Improved Management Practices for Water Use Efficiency in Floriculture Production

Principal Investigators:

Catherine M. Grieve
Plant Physiologist
USDA/ARS
George E. Brown, Jr.
Salinity Laboratory
Riverside, CA 92507
cgrieve@ussl.ars.usda.gov
Phone: (951) 369-4836
FAX: (951) 342-4963

James A. Poss
Soil Scientist
USDA/ARS
George E. Brown, Jr.
Salinity Laboratory
Riverside, CA 92507
jposs@ussl.ars.usda.gov
Phone: (951) 369-4863
FAX: (951) 342-4963

Christy T. Carter
Halophyte Biologist
USDA/ARS
George E. Brown, Jr.
Salinity Laboratory
Riverside, CA 92507
ccarter@ussl.ars.usda.gov
Phone: (951) 369-4841
FAX: (951) 342-4963

A. STATEMENT OF WORK, SECTION 1: RELEVANCE AND IMPORTANCE

a. Quantification of Growth and Development of Selected Cut Flower Crops as Influenced by Saline Irrigation Waters and Nutrients

Saline wastewaters may provide a valuable water source for the irrigation of selected floriculture crops as water quality and quantity becomes limited and as demand for quality water increases. Historically, the agriculture industry has been one of the primary users of water resources. This is especially true in the floriculture industry where many salt sensitive crops require high quality water for irrigation. In recent years, however, population growth has also increased demand for fresh water in many regions of California (Parsons, 2000). Additionally, a majority of cut flower growers are located in coastal areas where ground waters are becoming more saline. Many growers in these areas are also opting to sell their land and relocate further inland as coastal real estate values increase, and some are yielding to foreign producers. Inland agricultural soils typically contain higher concentrations of salts due to increased evaporative demand and can pose other limitations on flower production based on microclimate differences associated with the coast. Local economies can be negatively influenced by the loss of local flower producers to foreign markets. As competition for quality water continues, the use of saline ground waters and wastewaters for irrigation becomes a viable option for establishing and sustaining many salt tolerant floriculture crops. Local production can save energy and maintain local economic and environmental resources if irrigation and drainage issues are addressed.

The greenhouse and nursery industries are also facing increasing political and financial pressures due to restrictions on the release of effluents and the cost of improving the quality of local water resources. Specifically, the discharge of effluents from greenhouse and nursery operations has become a critical issue with regard to contamination of rivers, streams, aquifers, and tidal pools since effluents typically contain high concentrations of salts and nutrients, particularly nitrates.

In an attempt to address political, economic, and environmental issues, many growers have begun reclaiming these waters for use in agricultural systems.

When compared to agronomic crops, horticultural crops have been identified as being better adapted for use with newer water-efficient technologies due to their higher value and controlled growing conditions (Parsons, 2000). The cut flower industry is an economically important industry in the United States. In 1998, over 2 million cut flower operations nationwide conducted over $512 million in total sales. Of these operations, approximately 550,000 were located in California which brought in nearly $322 million (Census of Horticultural Specialties, 1998).

One goal of this investigation, therefore, is to develop improved methods for fertilization and irrigation for cut flower production under saline conditions, thereby reducing nitrogen waste. Mathematical models become important tools in this process as they aid our interpretation, understanding, and, most importantly, our ability to predict how patterns of growth will change as environmental conditions vary. Quantifying growth patterns is important in order to evaluate specifically how a crop will respond to increasing salinity and varying nitrogen treatments. In these investigations, patterns of plant growth will depend primarily on variations attributed to salinity and nitrogen based on the experimental design. Specifically, our goals are: (1) to utilize saline waters for the production of marketable cut flowers; (2) to have the minimal residual nitrogen waste (especially nitrates) possible while maintaining marketable productivity; (3) to quantify the water and nitrogen requirements for cut flower species under varying salinities; and (4) predict plant growth based on salinity, varying nitrogen treatments, and other environmental factors with the use of a mathematical growth model. These objectives build on findings of research conducted under a previous WUE grant (WUE contract no. 460000-1620) which partially focused on the production of cut flowers using irrigation waters typical of degraded waters present in three different areas of California. These waters differ markedly in ion composition. Saline “tail waters” in the southern inland valleys of Riverside and Imperial Counties are generally high in sodium, magnesium, chloride, and sulphate, whereas drainage waters in the San Joaquin Valley are dominated by sodium, sulphate, chloride, magnesium, and calcium, predominating in that order. Many floriculture operations are located in coastal areas where sea water intrusion is becoming problematic. The previous project addressed crop response to irrigation waters high in sodium and chloride, the dominant ions in sea water. In the proposed research, ion compositions for the simulated irrigation waters will be representative of sea water contaminated ground waters in the coastal areas of high floriculture production and those typical of “tail waters” present in Coachella Valley where floriculture operations are increasing.

b. Response of Selected Cut Flower Crops to Salinity Applied at Different Stages of Growth

Supplies of high-quality water for floriculture production are diminishing, requiring creative approaches to conserve fresh waters and to manage degraded, often saline, wastewaters more effectively. One viable approach is the application of saline irrigation waters at stage(s) of plant growth when the plant organs under development are relatively resistant to irreversible and/or injurious changes due to salt stress. Waters of higher-quality would be used only during stages of growth where salinity would diminish the commercial acceptability of the product.

With very few exceptions, the response of cut flower crops to salt stress imposed at different growth stages has not been addressed. Those few studies, however, describe positive effects of application of salt stress prior to flowering. Shillo et al. (2003) reported the effect of salinity on flower production of *Eustoma grandiflorum* (cv. Heidi Deep Blue). Plants were grown under non-saline conditions until the final stages of vegetative growth. Salinity (6 dS m^{-1}) was applied at two successive flushes of flowering, from bud appearance to full flower development. Between flushes, salinity was reduced to control levels. These investigators observed no deleterious effects of salinity (e. g. chlorosis, necrosis, stunting) on leaves or flowers. Number of flowers, stem weight and diameter significantly increased in response to salinity. A noticeable benefit of salt treatment was the production of more compact flower clusters, a desirable trait which prevents typical drooping of the *Eustoma* inflorescences. Baas et al. (1995) observed a similar positive effect with carnation. Salt stress during reproductive growth resulted in shorter, more robust peduncles, and larger inflorescences. Research conducted at the U. S. Salinity Laboratory showed that flower production of statice (*Limonium perezii* cultivar 'Blue Seas') was enhanced if salinization was delayed past the emergence and early seedling stages (Carter et al., manuscript submitted).

Several commercially-important cut flower crops have been screened for salt-tolerance at this Laboratory through research partially funded by the California Department of Water Resources, Office of Water Use Efficiency in 2001-2003. Species were identified whose yield components meet industry standards for consumer acceptability when grown under irrigation with moderately saline waters. Among these crops were: stock (*Matthiola incana*), sunflower (*Helianthus annuus*), celosia (*Celosia argentea*), snapdragon (*Antirrhinum majus*). With one (or more) of these species as the test crop, the goals of this section of the proposal are to determine the magnitude of crop salt sensitivity during discrete growth and development stages. From this information, a water management strategy will be designed whereby irrigation waters differing in salinity would be applied or withdrawn at specific periods of the growth cycle. Potential benefits from this research would ensue not only through enhanced management of low-quality waters, but also by improved floral characteristics and yield components such as peduncle length and weight, number and size of flowers, and vase life.

Literature reports concerning the salt tolerance of cut flower crops are extremely limited. In the overwhelming majority of these studies, the crops have been challenged by relatively constant salt stress throughout the cropping season. It is well-known, however, that other horticultural crops (Pasternak et al., 1986; Carvajal et al., 1998; Li et al., 2002) as well as many agronomic crops (Maas and Poss, 1989; Francois et al., 1994; Grieve et al., 2001) are sensitive to soil salinity changes at specific times during their growth and development.

c. Application of Non-invasive Methods for Remote Detection of Salinity Stress in Floriculture Plants

High resolution spectral signatures for many cultivated and native plant species have been obtained by non-invasive, remotely-sensed thermal imagery and spectroradiometry. Unique species-specific thermal and spectral patterns have been invaluable diagnostic tools for assessing crop response to stresses such as plant water deficit, nutrient deficiency or toxicity, herbicide-induced injury, and pests. (Pinter et al., 2003). Salinity-induced changes in spectral properties of agronomic crops have been reported from field trials, e. g. cotton (Wiegand et al., 1994), sugar cane (Wiegand et al., 1996), soybean (Wang et al., 2001, 2002b), and elephant grass (Wang et al., 2002a).

Interpretation of remotely sensed data requires isolating and identifying many different processes and factors acting simultaneously in the cropping system. Spectral reflectance information may be confounded or occluded by similarities in reflectance data for two (or multiple) stressors acting in combination, for example, salinity stress and water deficit.

Information is extremely limited regarding application of remote sensing technology to quantify changes that occur in floriculture crops irrigated with saline wastewaters. Application of this technology would be particularly useful for the detection of salinity stress prior to visual signs of plant damage or deterioration in field-grown flowers. If salinity stress could be detected in a timely manner, remedial action (e. g. increasing the leaching fraction or application of higher quality water) could then be taken to prevent or ameliorate irreversible changes affecting consumer acceptability and yield.

B. STATEMENT OF WORK, SECTION 2: TECHNICAL/SCIENTIFIC MERIT, FEASIBILITY

Equipment and Facilities

The laboratory is well equipped to perform the required studies on salinity research. Two greenhouses provide 6,000 ft^2 of space with a computer network for controlling environmental conditions. A total of 90 sand tanks each measuring 1.2 m x 0.8 m x 0.5 m deep, are located in the greenhouses. Each set of 3 tanks is irrigated from a 765-L reservoir located in the greenhouse basement. One outdoor facility contains 24 outdoor sand culture units measuring 0.76 x 2.0 x 1.5 m deep, <u>each</u> irrigated from a 1800-L reservoir and 24 units (1.5 x 3 m x 2 m deep), <u>each</u> irrigated from a 4000-L reservoir. In all tanks the sand has an average bulk density of 1.4 $Mg \cdot m^{-1}$ and, at saturation, has an average volumetric water content of 0.34 $m^3 \cdot m^{-3}$. Irrigation scheduling (time and duration) is automated. Irrigation solutions can easily be measured for electrical conductivity and pH, and sampled for mineral ion analysis. The outdoor sand tanks have been utilized for water use and crop productivity experiments related to saline water drainage reuse for irrigation. A Class I agrometerological station is installed immediately adjacent to the experimental site. This facility was recently developed as a volumetric lysimeter system (Poss et al., 2004) to measure evapotranspiration, irrigation, and drainage volumes. A rugged hyperspectral scanner will be used for remote detection of crop response to salinity and nutrient concentrations in the irrigation waters. The laboratory has a LICOR 6400 steady-state photosynthesis analyzer, LICOR LI-3000 leaf area meter, SPAD chlorophyll meter, Cardy nitrate meter, Sap Flow Sensor Technology, pressure bombs, osmometers, and many other analytical resources. Laboratory facilities and equipment exist for complete chemical analysis (Ca, Mg, Na, K, total-S, total-P, total-N, NH_4^+, and NO_3) including trace elements using inductively coupled plasma optical emission spectrometry or titrimetry (Cl) as appropriate. Assistance will also be provided by a statistician and laboratory helpers, hired through a Cooperative Agreement with UC Riverside. Laboratory helpers will collect and prepare plant samples for ion analysis, aid in preparation of irrigation waters, assist in data collection and in harvesting.

a. Quantification of Growth and Development of Selected Cut Flower Crops as Influenced by Saline Irrigation Waters and Nutrients

***Treatments*—**A 4 × 4 factorial design with partial replication will be used to assess the effects of salinity and nitrogen on the production of cut flowers. Seeds will be sown in each of twenty-three outdoor sand tanks at the George E. Brown, Jr., Salinity Laboratory in Riverside, CA. Four rows with 25 wells will be planted with two seeds each. Four salinity treatments with target electrical conductivity (EC) levels of 2, 5, 8, and 11 dS m^{-1} will be combined with four nitrogen levels of 35, 50, 75, and 100 ppm with some proportion of NH_4 included to be used as irrigation water. Irrigation waters used in the study will be prepared to simulate saline wastewaters available to cut flower growers in California, e. g. well waters affected by seawater intrusion, tail waters or drainage waters from agricultural cropping operations, direct or recycled nursery runoff waters. The salt solutions will be prepared with tap water to simulate the mineral composition ratios of the irrigation water being replicated and from predictions based on appropriate simulations of what long-term compositions would be after further concentrations by plant-water extraction and evapotranspiration (Suarez and Simunek, 1997). Planting density and cultivation will be based upon standard industry practices. To avoid salt shock, plants will be exposed to salt treatments incrementally after the appearance of first leaves. Seven of the sixteen treatments will be replicated once and one additional tank containing no plants will be irrigated with tap water only to allow for evaporation estimates from a bare surface. Hoagland's micronutrient solution will also be included in the 23 treatments. Osmotic potential and electrical conductivity of the solutions (within and among treatments) will be confirmed with an osmomoter and conductivity meter, respectively.

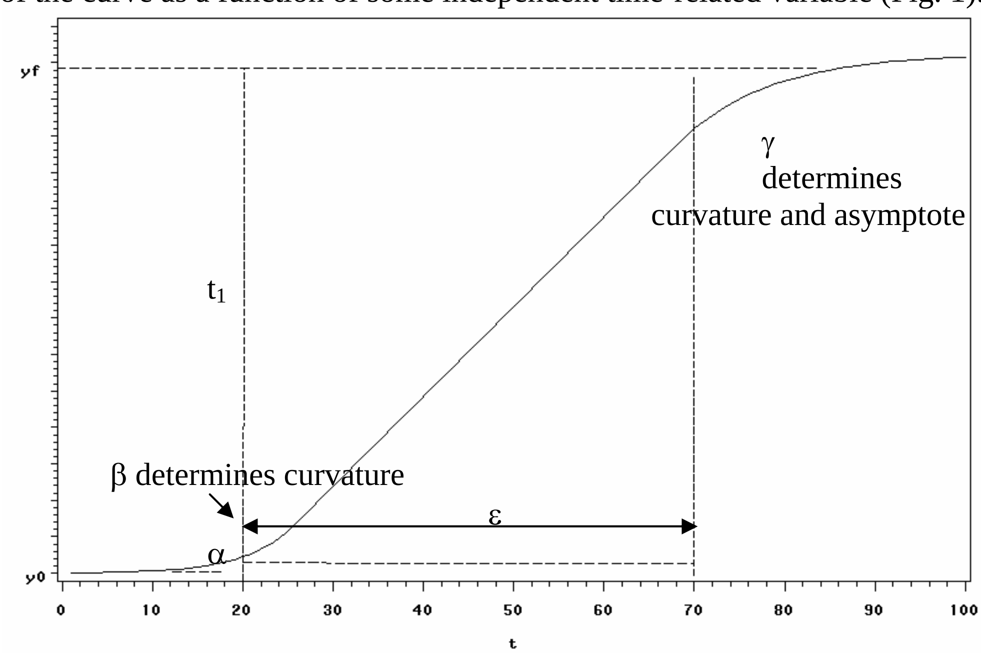
***Data collection*—**Plant height measurements will be taken on ten designated plants from each tank twice per week. Water samples will be collected weekly from each of the 24 reservoirs as well as tap water used to refill the reservoirs. Water will be analyzed for concentrations of nitrate and ammonium. Electrical conductivity and osmotic potential will also be monitored weekly. At 1/3 and 2/3 into the growing cycle, approximately three plants will be harvested from each tank for nutrient and mineral analysis (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, total S, total-N, and total-P). Leaf material will be weighed, dried, reweighed, and ground through a Wiley mill to pass a 60-mesh screen. The ten plants measured twice per week for height will be selected for the final harvest. Stem and inflorescence height, stem and inflorescence mass, and stem diameter data will be collected. Leaf material will be analyzed for nutrient and mineral content. Mass balance for nitrogen will also be calculated.

***Statistical analyses*—**Plant data will be analyzed with quadratic surface regressions using the RSREG procedure to determine any salinity and nitrogen effects or interactions. Ridge analysis will be used to find optimums and minimum combinations of nitrogen and salinity that maximize or minimize various variables (e.g. plant stem length, flower size, number of flowers) important for evaluating the marketability of the cut flower products. This will also be used to determine which treatment combination will optimize nitrogen-use-efficiency in the system. All statistical analyses will be performed in SAS v. 8.2 (SAS Institute, 2001).

***Growth model*—** The use of a phasic model described by Lieth et al. (1995) provides useful, biologically significant model parameters that can be tested for sensitivity to salinity and nitrogen treatments. The three-phase model is represented by an initial size parameter (α), an estimation of the intrinsic growth rate of the exponential phase (β), a transitional phase between the first two phases (t_l), the length of the linear exponential phase (ε), and the final intrinsic saturation rate (γ). Mathematically, this can be expressed as:

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

A graphical depiction of the sigmoid growth function shows the relation of the parameters to the shape of the curve as a function of some independent time-related variable (Fig. 1).



Temperature and other environmental effects are very important components of any growth model. Even though a primary objective of this study is to model salinity and nitrogen effects, certain baseline data related to evapotranspiration and growth rates (radiation, relative humidity, temperature/heat units) will also be monitored hourly and reported for the final response functions that enable further universal application testing in the future.

b. Response of Selected Cut Flower Crops to Salinity Applied at Different Stages of Growth

Our hypothesis is that saline waters used to irrigate floriculture crops may be managed more efficiently if (a) the sensitivity/tolerance of the crop to salts and specific ions at specific stages of its growth cycle is well-defined, and (b) application of irrigation waters of appropriate quality are scheduled in accordance with those specific stages. Research conducted in Statement of Work Part a. (above) will provide patterns of salinity-induced growth responses of selected crops plotted as a function of thermal time (^{0}C d). These models will be used as guides for defining growth stages under consideration. Potential test crops include (but are not limited to) stock, sunflower, snapdragon, celosia, and eustoma. The floriculture crop will be grown in greenhouse sand cultures and salt stress applied or withdrawn at discrete times and durations as appropriate. Resulting crop quality will be assessed by application of an appropriate index, such as the weight-length ratio of the flowering stems (Moricot et al., 1998).

Our experiments with stock (*Matthiola incana,* ‘stock’), for example, have shown that a commercially acceptable crop can be produced using saline waters with electrical conductivities up to 14 dS/m. The proposed research would study the response of stock to the effects of increases in external salinity at the end of the vegetative phase. The goal would be to determine if increased stress reduces internode lengths, yielding a more compact, more desirable inflorescence. This approach also shows promise for height control in cut flower crops which tend to produce excessively long, frequently weak, stems.

Irrigation waters used in the study will be prepared to simulate saline wastewaters available to cut flower growers in California, e. g. well waters affected by seawater intrusion, tail waters or drainage waters from agricultural cropping operations, direct or recycled nursery runoff waters.

c. Application of Non-invasive Methods for Remote Detection of Salinity Stress in Floriculture Plants

The proposed study will address spectral reflectance information as related to variations in salinity, volumes of applied irrigation water, and specific ion stress as related to crop yield and quality. Crops will be grown in greenhouse sand cultures as well as in an outdoor volumetric lysimeter system (VLS). Construction of the VLS was funded by a CAL-FED grant (Contract 460000-1620), administered by the California Department of Water Resources. The flexibility of the VLS permits simultaneous monitoring of electrical conductivity, soil matric potential, temperature, water applications, ET requirements for the crop, and drainage patterns with a high degree of control and resolution.

Ground-based spectral reflectance data will be collected with an ASD FieldSpec Pro spectroradiometer (Analytical Spectral Devices, Inc., Boulder, CO). Canopy temperatures will be obtained with an infrared thermal sensor. Non-invasive canopy leaf area indices will be determined with a LICOR LAI-2000 canopy analyzer or with image analysis software. Micro-meteorological measurements including soil and air temperatures, baseline evapotranspiration, photosynthetically active radiation, relative humidity, and wind velocity will be recorded.

Test crops for this portion of the project will be selected from cut flower species (e. g. stock, sunflower, snapdragon, celosia) whose performance under salt stress has been previously established in research also funded by Contract 460000-1620. Salt tolerance of these species range from relatively sensitive (snapdragon) to moderately tolerant (stock). All crops are potentially valuable candidates for production under field conditions in areas where use or reuse of saline wastewaters is an economically attractive option.

Initial experiments will be conducted by subjecting the test crop to a range of saline irrigation treatments which are constant over the growing season. Plant response to salinity will be evaluated by remotely sensed changes in foliar biochemical processes (e. g. photosynthesis, evapotranspiration) and products (e. g. chlorophyll, nitrogen, amino acids, sugars, anthocyanins). Floral quality and yield will be determined. These parameters will be used as “bench marks” for the subsequent experiments in which the same crop is subjected to periods varying in stress intensity. Stress will be applied or relieved at specific stages of plant growth. Remotely sensed changes will be measured and correlated with specific plant responses. See Section 2 of this Proposal.

Remotely-sensed measurements obtained under the controlled conditions available at this Laboratory will provide reliable inputs for crop water production function models. These models can then be evaluated for their ability to predict the impacts of soil salinity on crop water use and economic productivity.

Task List and Schedule

Tasks	Dec 2005	Mar 2006	Jun 2006	Sep 2006	Dec 2006	Mar 2007	Jun 2007	Sep 2007	Dec 2007	Projected Costs
Saline water and nutrient interaction experiments	■	■	■	■	■	■	■	■		$52,000

Salinity effects on developmental stages experiments										$52,000
Non-invasive methods for remote detection of salinity experiments										$52,000
Data analyses & software										$10,000
Preparation of manuscripts and reports										$5,000
Presentations at scientific and industry organizational meetings										$11,000
Quarterly expenditure projection (in thousands of dollars)	19.5	21.4	21.4	23.2	23.2	23.2	23.2	23.2	3.7	**TOTAL $182,000**

C. STATEMENT OF WORK, SECTION 3: MONITORING AND ASSESSMENT

Plant height (or stem length) and flower quality will be the final measures to determine marketability of flowers with respect to treatments in each investigation. Electrical conductivities (EC), pH, soil water potential, and evapotranspiration of treatment irrigation waters will be monitored and recorded weekly. Environmental data will also be collected weekly. Plants will be analyzed for mineral and inorganic ion content in order to correlate these findings with treatment water compositions. Additionally, treatment water compositions will be measured weekly. Water and nitrogen use efficiency will be calculated based on plant biomass with respect to each salinity and/or nitrogen treatment for each species studied.

Twice-weekly measurements of plant height will provide baseline data for use in a phasic growth model in conjunction with environmental data (Lieth, 1995). As stated above, temperature and other environmental effects are very important components of any growth model. Even though a primary objective is to model salinity and nitrogen effects, certain baseline data related to evapotranspiration and growth rates (radiation, relative humidity, temperature/heat units) will also be monitored hourly and reported for the final response functions. The information provided by this model will be species dependent.

Remotely sensed changes in plant foliar material will vary depending on water irrigation treatments and the timing of application (or plant developmental stage). These findings can also be correlated with environmental data and other variables to simulate field conditions. Results from all experiments will be shared with the Department of Water Resources through yearly reports and scientific publications. Results will also be made available to growers directly and through University of California and county extension specialists. Data may also be made available upon request.

D. QUALIFICATIONS OF APPLICANTS & COOPERATORS

This research project will be conducted by two USDA Agricultural Research Service scientists and one cooperative post-doctoral researcher appointed through the University of California-Riverside. With over 60 years of combined experience, the investigators have expertise in areas of plant physiology, soil science, plant nutrient-salinity interactions, nutrient availability, irrigation management, salinity effects on plant developmental stages, remote sensing, environmental restoration, and the biology of salt tolerant plants. Grieve and Poss were also part of the research team involved with evaluating salt-tolerant floral and forage crops for conserving fresh water resources conducted at the U. S. Salinity Laboratory (WUE contract no. 460000-1620). Resumes for the three researchers are attached.

Role of Investigators:

Grieve—Project leader; Oversees all phases of the project and project development; Assists in the selection of floral crops; Writes and prepares reports and manuscripts; Attends scientific meetings; Cooperates with growers.

Carter—Assists with project development; Selects of floral crops; Designs experiments; Actively involved in data collection and analysis and presentation of reports; Involved with plant physiological aspects of project. Writes and prepares manuscripts; Attends scientific meetings; Cooperates with growers.

Poss—Assists with project development; Actively involved in data collection and analysis and presentation of reports; Monitors soil and water chemistry and irrigations; Involved with remote sensing aspects of project; Cooperates with growers.

Cut flower representatives will advise as to industry standards for cut flowers and as to any specific growing conditions for particular crops.

E. OUTREACH, COMMUNITY INVOLVEMENT, AND ACCEPTANCE

The USDA's Agricultural Research Service considers outreach activities a high priority. Information obtained from these investigations will be shared with professors and extension specialists at UC Riverside (Dr. Stephen Wegulo) and UC Davis (Drs. Steve Grattan and Heinrich Lieth) in addition to county extension floriculture and environmental horticulture specialists (Dr. Karen Robb, San Diego County; Julie Newman, Ventura County; etc.). Additional efforts will be made to growers through industry/trade newsletters and organizations, such as the California Cut Flower Commission (CCFC) and California Nurseryman's Association.

We are committed to continuing and expanding our relationships with industry personnel. To date, we have been consulting with growers to determine research needs as they relate to nutrients and salinity. It can be expected that results will also be made to growers directly. The USDA/ARS also maintains a technology transfer database (TEKTRANS) on the internet which includes title summaries describing research projects and findings. This information is accessible by the public. Additional opportunities for community involvement include hiring student employees for the duration of the project.

Results of this project will also be disseminated through presentations at professional scientific meetings of horticultural societies, such as the annual meeting of the American Society for Horticultural Science (ASHS), and through publications in peer-reviewed scientific journals, such as *HortScience*, *Journal of the American Society for Horticultural Science*, or the *Journal of Horticultural Science*.

F. INNOVATION

As previously stated, remotely-sensed measurements obtained under the controlled conditions available at this Laboratory will provide reliable inputs for crop water production function models. These models can then be evaluated for their ability to predict the impacts of soil salinity on crop water use and economic productivity.

G. BENEFITS AND COSTS

Table C1: Project Costs (Budget)—The 'Projected Costs' (Budget) Table C1 is included at the end of this document. The table provided below is a summary and reflects the same categories provided in Appendix C of Table C1 to allow for ease of reading.

Category	Year 1 2006	Year 2 2007	Total
Administration			
Salaries & Wages	$50,000	$50,000	**$100,000**
Fringe benefits	$5,000	$5,000	**$10,000**
Supplies	$15,000	$15,000	**$30,000**
Equipment	$8,000	$8,000	**$16,000**
Travel	$5,500	$5,500	**$11,000**
Monitoring & Assessment	$5,000	$5,000	**$10,000**
Report & manuscript preparation	$2,500	$2,500	**$5,000**
Total	**$91,000**	**$91,000**	**$182,000**

Project funds are being requested for labor and benefits costs for undergraduate student workers to assist with conducting and maintaining experiments and performing chemical analyses and for a part-time statistician. Supplies and equipment include salts and nutrients for treatment irrigation waters, plant material such as seeds, fungicides and insecticides, pH meters, electrical conductivity (EC) meters, an osmometer, and other consumable items. Maintenance includes replacement costs for pumps and sand tank VLS sensors including computer upkeep. Funds for travel are being requested to permit PI's to attend professional scientific meetings, meetings with members of the California floriculture industry and trade organizations, and meetings with cooperative extension and university personnel. Monitoring and assessment funds are needed to process plant material and treatment water for ion and mineral analyses. Funding for publication costs is required to offset page charges in scientific journals and trade publications and for processing yearly reports to DWR.

It is difficult to quantify project outcomes given that water use efficiency will change depending on the crop, environmental conditions, growing techniques (as they vary by grower), and location (desert vs. coastal). However, the overall benefit is that fresh water resources will be increasingly conserved. In many cases, fewer nutrients and saline effluents will be discharged into the environment as salinity will also be optimized for ultimate treatment or disposal strategies. Additional benefits to the industry may include increased efforts for environmental management, lower production costs, and additional flexibility in product development. Some floral crops also benefit from the addition of salts in that they produce more flowers or more compact inflorescences. Many of these same models may also be applied to agronomic crops grown in the Imperial and Coachella Valleys and the San Joaquin Valley of California.

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Curriculum Vitae

Catherine M. Grieve Co-Principal Investigator
Research Leader, Supervisory Plant Physiologist
USDA-ARS George E. Brown, Jr. Salinity Laboratory
450 West Big Springs Road
Riverside, CA 92507
cgrieve@ussl.ars.usda.gov

Education
B. S. Chemistry, St. Lawrence University, Canton, New York
Ph.D. Botany, University of California, Riverside, CA

Major Research Interests: Salinity and trace element management in irrigated agricultural systems; salinity effects on nutrient availability, uptake and utilization by plants grown in saline environments.

Relevant Publications Since 2000

Wang, D., Shannon, M. C., Grieve, C. M., and Yates, S. R. Soil water and temperature regimes in drip and sprinkler irrigation, and implication to soybean emergence. Agric. Water Management 43:15-28. 2000.

Wilson, C., Lesch, S. M., and Grieve, C. M. Growth states modulates salinity tolerance of New Zealand spinach (*Tetragonia tetragonioides*, Pall.) and red orach (*Atriplex hortensis* L.) Annals of Botany 85:501-509. 2000.

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Grieve, C. M. and Poss, J. A. Wheat response to the interactive effects of boron and salinity. J. Plant Nutrition. 23:1217-1226. 2000.

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Shannon, M. C., Grieve, C. M., Lesch, S. M., and Draper, J. H. Analysis of salt tolerance of nine leafy vegetable species irrigated with saline drainage water. J. Am. Soc. Hort. Sci. 125:658-664. 2000.

Grieve, C. M., Shannon, M. C., and Poss, J. A. Mineral nutrition of leafy vegetable crops in response to sodium sulfate-dominated salinity. Journal of Vegetable Crop Production. 7:37-47. 2001.

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Zeng, L., Shannon, M. C., and Grieve, C. M. Evaluation of salt tolerance in rice genotypes by multiple agronomic parameters. Euphytica.127:235-235. 2002.

Suarez, D. L., Grieve, C. M., and Poss, J. A. Effect of irrigation method on selenium uptake by forage brassicas. J. Plant Nutr. 26:191-201. 2003.

Goldberg, S. and Grieve, C. M. Boron adsorption by maize cell walls. Plant and Soil 251:137-142. 2003.

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Poss, J. A. Russell, W. B., Shouse, P. J., Austin, R. S., Grattan, S. R., Grieve, C. M., Lieth, J. H. and Zeng, L. Volumetric lysimeter system simultaneously quantifies plant response to salinity and water stress. Computers and Electronics in Agriculture 43:55-68. 2004.

Rogers, M., Grieve, C. M., and Shannon, M. C. Plant growth and ion relations in lucerne (*Medicago sativa* L.) in response to the combined effects of NaCl and P. Plant and Soil 253:187-194. 2003.

Grieve, C. M., J. A. Poss, S. R. Grattan, D. L. Suarez, S. E. Benes, and P. H. Robinson. Evaluation of salt-tolerant forages for sequential water reuse systems. II. Plant-ion relations. Agric. Water Management. (In press).

Curriculum Vitae
James A. Poss
Soil Scientist

Work:
USDA/ARS
George E. Brown, Jr., Salinity Laboratory
450 W. Big Springs Road
Riverside, CA 92507

Telephone: (951) 369-4863
FAX: (951) 342-4963
e-mail: jposs@ussl.ars.usda.gov

Home:
12671 16th Street
Yucaipa, CA 92399

Telephone: (951) 795-5287
e-mail:yucaipa3@earthlink.net

Research Interests

Plant response to salinity. Water-nutrition-use-efficiency. Predicting plant response when grown under diverse saline environments. Hyperspectral remote sensing of salt-stressed plants. Carbon isotope discrimination in plants.

Education

B.S. 1980 Plant Science, University of California, Riverside.
M.S. 1984 Soil Science, University of California, Riverside.

Selected Awards

2001—Certificate of Merit for outstanding performance in scientific research support and Laboratory outreach activities.

1999—Certificate of Merit Award for exhibiting outstanding diligence and initiative in the team research programs of the Plant Science Unit, U. S. Salinity Laboratory.

1998—Certificate of Merit for making valuable contributions to the efforts of the Plant Science unit through diligence and dedication in data analysis and interpretation as well as in the preparation and presentation of final reports of exceptionally high caliber.

Selected Research Publications

Poss, J. A., W. B. Russell, P. J. Shouse, R. S. Austin, S. R. Grattan, C. M. Grieve, J. H. Leith, L. Zeng. 2004. A volumetric lysimeter system (VLS): an alternative to weighing lysimeters for plant-water-relations studies. Computers and Electronics in Agriculture: 43:55-68.

Poss, J. A. L. Zeng, and C. M. Grieve. 2004. Carbon isotope discrimination and salt tolerance of rice genotypes. Cereal Research Communications (In Press).

Zeng, L., J. A. Poss, C. Wilson, A. E. Draz, G. B. Gregorio, and C. M. Grieve. Evaluation of salt tolerance in rice genotypes by physiological characters. Euphytica 129:281-292.

Robinson, P. J., S. R. Grattan, G. Getachew, C. M. Grieve, J. A. Poss, D. L. Suarez, and S. E. Benes. Biomass accumulation and potential nutritive value of some forages irrigated with saline-sodic drainage water. 2003. Animal Feed Science and Technology 111:175-189.

Wang, D., J. A. Poss, T. J. Donovan, M. C. Shannon, and S. M. Lesch. 2002 Biophysical properties and biomass of elephant grass under saline conditions. Journal Arid Environments 52:447-456.

Suarez, D. L., C. M. Grieve, and J. A. Poss. 2001. Irrigation method affects selenium accumulation in forage *Brassica* species. Journal of Plant Nutrition 26:191-201

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Poss, J. A., S. R. Grattan, C. M. Grieve, and M. C. Shannon. 1999. Characterization of leaf boron injury in salt-stressed eucalyptus by image analysis. Plant and Soil 208:1-9

Poss, J. A., D. L. Suarez, C. M. Grieve, S. R. Grattan, and M. C. Shannon. 1999. Carbon isotope discrimination and transpiration efficiency in eucalyptus under salinity and boron stress. Acta Hort: Accepted 11-8-99.

Grieve, C. M., M. C. Shannon, and J. A. Poss. 2001. Mineral nutrition of leafy vegetable crops irrigated with saline drainage water. J. Vegetable Crop Production 7:37-47.

Grieve, C. M. and J. A. Poss. 2000. Wheat response to the interactive effects of boron and salinity. J. Plant Nutrition. 23:1217-1226

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Maas, E. V., G. J. Hoffman, G. D. Chaba, J. A. Poss, and M. C. Shannon. 1983. Salt sensitivity of corn at various growth stages. Irrigation Science. 4: 45-57.

Poss, J. A., E. Pond, J. A. Menge, and W. M. Jarrell. 1985. Effect of salinity on mycorrhizal onion and tomato in soil with and without additional phosphate. Plant and Soil 88:307-319.

Dalton, F. N. and J. A. Poss. 1990. Water transport and salt loading: A unified concept of plant response to salinity. Acta Horticulturae 278, pp. 187 - 193.

Dalton, F. N. and J. A. Poss. 1990. Soil water content and salinity assessment for irrigation scheduling using time-domain reflectometry: Principles and applications. Acta Horticulturae 278, 381 - 393.

Grieve, C. M., J. A. Poss, T. J. Donovan, and L. E. Francois. 1997. Salinity effects on growth, leaf-ion content and seed production of *Lesquerella fendleri* (Gray) S. Wats. Industrial Crops and Products 7:69-76.

CURRICULUM VITÆ
CHRISTY TUCKER CARTER

CONTACT INFORMATION

Current Address

U. S. Salinity Laboratory	*Phone*	(951) 369-4841
450 W. Big Springs Road	*FAX*	(951) 342-4963
Riverside, CA 92507	*Email*	ccarter@ussl.ars.usda.gov

EDUCATION

Post-doctoral studies. August 2003-present. University of California—Riverside & George E. Brown, Jr., U.S. Salinity Laboratory (USDA/ARS), Riverside, California

Ph.D. 2003. Plant Biology, Ohio University, Athens, Ohio

M.S. 1998. Environmental Studies, Ohio University, Athens, Ohio

B.S. 1995. Secondary Education, Alderson-Broaddus College, Philippi, West Virginia

PRIMARY RESEARCH INTERESTS

Salinity effects on the production of cut flowers; salinity effects on nutrient availability; halophyte ecophysiology; halophyte seed germination

SELECTED PUBLICATIONS

CARTER, C. T., C. M. GRIEVE, AND J. A. POSS. Salinity effects on emergence, survival and ion accumulation of *Limonium perezii*. *Journal of Plant Nutrition* (in press)

CARTER, C. T. AND I. A. UNGAR. 2004. Relationships between seed germinability of *Spergularia marina* (Caryophyllaceae) and the formation of zonal communities in an inland salt marsh. *Annals of Botany* 93: 119-125.

CARTER, C. T. AND I. A. UNGAR. 2003. Germination responses of dimorphic seeds of two halophyte species to environmentally controlled and natural conditions. *Canadian Journal of Botany* 81: 918-926.

CARTER, C. T., L. S. BROWN AND I. A. UNGAR. 2003/4. Effect of long term cold storage on the dormancy cycles of dimorphic seeds of *Atriplex prostrata* (Chenopodiaceae). *Biologia Plantarum* 47: 269-272.

Papers in Review

CARTER, C. T., C. M. GRIEVE AND J. A. POSS. Influence of salinity on production of *Celosia argentia* var. cristata. *Agriculture, Ecosystems and Environment*

Papers in Preparation

CARTER, C. T. AND C. M. GRIEVE. Production of *Antirrhinum majus* (Snapdragons) when exposed to differing salinity compositions.

CARTER, C. T. AND I. A. UNGAR. Effects of salinity on growth and ion accumulation of two halophytes at different developmental stages. *Plant and Soil*

SELECTED PRESENTATIONS (* with published abstract)

GRIEVE, C. M., C. T. CARTER (presenting author), AND J. A. POSS. 2004. Productivity of two *Limonium* species irrigated with saline wastewaters. American Society for Horticultural Science, Austin, Texas.*

CARTER, C. T., C. M. GRIEVE, J. A. POSS, AND J. DRAPER. 2004. Tolerance of *Limonium perezii* to differing irrigation water compositions and increasing salinity. A Symposium on High Salinity Tolerant Plants, Provo, Utah.

CARTER, C. T. AND I. A. UNGAR. 2004. Genetic diversity of three halophytic annuals over time. George E. Brown, Jr. Salinity Laboratory. Riverside, California.

Applicant: Grieve, Carter, and Poss

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Section A projects must complete Life of investment, column VII and Capital Recovery Factor Column VIII. Do not use 0.

Table C-1: Project Costs (Budget) in Dollars)

	Category (I)	Project Costs $ (II)	Contingency % (ex. 5 or 10) (III)	Project Cost + Contingency $ (IV)	Applicant Share $ (V)	State Share Grant $ (VI)	Life of investment (years) (VII	Capital Recovery Factor (VIII)	Annualized Costs $ (IX)
	Administration[1]								
	Salaries, wages	$100,000	0	$100,000	$0	$100,000	0	0.0000	$0
	Fringe benefits	$10,000	0	$10,000	$0	$10,000	0	0.0000	$0
	Supplies	$30,000	0	$30,000	$0	$30,000	0	0.0000	$0
	Equipment	$16,000	0	$16,000	$0	$16,000	0	0.0000	$0
	Consulting services	$0	0	$0	$0	$0	0	0.0000	$0
	Travel	$11,000	0	$11,000	$0	$11,000	0	0.0000	$0
	Other	$0	0	$0	$0	$0	0	0.0000	$0
(a)	Total Administration Costs	$167,000		$167,000	$0	$167,000			$0
(b)	Planning/Design/Engineering	$0	0	$0	$0	$0	0	0.0000	$0
(c)	Equipment Purchases/Rentals/Rebates/Vouchers	$0	0	$0	$0	$0	10	0.0000	$0
(d)	Materials/Installation/Implementation	$0	0	$0	$0	$0	0	0.0000	$0
(e)	Implementation Verification	$0	0	$0	$0	$0	0	0.0000	$0
(f)	Project Legal/License Fees	$0	0	$0	$0	$0	0	0.0000	$0
(g)	Structures	$0	0	$0	$0	$0	0	0.0000	$0
(h)	Land Purchase/Easement	$0	0	$0	$0	$0	0	0.0000	$0
(i)	Environmental Compliance/Mitigation/Enhancement	$0	0	$0	$0	$0	0	0.0000	$0
(j)	Construction	$0	0	$0	$0	$0	0	0.0000	$0
(k)	Other (Specify)	$0	0	$0	$0	$0	0	0.0000	$0
(l)	Monitoring and Assessment	$10,000	0	$10,000	$0	$10,000	0	0.0000	$0
(m)	Report Preparation	$5,000	0	$5,000	$0	$5,000	0	0.0000	$0
(n)	**TOTAL**	$182,000		$182,000	$0	$182,000			$0
(o)	Cost Share -Percentage				0	100			

1- excludes administration O&M.