The Effect of Salinity on the Growth and Nutrient Status of Zinnia Grown Under Short- and Long-cycle Subirrigation Management

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Abstract. As water resources become limited, agricultural producers must resort to alternative sources for irrigation, including municipal reclaimed water which may contain impurities such as salts that can adversely impact irrigation management practices and crop yield. To test the effects of salinity on plant growth and nutrient composition under greenhouse conditions, zinnia (*Zinnia elegans*) was produced under two different subirrigation management regimes and exposed to various concentrations of NaCl to simulate the crop production challenges associated with poor water quality. Plants received either short- or long-cycle subirrigation to achieve differing levels of potting medium saturation at each irrigation event. Plants under these two irrigation management regimes were challenged with NaCl at concentrations up to 1.5 g·L\(^{-1}\) or 3 dS·m\(^{-1}\). Zinnia plants accumulated more Na in shoot tissues as salinity in the irrigation water increased from 0 to 1.5 g·L\(^{-1}\). The electrical conductivity (EC) in the potting medium also increased over time, and the rate of leaf area expansion decreased with increasing levels of salinity in the irrigation water. Short-cycle irrigation management has been shown to increase fertilizer and water use efficiency (WUE), thereby reducing the costs associated with these resources and also reducing the environmental impacts of agricultural crop production. In our study, the medium under short-cycle subirrigation management had lower gravimetric water content (GWC), both before and after irrigation, than the medium under long-cycle subirrigation, but the drier medium conditions did not increase susceptibility to salt injury. Furthermore, plants grown under short-cycle irrigation management for 4 to 6 weeks accumulated less Na in shoot tissue than plants grown under long-cycle irrigation management. Sodium accumulation in the shoot tissues was a product of both the amount of sodium in the irrigation solution and the amount of water used by the plant over time. Therefore, short-cycle subirrigation can be used as an effective water management technique even when raw water quality is poor as represented by elevated salinity. Our research indicates that zinnia can be irrigated with saline water up to 0.5 g·L\(^{-1}\) NaCl (an EC of 1 dS·m\(^{-1}\)) in a 5-week production cycle without adverse effects on growth.

Water is essential for agricultural crop production, but globally, the availability of water of acceptable quality is increasingly becoming a limited resource. Irrigated agriculture is one of the largest yet most inefficient users of this resource. As population increases, competition for fresh water between civil uses and agriculture will only increase. Therefore, agricultural producers...
or bark in various proportions. More recently, other amendments such as coconut coir, rice hulls, and wood fibers have been tested for efficacy as media amendments. Coir-amended mixes have higher moisture-holding capacity than peat-based mixes (Stamps and Evans, 1997).

As no leaching occurs in subirrigation, excess salts from fertilizer and contaminants in the irrigation water such as salinity accumulate in the potting medium resulting in elevated EC (Argo and Biernbaum, 1996; van Iersel, 2000), a phenomenon that is similar to salt crust ing experienced in arid regions. The accumulation of salts can be a concern when raw water quality is low or when an alternate source of irrigation water carries unwanted ions. How such circumstances might affect greenhouse crop performance under short-cycle subirrigation, where the water available to the plant is restricted, has not been reported. Therefore, the focus of this research was to determine the effect of NaCl on the growth and nutrient composition of zinnia grown under different subirrigation management regimes.

*Zinnia elegans*, a species previously identified as salinity sensitive (Villarino and Mattson, 2011), was selected as the test crop in this study.

**Materials and Methods**

Two experiments were conducted to determine the effect of NaCl on the growth and nutrient composition of the zinnia (*Zinnia elegans*) cultivar ‘Dreamland’.

*Zinnia growth under short- and long-cycle irrigation, with or without supplemental NaCl.*

For the first experiment, zinnia plugs (512 cell trays) were obtained from a commercial propagator (Geremia Greenhouse, Wallingford, CT). Plugs were transplanted, one per pot, into a blend of coconut coir and Fafard 3B (Sun Gro Horticulture Canada Ltd.) at a 3:1 ratio in 12-cm containers (X-4PXD Extra Deep Square Pot with root channel; Landmark Plastics, Akron, OH). The potting containers were placed in troughs of 107 cm in size. Each trough, representing a single treatment combination, contained five plants, and each bench had four troughs. The treatment combinations were short- or long-cycle subirrigation at each irrigation event, using the following concentrations: 0, 0.3, 0.6, 0.9, and 1.2 g L⁻¹ NaCl. There were three replicates for each treatment and fifteen plants for each replicated treatment at weekly intervals, and the total leaf area was recorded. Tissue samples were oven-dried at 75 °C for at least 72 h. The potting medium and the shoot tissue samples were analyzed for nutrient composition as previously described.

**Experimental design and statistics.** For the first experiment, treatments were arranged in a split plot design with the main plot arranged in a randomized complete block design with three replications. The treatment combinations were short- or long-cycle subirrigation with or without the addition of NaCl. The main plot was salinity treatment; the subplot was length of irrigation cycle. Analysis of variance was used to determine treatment effects on plant growth, tissue nutrient content, and EC of the potting medium.

For the second experiment, treatments were arranged in a randomized complete block design with four replications. Analysis of variance was used to determine treatment effects on plant growth, tissue nutrient composition, medium nutrient composition, and EC of the potting medium.

**Results**

**Water uptake and plant growth in zinnia grown with or without addition of NaCl.**

Plants irrigated by a long-cycle had greater GWC than plants irrigated by a short-cycle, both before and after irrigation (Table 1). Plants treated with NaCl treatment had lower dry weights and less chlorophyll per unit leaf area compared with plants not exposed to supplemental NaCl (Table 1). Plants exposed to supplemental NaCl were shorter than those not exposed to elevated salinity, and the shorter plants also developed shorter internodes (Table 1). Irrigation management had no significant effect on any of the parameters measured except GWC.

**Nutrient composition in the shoot tissue of zinnia grown with or without addition of NaCl.**

Plants exposed to elevated salinity contained higher concentrations of P, K, Ca, and Mn in shoot tissue than plants not exposed to the supplemental NaCl treatment, but lower concentrations of Al and Fe (Table 2). Tissue Na content was most dramatically affected by salinity in the irrigation water with an average shoot tissue concentration of 0.19% (9900 mg L⁻¹) over weeks 4 to 6 in subirrigation. In this study, irrigation management had no effect on tissue nutrient content with the exception of Na. Here, zinnia produced under long-cycle subirrigation accumulated over 35% more Na.
Table 1. The effects of NaCl and irrigation management on zinnia water uptake and growth. Data represent the values at final harvest. Gravimetric water content (GWC) of the potting medium was recorded before and after each irrigation event.

| Treatment | GWC before (g·g⁻¹) | GWC after (g·g⁻¹) | Internode length (cm) | Dry wt (g) | Plant ht (cm) | Chlorophyll conc (mg·cm⁻²) |
|-----------|--------------------|-------------------|----------------------|------------|-------------|---------------------------|
| Salinity (S) |                    |                   |                      |            |             |                           |
| 1.5 g·L⁻¹ | 0.12               | 0.32              | 2.7                  | 2.1        | 20          | 0.019                     |
| 0 g·L⁻¹   | 0.09               | 0.32              | 3.6                  | 4.1        | 29          | 0.028                     |
| Irrigation (I) |                  |                   |                      |            |             |                           |
| Short-cycle | 0.10               | 0.28              | 3.2                  | 2.9        | 24          | 0.024                     |
| Long-cycle | 0.12               | 0.35              | 3.1                  | 3.4        | 25          | 0.023                     |

*P* ≤ 0.05, **P** ≤ 0.01, ***P*** ≤ 0.001 levels, and not significant, respectively.

**Table 2.** Average nutrient composition in the shoot tissue at 4- and 6-week harvest of zinnia plants grown with or without the addition of 1.5 g·L⁻¹ NaCl.

| Treatment | P (mg·kg⁻¹) | K (mg·kg⁻¹) | Ca (mg·kg⁻¹) | Na (mg·kg⁻¹) | Al (mg·kg⁻¹) | Fe (mg·kg⁻¹) | Mn (mg·kg⁻¹) |
|-----------|-------------|-------------|--------------|--------------|--------------|--------------|--------------|
| Salinity (S) |               |             |              |              |              |              |              |
| 1.5 g·L⁻¹ | 3.6          | 63          | 8.2          | 9,012        | 12           | 49           | 81           |
| 0 g·L⁻¹   | 3.0          | 53          | 5.7          | 564          | 16           | 62           | 56           |
| Irrigation (I) |            |             |              |              |              |              |              |
| Short     | 3.2          | 58          | 6.9          | 4,066        | 13           | 55           | 69           |
| Long      | 3.3          | 57          | 7.0          | 5,510        | 15           | 56           | 68           |

*P* ≤ 0.05, **P** ≤ 0.01, ***P*** ≤ 0.001 levels, and not significant, respectively.

Discussion

Plant growth in zinnia grown under varying concentrations of NaCl. As salinity levels in nutrient solution increased, both EC of the potting medium (Fig. 1) and Na accumulation in the shoot tissue increased (Fig. 2).

Salinity affected leaf area in all treatment groups. The rate of increase in leaf area decreased as salinity levels in the nutrient solution increased (Figs. 2). Salinity affected leaf area in all treatment groups. The rate of increase in leaf area decreased as salinity levels in the nutrient solution increased (Fig. 2).

At the end of week 5, plants exposed to the highest concentrations of salinity showed severe leaf injury and general water stress symptoms (Fig. 3). Leaf damage and adverse effects on growth were visibly evident on plants exposed to Na at 0.9 g·L⁻¹ or higher. This damage coincided with tissue Na concentrations over 6000 mg·L⁻¹ and potting medium EC over 6 dS·cm⁻¹. Plants exposed to the highest Na concentrations began to show visible water stress and leaf damage after 4 weeks exposure to supplemental Na.

Nutrient composition in the shoot tissue of zinnia grown under varying concentrations of NaCl. A linear correlation between Na concentration in the irrigation solution and shoot tissue accumulation of K, Ca, Mg, Mn, Zn, and Na (Table 3) was observed. Sodium accumulation in the shoot tissue increased with the increase in Na concentration in the nutrient solution from 0 to 1.2 g·L⁻¹. Sodium concentration at final harvest in plants treated with 1.5 g·L⁻¹ NaCl was less than in plants exposed to 1.2 g·L⁻¹, as plants treated with 1.5 g·L⁻¹ NaCl developed leaf damage and symptoms of water stress earlier in the crop cycle which resulted in lower water uptake and reduced Na accumulation over the final weeks of the study.

**Discussion**

Plants grown in agricultural systems are subjected to environmental stress from many sources, all of which have the potential to limit growth and development. With over 50% of arable land expected to be affected by salinity by 2050 (Vinocur and Altman, 2005), plant resistance to abiotic and biotic stresses such as drought and salinity has the potential to mitigate the impact on crop production under such conditions (Epstein, 1999). Suppression of plant growth under saline conditions may be because of the toxicity of NaCl or decrease in the availability of water (Munns, 2002). Salinity inhibits the expansion of leaf surface, thereby decreasing fresh and dry weight of leaves (Takemura et al., 2000). Our study shows similar results with plants exposed to continuous irrigation with 1.5 g·L⁻¹ NaCl having lower dry weight, shorter internode length and plant height, and lower chlorophyll concentration compared with plants not exposed to NaCl (Table 1). When plants were treated with varying concentrations of salinity, the rate of increase in leaf area from week 1 to 5 decreased as Na concentration in the nutrient solution increased.

Increase in salinity can cause severe chemical deficiencies in plants (Khan et al., 2000). Neto et al. (2012) reported that increased Na and Cl accumulation in leaves affected the uptake of other nutrients such as K and Ca. Miranda et al. (2007) reported a decrease in Mg concentration in Moringa oleifera. Neto et al. (2012) reported a decrease in Mg concentration under saline conditions in castor bean.

In our study, plants treated with 1.5 g·L⁻¹ NaCl accumulated more P, K, Ca, Na, and Mn and less Al in the shoot tissue (per gram of dry weight) than plants not supplemented with additional NaCl (Table 2). As salinity levels increase, leaf Na⁺ and Cl⁻ content tend to increase in bedding plants (Niu et al., 2010). In our study, increasing levels of salinity from 0 to 1.5 g·L⁻¹ NaCl at 0.3 g·L⁻¹ increments resulted in Na concentration in zinnia shoot tissue that increased linearly over time of exposure from week 1 to 5. This increase in tissue accumulation of Na simultaneously coincided with a similar increase in EC in the potting medium (Figs. 1 and 2).

Water uptake in containers under short-cycle management is lower than in containers under long-cycle subirrigation management (Gent and McAvoy, 2011). In our study, containers under short-cycle management
had lower GWC both before and after irrigation than containers under long-cycle management irrespective of salinity treatments (Table 1). Here, we report that leaf area was the first indicator of increasing salt stress in zinnia. The rate of leaf area expansion began to decline around week 4 with increasing levels of salinity and coincided with a simultaneous increase in EC of the potting medium. Even though plants produced under short-cycle irrigation developed under restricted water availability, exposure to elevated salinity was not more damaging to these plants. In fact, tissue accumulation of Na under long-cycle management was over 35% higher than in plants under short-cycle irrigation when both were exposed to the same salinity concentration. Previous studies on restricted irrigation management demonstrated greater WUE (Gent and McAvoy, 2011). Here, we found that Na accumulation in the medium was directly related to the total irrigation solution taken up over time, and tissue accumulation of Na in zinnia tracked closely to Na accumulation in the potting medium. Therefore, short-cycle irrigation management can be used as an effective water management technique even when raw water quality is poor as represented by elevated salinity and may be even more advantageous as the duration of the cropping cycle increases.

Table 3. Final nutrient composition in the shoot tissue for zinnia grown under subirrigation with a nutrient solution containing NaCl at 0, 0.3, 0.6, 0.9, 1.2, or 1.5 g·L−1.

| Treatment   | K (g·kg−1) | Ca (g·kg−1) | Mg (mg·kg−1) | Mn (mg·kg−1) | Zn (mg·kg−1) | Na (mg·kg−1) |
|-------------|------------|-------------|--------------|--------------|--------------|--------------|
| 0 g·L−1     | 49         | 5.4         | 5.5          | 38.5         | 36           | 1,537        |
| 0.3 g·L−1   | 49         | 6.7         | 7.2          | 31.5         | 41           | 2,825        |
| 0.6 g·L−1   | 51         | 7.0         | 6.4          | 36.2         | 37           | 6,637        |
| 0.9 g·L−1   | 56         | 7.3         | 7.1          | 50.6         | 41           | 7,355        |
| 1.2 g·L−1   | 57         | 7.3         | 7.1          | 62.5         | 44           | 9,732        |
| 1.5 g·L−1   | 57         | 7.3         | 7.2          | 67.7         | 50           | 9,027        |

**Significance**

- Linear ** ** ** ** **
- Quadratic NS NS NS * NS NS
- Cubic NS NS NS * NS NS

*, **, *** and NS denote significance at \( P \leq 0.05 \), \( P \leq 0.01 \), \( P \leq 0.001 \) levels, and not significant, respectively.

had lower GWC both before and after irrigation than containers under long-cycle management irrespective of salinity treatments (Table 1). Here, we report that leaf area was the first indicator of increasing salt stress in zinnia. The rate of leaf area expansion began to decline around week 4 with increasing levels of salinity and coincided with a simultaneous increase in EC of the potting medium. Even though plants produced under short-cycle irrigation developed under restricted water availability, exposure to elevated salinity was not more damaging to these plants. In fact, tissue accumulation of Na under long-cycle management was over 35% higher than in plants under short-cycle irrigation when both were exposed to the same salinity concentration. Previous studies on restricted irrigation management demonstrated greater WUE (Gent and McAvoy, 2011). Here, we found that Na accumulation in the medium was directly related to the total irrigation solution taken up over time, and tissue accumulation of Na in zinnia tracked closely to Na accumulation in the potting medium. Therefore, short-cycle irrigation management can be used as an effective water management technique even when raw water quality is poor as represented by elevated salinity and may be even more advantageous as the duration of the cropping cycle increases.

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