Effects of Plant Root Oxygen Deprivation in Relation to Water and Nitrate Uptake for Rose

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Abstract

Plants need oxygen to perform cellular respiration. Plants absorb oxygen through their roots. Past research has shown that reducing the concentration of oxygen in the rootzone of hydroponically grown rose plants will compromise the plants' ability to absorb nitrate and water, although this effect has not been quantified. The objective of this research was to quantify the effects of different oxygen concentrations in the rootzone on water and nitrate absorption rates. It was hypothesized that absorption rates would be reduced at the point at which the oxygen concentration in the rootzone became a limiting factor on the plants' ability to perform cellular respiration. Hydroponically grown rose plants, *Rosa hybrida* 'Kardinal', were exposed to different oxygen concentrations and the water and nitrate absorption rates of each plant were measured. No noticeable correlation between water and nitrate absorption rates and rootzone oxygen concentration were observed. These results were contrary to past research and have led to the conclusion that data at lower concentrations of oxygen must be gathered to demonstrate a critical oxygen concentration for water and nitrate absorption. Data from lower oxygen concentrations may demonstrate the point at which the rootzone oxygen concentration becomes a limiting factor on cellular respiration.

INTRODUCTION

The commercial use of hydroponics for production of food and ornamental crops has increased in recent years. In 2000, the worldwide area of hydroponically grown agriculture was about 25,000 ha and was considered to be increasing (Jeong et al., 2001). Hydroponics is an effective management intensive system for crop production that allows environmentally sensitive water management.

Optimization of many hydroponic techniques is still under development because the methods are relatively new to commercial production. Significant research has been completed regarding optimal fertilization and irrigation (fertigation) for plants (Lieth and Burger, 1989; Chimonidou Pavlidou and Papadopoulos, 1999; Malorgio et al., 2001; Raviv et al., 2001; Jovicich et al., 2003; Venezia et al., 2003).

Plants require oxygen for aerobic cellular respiration to produce energy consumed during growth Research has shown that reduced oxygen (O_2) concentrations in the rootzone reduce the plant absorbtion of nitrate and water (Bradford and Hsiao, 1982; Smit and Stachowiak, 1988; Morard and Silvestre, 1996; Kozlowski, 1997; Visser et al., 2003), but the concentration at which absorption rates are reduced have not been determined.

The objective of this research was to quantify the effects of different oxygen concentrations in the rootzone on the water and nitrate absorption rates of rose plants. Outcomes will help commercial flower growers efficiently manage fertigation schedules. Efficient management of irrigation and fertilization will reduce water and fertilizer waste and make commercial hydroponics more economical and environmentally sensitive.

MATERIALS AND METHODS

Four six-month-old rose plants, *Rosa hybrida* 'Kardinal', were grown from cuttings hydroponically in a growth chamber. Each plant was grown in an 8-liter hydroponic unit filled with modified half-strength Hoagland's solution (Hoagland and Arnon, 1950). The nutrient solution was changed three times per week to replenish absorbed nutrients. Plants received 1200 µmoles m^{-2} s^{-1} of light from 3 HID lamps from 0100-1600 HR and the temperature was maintained at 25°C while the lights were on and 18°C while the lights were off.

Each plant was subjected to a different concentration of oxygen in its nutrient solution. These concentrations varied between 2.5 and 8 mg/L. No one plant was held at extreme low or high oxygen concentrations for an extended period of time. Instead, the assignment of the oxygen concentration each plant received was changed three times each week on a rotating schedule; therefore each rose plant was given time to recover from possible periods of oxygen stress in the rootzone.

The desired oxygen concentrations were programmed into a Campbell Scientific CR23X datalogger. The datalogger continuously recorded the oxygen concentration of each pot and maintained the desired oxygen concentration by regulating the bubbling of air and nitrogen gas into the pot. Nitrogen gas generated by a Balston HFX-1 nitrogen generator was bubbled through the nutrient solution to reduce the oxygen concentration of the pot. Oxygen diffused down a concentration gradient into the bubbles of nitrogen and was carried to the surface and out of the solution by the bubbles. Air was bubbled through the nutrient solution to raise the concentration of oxygen as oxygen tended to move out of the air bubbles and into the surrounding solution.

Oxygen probes (Kernco Instruments) were used to constantly monitor the oxygen concentration in each hydroponic unit. Readings were recorded by the datalogger and compared the actual oxygen concentration to the programmed target concentration level. A water pump was placed in each container to move water over the oxygen probe and maintain accurate concentration readings. The sensors were recalibrated using an Oxan 600 Oxygen Sensor.

Samples (approximately 60 ml) were collected daily from the nutrient solution of each container. These samples were analyzed with a Nitrogen Analyzer (rapid diffusion conductivity method; Carlson, 1986) to determine the amount of nitrate present in the solution. From this, the amount of nitrate absorbed by each plant could be calculated with the following equation.

$$\text{Absorption} = ([\text{initial } NO_3^-] \times \text{initial volume}) - ([\text{final } NO_3^-] \times \text{final volume}) \quad (1)$$

The pH of each sample was measured with an Oakton pH meter during sample analysis.

Water absorbed by each plant was measured daily gravimetrically. The volume of water lost via transpiration was replaced with deionized water before samples were taken so that a known volume of 8 L could be used to calculate nitrate absorption. The difference in these weights was due to water lost by transpiration.

The volume of each plant's rootzone was measured by water displacement and the fresh weight of the plant was measured daily. These measurements were used to determine the effect of oxygen concentrations on the plant health and growth.

RESULTS

All four plants grew based on fresh weight increase, during the experiment (Fig. 1). The largest plant was plant 1, the smallest plant was plant 2, and plants 3 and 4 were of intermediate size. Plant 1 had an increase of about 40 g of fresh weight.

Plants 1, 3, and 4 showed no relationship of water absorption rate to dissolved oxygen concentration (Fig. 2). Plant 2 showed a weak positive trend of increased water absorption rate with increased dissolved oxygen.

There was no correlation between dissolved oxygen levels and nitrate absorption rate for plants 1, 3, and 4 (Fig. 3). Plant 2 may show a weak positive trend of increased nitrate absorption rate with increased dissolved oxygen if the outlying negative value is excluded. We were unable to achieve dissolved oxygen levels lower than 2 mg/L.

DISCUSSION

Oxygen concentrations in the rootzone of hydroponically grown roses did not affect the rates of nitrate or water absorption in this experiment. It is likely that concentrations were not low enough to impact plant growth. Dissolved oxygen concentrations of 0 - 3 mg/L, may have impacted plant growth. It appears that roses are less responsive to oxygen stress than previously thought.

The results show a broad range of nitrate concentrations in the nutrient solutions. An individual plants' demand for nitrate must be considered during the analysis of nitrate absorption rates. A broad range of nitrate absorption occurs in rose plants based on a cyclical pattern related to shoot development and harvest, and the rate of uptake can change as much as five-fold in a single cycle of flower shoot growth. At certain stages in the cycle, effluxes of nitrate into the nutrient solution can also be expected (Cabrera et al., 1995).

Increased oxygen concentrations may allow plants a greater capacity for nitrate uptake than low oxygen concentrations, but not all plants take advantage of this increased capacity (Fig. 3). Plant demand for nitrate can also explain this conclusion. If a plant has some nitrate conserved in its tissues from previous absorption, the plant's demand for nitrate will be low. If this plant is then subjected to a high concentration of oxygen, the plant's demand for nitrate will not be changed. This would result in low nitrate uptake at a high oxygen concentration. The same is true in the reverse. If a plant has a high demand for nitrate, it will absorb as much as it can from the surrounding nutrient solution, even if the nutrient solution of the plant has a low concentration of oxygen. This would result in relatively high nitrate uptake at a low concentration of oxygen.

The outliers in Figure 3 are extreme positive and negative values. These values do not correspond to the rates of nitrate absorption which would be predicted for rose plants of the sizes studied. This suggests that the driving force behind nitrate absorption in this experiment was plant nitrate demand rather than oxygen availability, which further implies that roses are not as responsive to low oxygen concentrations as previously thought.

The oxygen sensors used in this study to monitor dissolved oxygen concentrations were a new form of technology that has made this experiment possible. Previous sensors were large and required the monitored solution to pass through them; thus, impossible to monitor the oxygen concentration of the rootzone. Also, previous sensors could not measure low oxygen concentrations.

ACKNOWLEDGEMENTS

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Figures

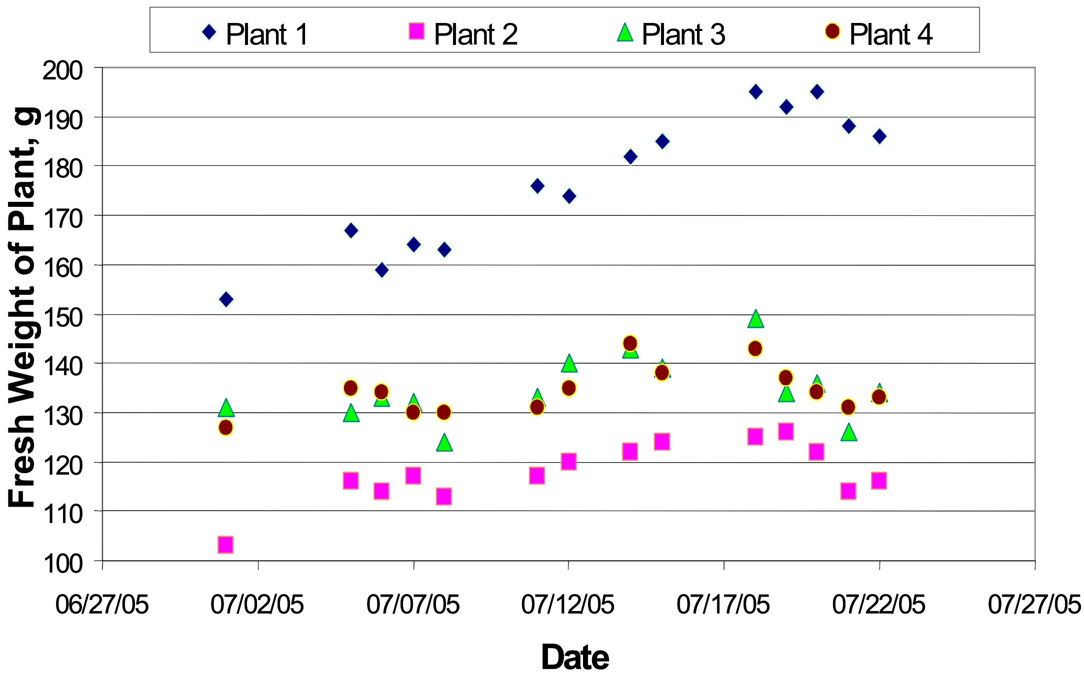

Fig. 1. Fresh weight of individual rose plants over time.

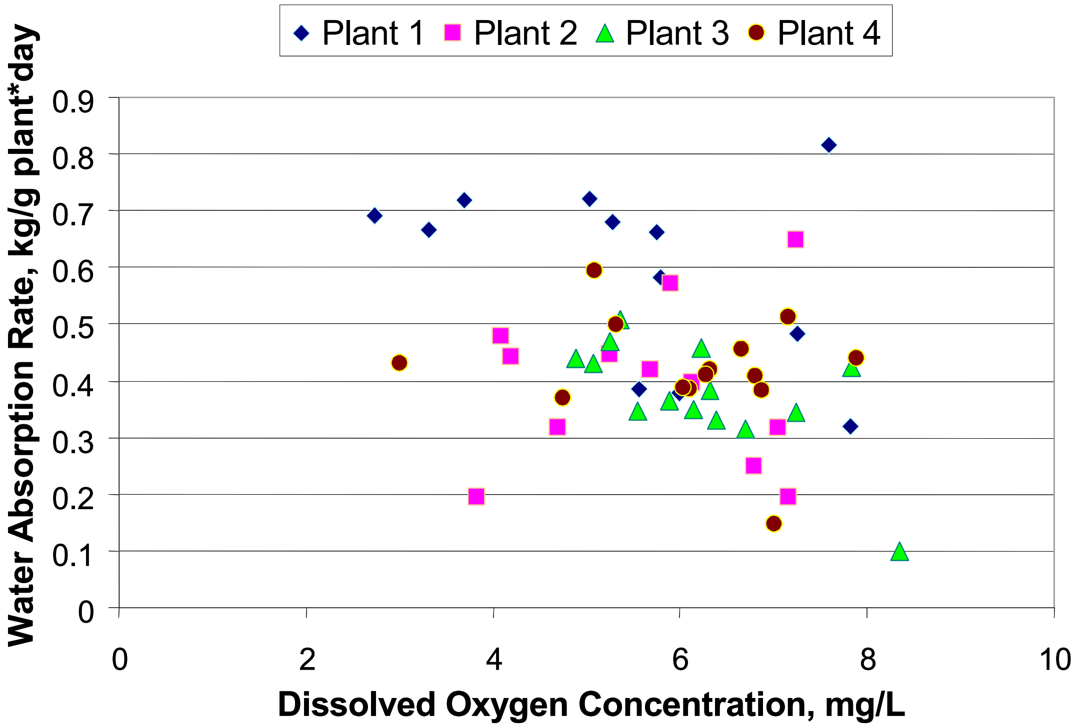

Fig. 2. Water absorption rate of rose plants in relationship to dissolved oxygen concentration of the rootzone.

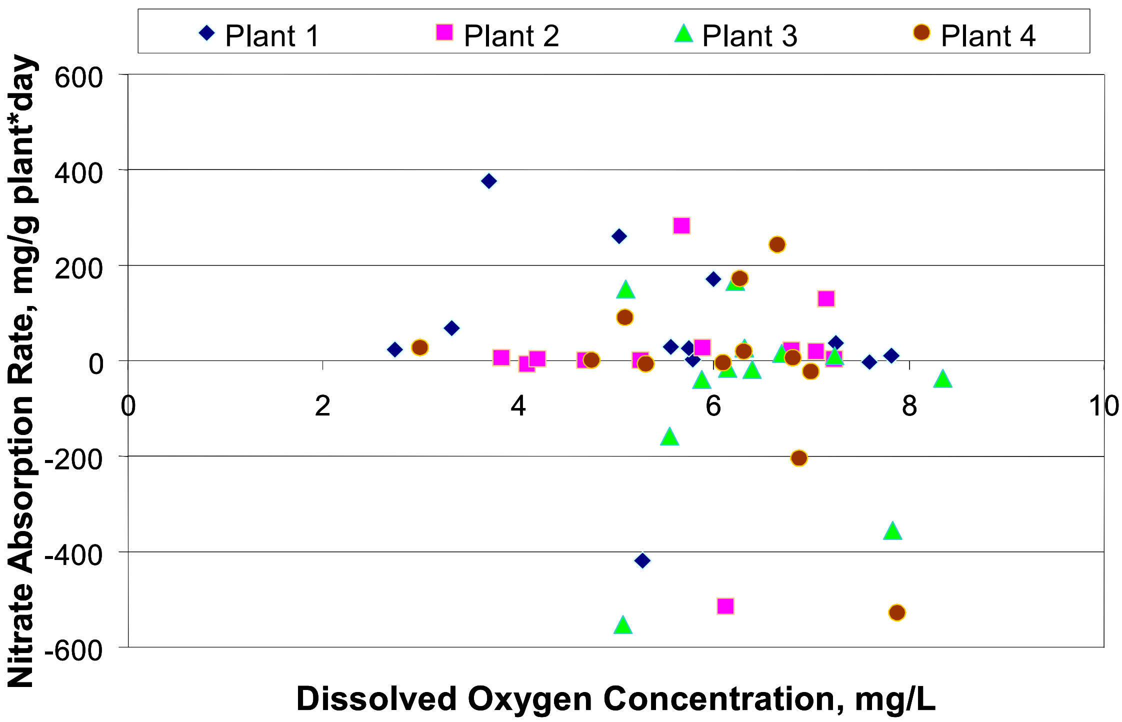

Fig. 3. Nitrate absorption rates of rose plants in relationship to dissolved oxygen concentration in the rootzone.