-nutrients-transport-in-2x628x8q

Atta-Aly, M. A., Saltveit, M. E., & El-Beltagy, A. S. (1998). Saline growing conditions induce ripening of the non-ripening mutants *nor* and *rin* tomato fruits but not of *Nr* fruit. *Postharvest Biology and Technology*, *13*(3), 225–234. https://doi.org/10.1016/S0925-5214(98)00010-6

Blumwald, E., Aharon, G. S., & Apse, M. P. (2000). Sodium transport in plant cells. *Biochimica et Biophysica Acta (BBA) – Biomembranes, 1465*(1–2), 140–151. https://doi.org/10.1016/S0005-2736(00)00135-8

Bugbee, B. (2004). Nutrient management in recirculating hydroponic culture. *Acta Horticulturae*, *648*, 99–112. https://doi.org/10.17660/ActaHortic.2004.648.12

Cabrera, R. I. (2003). Nitrogen balance for two container-grown woody ornamental plants. *Scientia Horticulturae*, *97*(3–4), 297–308. https://doi.org/10.1016/S0304-4238(02)00151-6

Cabrera, R. I., & Perdomo, P. (2003). Reassessing the salinity tolerance of greenhouse roses under soilless production conditions. *HortScience*, *38*(4), 533–536. https://doi.org/10.21273/hortsci.38.4.533

Cabrera, R. I., Solís-Pérez, A. R., & Cuervo-Bejarano, W. J. (2017). Tolerancia y manejo de salinidad, pH y alcalinidad en cultivos de flores. In V. J. Flórez (Ed.), *Consideraciones sobre producción, manejo y poscosecha de flores de corte con énfasis en rosa* *y clavel* (pp. 63–73). Editorial Universidad Nacional de Colombia. https://academia.ceniflores.org/CentroDocumental/consideraciones-sobre-produccion-manejo-y-poscosecha-de-flores-de-corte-con-enfasis-en-rosa-y-clavel/

Cabrera, R. I., Solís-Pérez, A. R., & Sloan, J. J. (2009). Greenhouse rose yield and ion accumulation responses to salt stress as modulated by rootstock selection. *HortScience*, *44*(7), 2000–2008. https://doi.org/10.21273/hortsci.44.7.2000

Cakmak, I., Brown, P., Colmenero-Flores, J., Husted, S., Kutman, B. Y., Nikolic, M., Rengel, Z., Schmidt, S., & Zhao, F.-J. (2023). Micronutrients. In Z. Rengel, I. Cakmak, & P. J. White (Eds.), *Marschner's mineral nutrition of plants* (4th ed., pp. 283–385). Academic Press. https://doi.org/10.1016/B978-0-12-819773-8.00017-4

Carmassi, G., Romani, M., Diara, C., Massa, D., Maggini, R., Incrocci, L., & Pardossi, A. (2013). Response to sodium chloride salinity and excess boron in greenhouse tomato grown in semi-closed substrate culture in a Mediterranean climate. *Journal of Plant Nutrition*, *36*(7), 1025–1042. https://doi.org/10.1080/01904167.2013.766209

Chapagain, B. P., Wiesman, Z., Zaccai, M., Imas, P., & Magen, H. (2003). Potassium chloride enhances fruit appearance and improves quality of fertigated greenhouse tomato as compared to potassium nitrate. *Journal of Plant Nutrition*, *26*(3), 243–658. https://doi.org/10.1081/PLN-120017671

Claassen, N., & Barber, S. A. (1974). A method for characterizing the relation between nutrient concentration and flux into roots of intact plants. *Plant Physiology*, *54*(4), 564–568. https://doi.org/10.1104/pp.54.4.564

Colmenero-Flores, J. M., Franco-Navarro, J. D., Cubero-Font, P., Peinado-Torrubia, P., & Rosales, M. A. (2019). Chloride as a beneficial macronutrient in higher plants: new roles and regulation. *International Journal of Molecular Sciences*, *20*(19), Article 4686. https://doi.org/10.3390/ijms20194686

Coskun, D., & White, P. J. (2023). Ion-uptake mechanisms of individual cells and roots: short-distance transport. In Z. Rengel, I. Cakmak, & P. J. White (Eds.), *Marschner's mineral nutrition of plants* (4th ed., pp. 11–71). Academic Press. https://doi.org/10.1016/B978-0-12-819773-8.00018-6

Cuervo-Bejarano, W. J., Flórez-Roncancio, V. J. (2024). Evaluation of electrical conductivity and pH in a nutrient solution with recirculating system in rose crop. *Agronomía Colombiana, 42*(2), Article e115607. https://doi.org/10.15446/agron.colomb.v42n2.115607

Cuervo, W. J., Flórez, V. J., & González, C. A. (2012). Aspectos a tener en cuenta para optimizar un sistema de cultivo en sustrato con reciclaje de drenajes. *Agronomía Colombiana*, *30*(3), 379–387. https://revistas.unal.edu.co/index.php/agrocol/article/view/29029

Cuervo, W. J., Flórez, V. J., & González, C. A. (2011). Generalidades de la automatización y control para el reciclaje de drenajes en cultivos bajo cubierta. In V. J. Florez (Ed.), *Sustratos, manejo del clima, automatización y control en sistemas de cultivo sin suelo* (pp. 247–275). Editorial Universidad Nacional de Colombia. https://academia.ceniflores.org/CentroDocumental/sustratos-manejo-del-clima-automatizacion-y-control-en-sistemas-de-cultivo-sin-suelo/

Domingues, D. S., Takahashi, H. W., Camara, C. A. P., & Nixdorf, S. L. (2012). Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. *Computers and Electronics in Agriculture*, *84*, 53–61. https://doi.org/10.1016/j.compag.2012.02.006

Dotaniya, M. L., & Meena, V. D. (2015). Rhizosphere effect on nutrient availability in soil and its uptake by plants: A review. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *85*, 1–12. https://doi.org/10.1007/s40011-013-0297-0

Farnham, D. S., Hasek, R. F., & Paul, J. L. (1985). *Water quality: Its effects on ornamental plants*. Cooperative Extension University of California. Division of Agriculture and Natural Resources. Leaflet 2995. https://ucanr.edu/sites/cetest/files/55088.pdf

Fujimoto, S. Y., Ohta, M., Usui, A., Shinshi, H., & Ohme-Takagi, M. (2000). Arabidopsis ethylene-responsive element binding factors act as transcriptional activators or repressors of GCC box-mediated gene expression. *Plant Cell*, *12*(3), 393–404. https://doi.org/10.1105/tpc.12.3.393

Griffiths, M., & York, L. M. (2020). Targeting root ion uptake kinetics to increase plant productivity and nutrient use efficiency. *Plant Physiology*, *182*(4), 1854–1868. https://doi.org/10.1104/PP.19.01496

Guzmán González, D. A. (1996). *Zonas de vida o formaciones vegetales. Área jurisdiccional CAR*. Corporación Autónoma Regional. https://sie.car.gov.co/server/api/core/bitstreams/4d8734ed-15b4-4992-955b-f696d6a4417c/content

Handreck, K., & Black, N. (2010). *Growing media for ornamental plants and turf* (4th ed.). University of New South Wales Press. https://archive.org/details/growingmediaforo0000hand

Hettiarachchi, E., Perera, R., Chandani Perera, A. D. L., & Kottegoda, N. (2016). Activated coconut coir for removal of sodium and magnesium ions from saline water. *Desalination and Water Treatment*, *57*(47), 22341–22352. https://doi.org/10.1080/19443994.2015.1129649

Kämpf, A. N., Fior, C. S., & Leonhardt, C. (2009). Lowering pH value with elemental sulfur in the substrate for *ex vitro* acclimatization. *Acta Horticulturae*, *812,* 415–420. https://doi.org/10.17660/ActaHortic.2009.812.58

Kertesz, M. A., & Mirleau, P. (2004). The role of soil microbes in plant sulphur nutrition. *Journal of Experimental Botany*, *55*(404), 1939–1945. https://doi.org/10.1093/jxb/erh176

Lee, M. K., & Van Iersel, M. W. (2008). Sodium chloride effects on growth, morphology, and physiology of chrysanthemum (*Chrysanthemum x morifolium*). *HortScience*, *43*(6), 1888–1891. https://doi.org/10.21273/hortsci.43.6.1888

Lorenzo, H., Cid, M. C., Siverio, J. M., & Ruano, M. C. (2000). Effects of sodium on mineral nutrition in rose plants. *Annals of Applied Biology*, *137*(1), 65–72. https://doi.org/10.1111/j.1744-7348.2000.tb00058.x

Lucheta, A. R., & Lambais, M. R. (2012). Sulfur in agriculture. *Revista Brasileira de Ciência do Solo*, *36*(5), 1369–1379. https://doi.org/10.1590/s0100-06832012000500001

Massa, D., Mattson, N. S., & Lieth, H. J. (2009). Effects of saline root environment (NaCl) on nitrate and potassium uptake kinetics for rose plants: A Michaelis-Menten modelling approach. *Plant and Soil*, *318*, 101–115. https://doi.org/10.1007/s11104-008-9821-z

Mendiburu, F. (2023). *R package version 1.3-7 Statistical procedures for agricultural research* (Version 1.3-1). https://CRAN.R-project.org/package=agricolae

Metwally, A. M., Radi, A. A., El-Shazoly, R. M., & Hamada, A. M. (2018). The role of calcium, silicon and salicylic acid treatment in protection of canola plants against boron toxicity stress. *Journal of Plant Research*, *131*(6), 1015–1028. https://doi.org/10.1007/s10265-018-1008-y

Niu, G., & Rodriguez, D. S. (2008). Responses of growth and ion uptake of four rose rootstocks to chloride- or sulfate-dominated salinity. *Journal of the American Society for Horticultural Science*, *133*(5), 663–669. https://doi.org/10.21273/jashs.133.5.663

Olympios, C. M. (1999). Overview of soilless culture: advantages, constraints, and perspectives. In R. Choukr-Allah (Ed.), *Protected cultivation in the Mediterranean region* (pp. 307–324).

Riley, M. M. (1987). Micronutrients: Boron toxicity in barley. *Journal of Plant Nutrition*, *10*(9–16), 2109–2115. https://doi.org/10.1080/01904168709363761

Rodríguez, M., & Flórez, V. (2012). 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. *Agronomía Colombiana*, *30*(2), 266–273. https://revistas.unal.edu.co/index.php/agrocol/article/view/15773

Roig, A., Cayuela, M. L., & Sánchez-Monedero, M. A. (2004). The use of elemental sulphur as organic alternative to control pH during composting of olive mill wastes. *Chemosphere*, *57*(9), 1099–1105. https://doi.org/10.1016/j.chemosphere.2004.08.024

Roy, S. J., Negrão, S., & Tester, M. (2014). Salt resistant crop plants. *Current Opinion in Biotechnology, 26*, 115–124. https://doi.org/10.1016/j.copbio.2013.12.004

Sambo, P., Nicoletto, C., Giro, A., Pii, Y., Valentinuzzi, F., Mimmo, T., Lugli, P., Orzes, G., Mazzetto, F., Astolfi, S., Terzano, R., & Cesco, S. (2019). Hydroponic solutions for soilless production systems: issues and opportunities in a smart agriculture perspective. *Frontiers in Plant Science*, *10*(923), 1–17. https://doi.org/10.3389/fpls.2019.00923

Savvas, D. (2003). Nutritional management of vegetables and ornamental plants in hydroponics. In R. Dris, R. Niskanen, & S. M. Jain (Eds.), *Crop management and postharvest handling of horticultural products fruits and vegetables* (Vol. 1, pp. 37–87). Science Publishers.

Savvas, D., & Adamidis, K. (1999). Automated management of nutrient solutions based on target electrical conductivity, pH, and nutrient concentration ratios. *Journal of Plant Nutrition*, *22*(9), 1415–1432. https://doi.org/10.1080/01904169909365723

Schippers, P. A. (1980). Composition changes in the nutrient solution during the growth of plants in recirculating nutrient culture. *Acta Horticulturae*, *98*, 103–118. https://doi.org/10.17660/actahortic.1980.98.9

Solís-Pérez, A. R., & Cabrera, R. I. (2007). Evaluating counter-ion effects on greenhouse roses subjected to moderately-high salinity. *Acta Horticulturae*, *751*, 375–380. https://doi.org/10.17660/ActaHortic.2007.751.47

Sonneveld, C. (2000). *Effects of salinity on substrate grown vegetables and ornamentals in greenhouse horticulture* [Doctoral dissertation, Wageningen University]. https://doi.org/10.18174/121235

Sonneveld, C., Baas, R., Nijssen, H. M. C., & De Hoog, J. (1999). Salt tolerance of flower crops grown in soilless culture. *Journal of Plant Nutrition*, *22*(6), 1033–1048. https://doi.org/10.1080/01904169909365692

Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). *Plant physiology and development* (6th ed.). Sinauer Associates, Inc., Publishers.

Tourna, M., Maclean, P., Condron, L., O'Callaghan, M., & Wakelin, S. A. (2014). Links between sulphur oxidation and sulphur-oxidising bacteria abundance and diversity in soil microcosms based on *soxB* functional gene analysis. *FEMS Microbiology Ecology*, *88*(3), 538–549. https://doi.org/10.1111/1574-6941.12323

Trejo-Téllez, L. I., & Gómez-Merino F. C. (2012). Nutrient solutions for hydroponic systems. In T. Asao (Ed.), *Hydroponics - A standard methodology for plant biological researches* (pp. 1-22). InTech. https://doi.org/10.5772/2215.

Vélez Carvajal, N. A. (2012). *Comportamiento de macronutrientes en un sistema de cultivo sin suelo para clavel estándar cv. Delphi con recirculación de drenajes en la Sabana de Bogotá* [Master thesis, Universidad Nacional de Colombia]. https://repositorio.unal.edu.co/handle/unal/11550

Wen, Z., Tyerman, S. D., Dechorgnat, J., Ovchinnikova, E., Dhugga, K. S., & Kaiser, B. N. (2017). Maize NPF6 proteins are homologs of Arabidopsis CHL1 that are selective for both nitrate and chloride. *The Plant Cell*, *29*(10), 2581–2596. https://doi.org/10.1105/tpc.16.00724

Wickham, H. (2016). *Ggplot2: Elegant graphics for data analysis* (2nd ed.). Springer. https://link.springer.com/book/10.1007/978-3-319-24277-4

Zhang, X., Franzisky, B. L., Eigner, L., Geilfus, C. M., & Zörb, C. (2021). Antagonism of chloride and nitrate inhibits nitrate reductase activity in chloride-stressed maize. *Plant Growth Regulation*, *93*(3), 279–289. https://doi.org/10.1007/s10725-020-00685-2