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SODIUM ACCUMULATION AND NUTRIENT DISCHARGE IN RECIRCULATION SYSTEMS: A CASE STUDY WITH ROSES

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Abstract

The accumulation of substances can limit the continued use of nutrient solution in recirculation systems in greenhouse production. Under commercial conditions, particularly sodium (Na) accumulates in the drainage solution. In the Netherlands, discharge is only allowed if Na concentrations in the drainage solution (Na_d) have reached concentrations of e.g. 4 mM (cut rose) or 8 mM (tomato).
To determine salinity-sensitivity of rose c.v. ‘Madelon’ in a rockwool system, Na-concentrations in the recirculation tank (Na_t) were allowed to accumulate to 6 or 12 mM; electrical conductivity (EC) of the recycled solution increased with Na_t and was 2 – 4.8 mS/cm. Cut rose appeared to be relatively salinity-tolerant with a yield decrease of only 2% per mS/cm increase. Flower quality and vase life were not affected by salinity.
Na in- and output of the system were calculated and compared with the experimental Na_t. Na uptake concentrations (Na_u, in mM) based on output data (using Na concentrations in the tissue and production data) were far lower than based on input data (using Na concentrations in the irrigation water Na_{iw}). Calculations showed that the higher Na_u based on input data corresponded better with the experimental Na accumulation possibly due to higher Na-accumulation in the growing media than anticipated. Possibilities to decrease discharge of nitrogen from (semi-)closed nutrient systems are quantified, including decreased N concentrations in the nutrient solution.

1. Introduction

In order to decrease the discharge of nutrients into the environment and limit the use of irrigation water, recirculation systems have been developed in greenhouse horticulture. In these recirculation systems, in- and output of nutrients and other substances has to be balanced in order to avoid depletion or accumulation. Output is considered to be predominantly the result of crop uptake, and is generally determined using data on production and chemical analysis (Sonneveld and Van der Burg 1991, Baas et al. 1995). Due to the efficient exclusion of Na by non-halophytic species such as most horticultural crops, Na accumulation can occur in closed nutrient systems. This accumulation can eventually inhibit plant growth/production by ion-specific toxicity effects (sodicity), by osmotic effects (salinity), and/or by ion imbalance (Greenway and Munns 1980). Previous research on a number of horticultural crops indicated that salinity caused by Na (and Cl) accumulation is responsible for yield decrease in most cut flowers (Sonneveld and Van der Burg 1991; Baas et al. 1995; Sonneveld et al. 1999).

In the Netherlands, discharge of recirculation water is only allowed in case the Na concentration in the drainage water (Na_d) has reached a crop-dependent concentration (between 3 and 8 mM). For instance, discharge of nutrient solution for cut roses is only allowed if $Na_d > 4$ mM.

The present study was undertaken to investigate the effects and extent of Na-accumulation in a rockwool system on cut rose productivity and quality in order to study possibilities for decreasing discharge of polluting elements such as N.

2. Materials and methods

2.1 Greenhouse experiment

The experiment took place in a 150 m^2 greenhouse equipped with automatic screening, assimilation lighting and humidification facilities. Twelve recirculation systems were present, each consisting of a 400 liter recirculation tank, and 6 m^2 cultivation area with 90 rose plants c.v. ‘Madelon’. The rose cuttings were planted on rockwool slabs (width 0.15m, height 0.07 m; 5 roses/slab) in 0.18 m wide gutters. Distance between the gutters was 0.17 m. The rockwool was covered with plastic to avoid evaporation. Each rose was supplied intermittently with nutrient solution by a dripper (40 ml/min), and the total amount given varied between 11 and 13 liter per m^2 /day (11-18 pulses) during the 1.5 year lasting experiment.

Na was allowed to accumulate up to 6 or 12 mM during the experiment by compensating transpiration with nutrient solution containing on average 1.8 mM NaCl. The EC increased with increasing Na and Cl concentrations, whereas the concentrations of the major and minor elements were kept constant. The following treatments were applied:

treatment EC/Na	Na-accum.	EC_t mS/cm	N_t	P_t mM	K_t	final Na_t mM	estimated final EC_t mS/cm
2.0/0	no	2.0	13	0.9	5	0	2.0
2.7/6	yes	2.0	13	0.9	5	6	2.7
3.4/12	yes	2.0	13	0.9	5	12	3.4
3.4/0	no	3.4	25	1.8	10	0	3.4
4.1/6	yes	3.4	25	1.8	10	6	4.1
4.8/12	yes	3.4	25	1.8	10	12	4.8

After the final Na concentrations had been reached, irrigation water that was added to maintain the Na_t contained 0.21 mM Na and 0.24 mM Cl, respectively.

During the experiment transpiration was recorded by measuring tank volume at weekly intervals. Nutrient concentrations in the recirculation tanks were also determined every week. Number and weight of harvested roses were recorded. Several times during the experiment different plant parts were analyzed for major nutrients and Na and Cl. Post-

harvest vase life and final flower diameter were recorded in week 9-10 1996 in a post-harvest chamber (20^0C, r.h. 60%, light intensity 1.5 W/m^2 during 12 h/d).
Twice during the experiment (week 15 and 27 1995) Na concentrations in the rockwool slabs were determined for comparison with Na_t.

2.2 Calculations and statistics

Uptake of Na was calculated in two ways, using input or using output data. Uptake by output was calculated by multiplying biomass production (week 37 1995 – 26 1996) by Na concentrations and percentage dry weight as measured in week 12 1996. Uptake by input was calculated by multiplying transpiration by the concentration of Na in the nutrient solution used to fill up the recirculation tanks (Na_{iw}). Uptake divided by total transpiration during the experimental period is defined as the uptake concentration (Na_u). Cl_u was calculated in a similar way. For EC_u (in mS/cm), only input data were available.

Data were subjected to one-way analysis of variance. In case of significant treatment effects ($P<0.05$) comparisons of means was performed using the LSD test ($\alpha=0.05$).

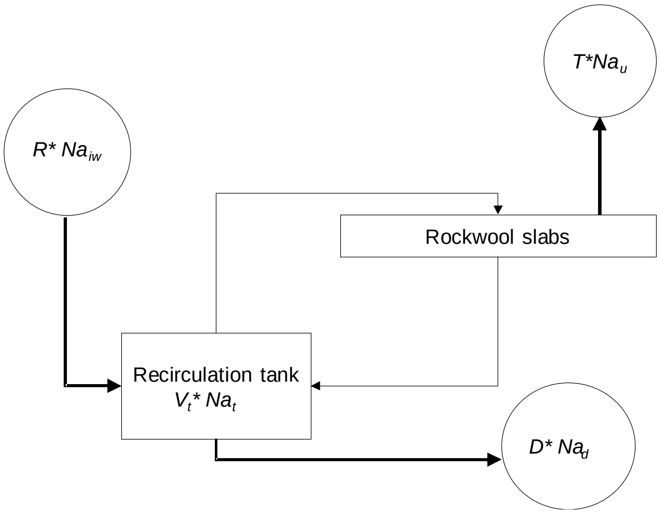

Fig. 1 Relational diagram representing Na fluxes in a recirculation system.

2.3 Simulation

Mass balance of Na in a recirculation system (Fig. 1) is decribed by

$$R*Na_{iw} = D*Na_d + T*Na_u + \Delta (V*Na_t) \qquad (1)$$

in which D, T and R are the flow rates (e.g. in liter/day) of nutrient solution of the discharged solution (D), transpired solution (T), and solution for refilling the tank (R), respectively. V is the volume of the nutrient solution in recirculation tank and rockwool.

Na_d, Na_u and Na_{iw} are the Na concentration in the leached solution, the uptake concentration of Na and the Na concentration in the refill solution, respectively.
Na_t in week W can then be calculated as:

$$Na_{t\,(W)} = [(V_{(W-1)}*Na_{t\,(W-1)}) - D*Na_{d(W)} - T*Na_{u(W)} + R*Na_{iw(W)}]/V_{t(W)} \quad (2)$$

For simulation of the EC3.4/Na12 treatment of the experiment, D was set to 0 and T to R. It was assumed that Na_d equalled Na_t during the experiment. Experimental transpiration and experimental Na_{iw} combined with the initial data on volume of nutrient solution in the recirculation tank and in the rockwool (with a volumetric water content of 70%) were used.
Na_u as calculated both by input and output as a function of Na_t was used (see 3.3 and Fig. 3 left).
For Cl_t similar calculations were performed.

3. Results and Discussion

3.1 Experimental EC, Na and Cl in recirculation tanks

EC_t increased during the period of accumulation (Fig. 2). After reaching the threshold EC's, EC levels remained constant .

Na_t increased during the experiment from week 7 at 0.6 mM to 6 mM in week 23 until week 37 up to 12 mM (Fig. 3 left). In the control treatment (in which Na_{iw} was 0.21 mM) Na slowly increased up to 2 mM after which the nutrient solution was refreshed in week 39.
Cl_t increased slightly slower than Na_t (Fig.3. right), and eventually reached concentrations of 5 and 11 mM in the accumulation treatments, and 1 mM in the control treatments.
Na in the rockwool was compared with Na_t in week 15 and 27 1995 (not shown). On average, concentrations in the rockwool were 13-24% higher than Na_t. EC in rockwool was on average 3-22% higher than EC_t.

3.2 Production, quality and transpiration

Production data of the period that the final concentrations were maintained (week 37 1995– 24 1996) are given in Table 1. There were no significant treatment effects on total number of stems produced and total production. No sodicity effects were apparent. Using linear regression, an average salinity production decrease of 2% per unit EC (mS/cm) was calculated. This is slightly lower compared to previous research on cut roses where salinity yield decreases were found in the order of 3-7% (De Kreij and Van der Berg 1990, Feigin et al. 1989, Sonneveld et al. 1999).
Post-harvest performance, determined once during the experiment, showed no differences in vase life and bud opening.
Transpiration was significantly affected by the treatments (Table 1), with a 3% lower transpiration per unit EC increase.

3.3 Chemical analysis and uptake concentrations

In Table 1 average Na and Cl concentrations of stems in week 12 are given. Except for higher K and lower Mg concentrations at the higher nutritional EC levels (not shown), concentrations of the other major elements were not different. Na concentrations in cut rose were extremely low compared to other horticultural crops, but comparable to other experiments with cut rose (Sonneveld et al. 1999). To investigate whether Na could be present in older – not harvested – leaves, fallen leaves and bent-down leaves were sampled. Na concentrations in old, fallen leaves were 30-40 mmol/kg DM; however, in leaves of bent-down leaves no Na could be detected.

Using the data of production, percentage dry weight, and Na and Cl concentrations, and transpiration, Na_u and Cl_u were calculated as output, and compared with data as calculated by input (Fig. 4). There was a large difference between Na_u and Cl_u determined by in- and output. A higher in- than output is normally found (e.g. Heinen et al. 1991, 1996), and can be the result of a number of errors. For the output data, underestimation can be the result of e.g. not-determined accumulation in fallen leaves, roots, and growing medium or underestimation of Na concentrations and dry weight of stems. In sweet pepper, as cut rose known for its small uptake of Na (Sonneveld and van der Burg 1991), Na accumulated predominantly in the root and in pith cells of the stems (Blom-Zandstra 1998). In Gerbera grown in expanded clay, the large discrepancy between in- and output could be ascribed to Na accumulation in the (non-covered) growing medium (Baas et al. 1996). For rose in plastic covered rockwool, this accumulation could not be found (see 3.1), although precipitation of salts cannot be excluded.

For Na_u determined by input, overestimation can be the result of analytical errors in Na_{iw}.

3.4 Simulation

In order to get more insight in the effects of differences in Na_u and Cl_u on Na accumulation, treatment EC3.4/Na12 of the experiment was simulated. In Fig. 5 the results are given using the in- or output relations as given in fig 4.

A relatively good fit was found using Na_u from input data (Fig. 5 left). This relation was therefore used for calculations given in 3.5

3.5 Possibilities for discharge reduction

To keep the concentration Na_t (and V_t*Na_t) constant, and assuming that $Na_d = Na_t$, from (1) the required leaching fraction D/R becomes (f_d in Sonneveld and Van der Burg 1991):

$$D*Na_t = R*Na_{iw} - (R-D)*Na_u \Leftrightarrow$$

$$D/R = (Na_{iw} - Na_u)/(Na_t - Na_u) \qquad \text{with } 0<D/R<1 \qquad (3)$$

As an example, if Na_t is increased from 4 – the present norm in the Netherlands - to 8 mM, and Na_{iw} contains 1.8 mM NaCl, D/R will decrease from 0.40 to 0.18 using the input data, and from 0.44 to 0.22 using the output data. It therefore appears that differences in Na_u are much less effective in influencing D/R than differences in Na_{iw} or Na_t.

By definition, discharge of N is $D*N_d$ (in mmol/day.m^2), where N_d is the N concentration in the drain solution. For decreasing N_d, the following considerations can be made: the uptake concentration of N by cut rose is approximately 5-6 mM when N_t =13 mM under Dutch conditions. This large difference between recommended and uptake concentration is essential when relatively low irrigation frequencies are used, since nutrient depletion in the rhizosphere may occur at lower N_t. However, by decreasing irrigation frequencies/fluxes, depletion may be prevented. For example, in chrysanthemums grown in a soilless ebb/flow system, higher irrigation frequencies indeed increased nutrient uptake, and also decreased salinity sensitivity (Warmenhoven and Baas 1995). In Table 2 the effects of increased Na_t and decreased N_t on N-discharge are quantified, showing that potentially large discharge reductions can be realized.

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Table 1. Production (absolute and relative) and transpiration after reaching the final Na and EC levels (trial week 37 1995-week 24 1996). Na, Cl and dry matter concentrations as determined in week 12 1996.

EC/Na	No. stems/m^2	total wt. kg/m^2	production %	transpir. l/m^2	Na$_{stem}$ mmol/kg DM	Cl$_{stem}$	%D.M.
2.0/0	232	8.4	100	781	14	29	25.8
2.7/6	218	7.7	92	754	20	45	25.7
3.4/12	206	7.8	94	713	40	80	25.9
3.4/0	226	7.0	96	707	22	29	25.2
4.1/6	222	8.1	97	753	24	42	25.5
4.8/12	217	7.6	91	683	30	73	25.1
LSD(0.05)	n.s.	n.s.	n.s.	41	10	10	n.s.

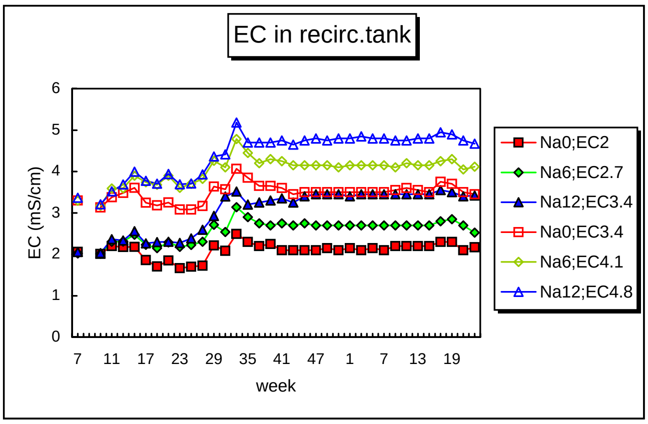
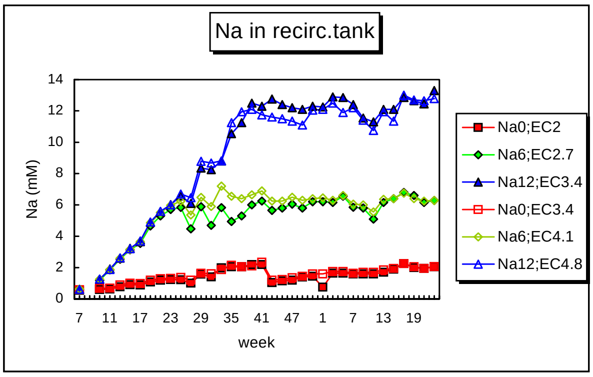


Fig. 2. Experimental EC in the different treatments during the experiment.



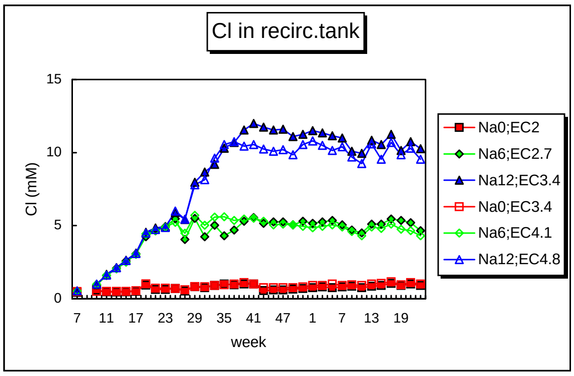


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Fig. 3. Experimental Na_t (left) and Cl_t (right) in the different treatments during the experiment

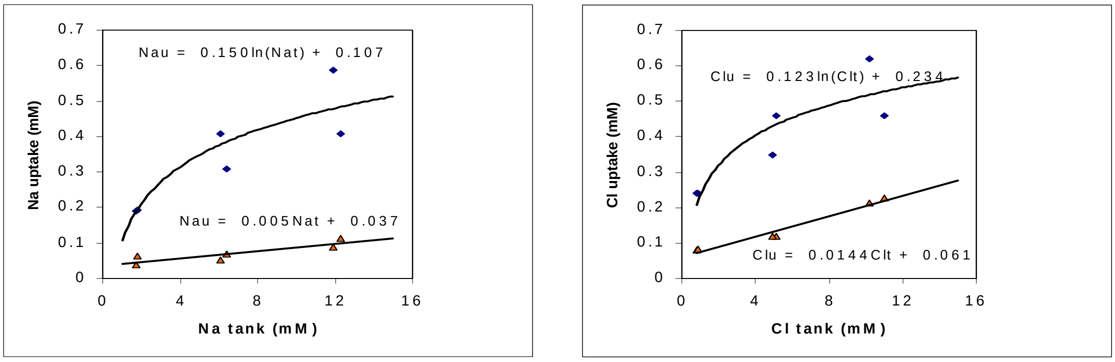

Fig. 4. Uptake concentratations of sodium (Na_u) and chloride (Cl_u) as a function of Na_t and Cl_t as determined using input data (•) or output data (•).

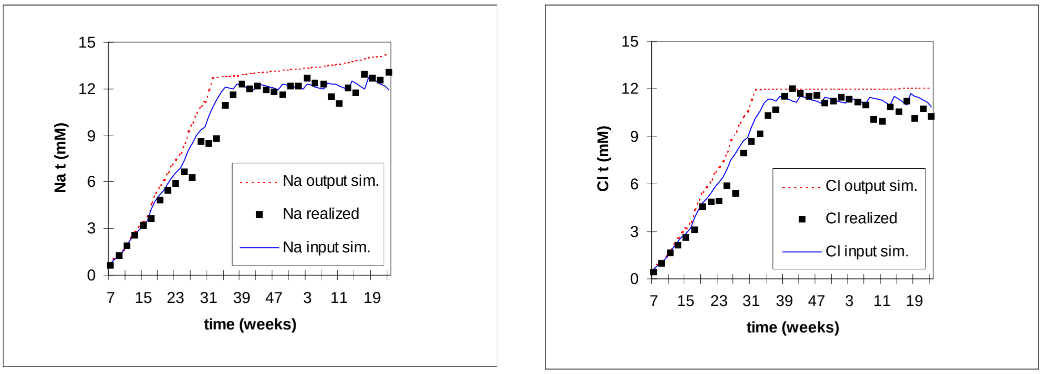

Fig. 5. Simulated Na_t (left) and Cl_t (right) of the 12 mM treatment using the relations from Fig. 4, experimental transpiration data and Na_{iw} and Cl_{iw} of 1.8 mM. V_t=530 l. At $Na_t > 12$ mM, Na_{iw} and Cl_{iw} were 0.21 and 0.24 mM, respectively.

Table 2. Effect of variation in Na_t and N_t on N-discharge ($D*N_t$) in a recirculation system based on equations (3) and (4). For Na_u, the relation based on input data is used (Fig. 4). Between brackets the calculations for Na_u based on the output data are given. Na_{iw} = 1.8 mM.

	Na_t	Na_u	D	D/R	N_t	$D*N_t$
	mM	mM	mM		mM	mmol/m^2.day
Present situation	4	0.3	2.7	0.4	7.0	18.9
		(0.0)	(3.2)			(22.3)
200% Na_t	8	0.4	0.9	0.2	7.0	6.2
		(0.0)	(1.1)			(7.9)
50% N_t	4	0.3	2.7	0.4	3.5	9.5
		(0.0)	(3.2)			(11.2)
200% Na_t, 50% N_t	8	0.4	0.4	0.2	3.5	1.6
		(0.0)	(0.6)			(2.0)