The influence of irrigation method and controlled-release fertilizer on water quality and growth parameters of chrysanthemum

by

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GENERAL INTRODUCTION

Preservation of water quality has become a national priority and is the focus of many environmental and grassroot organizations at the local, state, and federal levels. Groundwater pollution can come from two sources: non-point and point. Greenhouse production practices produce point source pollution, which has been largely overlooked in the past due to the small acreage involved. Recently, however, attention has focused on the greenhouse industry because of the its intensive use of fertilizers and chemicals. Several countries in Europe have already implemented strict regulatory policies for their horticultural industries due to published research reports indicating the industry's high potential for groundwater pollution (Gassman, 1993; Molitor 1990). The focus of this effort is the reduction of nitrate-nitrogen and pesticide concentrations entering the groundwater. Concentrations of these compounds have been reported in the groundwater supply of large areas of the United States (Duffy and Johnson, 1988; Richardson, 1991) and European countries..

The United States greenhouse crops industry is expecting increased regulations involving the quality and quantity of the effluent entering the ground water system. Regulatory measures may be minimized if methodologies are developed which reduce the amount of fertilizers and water which are used in crop production. Several investigators have reported modifications of existing alternative production methods (Weatherspoon and

Harrell, 1980; Wilfret and Harbaugh, 1977; Lieth and Burger, 1989), which reduce the quantity and improve the quality of the effluent. Benefits associated with these drip-irrigation and subirrigation systems are reduced labor due to automation (George et al., 1989), reduced water usage (Elliot, 1990; Evans et al., 1989), reduced fertilizer usage (Elliot, 1990; Evans et al., 1989). and a more uniform application of the irrigation water and fertilizer leading to a more uniform crop. The major disadvantage of these alternative systems when compared to the traditional top-water system is the initial cost, which can be two to three times higher than standard expanded metal benching. The improved labor and material usage efficiency can improve the profitability of the products produced and offset the initial construction cost of these systems.

The overall objective of this study was to develop a zero-leachate production system using a combination of resin encapsulated, controlled-release fertilizer and irrigation method for chrysanthemum production. This study is presented in two sections. The first section is concerned with the effects of this system on development of the plant growth and quality. The second section is concerned with the chemical properties of the growing medium environment and the effluent chemical properties and nitrate concentrations.

Explanation of Thesis Format

This thesis consists of two manuscripts suitable for publication in

HortScience Journal. A comprehensive literature review and a general summary of the research are included. References cited in the introduction and general literature review follow the general summary. The arrangement of the papers follows the guidelines set forth by the American Society of Horticultural Science publication manual.

REVIEW OF LITERATURE

Fertilizer Types

Controlled-release fertilizer and liquid fertilizer are the two principal types of fertilizer available for use by the greenhouse crops industry. Controlled-release and liquid fertilizers have been shown to influence plant quality (Bivines and Kofranek, 1961; Simpson, 1975). Highest plant quality has been produced in production systems utilizing top-water irrigation and a fertilizer combination of controlled-release fertilizer and liquid fertilizer or solely liquid fertilizer (Simpson, 1975; Kofranek and Lunt, 1962; Bivins and Kofranek, 1961). Kofranek and Lunt (1961) described chrysanthemum plants of equal quality being grown with either liquid or controlled-release fertilizer with the only difference being the plants produced with controlled-release fertilizer were harvested three to five days earlier. Liquid and controlled-release fertilizers have produced similar developmental characteristics of chrysanthemum plants, like dry matter, elemental accumulation, and appearance (Sharma and Patel, 1978).

Type of fertilizer applied has influenced the nitrogen concentrations in the effluent. Controlled-release fertilizers have a higher nitrogen load in the effluent at the first half of the cropping cycle than liquid fertilizers, but still reduced the total amount of nitrogen lost over the production cycle by 50% (Hershey and Paul, 1982).

Patel and Sharma (1977) tested fourteen controlled-release fertilizers and discovered that nitrogen release rates varied among fertilizers and that sulfur-coated urea (36-0-0K) and Osmocote 18N-2.6P-9.8K had the most desirable nitrogen release pattern for 90 day floricultural crops. Sulfur-coated urea and Osmocote fertilizers had nitrogen release rates of 7%N and 9.1%N, respectively, during the first week and continually released adequate nitrogen concentrations through the first two months after fertilizer incorporation (Patel and Sharma, 1977). Resin-coated fertilizers, like Osmocote, have been well documented as the controlled-release fertilizers that produce the best quality in *Euphorbia pulcherrima* (Tayama and Carver, 1992), *Chrysalidocarpus lutescens* Wendl (Yahata and Murakami, 1988), and *Brassaia actinophylla* Endl. (Conover and Poole, 1983).

Methods of controlled-release fertilizer application, which include top-dressing, incorporating, and depositing, can influence the growth of the crop. Incorporation of the controlled-release fertilizer can reduce the quantity of required fertilizer by 35% (Waters, 1963) or by 50% (Oertti and Lunt, 1962) and increase the plant quality of 'Iceberg' chrysanthemum (Waters, 1965). However, incorporation has also been known to reduce the average flower diameter in potted chrysanthemums (Simpson et al., 1975).

Leachate quality is linked to the placement of the controlled-release fertilizer. Incorporation of the controlled-release fertilizer affects the concentration of nitrogen in the leachate. Furuta (1976) reported that the nitrate runoff concentrations could be reduced to similar background concentrations present in tapwater by incorporating the controlled-release fertilizer, but Cox (1993) shows that incorporation of controlled-release fertilizer increased the nitrate concentrations in the leachate. Cox (1993) also showed that the predominant nitrogen form in the leachate was the nitrate form.

Irrigations System Interactions With Fertilizer Types

Irrigation methods influence plant growth as well as the amount of water and fertilizer lost into groundwater systems. Irrigation systems are divided into three categories: top-water, drip, and subirrigation. Weatherspoon and his coworkers (1980) reported that as much as 90% of the applied solution in a top-water system can be leached into the groundwater. This system results in applied N losses ranging from 12% to 48% (Hershey and Paul, 1982). Nitrate-nitrogen loss can be reduced by using a drip irrigation system combined with controlled-release fertilizer, but effluent concentrations above the 10-ppm nitrate federal drinking water standard (U.S. Environmental Protection Agency, 1982) can be lost to the groundwater system (Rathier and Frink, 1989).

Subirrigation systems are gaining popularity because these systems can be a closed loop, which reduces labor, fertilizer, and water usage (Roberts, 1993; Hamrick, 1989). Subirrigation systems provide water to the plant by capillary action. These systems have the potential of being completely closed (recirculated), thus virtually eliminating any potential pollution problems from fertilizer components of the effluent. Problems occur when residues of nutrients and pesticides accumulate in the effluent. Ruijs and Os (1991) reported that a closed system can reduce fertilizer discharge by 65%, but effluent must not need complete disinfecting to be environmentally and economically feasible. Fertilizer components that are collected in the effluent would be reapplied to the plant thus reducing the initial concentrations of fertilizer (Koch and Holcomb, 1983). Due to the upward water movement of subirrigation and no downward leaching, fertilizer components can cause distinct soluble salt stratification within the growing medium. Guttormson (1969) reported that pots placed in a subirrigation systems using liquid fertilizer can have five times greater concentration of salts in the upper zone than the lower zone of the growing medium after ten weeks in the production cycle. Yelanich and Beirnbaum (1990) reported that increases in medium electrical conductivity from 1.0 to 8.7 mS resulted in reduction of height, fresh weight, dry weight, and leaf and bract area in *Euphorbia pulcherrima* 'V-14 Glory.' The reduction in growth parameters has been linked to the reduction of C allocated to leaf growth (Brugnoli and Björkman, 1992). Salinity of the growing medium has also been known to reduce chlorophyll a and b concentrations in citrus leaves(Alva and Syvertsen, 1991).

Guttormsen (1969) also observed that increasing the N and K supplies lead to lower pH readings in the growing medium due to K replacing H on some of the collodial complexes. But pH differences were not observed between the upper and lower halves of the growing medium in the same fertilizer treatment (Guttormsen, 1969).

The large volumes of nutrient solutions in current subirrigation systems can be eliminated by combining the technologies of subirrigation and controlled-release fertilizer. Kovacic and Holcomb (1981) found that placement of controlled-release fertilizer (top-dressed or incorporated in the medium) in a capillary mat system (subirrigation system) did not influence growth of *Kalanchoe blossfeldiana* plants. However, Payne and Adam (1980) reported that the placement method directly influenced the quality of African violet plants in a capillary mat system. They also observed the lowest plant quality from bottom deposits of controlled-release fertilizer and the highest from top dressings. Plant development and quality are also influenced by type of controlled-release fertilizer. Resin-encapsulated controlled-release fertilizers like Osmocote have been shown to be the best type of controlled-release fertilizer for use in a controlled-release fertilizer-subirrigation system (Kovacic and Holcomb, 1981). Incorporated and topdressed Osmocote fertilizers, at the manufacturer's recommended rate, produced the tallest and heaviest kalanchoe plants in a subirrigation (capillary mat) system (Kovacic and Holcomb, 1981).

Summary

The type of fertigation systems used for production of floriculture crops will influence plant development, water usage, and groundwater pollution. Strict water quality regulations in European countries and in certain states of the United States may alter fertigation for greenhouse crops by mandating reduced fertilizer levels lost to the environment. Potential concentrations of pollutants can be reduced through the usage of drip or subirrigation systems and/or controlled release fertilizers. Further reduction in the amount of water and fertilizer used can be implemented by using a closed irrigation system implementing both drip irrigation or subirrigation and controlled-release fertilizer. Closed systems must be closely monitored for salts, chemicals and pathogens because any additions to the irrigation water will be reapplied to the growing medium at every irrigation cycle. Recirculated water can greatly influence the chemical characteristics in the growing medium and ,thus, alter plant development. Saline medium conditions have been shown to reduce shoot dry weight, height, chlorophyll a and b concentrations, flower quality, and alter plant elemental accumulations. A proper combination of irrigation system and fertilizer type can help the grower reduce the production costs of the product while creating a cleaner environment for the grower and the consumer.

CONTROLLED-RELEASE FERTILIZER RATE AND IRRIGATION METHOD INFLUENCE GROWTH OF POTTED CHRYSANTHEMUM

A paper to be submitted to HortScience.

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Production of Floricultural Plants

Additional index words. subirrigation, top-water, Osmocote, *Dendranthema grandiflora* Tzvelev.

Abstract. Rooted 'Iridon' chrysanthemum (*Dendranthema grandiflora* Tzvelev.) cuttings were transplanted into pots filled with an artificial growing medium. Osmocote 12N-4.4P-13.9K at 0.87, 1.75, 3.5, and 7.0 g CRF/pot was deposited directly below the cutting before transplanting. Plants were subirrigated or top-watered using deionized water. Shoot height was reduced as fertilizer concentrations increased. Shoot dry weight was reduced by 8% in the subirrigated plants. Shoot diameter was maximized at 5.0 and 4.5 g CRF/pot in the top-watered and subirrigated plants, respectively. Visual plant quality decreased for subirrigated plants as the controlled-release fertilizer rates increased. Days to flower, number of flowers, and flower diameter was not influenced by the treatments, but flower dry weight was altered by CRF rate. Elemental accumulations of N, P, K, Ca, and B were influenced by irrigation treatment and CRF rate. Mg and Mn was altered by only CRF rate. Interactions were shown in the accumulation of P, K, Ca, B, and Zn.

The traditional chrysanthemum production method of top-watering with liquid fertilizer can result in 90% loss of the applied liquid solution through misapplication (Weatherspoon and Harrell, 1980). Nitrogen in irrigation water can contribute to groundwater pollution (McAvoy, 1994) and increase production costs (Roberts, 1993).

Several production systems can reduce nitrogen runoff without influencing plant development. Controlled-release fertilizers (CRF) have produced satisfactory plants of *Saintpaulia ionantha* Wend. 'Ulli' and 'Lisa' (Payne and Adams, 1980), *D. grandiflora* Tzvelev. (Maynard and Lorenez, 1979), and *Euphorbia pulcherrima* Willd. (Maynard and Lorenez, 1979). Use of CRF at similar rates as in liquid irrigation systems reduces the potential lose of fertilizer components into the environment by increasing the crop's nutrient recovery (Maynard and Lorenz, 1979; Hershey and Paul, 1982). Systems using specific CRF (i.e. Osmocote) and subirrigation have produced plants of acceptable quality when using Osmocote at manufacturer's recommended rates or higher (Kovacic and Holcomb, 1981). However, the growing medium in subirrigation systems can accumulate higher levels of soluble salts and have greater salt stratification (Guttormsen, 1969) than top-watering systems due to the lack of leaching from the top of the growing medium. High soluble salt levels can reduce the quality factors of height, fresh and dry weight, and leaf and bract area of *E. pulcherrima* (Yelanich and Biernbaum, 1990). Payne and Adam (1980) observed that the placement of the CRF altered the plant quality of *Saintpaulia ionantha* Wend. in a subirrigation system. Information is limited on the influences of subirrigation and CRF on chrysanthemum development.

Our objective was to determine the effects of deposited resin-coated CRF in a closed subirrigation (zero-leachate) system and a top-water (traditional) irrigation system on growth and quality of chrysanthemum.

Materials and Methods

Plant material and experimental manipulation. Rooted 'Iridon' cuttings (Yoder Brothers, Barberton, Ohio) were planted on 10 Oct. 1993 into 10-x 5-cm pots (volume = 390 ml, 4-in azalea pot) filled with 1 Sphagnum peat : 1 horticultural perlite (by volume) amended with dolimitic limestone at 2.5 kg/m^3 of medium. The pH of the growing medium was 6.0. Electrical conductivity (EC) of the medium was <0.1 dS/m. Before the rooted cuttings were transplanted into dibble holes, preweighed quantities of CRF were placed into the bottoms of the holes. Four rates of Sierra Chrysanthemum Mix Osmocote 12N-4.4P-13.9K (Grace-Sierra Horticultural Products, Milpitas, Calif.) were used: 0.87, 1.75, 3.5, and 7 g Osmocote/pot. The plants were top-watered with 150 ml of a 350 mg N/liter solution of 20N-4.4P-16.8K Peat-lite (Grace-Sierra Horticultural Products) to establish an initial nutrient charge in the medium before the CRF was activated and to provide the moisture for capillary action.

The pots were placed into 52- x 26- x 6-cm black, vacuum-formed flats and spaced on 1.82- x 1.21-m ebb-and-flow benches in a glasshouse kept at 21 ± 4C. Each pot received 230 cm^2 of bench space. The ebb-and-flow benches were white, molded plastic trays with perpendicular grooves that allowed the irrigation water to contact the bottom of every pot simultaneously. Pots for the top-water treatment were placed into flats with no drainage slots so the leachate would not enter the ebb-and-flow irrigation water. Plants were irrigated when growing medium of over 50% of the pots from each treatment appeared dry, every 2 days for the first 10 weeks and once daily thereafter. Irrigation tanks were calibrated to 38 liters and refilled after every cycle. Each cycle for the subirrigated plants filled the bench for nine min and the water remained the bench for an additional 10 min before being drained. Approximately 0.7 cm of the growing medium was in direct contact with the irrigation water. Average leaching fraction (volume leached/ volume applied) for the top-water treatment was 0.24 with a range from 0.18 to 0.34. Irrigation water for both treatments was deionized.

Photosynthetically active radiation, which was measured by using a LI-COR LI-183A Quantum Meter (LI-COR, Lincoln, Neb.), was 126 $\mu\text{mol/s}^{1}\cdot\text{m}^{2}$ at the start of the experiment and averaged 132 $\mu\text{mol/s}^{1}\cdot\text{m}^{2}$ during the growth period. Incandescent lamps were used to provide long days of 18 h by night interruption from 0100HR to 0700HR. On 26 Oct., all of the plants were pinched by removing 1 cm of the youngest stem growth, and short days of 9 h were started and maintained throughout the experiment by using black, 4-mil polyethylene sheeting. Plants were disbudded on 22 Nov.

Plant development. Plant height from top of medium was measured at maturity when 60% of the flowers had ray petals perpendicular to the stem. Shoot dry weight was determined after the shoot was cut at the medium surface, washed in a solution of Alconox (Alconox, New York, N.Y.), rinsed three times in deionized water, and dried in an oven at 20C for a minimum of 72 h.

At maturity, the plants were measured or rated for these various quality attributes: diameter at the widest portion of the shoot, height from top of medium to top of shoot, bud and flower number, mature flower dry weight, total number of flowers per plant, leaf chlorophyll concentrations by ethanol extraction (Knudson et al., 1977), and overall plant quality. Quality was rated on a visual scale from 1 (lowest) to 5 (highest) based on several ornamental qualities, such as overall appearance, flower display and foliage display. The upper seven leaves from shoots that developed from axillary buds and terminated with a bud or flower were analyzed for essential element concentrations at the termination of the experiment. Tissue samples were ground to pass through a 40-mesh screen and analyzed for inorganic metal content by ICAP spectroscopy for P, K, Ca, Mg, Mn, Fe, Cu, B, and Zn. Nitrogen was determined by the Kjehdahl N procedure.

Statistical Design and Analysis. Three completely randomized blocks were arranged in a split-plot design. The CRF rate was the major factor, and irrigation method was the subfactor. An experimental unit was the mean of the plants from three randomly selected pots within a treatment. Statistical analysis included analysis of variance and regression by SAS statistical software (SAS Institute, Cary, N.C.).

Results

Plant Characteristics. The interaction of CRF rate and irrigation method significantly influenced the shoot height (Table 1). Height of the plants decreased linearly as the rate of CRF increased for both irrigation treatments (Fig. 1). At the lowest CRF rate of 0.87 g/pot, height of plants in both of the irrigation treatments was the tallest at 22 cm. Rate of decrease in height of subirrigation was 1.6X greater than for top-watered plants (slope of -1.18 and -0.71, respectively).

Irrigation method significantly influenced accumulation of dry matter (*P*=0.06), but CRF rate and the interaction of CRF rate and irrigation method was not significant (Table 1, Fig. 2). CRF rate maximized dry matter accumulation at 4.6 and 4.1 g/pot in the top-water and subirrigation treatments, respectively. The dry matter accumulation was reduced by 10% in the subirrigated shoots compared with the top-water treatment (from 4.08 g to 3.66 g, respectively).

Plant diameter was influenced by both CRF rate and irrigation method, but their interaction was not significant (Table 1). Most the difference in diameter due to CRF rate for subirrigated plants is expressed in the 0.87 to 1.75 g/pot rate, with a maximum diameter of 22.4 cm (Fig. 3). There was no further increase in plant diameter with rates >1.75 g/pot. Diameter of top-watered plants was maximized at 25 cm with the 4.3 g/pot rate.

Only irrigation method influenced the concentration of chlorophyll a

(Table 1). Irrigation, CRF rate and their interactions did not influence the concentration of chlorophyll b (Table 1). Chlorophyll a concentrations were 9.67 and 9.42 µg Chl/mg for top-water and subirrigation methods (data not shown). Mean chlorophyll b concentration was 9.34 µg Chl/mg dry weight.

Irrigation, rate of CRF and their interaction did not significantly alter the flowering characteristics of the days to flower, flower number, and the diameter of mature flowers (Table 2). Mean flowers per plant was 3.84, days to flower across the treatments was 82.5 days, and mature flower diameter of top-watered and subirrigated plants was 6.80 cm.

Mean flower dry weight was influenced by CRF rate (Table 2), but dry weight was not significantly influenced by irrigation method or the irrigation x CRF rate interaction. CRF rates >3.50 g/pot significantly reduced flower dry weight (Fig. 4).

CRF rate, irrigation treatment and their interaction influenced plant quality (Table 1). The quality of subirrigated plants decreased linearly with increasing CRF rate (Fig. 5). For subirrigated plants, the plant quality decreased by 0.31 for every gram of CRF used. The quality of top-watered plants was not influenced by the CRF rate. The mean plant quality of top-watered plants was 4.54.

Nutrient Analysis. Top-watered plants have higher concentrations of P, Ca and B when compared with foliar concentrations of subirrigated plants (Table 3, 4 and 5, Fig. 6 and 7). For both irrigation methods, P and B concentrations increased with CRF rate. Concentrations of P and B were 1.5X and 2.5X greater in the top-water treatment than the subirrigation treatment. Ca concentrations in top-watered plants was not effected by CRF rate, but the CRF rate and subirrigation treatment depressed Ca concentrations at CRF rates >1.75 g/pot (from 2.5% to 2.1%).

The reverse was true for N, K and Zn foliar concentrations (Table 3, 4 and 5, Fig. 6 and 7), where subirrigation treatment has 1.13X and 1.6X more K and N, respectively, than top-watered plant. Increasing CRF rate increased foliar K and N concentration linearly with both irrigation treatments. But for Zn concentrations, increasing CRF rates depressed Zn concentrations with top-water treatment and increased with the subirrigation treatment.

Irrigation method did not effect the foliar concentrations of Mg and Mn (Table 3, 4 and 5, Fig. 6 and 7). CRF rate maximized Mg concentrations at 0.6% at the 1.75 g rate, while Mn concentration maximum of 312 µg/g was reached with 7.50 g/pot.

Foliar concentrations of Fe (196 µg/g dry wt) and Cu (14 µg/g dry wt) were not significantly influenced by irrigation method, CRF rate and their interaction (Table 4).

Discussion

Height (Fig. 1) and dry weight (Fig. 2) of the shoot were influenced by the irrigation and CRF treatments. Height decreased as the CRF rate increased in both of the irrigation methods, while dry weight measurements expressed quadratic relationships with CRF rate. Reductions in height and dry weight were observed by Yelanich and Biernbaum (1990) in *Euphorbia pulcherrima* grown in top-water and subirrigation systems. They found height and dry weight decreased as the medium EC increased from 1.0 to 8.7 dS/m. In this project, the mean EC of the growing medium ranged from 0.3 to 2.2 dS/m over the duration of the experiment (Bruning, ----). As the mean EC of the growing medium increased, shoot heights decreased (r=-.99). The decrease in osmotic potential from the additional salts could have reduced the water availability to the plant and limited the water available for cellular expansion. Dry weight reductions with CRF at rates >3.5 g CRF/pot could have resulted from decreased allocation of carbon to leaves as Brugnoli and Björkman (1992) reported. Another possible explanation is a high nitrate environment the plants were grown in due to the fertilizer containing 60% nitrate-nitrogen. Kraus and Kraybill (1918) observed a suppression of dry matter accumulation in tomatoes in a high nitrate environment.

CRF rates influence on plant diameter in this study is consistent with a study showing the widest chrysanthemum plants resulted from high rates of CRF in a top-water system (Tayama and Carver, 1992) (Table 1). Subirrigation did not influence this relationship in our project. Our study showed a maximum plant diameter with top-watering of 25 cm with the 3.75 g CRF/pot rate. However, maximum diameter in subirrigated plants was 22.8 cm, which occurred at the same CRF rate of 3.75 g/pot but was 9% lower than the top-water diameter.

Irrigation method and CRF rate did not change the average number of flowers per plant (Table 2). These data do not agree with a previous report that chrysanthemum flower numbers increased as 12N-4.4P-13.9K CRF rates increased to 7.9 kg CRF/m^3 without a continuous liquid fertilizer feed of 200 mg N/liter (Tayama and Carver, 1992). This discrepancy may be explained by the nitrogen levels not dropping below a critical flowering threshold. Critical threshold of 100 mg N/liter has been observed in impatiens and marigolds by Jacques et al. (1992).

We expected flower diameter, number of flowers and mature flower diameter (Table 2) to be influenced by irrigation and CRF rate due to higher concentrations of all of the nutrients. Since these flowering characteristics were not affected, fertilization appears to have been adequate in all treatments. The lack of treatment effect on days to flower in this study is supported by Kovacic and Holcomb (1981), who reported CRF rate did not affect the days to flower in *Kalanchoe blossfeldiana* Poelln. 'Pixie'.

CRF rate did significantly alter the flower dry weight (Fig. 4). The rate influence on the flower dry weight may suggest that the 7.0 g CRF/pot, which accounted for most of the dry weight change, is showing the signs of excess fertilizer. Kraus and Kraybill (1918) indicated a high-nitrate environment can reduce the dry weight of plants due to carbohydrate concentrations becoming the limiting factor, which would explain the flower dry weight reduction.

Leaf chlorophyll b concentrations were not significantly different among treatments, but irrigation influenced chlorophyll a. Our chlorophyll b concentration results were unexpected. Foliar chlorophyll concentrations decline in response to stressful environments, like salinity in the growing medium of *Prunus salicina* L. leaves (Ziska et al., 1990). Environmental conditions, such as light levels, have been reported as causing differences in chlorophyll concentrations as light levels increased or decreased (Anderson et al., 1991) and could mask any treatment differences present in this study.

Quality (Fig. 5) of subirrigated plants was reduced as the CRF rate increased, while the top-watered plants were similar in quality across all of the CRF rates. The reduction of plant quality in the subirrigation system is likely due to excess soluble salts in the root environment that was not present in the top-water system.

Influences of CRF rate and irrigation method on elemental accumulation can be explained in several ways. The reduction in Ca and P by subirrigation, compared with top-water treatment, could be due to the more thorough saturation of the growing medium with the irrigation water than in the top-watering treatment. Higher N and K concentrations in the subirrigated plants than in top-watered plants at the same CRF rate could be related to the lack of leaching among subirrigated plants. K concentrations could be the same for both irrigation treatments due to the lower shoot dry weight in the subirrigated plants than the top-watered plants (Fig. 2). CRF rate effects could also be due to the concentration of nutrients in the growing medium (Bruning, ----), but Waters (1965) did not observe rate effects on N and Ca concentrations in field-grown spray chrysanthemums. This discrepancy could be due to the field production in Waters' study and the glasshouse production in artificial growing medium in this study. Field soil can contain more elements on the exchange sites at the start of the experiment and rain water could leach some of the salts out of the root zone. Leaching was not a factor in the subirrigated pots in our study. Significant interactions between irrigation methods in nutrient accumulation could be explained by the lack of leaching in the subirrigation method and the buildup of soluble salts. Salt concentrations in the growing medium have been known to influence foliar accumulations of Ca, K, and Mg in citrus trees (Alva and Syvertsen, 1991).

Interestingly, irrigation method has an effect on those elements taken up primarily as anions (P and B). These elements were higher in shoot concentrations from top-watered plants than plants subirrigated. Elements taken up as cations (K and Zn) were higher in shoot concentrations from subirrigated plants than plants top-watered. The exception was Ca.

We conclude that combinations of deposited CRF and subirrigation can influence plant quality by altering the height, dry weight, and shoot diameter of a chrysanthemum crop. Quality of subirrigated plants will be altered by the rate of CRF use. Most flowering characteristics, except for flower dry weight, are not influenced in a system using CRF and subirrigation. CRF and subirrigation could reduce production costs by reducing fertilizer by as much as 50% of the current recommended rates, water, and chemical growth regulator usage. CRF rate in a subirrigation system will significantly influence several important plant growth characteristics of the chrysanthemum.

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Table 1 Statistical analysis of the effects of irrigation treatment, CRF rate, and their interaction on shoot height, dry weight, diameter, visual quality and chlorophyll a and b.

		Height		Dry weight		Diameter		Visual quality		Chlorophyll a		Chlorophyll b	
Model	df	SS	P>F	SS	P>F	SS	P>F	SS	P>F	SS	P>F	SS	P>F
Block	2	1.94	0.70	0.64	0.47	4.92	0.22	1.17	0.009	12.38	0.52	3.20	0.75
Rate	3	119.50	0.003	2.66	0.17	41.58	0.01	5.41	0.001	5.40	0.89	8.22	0.69
Error a	6	15.89		2.27		7.50		0.30		51.54		32.52	
Irrigation	1	18.00	0.001	0.48	0.06	3.35	0.06	3.60	0.001	0.36	0.04	6.71	0.08
Irrigation*Rate	3	7.61	0.05	0.23	0.55	4.83	0.15	2.02	0.005	8.40	0.80	7.86	0.29
Error b	8	5.09		0.84		5.52		0.58		69.36		14.16	
Total	23												

Table 2 Statistical analysis of the effects of irrigation treatment, CRF rate, and their interaction on days to flower, number of flowers, flower diameter, and flower dry weight.

		Days to flower		Number of flowers		Flower diameter		Flower dry weight	
Model	df	SS	P>F	SS	P>F	SS	P>F	SS	P>F
Block	2	48.88	0.28	0.78	0.38	1.05	0.27	0.001	0.11
Rate	3	130.02	0.23	2.34	0.18	1.77	0.24	0.014	0.01
Error a	6	281.40		2.13		1.96		0.001	
Irrigation	1	12.47	0.06	0.04	0.66	0.24	0.44	0.003	0.10
Irrigation*Rate	3	72.27	0.08	0.80	0.33	1.15	0.43	0.004	0.27
Error b	8	20.40		1.64		3.07		0.007	
Total	23								

Table 3 Statistical analysis of the effects of irrigation treatment, CRF rate, and their interaction on shoot elemental concentrations of N, P, K, Ca, and Mg.

		N		P		K		Ca		Mg	
Model	df	SS	P>F	SS	P>F	SS	P>F	SS	P>F	SS	P>F
Block	2	0.10	0.45	0.04	0.08	0.32	0.35	0.09	0.073	0.001	0.11
Rate	3	3.42	0.001	2.13	0.01	26.74	0.01	0.88	0.001	0.120	0.46
Error a	6	0.36		0.03		0.48		0.06		0.060	
Irrigation	1	0.12	0.03	0.58	0.01	1.53	0.01	1.02	0.001	0.004	0.13
Irrigation*Rate	3	0.18	0.05	0.09	0.01	2.01	0.01	0.75	0.001	0.030	0.95
Error b	8	0.08		0.04		0.67		0.08		0.008	
Total	23										

Table 4 Statistical analysis of the effects of irrigation treatment, CRF rate, and their interaction on shoot elemental concentrations of Fe, B, Zn, Cu, and Mn.

		Fe		B		Zn		Cu		Mn	
Model	df	SS	P>F	SS	P>F	SS	P>F	SS	P>F	SS	P>F
Block	2	73039	0.11	264	0.28	379	0.12	77.5	0.03	3740	0.30
Rate	3	14852	0.46	2625	0.15	476	0.15	29.8	0.27	50439	0.005
Error a	6	46222		510		370		36.3		7785	
Irrigation	1	4374	0.13	386	0.03	392	0.03	24.0	0.13	3528	0.07
Irrigation*Rate	3	491	0.95	553	0.01	1130	0.01	81.3	0.09	2537	0.43
Error b	8	12758		366		464		70.6		6672	
Total	23										

Table 5 Regression equations and coefficient of determination for the elemental foliar concentrations in figures 6 and 7.

Element	Regression[z]	r^2
N	$\text{concen}_{TW}=0.18x+4.92$	0.78
	$\text{concen}_{SUB}=0.11x+5.31$	0.64
P	$\text{concen}_{TW}=0.14x+1.05$	0.88
	$\text{concen}_{SUB}=0.09x+0.91$	0.77
K	$\text{concen}_{TW}=0.57x+1.88$	0.95
	$\text{concen}_{SUB}=0.49x+2.66$	0.75
Ca	$\text{concen}_{TW}=-0.06x^2=0.48x+1.99$	0.76
	$\text{concen}_{SUB}=0.02x^2-0.25x+2.56$	0.88
Mg	$\text{concen}=-0.01x+0.55$	0.35
Mn	$\text{concen}=17.8x+200.9$	0.56
B	$\text{concen}_{TW}=6.13x+55.62$	0.73
	$\text{concen}_{SUB}=2.42x+59.97$	0.42
Zn	$\text{concen}_{TW}=-2.08x+41.41$	0.47
	$\text{concen}_{SUB}=3.74x+30.37$	0.41

[z] concen_{TW} and concen_{SUB} corresponds to top-water and subirrigation treatments, respectively.

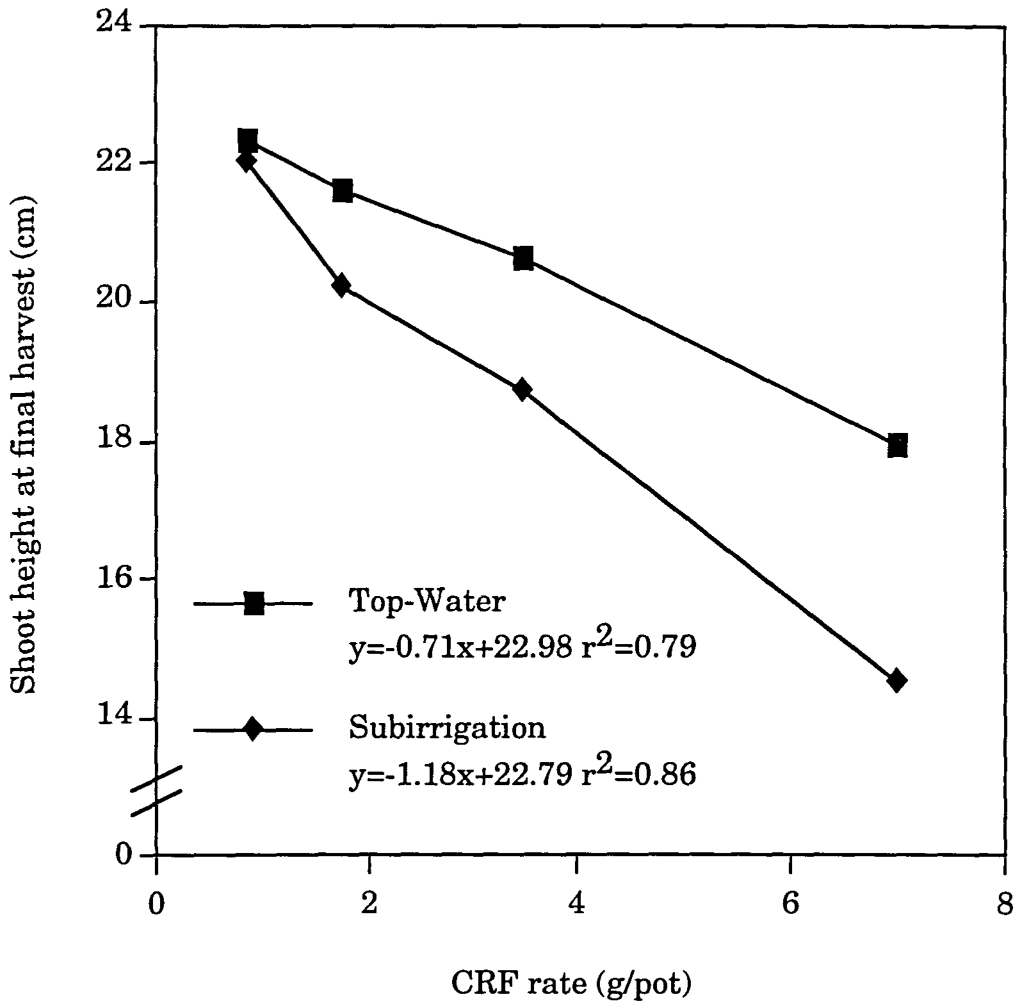

Fig. 1 Shoot height at final harvest for the top-water and subirrigation methods across CRF rates. Linear regression equations are shown below corresponding irrigation treatment.

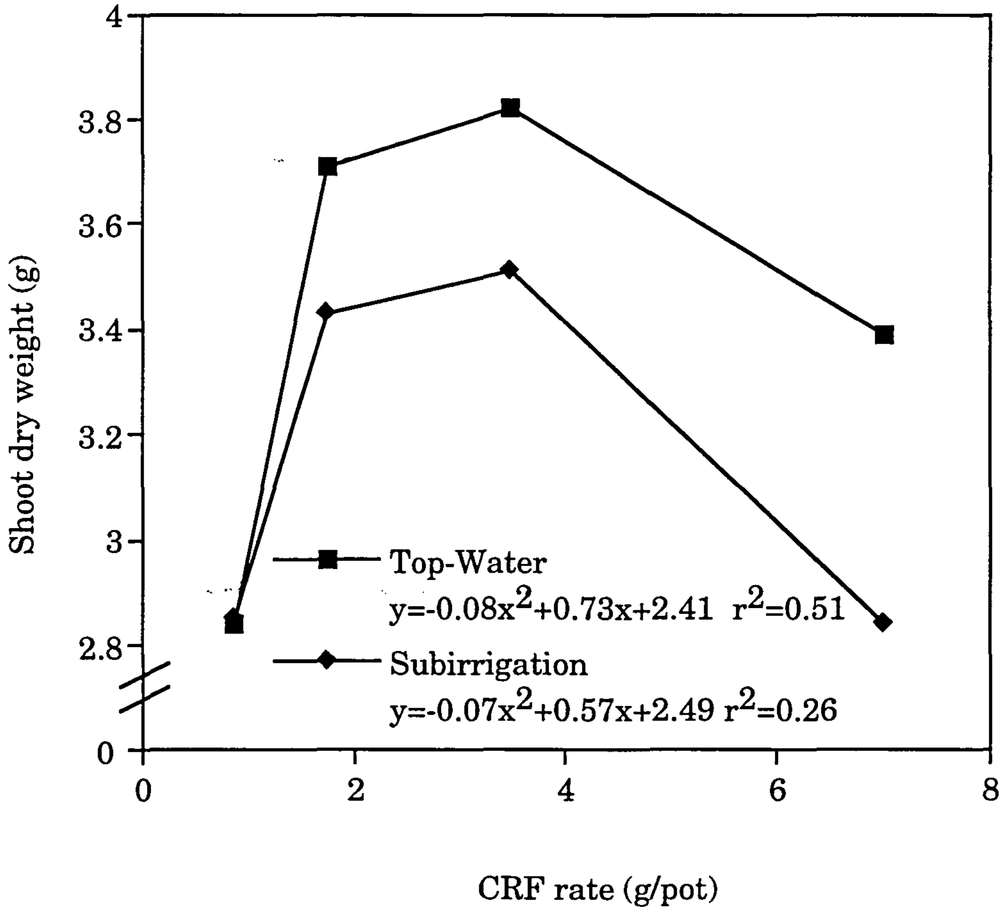

Fig. 2 Total shoot dry weight at final harvest across irrigation methods and CRF rates. Points on graph represent means of CRF treatments. Quadratic regression equations are shown below corresponding irrigation treatment.

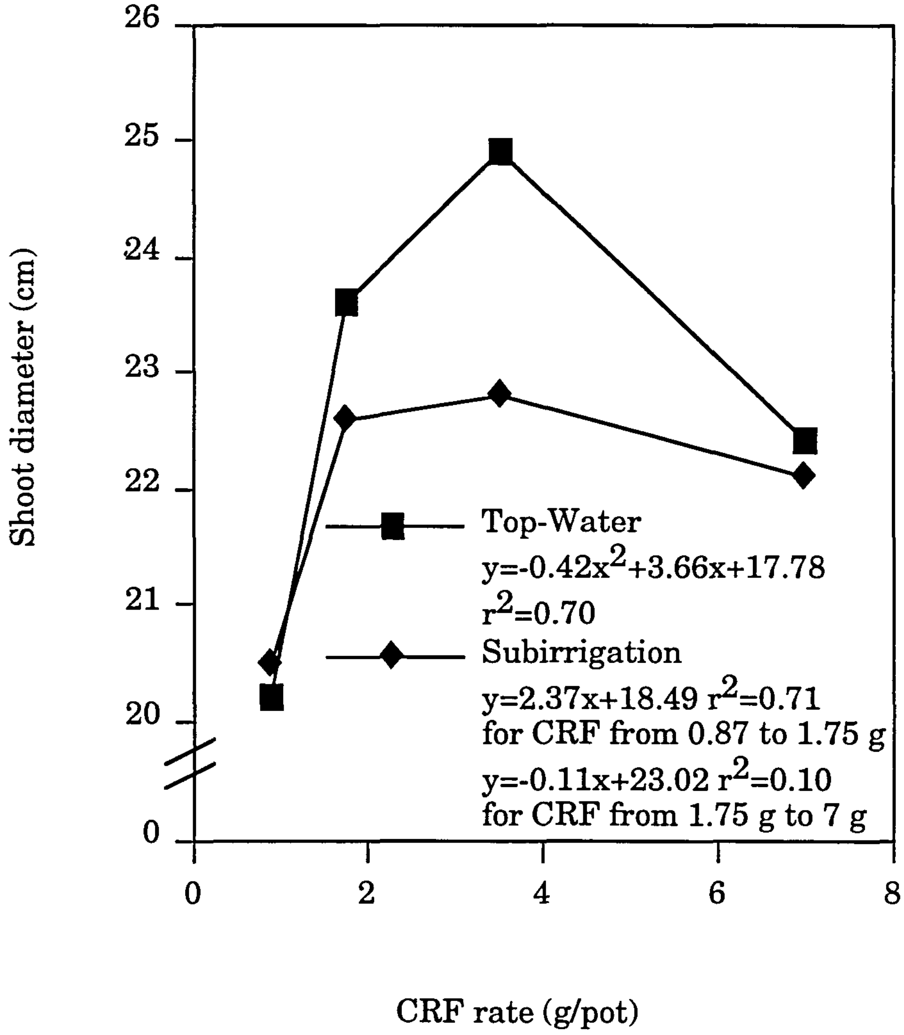

Fig. 3 Shoot diameter across irrigation treatment and CRF rate. Quadratic equations are shown below corresponding irrigation treatment.

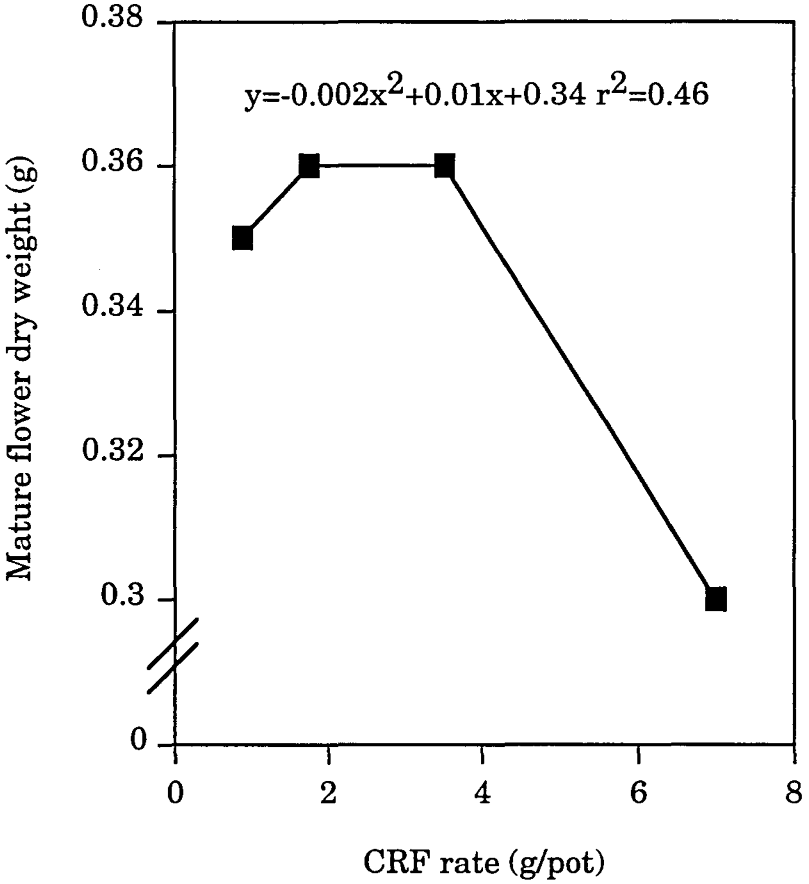

Fig. 4 Mature flower dry weight across the CRF rates.

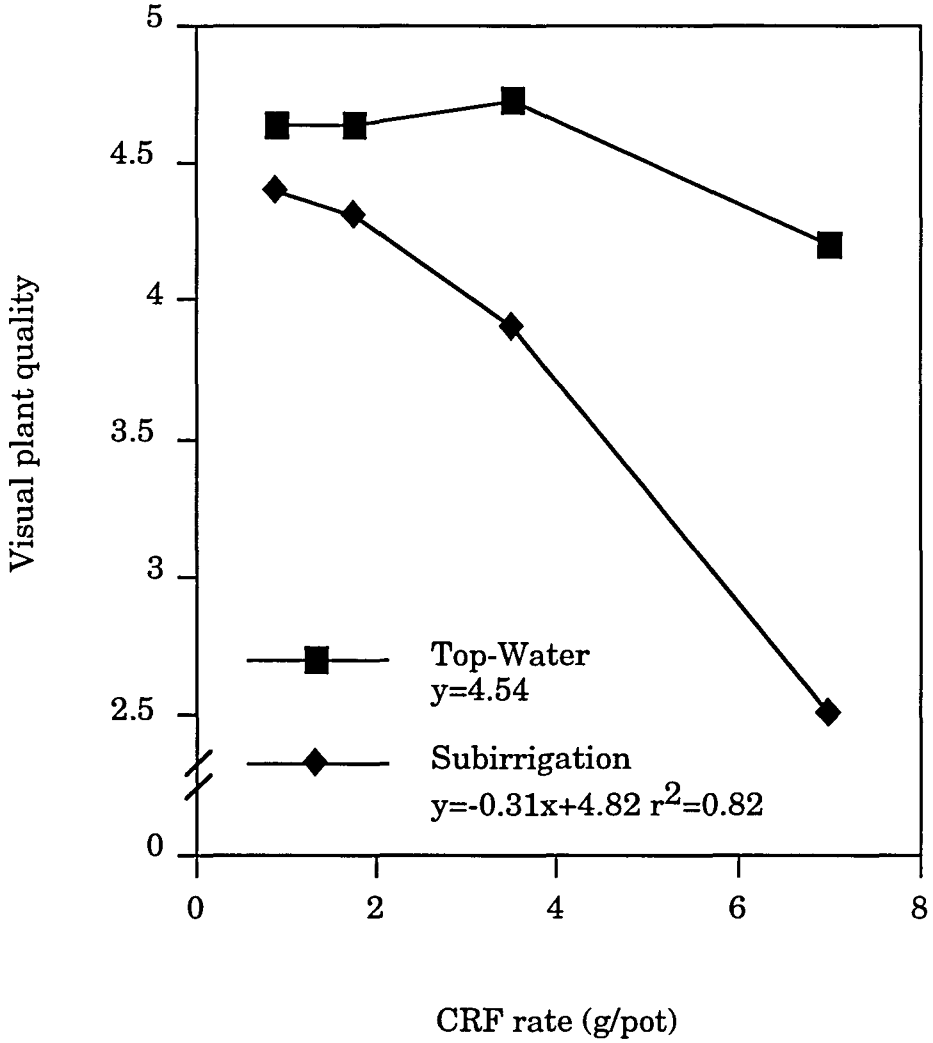

Fig. 5 Visual quality of shoot at final harvest for top-water and subirrigation methods across CRF rates. Quality ratings are based on a scale of 1 (lowest) to 5 (highest). Linear regression equation given for subirrigation method. Slope for top-water method was nonsignificant.

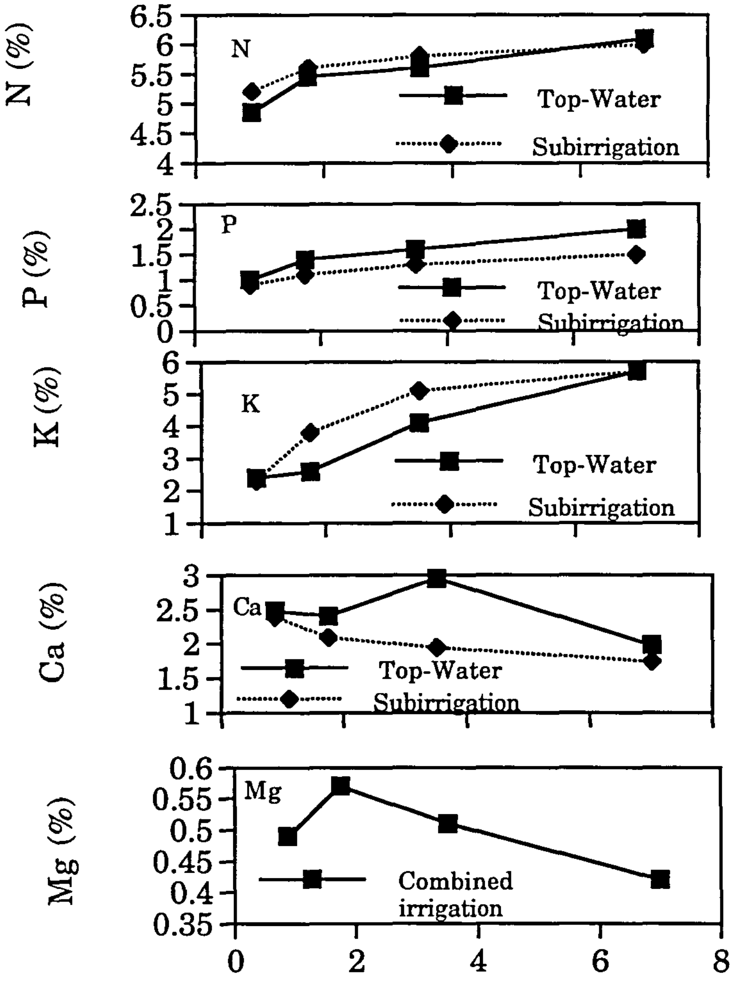

Fig. 6 N, P, K, Ca, and Mg (% dry weight basis) in chrysanthemum leaf tissue at termination of experiment.

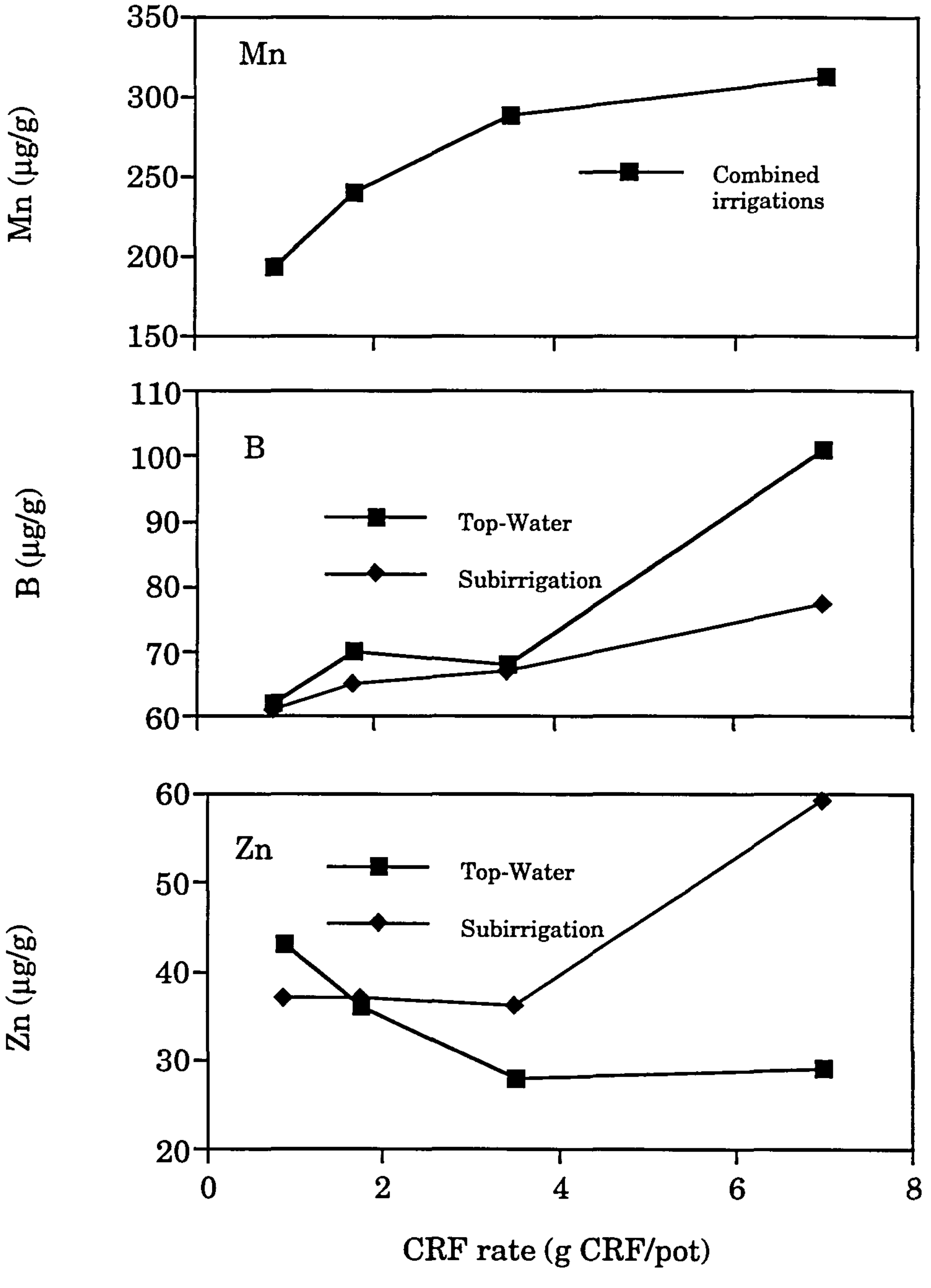

Fig. 7 Dry weight concentrations of Mn, B, and Zn in chrysanthemum leaf tissue at termination of experiment.

CONTROLLED-RELEASE FERTILIZER AND IRRIGATION METHOD INFLUENCE MEDIUM ENVIRONMENT AND LEACHATE QUALITY OF POTTED CHRYSANTHEMUM

A paper to be submitted to HortScience.

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Soil, Fertilization, and Irrigation

Additional index words. subirrigation, top-water, Osmocote, electrical conductivity, pH, nitrate-nitrogen

Abstract. Rooted 'Iridon' chrysanthemum cuttings were transplanted into 10-cm pots filled with a soilless medium. Preweighed amounts of 12N-4.4P-13.9K controlled-release fertilizer, which were 0.87, 1.75, 3.50, and 7.00 g CRF/pot, were deposited directly below the cutting. The pots were spaced into either an ebb-and-flow or top-water irrigation system. The pH of both of the growing medium zones was lowered to 4.5 at the termination of the experiment by the higher CRF rates. Subirrigation reduced the pH of the upper zone by 9%. EC readings and nitrate-nitrogen concentrations in the upper 1.8 cm of the growing medium increased as much as 4 times above the other zones measured in both the subirrigation and top-water systems. Nitrate-nitrogen concentrations in the root zone of both irrigation treatments were similar. Concentrations of soluble salts and nitrate-nitrogen in the leachate and irrigation water was reduced by the subirrigation method by as much as 16x. Nitrate-nitrogen concentrations in the recirculated water of the subirrigation method were below 13 mg/l for every sample analyzed.

State and federal governmental agencies are investigating degradation of water quality from groundwater pollution. Due to the intense use of chemicals and fertilizers in greenhouse production, this industry's contribution to the groundwater pollution is being monitored. Researchers are investigating the effects of zero leaching or closed systems have on plant growth. Problems associated with these types of systems are that the stratification of high soluble salts concentrations in the growing medium (Guttormsen, 1969). These high concentrations have been known to reduce shoot dry weight (Yelanich and Biernbaum, 1990; Brugnoli and Björkman, 1992), shoot height (Yelanich and Biernbaum, 1990), leaf area (Yelanich and Biernbaum, 1990) and chlorophyll a and b concentrations (Alva and Syvertsen, 1991). Commonly leached ions, like nitrate and potassium, are retained in the medium for plant usage and not introduced into the environment. Retention of these ions have reduced the concentrations of fertilizers required for the crop and water usage required for the traditional leaching. Water usage is also reduced by applying the water used more efficiently and the water remaining after an irrigation cycle is stored and utilized in the next irrigation cycle. Introduction of any contaminants in the irrigation water into the groundwater system is eliminated.

The objectives of this study were to determine the influence of controlled-release fertilizer concentrations on the chemical properties of the growing medium and effluent in a zero-leachate subirrigation system and the traditional top-water system.

Materials and Methods

Plant material and experimental manipulation. Rooted 'Iridon' cuttings (Yoder Brothers, Barberton, Ohio) were planted on 10 Oct 1993 into 10-cm diameter pots with a depth of 5-cm (volume=390 ml) filled with the prepared growing medium. The medium consisted of 1 Sphagnum peat: 1 horticultural perlite (by volume) amended with dolimitic limestone at 2.5 kg/m^3. The pH of the growing medium was 6.0. Electrical conductivity (EC) of the medium was <0.1 dS/m. Before the rooted cuttings were transplanted into the dibble holes, preweighed quantities of CRF were poured into the bottoms of the holes. Four rates of Sierra Chrysanthemum Mix Osmocote 12N-4.4P-13.9K (Grace-Sierra Horticultural Products, Milpitas, CA) were used: 0.87, 1.75, 3.50, and 7.00 g CRF/pot. All plants were top-watered using 150 ml of a 350 mg N/l solution from a 20N-4.4P-16.6K Peat-lite fertilizer (Grace-Sierra Horticultural Products) to establish an initial nutrient charge in the medium before the CRF was activated and to provide moisture for the capillary action for the subirrigated pots. Pots were placed into a 52- x 26- x 6-cm black, vacuum-formed flats and spaced (230 cm^2/pot) on 1.82- x 1.21-m, ebb-and-flow benches located in a glasshouse kept at 20±4C. Ebb-and-flow benches consist of a grid of perpendicular troughs that allow the water to contact every pot's bottom simultaneously. The irrigation water would enter the pot through its drainage holes and be pulled up the column of growing medium by capillary action. The irrigation water was in direct contact with 0.7 cm of the growing medium. Irrigation water entered the bench for a nine min period and remained in the bench for an additional ten min. Photosynthetically active radiation, which was measured using a LI-COR LI-183 (LI-COR, Lincoln, Neb.), measured 126 μmol/s^1·m^2 at the initiation of the experiment and averaged 132 μmol/s^1·m^2 at foliage level for the weekly measurements over the duration of the experiment.

Pots for the top-water treatment were placed into flats with no drainage slots so the leachate would not enter the ebb-and-flow irrigation water. Plants were irrigated when the growing medium appeared dry, every 2 days on average. Irrigation tanks were refilled after every cycle. Average leaching fraction (volume leached by volume applied) for the top-water treatment was 24% with a range from 19% to 34%. Irrigation water was deionized and had a pH of 5.63. Incandescent lamps were used to provide long days of 18 h by night interruption of from 0100 HR to 0700 HR. On 26 Oct., all of the plants were soft-pinched by removing 1 cm of the youngest growth and short days of 9 h were started using black, 4-mil polyethylene sheeting and continued for the duration of the experiment. The plants were disbudded on 22 Nov.

Medium and water quality. The growing medium samples were tested for pH, EC, and nitrate-nitrogen concentration after dividing the growing medium into two zones, the upper zone and root zone. The upper zone consisted of the upper 1.75 cm, which contained few roots, and the root zone contained medium profiles from the remaining medium around the CRF deposit. These samples were frozen at -20C and thawed for 24 h before being analyzed. Saturated extracts were preformed according to NCR-13 guidelines (Warncke, 1988) except the pH was measured in the leachate and not the slurry. Nitrate concentrations were measured using a nitrate ion-specific electrode (Hach Company, Loveland, Colo.). Media leachate samples of 5-ml were diluted into 20-ml of the standard extracting solution and stirred with magnetic stirrers as the readings were collected. Leachate from the top-water treatment and stock solution from the ebb-and-flow benches were collected after every irrigation cycle, which occurred every two to three days. Samples of irrigation water were pooled for every week of the experiment. Liquid samples were analyzed for EC, and nitrate concentration. Nitrate-nitrogen samples were analyzed with the same procedure as the saturated media extract samples. Due to a handling error, leachate samples for week 8 were lost.

Statistical Analysis. Three completely randomized blocks were arranged in a split-plot design. The CRF rate was the whole plot and irrigation method was the split plot. An experimental unit consisted of the average reading from three randomly selected pots. Statistical analysis included analysis of variance and regression where appropriate. SAS statistical software (SAS Institute, Cary, N.C.) was used to analyze the data.

Results

Properties of the Growing Medium. pH of the growing medium zones was significantly altered by the treatment factors of irrigation, CRF rate, and week as well as all the interactions except the week*irrigation and week*irrigation*rate in the root zone (Table 1, Fig. 1 and 2). The pH of the upper zone of the top-watered medium was 1.1x the pH of the upper zone of the subirrigated medium (Fig. 1). CRF rate linearly decreased the overall pH of the growing medium to a pH reading of 4.5 as the rate increased to 7.00 g

CRF/pot (Fig. 1 and 2). The top-water treatment reduced pH in the upper zone over the eleven week period for only rates >3.50 g CRF/pot (Fig. 1). While with subirrigation, all CRF rates lowered the pH of the growing medium's upper zone (Fig. 1). Similar to the upper zone, the pH of the root zone was decreased by CRF rates >3.5 g/pot. But with subirrigation, there was a marked contrast between the upper and lower zone. Only CRF rates >3.50 g CRF/pot lowered medium pH over the duration of the experiment.

EC of the medium was altered by the interactions of CRF rate, irrigation treatment, and week except for the week*irrigation and week*irrigation*CRF rate in the root zone (Table 1, Fig. 3). Soluble salt levels increased from 1.1 to 4.5 dS/m as the CRF rate increased from 0.87 to 7.00 g CRF/pot (data not presented). Subirrigation increased the mean EC readings in the upper zone of the growing medium compared to the upper zone of the top-water treatment, but the EC of the root zone for both irrigation treatments was similar at 0.45 dS/m.

Interactions significantly altered the nitrate-nitrogen concentrations in the upper zone of the growing medium, but only the main effects of CRF rate and week and their interaction influenced the nitrate-nitrogen concentrations in the root zone (Table 1, Fig. 4). Average nitrate-nitrogen levels in the upper zone of the top-watered and subirrigated medium increased from 45 to 600 mg/l and 173 to 2013 mg/l, respectively, as the CRF rate increased from 0.87 to 7.00 g CRF/pot (Fig. 4). Nitrate-nitrogen concentrations in the samples increased over 11 times from the 0.87 to the 7.00 g CRF/pot when comparing the subirrigation method to the top-water method. Concentrations of nitrate-nitrogen was identical in the root zones of both irrigation treatments.

Properties of the Leachate and Recirculated Water. CRF rate, irrigation method, week and their interactions significantly influenced the accumulation of soluble salts in the leachate or recirculated water (Table 2, Fig. 5). Recirculated water in the subirrigation treatment did not accumulate any soluble salts (EC<0.10 dS/m) during the first 10 weeks of the experiment for the lower three rates of the CRF (data not shown). The 7.00 g CRF/pot rate in week 11 of the subirrigated method registered an average EC reading of 0.13 dS/m. Average EC readings in the top-water leachate (Fig. 5) increased by 5.2x as the CRF rates increased from 0.87 to 7.00 g CRF/pot. The first three weeks of the top-watered medium shows a large loss of soluble salts by the higher EC values in the the top-water leachate. After this period, the similar EC readings within a CRF rate show the development of a steady-state release of salts from the CRF (Fig. 5).

Nitrate-nitrogen concentrations was significantly altered by CRF rate, irrigation method, week and all of their interactions (Table 2, Fig. 6). Subirrigation reduced the average nitrate-nitrogen content of the irrigation water through the entire production cycle by 30x when compared to the top-water irrigation method (3 mg/l in subirrigation and 30 mg/l in top-water). Higher rates of deposited CRF increased the average (across the weeks) concentrations of nitrate-nitrogen in the top-water water samples from 21 mg nitrate/liter at the 0.87 g CRF/pot application to 226 mg nitrate/liter in the 7.00 g CRF/pot application (Fig. 6). The nitrate-nitrogen concentration in the recirculated water over the duration of the experiment ranged from 0 to 7 mg/liter as the CRF rate increased from 0.87 to 7.00 g CRF/pot.

Total nitrate-nitrogen collected in the leachate differed from the accumulation in the recirculated water. The recirculated water accumulated <1% of the N applied, while the top-water leachate accumulated up to 53% of the applied nitrogen in the 7.00 g CRF/pot rate. The three lower CRF rates in the top-water system lost an average of 39% of the N applied in the leachate.

Discussion

The pH decrease in the upper medium zone of the subirrigated medium 10% was not expected. Past experiments by Guttormsen (1969) observed a significant soluble salt stratification when using a subirrigation systems, but he did not observe any significant pH stratification. Subirrigation caused an average reduction of 0.8 pH units from the upper zone to the root zone (Fig. 1 and 2). Possible explanations are a buildup of ammoniacal-nitrogen and excess potassium in the upper zone, but both of these explanations are not supported by the data. Increased concentrations of ammoniacal-nitrogen should have increased the pH gradient in the higher rates of CRF, but the pH gradient in the subirrigated growing medium of 0.8 units was greater than the average pH difference of 0.2 in the top-water treatment.

EC readings of the medium extract show the accumulation of "excess" nutrients of the upper zone of the subirrigation and top-water treatments (Fig. 3). Gradients of salts did exist in the top-water treatment due to the effects of evaporation of water, but zonal differences were reduced due to the downward movement of the irrigation water and removal of soluble salts in the leachate. The upper zone of the subirrigated growing medium did not have this leaching effect and a greater gradient developed. This salt accumulation could influence the postharvest life of the plant based on information reported by Crater (1992), which showed that low fertilizer charges in the medium extended the longevity by 10 to 14 days.

The high nitrate-nitrogen concentrations in the upper zone of the subirrigated medium (4x > than the upper zone of the top-watered medium) corresponds to the high EC readings in this zone. This buildup was expected due to the lack of leaching in the subirrigated pots. The surprising data were the similar nitrate-nitrogen concentrations in the root zone of both of the irrigation treatments for the duration of the experiment (Fig. 4). This similarity was unexpected due to the different irrigation water movement in the two irrigation treatments. Even with similar nitrate-nitrogen in the root zone, nitrogen concentrations in the foliage was influenced by irrigation method (Bruning, ----). This contradiction may be due to ammoniacal-nitrogen present in the growing medium from the CRF.

The leaching effect in the top-water treatment could be seen in the EC of the top-water leachate (Fig. 5). EC readings increased dramaticly as the CRF rate increased, while CRF rate did not induce any soluble salt accumulation in the recirculated water in the subirrigation treatment. The capillary action of the subirrigation system did not allow any leaching of soluble salts from the growing medium.

Concentrations of nitrate-nitrogen in the leachate or recirculated water was dramaticly affected by irrigation treatment and CRF rate. Subirrigation reduced the concentrations of nitrate in the irrigation water to levels acceptable to the E.P.A. drinking water standards of 10 mg/liter across the duration of the experiment. Nitrate levels in all of the top-water treatment exceeded the E.P.A. nitrate standards during the first four weeks of the production cycle in all of the rates, while the 3.50 and 7.00 g CRF/pot rates exceeded the E.P.A. standards for the entire production cycle (data not shown). Nitrate concentrations could have been elevated in the early portion of this study (up to week four) by the initial fertiligation with liquid fertilizer.

Crops produced in a subirrigation and CRF system will develop stratification of soluble salts within the growing medium. This salts can accumulate to harmful levels if not monitored closely. Rate of CRF fertilizer application can be reduced by 75% of the manufacturer's recommended rate to produce a similar plant quality as the traditional, top-water system. This reduction of quantity and form of fertilizer application will greatly reduce the potential of ground water pollution that is present in the traditional production method.

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Table 1 Statistical analysis of the effects of irrigation treatment, CRF rate and their interation on the chemical properties of the growing medium.

		pH				Electrical conductivity (dS/m)				Nitrate concentration (mg/l)			
		Upper zone		Lower zone		Upper zone		Root zone		Upper zone		Root zone	
Model	df	SS	P>F	SS	P>F	SS	P>F	SS	P>F	SS	P>F	SS	P>F
Block	2	4.80	0.001	5.25	0.001	2.13	0.08	0.37	0.14	915572	0.16	132295	0.14
Rate	3	20.23	0.001	36.68	0.001	176.20	0.01	16.26	0.01	57595556	0.01	3334133	0.01
Error a	6	0.62		0.50		1.63		0.40		1088004		146357	
IR^z	1	8.30	0.001	5.14	0.001	77.66	0.01	0.35	0.01	28681726	0.01	496	0.82
IR*Rate	3	9.09	0.001	1.92	0.001	36.08	0.01	0.45	0.01	16746923	0.01	7769	0.84
Error b	8	0.53		0.82		2.26		0.09		1597775		75465	
Week	10	24.76	0.001	18.60	0.001	6.72	0.01	3.85	0.01	3702423	0.01	764260	0.01
Week*Rate	30	9.75	0.001	18.60	0.001	8.89	0.01	1.95	0.01	9121599	0.01	339332	0.01
Week*IR	10	2.57	0.001	0.97	0.230	12.63	0.01	0.08	0.84	7924643	0.01	38785	0.35
Week*Rate*IR	30	6.32	0.001	2.44	0.35	13.29	0.01	0.44	0.54	9864655	0.01	67597	0.92
Error c	160	7.58		11.99		15.28		2.31		6002715		559523	
Total	266												

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^{z}IR corresponds to irrigation.

Table 2 Statistical analysis of the effects of irrigation treatment, CRF rate, and their interaction on the chemical properties of the leachate/recirculated water.

Model	df	Electrical conductivity (dS/m) SS	Electrical conductivity (dS/m) P>F	Nitrate concentration (mg/l) SS	Nitrate concentration (mg/l) P>F
Block	2	0.82	0.23	10559	0.25
Rate	3	52.81	0.01	423077	0.0001
Error a	6	1.34		18069	
IR	1	76.43	0.01	448208	0.0001
IR*Rate	3	51.79	0.01	381798	0.0001
Error b	8	2.14		26119	
Week	9	22.55	0.01	89735	0.0001
Week*Rate	27	2.74	0.01	31044	0.0001
Week*IR	9	23.05	0.01	88097	0.0001
Week*Rate*IR	27	2.95	0.01	27177	0.0001
Error c	144	2.71		15989	
Total	239				

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[z] IR corresponds to irrigation.

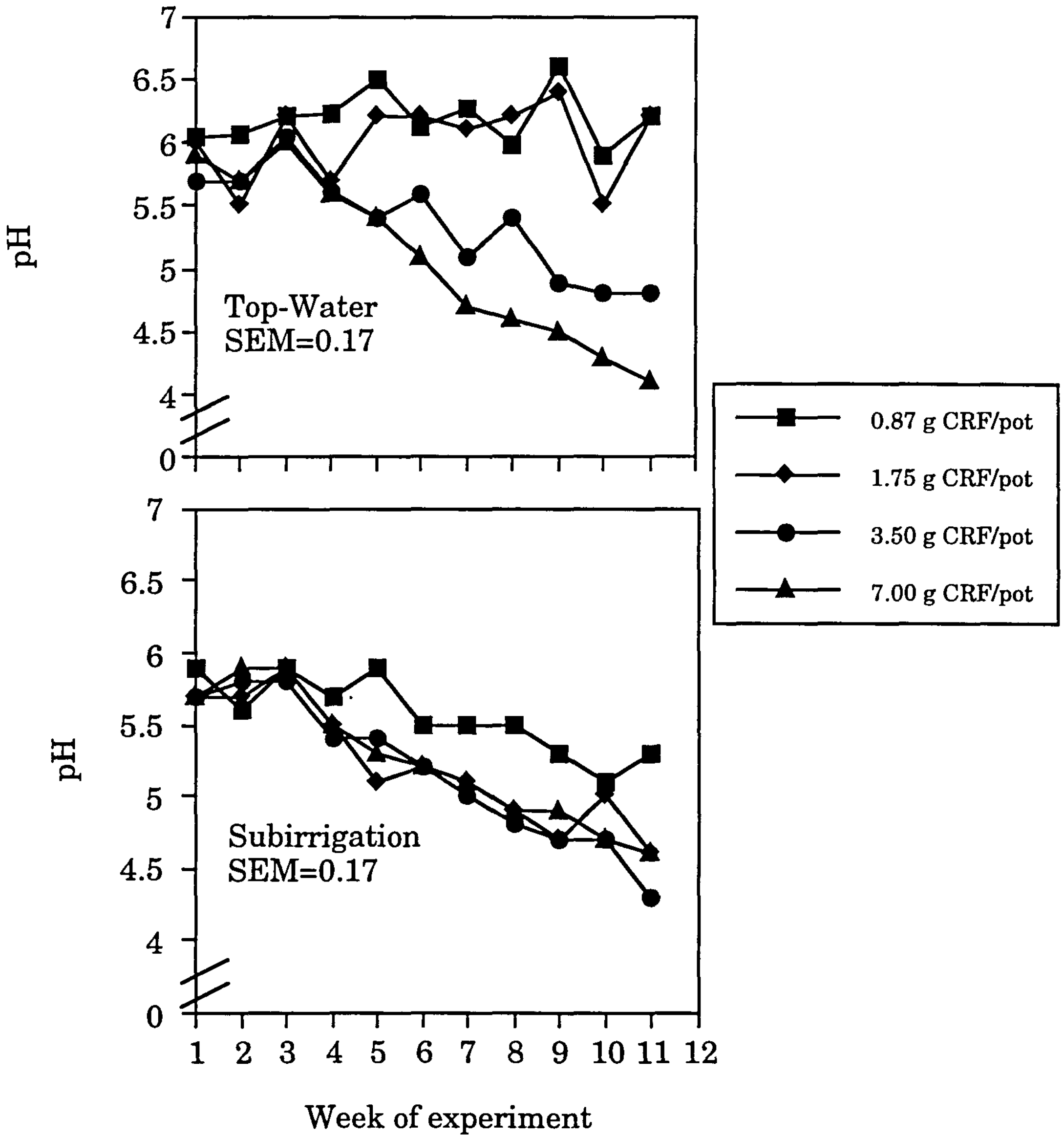

Fig. 1 Weekly pH readings of the upper zone of the growing medium across duration of experiment.

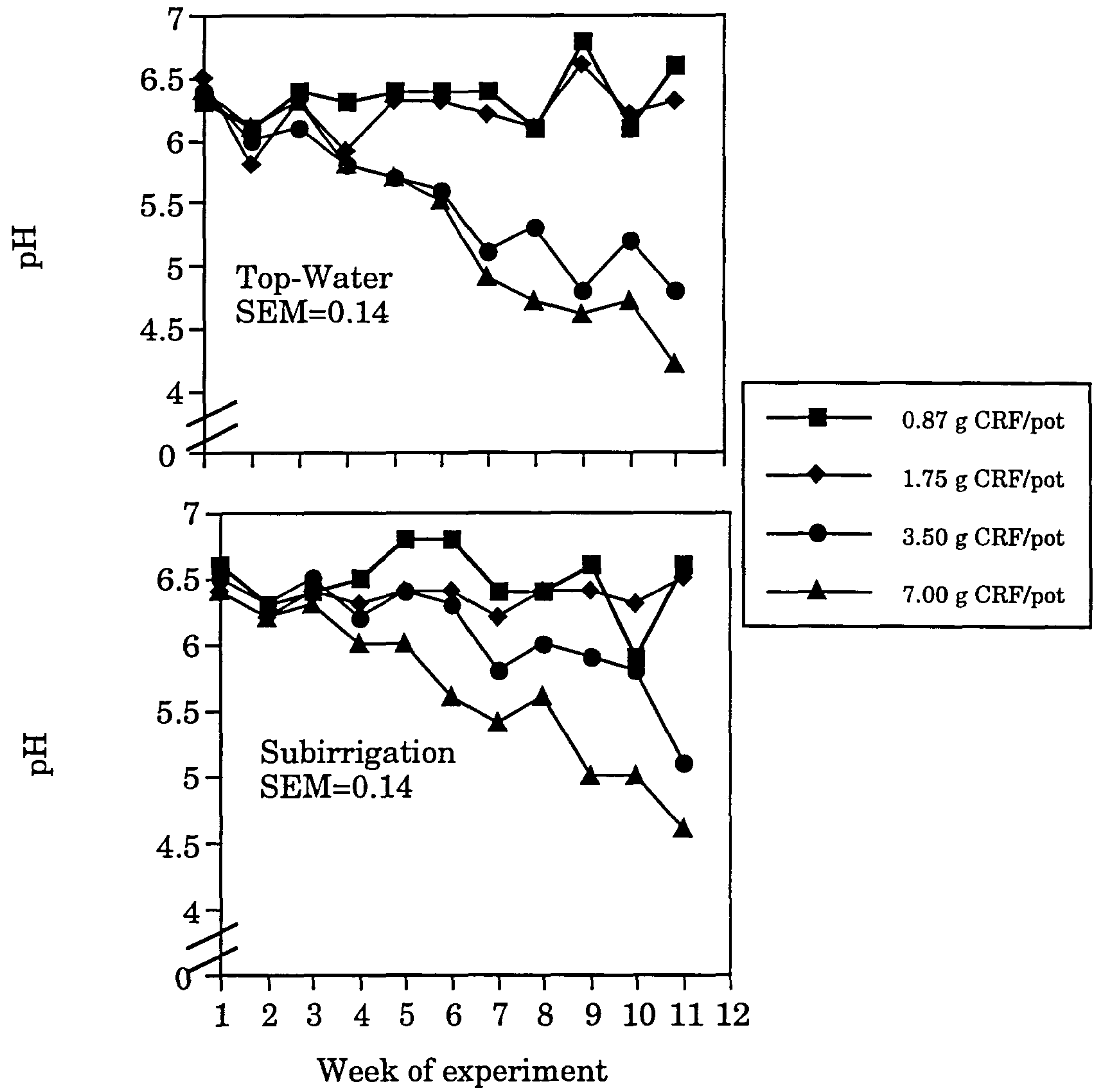

Fig. 2 Weekly pH readings of the root zone of the growing medium across duration of experiment.

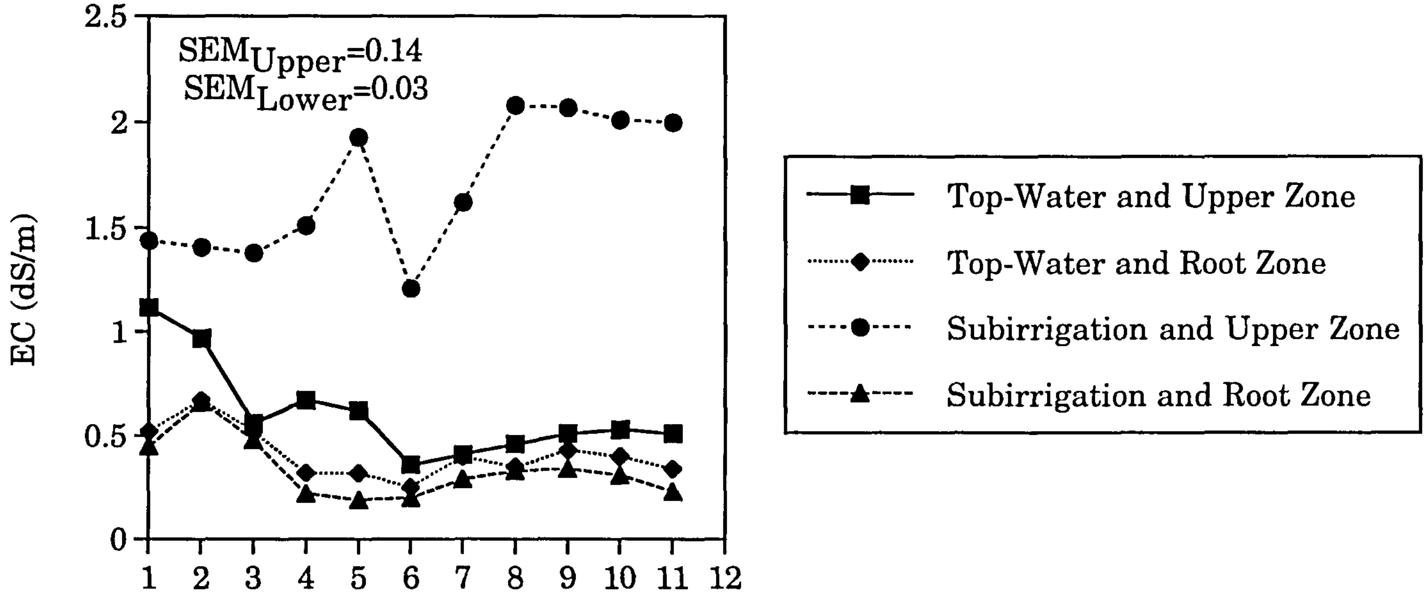

Fig. 3 Electrical conductivity of the upper and root zones of the growing medium under top-water and subirrigation treatments across duration of experiment.

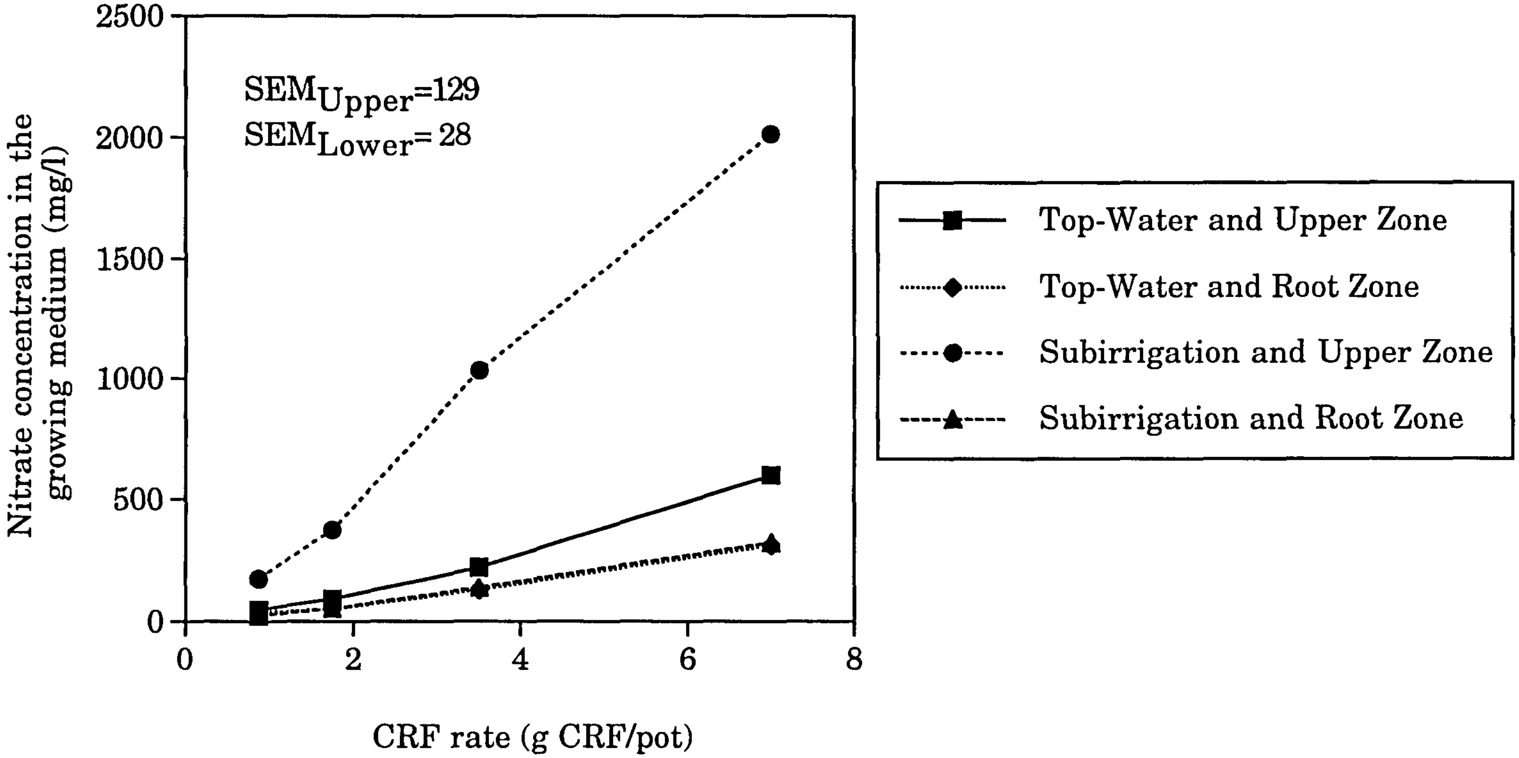

Fig. 4 Nitrate concentrations (expressed as mg NO_3-N/l of extract) in the growing medium zones across CRF rates.

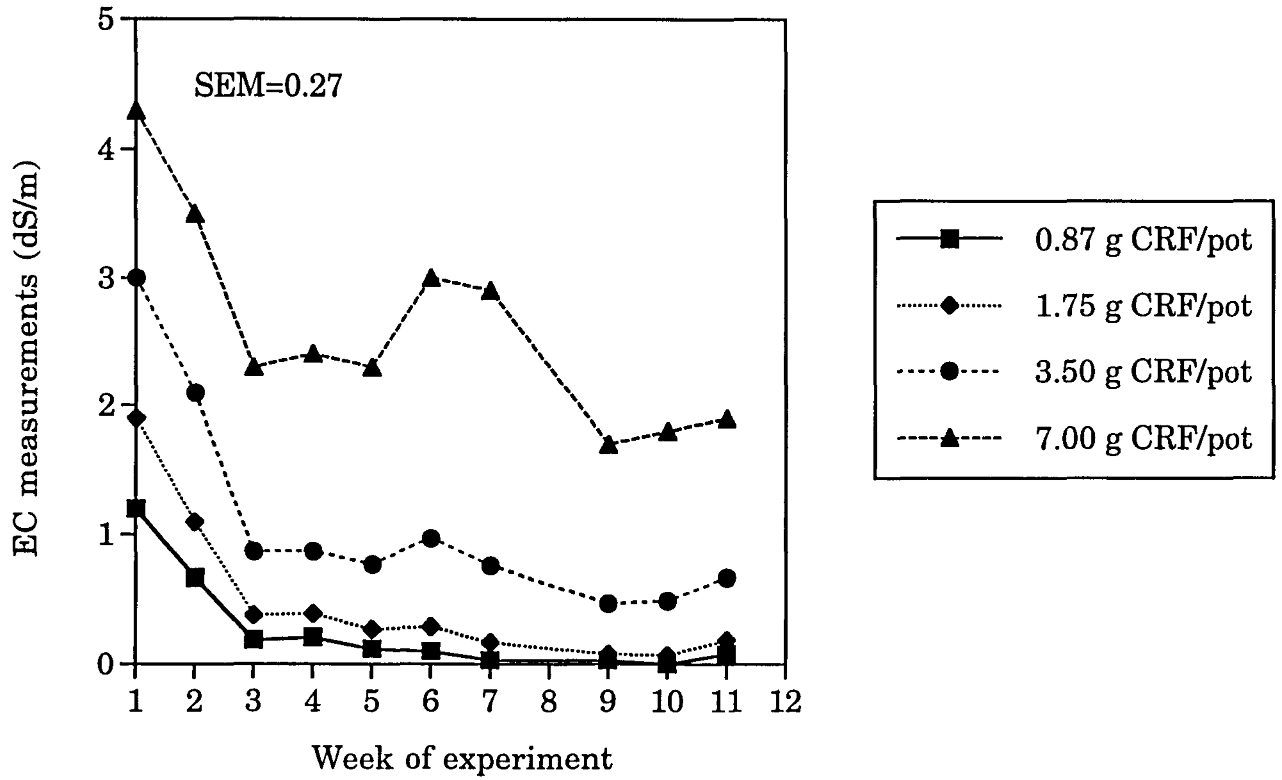

Fig. 5 EC measurements in top-water leachate for each CRF rate across duration of experiment.

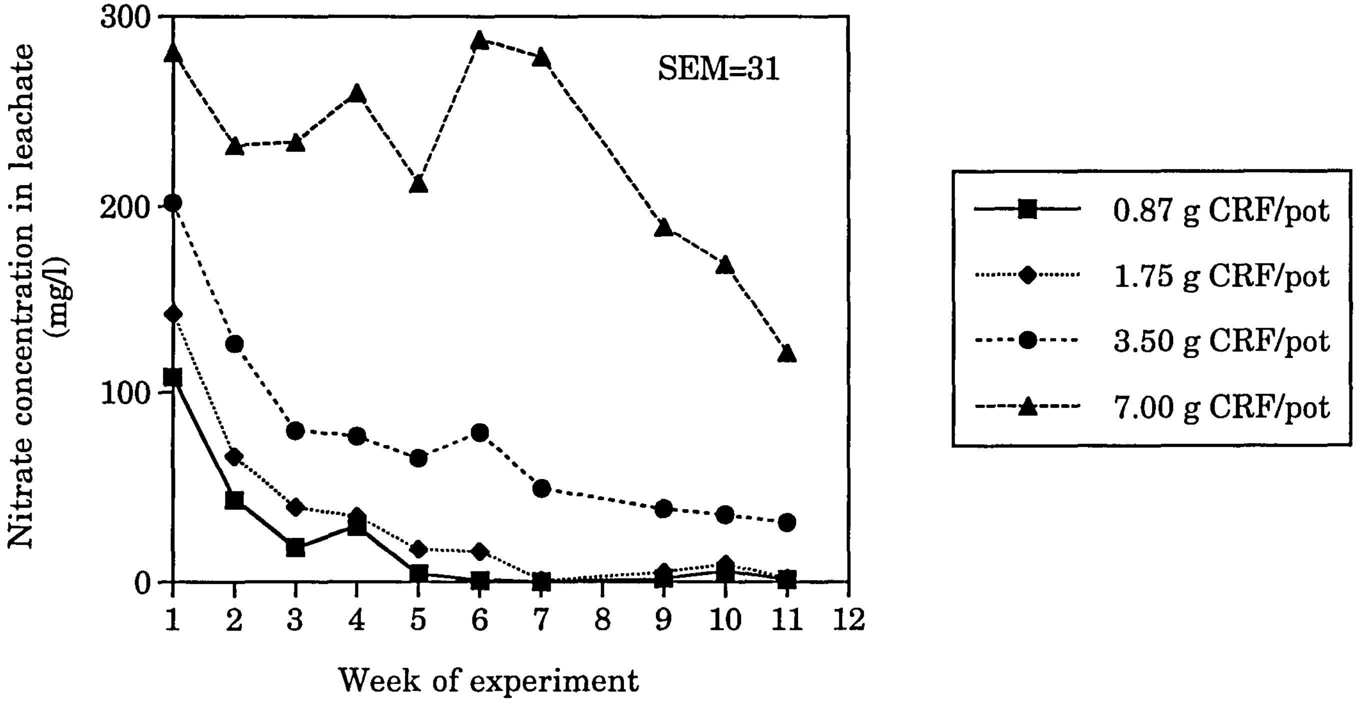

Fig. 6 Nitrate concentrations in top-water leachate of the CRF rates across duration of experiment.

GENERAL SUMMARY

A wide diversity of alternative production systems are being investigated to prevent groundwater pollution. Several of these systems have shown promise in reducing the amount of nitrate-nitrogen entering the environment.

The controlled-release fertilizer and ebb-and-flow (subirrigation) system appears to be a practical production method in chrysanthemum production. This system greatly reduced the accumulation of soluble salts, especially nitrate-nitrogen, in the waste water. Any accumulation of salts was recirculated to eliminate the introduction of these salts into the environment. The elimination of the liquid fertilizer irrigation water reduces the problems of storing and disposing of these nutrient solutions, which contain significant concentrations of groundwater polluting compounds.

Due to the lack of leaching of the salts, application rates of CRF is more sensitive in the subirrigation system than the traditional top-watering system. Rates for chrysanthemum production should be reduced by at least 50%. Salt accumulation in the growing medium becomes highly stratified and the EC readings in the root zone should be closely monitored or plant quality could be reduced. Subirrigation does appear to change the pH gradient within the growing medium. Flowering characteristics of chrysanthemums are not influenced by this system as long as the deposited controlled-release fertilizer rates were in an acceptable range.

Other growth characteristics were influenced. Shoot height was reduced with increasing controlled-release fertilizer rates, while shoot dry weight remained similar for several of the fertilizer rates. Accumulations of certain nutrients, like K, P, Ca and Zn, were influenced by the rate of fertilizer application and the type of irrigation method. Subirrigation increased some the concentrations of some of these nutrients and reduced other nutrient concentrations.

From the data collected for this study, the combination of controlled-release fertilizer and subirrigation could be implemented in an automated operation without reducing plant quality. This system would reduce the production costs due to reduced water, fertilizer, and labor usage, while greatly reducing the potential of additional groundwater pollution from compounds in the leachate water and misapplied irrigation water.

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