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Evaporative cooling pad attenuates osmotic stress in closed-loop irrigated greenhouse roses

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Abstract

Ecological and economic considerations motivate the use of closed-loop irrigation to grow greenhouse crops on artificial substrates, submitting plants to increased osmotic stress due to heightened solute concentration of the irrigation solution. High solute concentration of re-circulated irrigation water, measured as electrical conductivity (EC), lowered the transpiration rate of flowering rose stems measured by the heat pulse method. The operation of an evaporative cooling pad decreased the transpiration rate by diminishing the water vapor deficit of the air in the greenhouse and slowed the rate of solute accumulation. Weaker evaporative demand also attenuated salinity induced decrease of transpiration rate. Leaf water potential and stomatal conductance corroborated that the wet-pad and fan alleviated osmotic stress caused by high concentration of the re-circulated irrigation solution.

Keywords: Leaf water potential; Stomatal conductance; Climate control; Vapor pressure deficit; Artificial substrate; *Rosa indica* L.

1. Introduction

Roses grown in greenhouses on artificial substrates transpire annually an estimated 1500 mm of water in Israel. To prevent solute accumulation in the root medium, growers use nearly twice this amount for irrigation. The excess water leaches out leading to a considerable waste of water and fertilizers. Collecting the drainage and returning it into the irrigation system entails water and fertilizers savings. Leached fertilizers may pollute ground water. Hence, environmental protection considerations are additional incentives for enforcing the use of closed-loop irrigation.

For perennial crops like roses, grown in soil-less substrates, the build-up of salinity in the recycled irrigation solution is a serious problem (Ehret et al., 2005). As transpiration is the cause of the accumulation of solutes in the water, manipulations of climatic conditions to decrease transpiration may alleviate the salinity damage. Physiological changes induced by a climatic reduction of the transpiration rate may enhance tolerance to salinity of the roses grown in greenhouses. Increasing relative humidity attenuated the negative effect of salinity on cotton growth (Hoffman et al., 1971). Low transpiration rate improved salinity tolerance of greenhouse tomatoes (Li et al., 2001), but without a detectable attenuation of salinity induced reduction of transpiration per unit leaf area. Roses grown on a closed-loop system, in which the salinity rise was progressive, had tolerance extended to 7.5 dS m^{-1} (Raviv and Blom, 2001). Therefore, it is important to investigate management practices that modify the rate of salinity level rise in the root medium and promote salinity tolerance to attempt minimizing yield depression.

Climate modification in the greenhouse affects transpiration rate. Increasing relative humidity by fog decreased transpiration rate by 40% as compared to normal (Katsoulas et al., 2001), and decreasing water vapor pressure deficit in the greenhouse elevated significantly stomatal conductance (Baille et al., 1994, 1996; Katsoulas et al., 2001). This stomatal response to humidity hints to physiological changes affecting water uptake and CO_2 assimilation by the plants (Bunce, 2006). The first objective of the present study is to quantify the reduction of transpiration caused by pad evaporative cooling as a function of the solar radiation, temperature and humidity prevailing outside. The second objective is to examine if microclimatic reduction of transpiration modifies the effect of salinity rise on water uptake of roses.

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2. Materials and methods

2.1. Greenhouse construction

The closed-loop irrigation experiments were integrated in a larger experiment checking effects of summer cooling treatments on greenhouse rose production in a multi-span greenhouse at the Besor Experiment Station in Israel (31°16′N, 34°24′E). Each span was 7.5 m wide by 23 m long, with ridge at 5.6 m and gutter at 4 m. The ridge was oriented north south. The covering material was a 150-μm polyethylene film, with terrestrial infrared and solar ultraviolet absorbing additives. The polyethylene walls could roll up from 0.8 m above the floor to 2.0 m on the south wall and to 2.8 m on the north, east and west walls. Plastic nets (50 mesh grid) allowing the passage of spheres with 0.35 mm maximum diameter covered the side openings. For roof-ventilation a polyethylene curtain rolled up to the ridge leaving a 1 m wide unscreened opening on the entire length of the span. Ventilation rate with all vents open depended on wind speed and direction. Earlier measurements estimated an average air change rate of 30 h^{-1} (Fuchs et al., 1997). For the evaporative cooling treatment, a corrugated cardboard wet-pad, 1.2 m height and 7.5 m width, was installed on the southern air inlet of the greenhouse. When the pad was in operation all other vents were shut. Two exhaust window fans 0.75 m in diameter with a rated outflow of 16,000 m^3 h^{-1} at zero static pressure, on the north gable pulled air through the pad. The presence of the insect-proof nets reduced the nominal air volume change rate from a nominal 39 to 27 h^{-1}. To separate climate control treatments, sidewalls between compartments were rolled down when the climate control devices were in operation.

2.2. Climate control algorithms

Two one-span wide compartments were used for the study. In one compartment, the tested climate control device was roof-vent opening. In the other compartment, the evaporative cooling pad was examined. Air temperature of less than 24 °C, at mid-canopy height, closed all vents. At 24 °C, the south walls opened; at 25 °C, the north walls opened. The temperature set point for roof-vent opening and turning on the evaporative cooling pad was 28 °C. These operations were interrupted at 26 °C. Operation of the wet-pad was prevented for phytosanitary reasons before 08:00 h and after 15:00 h. During the prohibited hours the roof-vent was opened if internal air temperature reached set-point range, but it closed as soon as the wet-pad was on. The control set points for the wet-pad resulted in full-time operation during the permissible hours.

2.3. The crop

Rose seedlings (*Rosa indica* L. cv. Mercedes), were planted on 16 September 1996, in 0.56 m (width) × 1.04 m (length) × 0.23 m (depth) containers, filled with 0.8 mesh, yellow volcanic scoria, enriched with 15% organic material. The containers laid in four rows, 1.82 m center to center apart, 20 m in length each, parallel to the gutters. Fourteen seedlings were planted, in paired rows in each container, resulting in 7.5 plants m^{-2}. Blind shoots were bent over the paths leading to full ground cover.

2.4. Fertigation

Water and plant nutrients (N, P, K and microelements) were applied 4 times/day, through an automatic drip irrigation system. Water quantities, 12–16 l m^{-2} day^{-1} at an electrical conductivity (EC) between 1.9 and 2.1 dS m^{-1}, resulted in a 50% leaching fraction with EC between 2.0 and 2.2 dS m^{-1}. Pesticide applications followed commercial instructions.

2.5. Closed-loop irrigation

Closed-loop re-circulation was installed in a 5 m long row section in each of the two greenhouse compartments. A 200 l drain collector below the soil surface adjacent to the 5 m section collected drainage that was re-pumped into the irrigation storage tank located outside the greenhouse. Fresh solution was added daily to replace plant water uptake. The threshold value of EC for dumping and replacing the irrigation solution was 4.0 dS m^{-1}. Nutritional level and pH of the solution were controlled in the irrigation container.

2.6. Measurements

The experiment started on DOY (day of year) 166 (15 June 2000). Global radiation, wind speed, relative humidity, temperature outside and relative humidity and temperature inside the greenhouse were measured every minute and recorded as 30-min averages. A calibrated heat pulse system (Cohen et al., 1988) measured transpiration rate as sap flow in 10 selected flowering stems in the two climate treatments and in the two irrigation systems. Probes were moved to a different set of stems every week. Equipment limited to 20, the total number of monitored probes. Therefore, the study first examined the climate treatment on plants under normal open-loop irrigation. The measurements were later repeated on plants submitted to closed-loop irrigation. At the end of each period the stems were cut, the leaves were counted and their area measured with an optical area meter. EC, pH and nutrient concentration (N, P, K and microelements) in the drained and irrigation water were monitored 2–3 times/week.

The experiment was repeated the following year. A steady state porometer (LI 1600, Licor, Lincoln NE, USA) was used to measure stomatal conductance on the abaxial leaflet side on plants of the open-loop and closed-loop irrigation treatments in the roof-ventilated and fan-wet-pad chambers. The measurements were made at hourly intervals on DOY 205 (24 July 2001) from 8:00 to 16:00 h. On the same day, xylem leaf water potential was measured on six rose leaves with a pressure chamber (Arimad 2, Kefar Haruv, Israel).