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Modeling Growth of *Matthiola incana* in Response to Saline Wastewaters Differing in Nitrogen Level

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Abstract. **The capture and reuse of nutrient-rich greenhouse effluents may be an environmentally sound option for floriculture production, which would conserve fresh water resources and reduce off-site pollution of surface and groundwaters. This study was initiated in 24 outdoor lysimeters to determine effects of salinity and varying concentrations of nitrogen on the growth, yield, and ion relations of stock [*Matthiola incana* (L.) R. Br.] cultivar Cheerful White. The experiment was a 4 × 4 factorial, partially replicated design with four irrigation water salinities (2, 5, 8, and 11 dS·m^{-1}) and four nitrate concentrations (2.5, 3.6, 5.4, and 7.1 mmol·L^{-1}; N = 35, 50, 75, and 100 ppm). Ammonium nitrogen was included in the nutrient solutions. Stem lengths were measured three times weekly. Measurements at final harvest were stem and inflorescence lengths, stem and floret diameters, number of axillary buds and florets, and shoot and root fresh weights. Time course of stem elongation was quantified as a function of thermal time with a phasic growth model. Salinity significantly delayed initiation of the exponential growth phase, shortened its duration, and reduced the rate of plant development. The overall effect was to delay time to harvest of marketable stems. Although length of the flowering stems decreased with increasing salinity, marketable stems (≈60 cm) were produced in all treatments. Mineral ion relations in the plant tissues were influenced significantly, but independently, by both salinity and nitrogen. Leaf sodium, magnesium, and chlorine concentrations increased with increasing salinity; calcium and potassium decreased. In response to increasing external nitrogen, both potassium and chlorine decreased; sodium increased, whereas calcium and magnesium were unaffected. We conclude that in closed-loop irrigation systems, the nitrogen requirements for stock are low and that growers could minimize costs and limit off-site pollution by reducing nitrogen inputs.**

As water quality and quantity become more limited in many parts of the world, creative management approaches are sought to make more efficient use of degraded, generally saline, waters. The reuse of runoff from floricultural production represents an opportunity for producers to greatly reduce fresh water consumption and to prevent surface and groundwater contamination. The concept of recycling irrigation runoff from floral and nursery operations, however, is not a recent innovation. Once the federal Water Pollution Control Acts of 1956 as amended in 1972 (Enacted by Public Law 92-500) were in place, commercial growers such as C.A. Skimina, director of the highly successful Monrovia Nursery Co., Azusa, CA, concluded that problems of wastewater disposal and nitrogen pollution of the environment posed serious implications for the industry (Skimina, 1980). Extensive research by that company led to the construction at the Azusa site of a water recycling plant capable of processing 5.3 × 10^6 L·d^{-1} (1.4 million gal/d) of runoff water. Among the benefits accruing to the floricultural industry from effluent recycling were water conservation, nutrient savings, energy conservation, protection of the environment, and a favorable public image (Skimina, 1992).

Although many floricultural crops are rated salt-sensitive, numerous economically important cut flower species do, in fact, possess some degree of salt tolerance. Success of the reuse approach, therefore, depends on identification of floral species that will produce commercially and aesthetically acceptable products when irrigated with brackish water (Skimina, 1992). Crop selection, coupled with management practices that limit salt accumulation in the root media, will provide the grower with appropriate reuse options. Cut flower crops such as *Limonium*, *Dianthus, Gypsophila, Helianthus, Matthiola*, and *Chrysanthemum* are successfully produced under irrigation throughout the Negev Desert of Israel using local saline well waters with electrical conductivities (ECs) ranging from 2.5 to 4.5·dS·m^{-1} (Shillo et al., 2002). Likewise, the glasshouse flower crop industry in the western part of The Netherlands traditionally uses moderately saline surface waters from canals and ditches (Sonneveld and Voogt, 1983).

Although the capture and reuse of greenhouse effluents for floriculture production may be environmentally and economically attractive, this practice may alter the progress of plant development as a result of the concentration of salts dissolved in the waters. Salinity-induced variations in the timing of morphological events that, in turn, affect harvest date have been documented for agronomic crops. The response is clearly species-specific. Salinity, for example, accelerates wheat development, resulting in early maturity (Grieve et al., 1993, 1994), whereas salinity slows down the development of rice so that the nonsalinized plants are the first to mature (Zeng et al., 2002). Little information is available, however, on the influence that the reuse of degraded waters has on phenological development of floriculture crops.

The purpose of this study was to determine the effects of saline wastewaters containing different concentrations of fertilizer nitrogen on developmental timing, ion relations, growth, and quality of a commercially important cut flower. A modeling approach based on stem length development as a function of thermal time provides future

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Table 1. Composition of salinizing salts and nitrate concentrations in solutions used to irrigate *Matthiola incana* grown in a lysimeter system.

Electrical conductivity (dS·m^{-1})	Ca^{2+}	Mg^{2+}	Na^+	SO_4^{2-}	Cl^-	KNO_3^{-z}
	---------- (mmol·L^{-1}) ----------					
2	2.6	3.0	10.6	3.3	13.2	2.5^y, 3.6, 5.4^y, 7.1^y
5	4.8	7.7	26.6	8.3	34.8	2.5, 3.6, 5.4^y, 7.1
8	7.6	12.7	43.6	13.6	57.2	2.5, 3.6y^Y, 5.4, 7.1
11	10.0	17.9	61.0	19.1	80.2	2.5^y, 3.6, 5.4, 7.1^y

[z]Four separate KNO_3 concentration treatments were imposed at each salinity level.
[y]Duplicated KNO_3 × salinity treatments.

growers and researchers a potentially useful tool to estimate harvest dates for marketable flowers. The test species chosen for this study was stock (*Matthiola incana*) cultivar Cheerful White, a relatively salt-tolerant crop (Grieve et al., 2006; Lunt et al., 1954).

Materials and Methods

The experiment was conducted in a recirculating volumetric lysimeter system composed of 24 sand tanks (Poss et al., 2004). The tanks, each 82 cm wide × 202 cm long × 84 cm deep, were filled with washed coarse sand having an average bulk density of 1.4 $Mg \cdot m^{-3}$ and a volumetric water content at saturation of 0.34 $m^3 \cdot m^{-3}$ and 0.1 $m^3 \cdot m^{-3}$ after drainage nearly stopped. Treatment irrigation waters were pumped from 1740-L reservoirs into the lysimeters and returned by gravity through a subsurface drainage system for reuse in the next irrigation. Water lost by evapotranspiration was replenished and measured automatically to maintain constant volumes and osmotic potential in the reservoirs.

Seeds of stock (cv. Cheerful White), donated by Sakata Seed America (Morgan Hill, CA), were sown 0.5 cm deep in four rows (2 m long) in each of 23 tanks on 2 Feb. 2004. Rows were spaced 16 cm apart; within-row spacing was 8 cm. One sand tank was unplanted and dedicated to estimation of water evaporation from the growing substrate. Tanks were irrigated daily with a nutrient solution consisting of (in $mol \cdot m^{-3}$): 2.5 Ca^{2+}, 3.0 Mg^{2+}, 10.5 Na^{+}, 5.0 K^{+}, 3.3 SO_4^{2-}, 1.3 Cl^{-}, 1.0 $NH_4H_2PO_4$, 0.10 Fe as NaFeDTPA, 0.023 H_3BO_3, 0.005 $MnSO_4$, 0.0004 $ZnSO_4$, 0.0002 $CuSO_4$, and 0.0001 H_2MoO_4 made up with city of Riverside municipal water. Two tanks, irrigated with this solution augmented with KNO_3 (2.5 $mol \cdot m^{-3}$) served as the nonsaline control treatments (EC = 2 $dS \cdot m^{-1}$). Nitrate treatments were imposed by adding KNO_3 at sowing; salinizing salts were not added until seedling establishment. After emergence, seedlings were thinned to 25 plants per row.

The experiment was a 4 × 4 factorial, partially replicated design with four irrigation water salinities (2, 5, 8, and 11 $dS \cdot m^{-1}$) and four nitrate concentrations (35, 50, 75, and 100 $mg \cdot L^{-1}$) (KNO_3 = 2.5, 3.6, 5.4, and 7.1 $mmol \cdot L^{-1}$, respectively) (Table 1). The experimental design included seven replicated nitrate treatments: EC = 2 $dS \cdot m^{-1}$, NO_3 = 2.5 and 5.4 $mmol \cdot L^{-1}$; EC = 5 $dS \cdot m^{-1}$, NO_3 = 5.4 $mmol \cdot L^{-1}$; EC = 8 $dS \cdot m^{-1}$, NO_3 = 3.6 $mmol \cdot L^{-1}$; and EC = 11 $dS \cdot m^{-1}$, NO_3 = 2.5 and 7.1 $mmol \cdot L^{-1}$.

Salinizing ion concentrations were prepared to mimic the composition of typical saline tailwaters in the Coachella Valley of California and from predictions based on appropriate simulations of what the long-term composition of the water would be on further concentrations by plant–water extraction and evapotranspiration (Suarez and Simunek, 1997). Salts (Table 1) were added in two equal increments (9 Feb. and 23 Feb. 2004) to minimize osmotic shock to the seedlings. Solution pH was not controlled and ranged between 7.7 and 8.2.

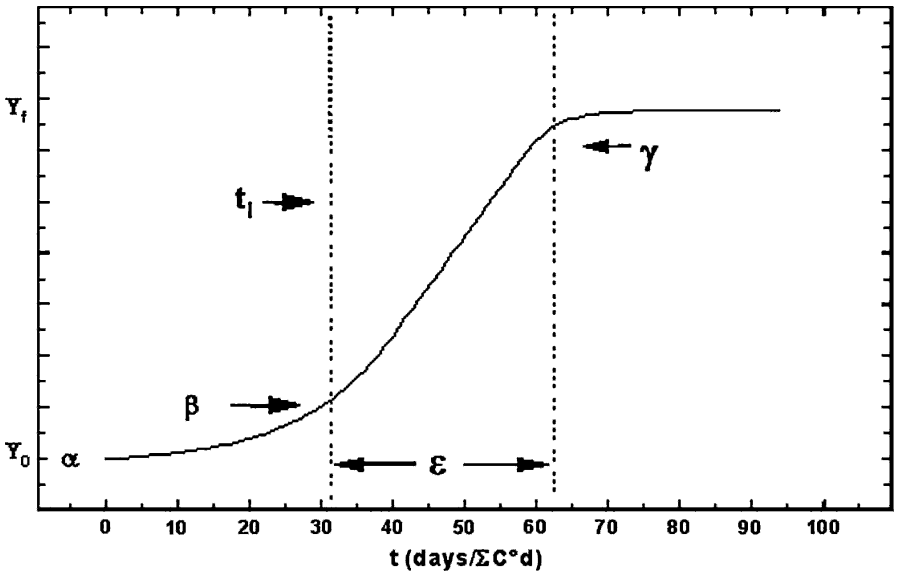

Fig. 1. Schematic of a five-parameter phasic growth model where stem length is a function of cumulative thermal time: α is the initial stem length 1 week after emergence, β represents the intrinsic growth rate of the exponential phase, t_1 is the transition point between the first two phases, ε is the duration of the exponential growth phase, and γ is the intrinsic saturation rate and equals t_2, the end of the exponential growth phase (Lieth et al., 1995).

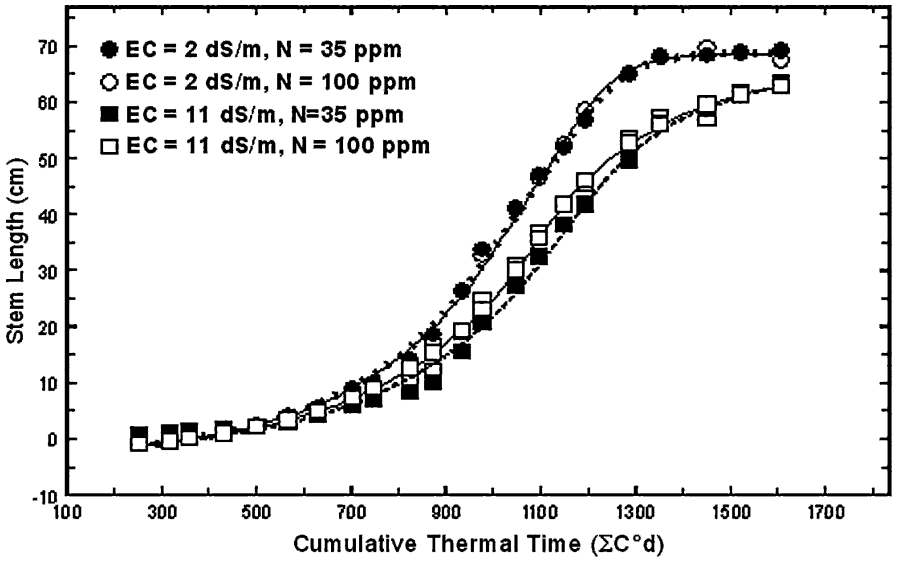

Fig. 2. Shoot growth of *Matthiola incana* (cv. Cheerful White) irrigated with waters at two levels of salinity (2 and 11 $dS \cdot m^{-1}$) containing two concentrations of nitrogen (35 and 100 ppm). Plant height is shown as a function of thermal time ($°C \cdot d^{-1}$). Fitted lines were generated by the phasic growth model. Each data point is the mean of 10 measurements.

Nitrate concentration in the irrigation waters was measured weekly with an OI Analytical Spectrometer System Flow Solution IV (Houston, TX). Irrigation waters were analyzed by inductively coupled plasma optical emission spectrometry (ICPOES, Model Optima 3300DV; Perkin Elmer, Cambridge, MA) three times during the experiment to confirm that target ion concentrations were maintained. Chloride was determined by coulometric–amperometric titration (Cotlove, 1963).

Standard meteorological measurements were made adjacent to the experimental site with an agrometerological station. Ambient daytime air temperatures during the experiment ranged from 3.5 to 37.9 °C (mean, 19.3 °C); nighttime temperatures ranged from 4.1 to 27.8 °C (mean, 12.9 °C). Relative humidity ranged from 5.5% to 97.8% with a mean of 67.0% during the night and 45.2% during the day. Hourly mean temperatures were integrated over the 24-h period and summed to give cumulative thermal time (Σ°C·d) (Hodges, 1991).

Beginning on 24 Feb, stem length was measured three times weekly on 10 plants

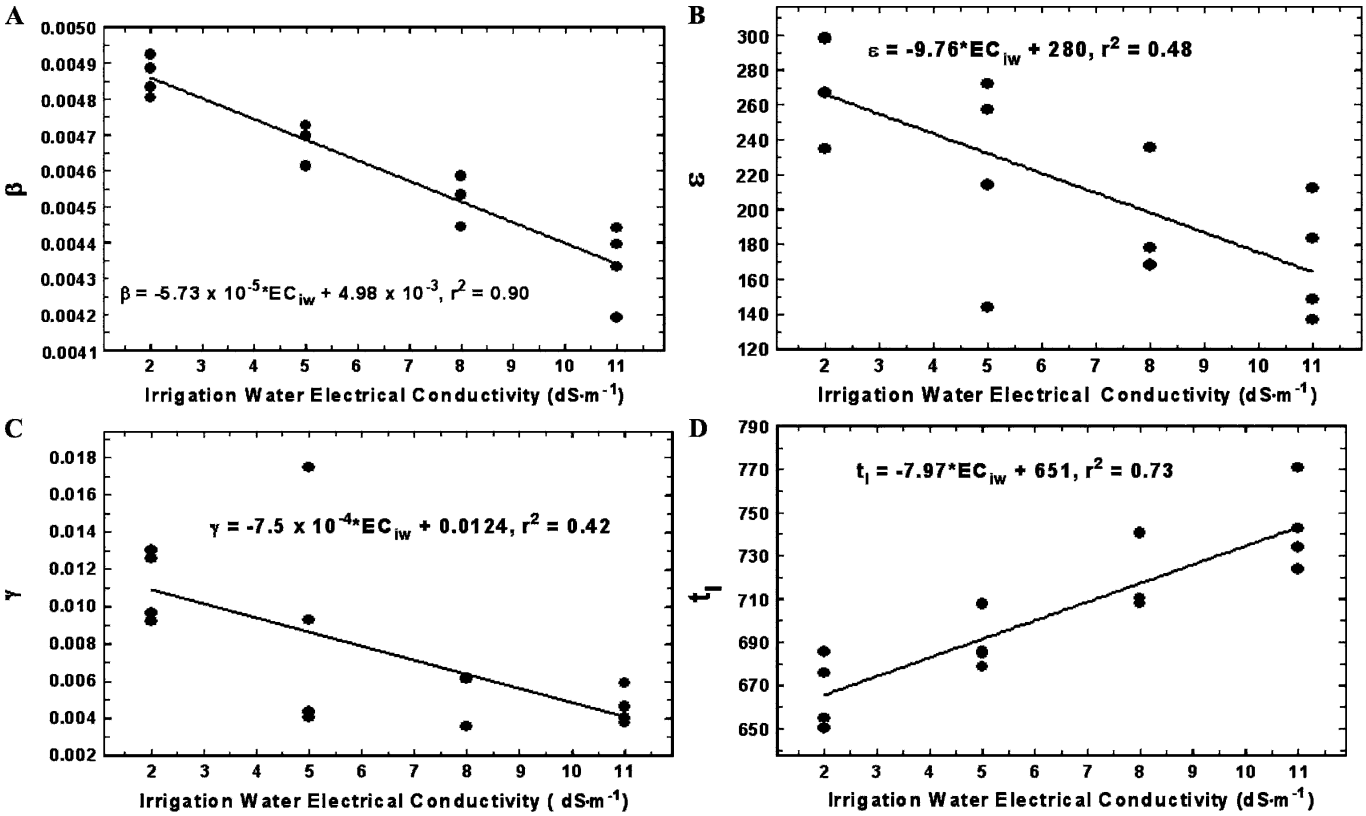

Fig. 3. Correlations between model parameters and irrigation water salinity. (**A**) Intrinsic growth rate of exponential phase (β); (**B**) duration of exponential phase (ε); (**C**) intrinsic saturation rate (γ); (**D**) transition point between the first two phases (t_1).

Table 2. Effect of irrigation water salinity on phasic growth model parameters.

Electrical conductivity (dS·m^{-1})	Growth rate (β) (cm·d^{-1} °C)	Duration (ε)^z (°C·d^{-1})	t_1^{y} (°C·d^{-1})	t_2^{x} (°C·d^{-1})	Stem length t_1 (cm)	Stem length t_2 (cm)
2	0.00486	274	667	940	25	60
5	0.00469	220	688	910	24	53
8	0.00452	181	722	903	25	53
11	0.00434	187	736	923	24	43

[z]Duration of exponential growth phase.
[y]Start of exponential growth phase.
[x]End of exponential growth phase.

that had been randomly selected and tagged in each tank. On 8 Apr., three plants were randomly selected from each tank and separated into shoots and roots. On 28 Apr., five plants were randomly selected from each tank and separated into leaves, stems, and flowers. Samples were weighed, washed in deionized water, dried in a forced-air oven at 70 °C for 72 h, then reweighed, ground to pass a 60-mesh screen, and stored in a glass vial for mineral ion analysis. Total S, total P, Ca^{2+}, Mg^{2+}, Na^+, and K^+ were determined on nitric–perchloric acid digests of the tissues by ICPOES. Chloride was determined on nitric–acetic acid extracts by coulometric–amperometric titration. Tissue N analyses were performed with a LECO Carbon-Nitrogen Analyzer (Model CN2000; LECO, St. Joseph, MO).

By 28 Apr., ≈50% of the nonsalinized plants had reached marketable stage with ≈50% of the florets on the inflorescence open (Armitage, 1993; Healy, 1998). To test the phasic growth model described by Lieth et al. (1995) (Fig. 1), however, plants were grown to full bloom. The following plant measurements were recorded at that time: stem length, diameter, and weight; inflorescence length; numbers of open florets, buds, and axillary buds; floret diameter; and root weight.

Stem length data were regressed against thermal time (°C·d) with a phasic growth model as shown in Figure 1. The model was fit to the data with SAS proc NLIN, DUD method (SAS Institute, 1985). Mathematically, the model may be expressed as:

$$F(t) = \begin{cases} \alpha - 1 + e^{\beta(t-t_0)} & \ldots \text{for } t_0 \le t \le t \\ \alpha - 1 + (1 + \beta(t - t_1))e^{\beta(t_1 - t_0)} & \ldots \text{for } t_1 < t \le t_1 \\ \alpha - 1 + \left(1 + \beta\varepsilon + \frac{\beta}{\gamma}\left(1 - e^{-\gamma(t-t_1-\varepsilon)}\right)\right)e^{\beta(t_1-t_0)} & \ldots \text{for } t > t_1 + \varepsilon \end{cases}$$

where $F(t)$ is plant height as a function of time, α is the initial plant height 1 week after emergence, β represents the intrinsic growth rate of the exponential phase, t_1 is the transition point between the first two phases, ε is the length of the linear phase, and γ is the intrinsic saturation rate and is equal to t_2, the end of the exponential growth phase (Lieth et al., 1995).

Nitrogen depletion from the solutions was calculated as the difference between the maximum and minimum NO_3^- concentrations over the course of the experiment. Ion selectivity coefficients were calculated from the ratio of specific ions in the plant divided by the ratio of those ions in the external medium (Flowers and Yeo, 1988).

A quadratic surface response model was used for analysis of variance to test the level of significance that salinity and nitrogen treatments contributed to the fit of the experimental design response variables (y) expressed as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1^2 + \beta_4 x_2^2 + \beta_5 x_1 x_2 + \varepsilon \quad [1]$$

where y represents the response variable, x_1 and x_2 represent the actual measured average

Table 3. Plant stem length and diameter, number of axillary buds, inflorescence dimensions, and shoot and root fresh weight of *Matthiola incana* as influenced by increasing salinity and nitrogen in solution[z].

Electrical conductivity ($dS \cdot m^{-1}$)	N ($mg \cdot L^{-1}$)	Stem length (cm)	Inflorescence length (cm)	Stem diam. (cm)	Axillary buds (no.)	Florets (no.)	Floret diam. (cm)	Shoot fresh wt. (g)	Root fresh wt. (g)
2	35	70.4 ± 1.7	23.5 ± 1.3	0.92 ± 0.0	0.39 ± 0.0	17 ± 0.7	5.1 ± 0.0	109.1 ± 2.9	9.1 ± 0.2
2	50	70.0	21.21	0.98	0.36	16	5.09	119.4	9.90
2	75	69.8 ± 1.3	21.5 ± 1.6	0.96 ± 0.02	0.35 ± 0.2	16 ± 0.5	5.2 ± 0.0	117.0 ± 3.1	9.9 ± 0.1
2	100	67.5 ± 1.6	20.4 ± 0.8	0.97 ± 0.01	0.30 ± 0.1	15 ± 0.5	5.0 ± 0.1	116.7 ± 5.0	10.7 ± 0.2
5	35	67.8	23.4	0.84	1.07	18	4.95	97.41	7.66
5	50	67.3	23.8	0.85	0.75	17	5.98	107.2	8.04
5	75	68.3 ± 3.7	22.4 ± 3.1	0.91 ± 0.01	1.0 ± 0.2	18 ± 2.4	5.2 ± 0.3	115.2 ± 5	8.4 ± 0.0
5	100	69.5	24.2	0.90	0.54	17	4.83	113.2	8.52
8	35	63.3	22.1	0.81	1.31	16	4.86	96.00	7.03
8	50	66.5 ± 1.7	23.3 ± 1.0	0.81 ± 0.0	1.3 ± 0.1	19 ± 0.1	4.7 ± 0.2	103.3 ± 1.0	7.0 ± 0.3
8	75	65.6	25.5	0.84	2.02	18	4.68	103.3	6.65
8	100	66.2	22.1	0.82	1.47	19	4.59	102.6	7.06
11	35	60.1 ± 2.7	19.9 ± 0.8	0.77±.03	1.6 ± 0.1	16 ± 1.3	4.4 ± 0.1	86.6 ± 5.1	6.1 ± 0.2
11	50	61.2	20.4	0.77	1.25	19	4.31	85.3	5.99
11	75	63.0	21.5	0.75	1.65	17	4.44	87.4	5.88
11	100	59.6 ± 1.0	19.4 ± 1.6	0.77±.03	1.9 ± 0.1	16 ± 1.3	4.5 ± 0.1	87.8 ± 4.8	5.9 ± 0.4

[z]Absence of some SE as a result of partial replicated design.

root zone salinity and initial irrigation water nitrogen concentrations, respectively, and ε is experimental error. Coefficients of the model are calculated and the significance value or probability of obtaining at least as great an F ratio given that the null hypothesis is true was calculated as part of the regression analysis (RSREG procedure; SAS Institute, 1997) as was the significance of the contribution of each factor (N and EC). Partial replication allowed for partitioning the total error sum of squares into lack of fit and pure error to verify that error variation in the model was not attributed to factor variables. The significance of the linear, quadratic, and crossproduct terms in the regression equation was determined.

Results and Discussion

Plant growth. The phasic growth model successfully fitted the plant height data as shown in Figure 2 where height for four treatments is plotted against thermal time. Correlations between model parameters (β, t_1, ε, and γ) and measured EC were significant (Fig. 3). Solution N concentration, however, had no influence on any of these parameters. The initial size parameter (α) was not significantly affected by either treatment. The intrinsic exponential growth rate (β) decreased as salinity stress increased (r^2 = 0.90; Fig. 3A). The onset (t_1) of the exponential growth phase (Fig. 3D) for plants stressed at 11 $dS \cdot m^{-1}$ was delayed 70 thermal units (≈4 d) relative to the controls. Stem lengths at t_1 were not significantly affected by salinity, e.g., 25 and 24 cm for the plants grown at 2 and 11 $dS \cdot m^{-1}$, respectively (Fig. 2; Table 2). The duration (ε) of the exponential growth phase (Fig. 3B) also decreased from 274 to 187 thermal units as salinity increased from 2 to 11 $dS \cdot m^{-1}$. By the end of the exponential phase, t_2 or (ε + t_1), the nonsaline control stems had reached marketable height (≈60 cm) with ≈50% of the florets in the inflorescence open. At the same time, stems from the 11 $dS \cdot m^{-1}$ treatment were ≈40 cm long with only a few of the inflorescences showing color, and these plants required an additional 200 °C·d to reach marketable height.

The delay in developmental timing found in this study contrasts markedly with the results reported by Heuer and Ravina (2004) who observed that salinized stock plants were the first to flower and senesce. Reasons for this discrepancy may include differences in irrigation water composition and also time under treatment. Heuer and Ravina (2004) ended saline treatments and continued irrigating all plants with nonsaline water 2 months before final harvest.

For purposes of testing the growth model, plants were grown to full bloom and the effect of treatment on stock yield components at full maturity is shown in Table 3. Salinity generally reduced stem and inflorescence length, stem and floret diameter, and root and shoot fresh weights. The numbers of florets per inflorescence was unaffected by salt stress. Numbers of axillary buds increased markedly as salinity increased from 2 to 11 $dS \cdot m^{-1}$. With the exception of root fresh weight and root/shoot ratio, the interactive effects of salinity and irrigation water N concentration did not significantly affect plant growth parameters (Table 4).

Yield components of stock cv. Cheerful White were considerably different from those obtained for the same cultivar and seed source grown in the greenhouse under similar

Table 4. Probability of significant effects of salinity and nitrogen treatment factors on plant harvest variables[z].

	Factor			Quadratic regression coefficients						Regression		
Variable	EC	N	r^2	Intercept	EC	N	EC^2	EC*N	N^2	Linear	Quadratic	Crossproduct
Shoot fresh wt.	<0.0001	0.0365	0.89	87.8	0.6410	0.7580	–2.3E-01	–0.01	–4.40E-03	<0.0001	0.019	0.3367
Root fresh wt.	<0.0001	<0.0001	0.98	9.34	–0.4710	0.0270	1.8E-02	–0.003	6.00E-06	<0.0001	0.0311	<0.0001
Root/shoot	<0.0001	0.0322	0.9	0.099	–0.0046	0.0000	3.0E-04	–1.9E-05	2.90E-06	<0.0001	0.0005	0.0143
Plant height	<0.0001	0.5948	0.78	66.6	0.0490	0.1260	–9.8E-02	4.10E-03	1.11E-03	<0.0001	0.0875	0.4240
Inflorescence ht.	0.0316	0.5555	0.45	20.1	1.2100	0.2200	–1.3E-01	–3.90E-03	–4.60E-04	0.2361	0.0209	0.3435
Axillary buds	<0.0001	0.3197	0.88	–0.057	0.2170	0.0020	–1.0E-02	9.30E-04	–4.50E-05	<0.0001	0.1898	0.0958
Number of flowers	0.0926	0.4477	0.39	12.2	0.8190	0.0930	–6.7E-02	2.70E-03	–8.80E-04	0.2534	0.0545	0.3963
Flower diameter	0.0008	0.666	0.64	4.74	0.0360	0.0150	–1.0E-02	2.70E-03	–1.30E-04	0.0004	0.1369	0.6671
Stem diameter	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Leaf N	0.0158	0.0808	0.53	2.37	0.0910	0.0150	–5.5E-03	–6.40E-04	–6.50E-05	0.0158	0.1273	0.0607
Stem N	0.0027	0.0592	0.6	1.05	–0.0390	0.0067	4.6E-03	–8.20E-04	7.00E-06	0.0021	0.4512	0.0293
Inflorescence N	<0.0001	0.0563	0.78	4.4	–0.0890	0.0003	6.7E-03	–8.70E-04	5.30E-05	<0.0001	0.1294	0.0203
Root N	0.0069	0.0407	0.63	1.19	–0.0780	0.0029	5.0E-03	–3.60E-05	3.80E-05	0.0012	0.0279	0.8447
Shoot N	0.1816	0.003	0.56	3.3	0.0680	0.0120	–1.6E-03	6.10E-04	3.10E-05	0.0044	0.6504	0.0367

[z]Coefficients of determination, quadratic surface response model coefficients, and regression term probabilities for linear, quadratic, and crossproduct terms in the model are given for each variable.
EC = electrical conductivity.

levels of salt stress (Grieve et al., 2006). Under nonsaline conditions, stems and inflorescences were ≈15% shorter with fewer florets than the greenhouse plants. Lysimeter-grown plants were sturdier, however, with thicker stems (diameter, 9.5 mm) compared with the greenhouse plants (5.3 mm). Yield, expressed as stem length of plants grown in the greenhouse, was not significantly reduced until irrigation water EC exceeded 8 dS·m^{-1}, whereas quality of the stems produced in the outdoor lysimeters was significantly reduced when salinity exceeded 5 dS·m^{-1} (Table 3).

Stock is highly valued not only for its marketable flowering stems, but also as a new crop, potentially useful for dietary and industrial oils (Heuer et al., 2005). Heuer and Ravina (2004) reported that dry matter production and seed yield of stock were not significantly reduced if the EC of the irrigation waters remained less than 6 dS·m^{-1}. Stem length, however, was unaffected until the EC exceeded 6 dS·m^{-1}. Plant heights reported from the Heuer studies (≈140 cm) were considerably taller than the ones produced in either of our experimental locations.

Mineral ion relations. Plants in all treatments remained healthy during the course of the experiments and no visible symptoms of ion toxicities or nutrient deficiencies were observed. It is noteworthy that no symptoms of N deficiency were observed and that plant N status appeared to be adequate even though the lowest N level (35 ppm) was less than half the concentration in the modified nutrient solution recommended by Hoagland and Arnon (1950).

Quadratic surface regression analysis showed significant, but independent, effects of salinity and irrigation water N on plant–ion relations. Calcium, Mg^{2+}, Na^+, K^+, and Cl^- were significantly affected by salinity; Na^+, K^+, and Cl^- were significantly influenced by N. As salinity increased from 2 to 11 dS·m^{-1}, leaf Ca decreased from 814 to 628 mmol·kg^{-1} dry weight despite a fourfold increase of Ca^{2+} in the irrigation water. Leaf Mg increased slightly but significantly from 178 to 201 mmol·kg^{-1} dry weight as salinity increased and external Mg increased sixfold (data not shown).

Leaf Na increased from 315 to 1200 mmol·kg^{-1} as salinity and external Na increased (Fig. 4). Increases in N also increased Na^+ uptake. For example, as irrigation water N increased from 35 to 100 ppm, leaf Na of plants grown in the 11 dS·m^{-1} treatment increased from 1200 to 1380 mmol·kg^{-1} (Fig. 4). Both salinity and increased N acted separately to cause significant reductions in leaf K (Fig. 5). The dominant stress was salinity; leaf K decreased from 1280 to 800 mmol·kg^{-1} as salinity increased. Under control conditions, leaf K decreased from 1400 to 1280 mmol·kg^{-1} as N increased from 35 to 100 ppm (Fig. 5). The ratio of K^+ to Na^+ in leaf tissue decreased markedly from 3.6 to 0.59 as salinity increased to 11 dS·m^{-1} and external Na increased from 10 to 61 mmol·L^{-1}. Ordinarily, such a low K^+: Na^+ would suggest that plant K would be inadequate for the normal

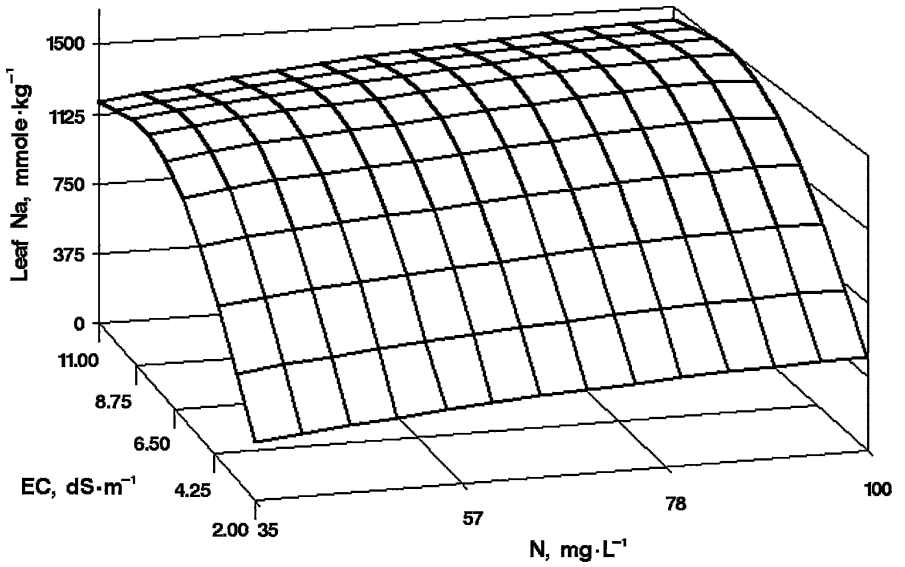

Fig. 4. Predicted surface relationship of sodium concentration in *Matthiola incana* leaves as a function of salinity and nitrogen in the irrigation water.

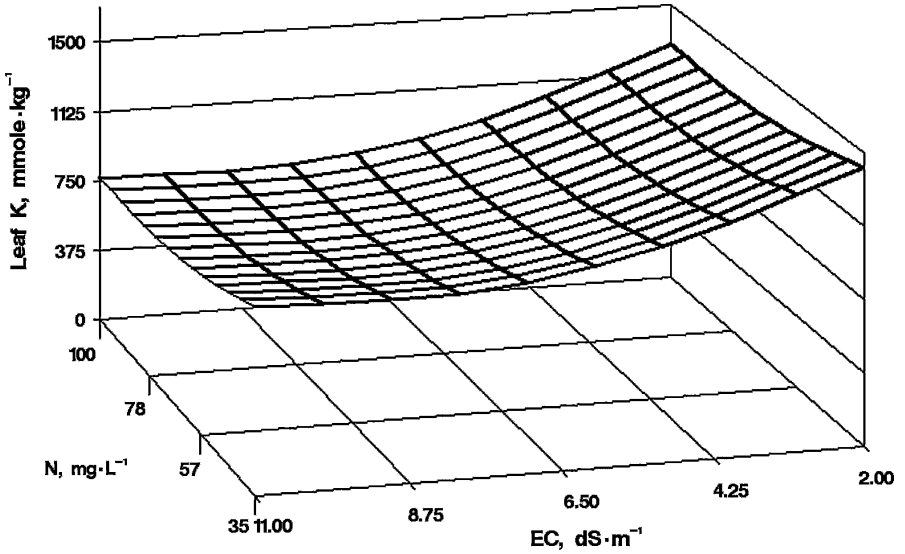

Fig. 5. Predicted surface relationship of potassium concentration in *Matthiola incana* leaves as a function of salinity and nitrogen in the irrigation waters.

functioning of many metabolic processes (Ashraf, 1994; Maathuis and Amtmann, 1999). However, the K status of stock did not appear to be impaired. The cultivar showed a strong preference of K^+ over Na^+, and the value of the selectivity coefficient ($S_{K,Na}$) at the highest salinity (7.2) was only slightly lower than that in the nonsalinized leaves (7.6).

Leaf Cl increased significantly from a mean of 380 to 980 as salinity increased to 11 dS·m^{-1}. At each salinity level, however, leaf-Cl decreased as external N increased from 35 to 100 ppm (2.5 to 7.1 mM). This effect was most pronounced in the control plants in which leaf Cl decreased 40% (480 to 290 mmol·kg^{-1}) as N rose from 35 to 100 ppm (2.5 to 7.1 mM) (Fig. 6). Antagonism of NO_3^- on Cl^- uptake and accumulation has been observed in numerous annual horticultural species (Bar et al., 1997; Kafkafi et al., 1982; Martinez and Cerdá, 1989). Leaf damage and growth reduction resulting from Cl^- toxicity in many plants is often mitigated through application of nitrate (Grattan and Grieve, 1999). Stock, however, does not appear to be prone to specific ion toxicities and increases in substrate N did little to improve the salt tolerance of the crop. Moreover, stock appears to be tolerant of substrate Cl concentrations less than 85 mM (Lunt et al., 1954) as was the case in this lysimeter study.

Nitrogen was differentially distributed among plant parts and lower in the roots (0.9%) and stems (≈1.1%) than in the inflorescences (≈4%) and leaves (3%). Total leaf N significantly increased from 2.9% to 3.3% in the nonsaline control plants as external N

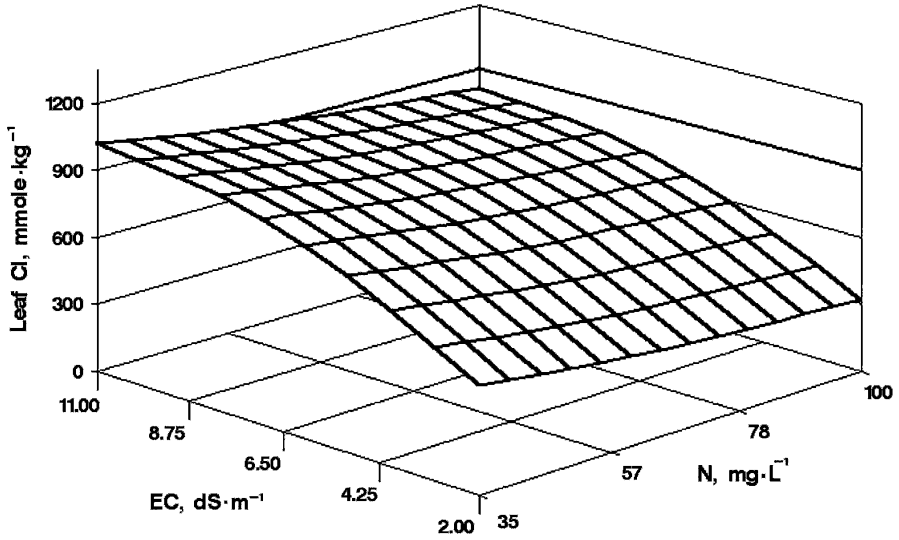

Fig. 6. Predicted surface relationship of chloride concentration in *Matthiola incana* leaves as a function of salinity and nitrogen in the irrigation waters.

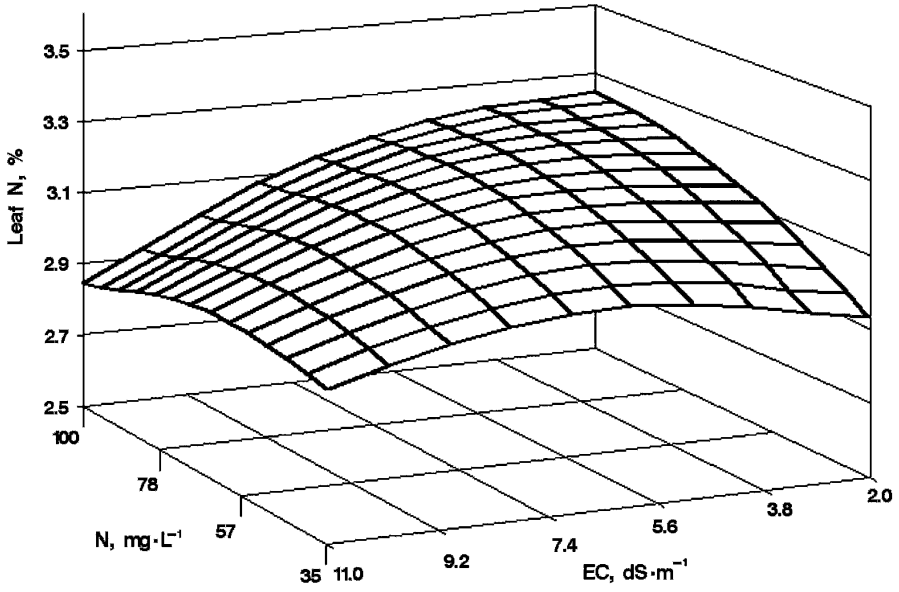

Fig. 7. Predicted surface relationship of nitrogen concentration in *Matthiola incana* leaves as a function of salinity and nitrogen in the irrigation waters.

increased from 35 to 100 ppm (Fig. 7). Total N in inflorescences of nonsaline stems showed a similar response, increasing from 4.2% to 4.7%. At higher salinity levels, neither leaf nor inflorescence N was affected by N concentration in the irrigation waters. Leaf N in young, actively growing stock leaves reportedly contain 4.5% to 5% total N, which decreases with age (Yang et al., 1998). Lower leaf N concentration (≈3%) determined in the present study may have been a result of sampling and compositing fully expanded, older leaves.

Conclusions

This study demonstrates that a commercially important cut flower species is a suitable candidate for saline water reuse systems. Stock (*Matthiola incana*), a relatively salt-tolerant species, produced marketable stems under irrigation with saline solutions ranging from 2 to 11 $dS \cdot m^{-1}$ amended with substrate N concentrations ranging from 35 to 100 ppm. The phasic growth model satisfactorily described the time course of plant development. Salinity reduced growth rate and delayed time to harvest. Neither growth parameters nor yield components were significantly affected by increases in substrate N. This study established that, in closed-loop irrigation systems, the N requirements for stock are low and that growers could minimize costs and limit offsite pollution potential by reducing N inputs. Mineral ion relations were influenced significantly, but independently, by both salinity and N.

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