THE EFFECT OF ROOT-ZONE PHYSICAL PROPERTIES OF COIR AND UC MIX ON PERFORMANCE OF CUT ROSE (CV. KARDINAL)

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Keywords: free air space, hydraulic conductivity, Rosa x hybrida, soilless media, transpiration, water retention

Abstract

Rose plants (Rosa x hybrida L. CV. Kardinal, grafted on Natal Brier) were grown in UC mix and in coconut coir. Water release curves and hydraulic conductivity of the media were measured. Water tensions in the media were maintained within a predetermined narrow range by tension-actuated irrigation, using high-flow electronic tensiometers. Transpiration rate of plants sitting on load cells was measured between February 2 and September 8, 1999. Specific transpiration rate (STR) was calculated based on measured leaf area. Both STR and stomatal conductance were also determined using a steady-state porometer (Li-Cor 1600).

Physical characteristics of the media determine water availability to plants, as reflected in STR. STR values of UC mix at water tension lower than 1.5 kPa are low, suggesting that at this tension UC Mix has insufficient free air space for proper root activity. Above 2.3 kPa, unsaturated hydraulic conductivity of UC mix is lower than that of coir. At this range, STR values may be related to the difference in hydraulic conductivity of the two media.

Yield of coir-grown plants was 19% higher than that of UC mix-grown plants. It is suggested that the choice of growing medium can be optimized using detailed study of physical and hydraulic characteristics of the growing medium. Then water availability can be optimized using high-flow tensiometers or moisture content measurement, using load cells, TDR or FD sensors.

1. Introduction

Transpiration (T) is an essential process in plant life. Maximal dry matter production can be realized when actual T is close to potential T due to the dual role of stomata in controlling water vapor exit and CO₂ entry. The transpiration stream drives translocation of ions (including essential nutrients) and organic molecules into, within and out of the plant. T also has a key role in maintaining a temperature range that enables normal plant life. There is general consensus that most horticultural crops can produce maximal yields only when water availability is kept high throughout the whole growing period.

The role of transpirational cooling in maintaining optimal tissue temperature range is more critical in greenhouse-grown crops than in field-grown crops. Daytime air temperature within a greenhouse is generally higher than ambient. Moreover, radiative and convective heat losses from plant surfaces are smaller due to the greenhouse effect. It is, therefore, clear that the well being of a greenhouse-grown plant is more dependent on uninterrupted T than its field-grown counterpart. Since water storage capacity of a rose plant is relatively small, a delicate balance must be maintained constantly between water
flux into and out of the plant.

Water flux from the root zone to the air surrounding the canopy is affected by the hydraulic conductance \((C, \text{L} \ t^{-1} \ \text{Ψ}^{-1})\) of the soil-plant-air continuum. This variable is determined among other factors by the root zone hydraulic conductivity \((K, \text{L} \ t^{-1})\), which, in turn, is affected by the properties of the medium and its moisture content \((\theta)\).

Roses represent an important cut-flower crop in many countries. This crop is typically grown in greenhouses where optimal conditions are sought, so as to maximize production and timing of harvest to satisfy markets. In recent years most rose growers have switched from soil to various containerized substrates. These substrates have superior physical characteristics, as compared to soil. Unlike in soil, moisture tension \((\Psi_m)\) values, measured in porous media, are usually quite low. Still, in many cases water flux across the medium/root interface cannot cope with atmospheric demand for water, even under near-ideal aerial conditions. This is due to a sharp decrease in \(K\) with \(\theta\), typical to most substrates (da Silva et al., 1993). Decreasing \(\theta\) by as little as 1-5% may decrease \(K\) by an order of magnitude and thus greatly affect water availability to the roots (Wallach et al., 1992). This rate of decrease of \(K\) with \(\theta\) is much sharper than that of soils. Low \(K\) means that the rhizoplane is exposed to tensions that are much higher than those of the bulk soil solution. da Silva et al., (1993) showed that in substrates, the main limiting factor to water uptake is \(K\). To make an informed choice of a growing medium, the relationship between \(\theta\) and \(K\) must be known. Since it is not practical to measured \(K\) in porous media, a model for \(K\) vs. \(\theta\) and \(\Psi_m\), allows the use of \(\theta\) or \(\Psi_m\) for control purposes, as demonstrated by Raviv et al. (1999).

2. Materials and methods

2.1. Plant growth and measurement of transpiration rate

In this study, rose plants (Rosa x hybrida L., CV. Kardinal, grafted on Rosa canina L. CV. Natal Brier rootstock) were planted in 5-liter containers, filled with one of two media: coconut coir made of shredded, partly composted husk fibers and University of California (UC) mix (42% composted fir bark, 33% peat and 25% sand). The plants were grown in a glass-covered greenhouse at the greenhouse facility in the Department of Environmental Horticulture, UC Davis. The experimental set up consisted of 10 pots per medium, one plant per pot. Each pot had a space of 2700 cm\(^2\) (including path space). Since the plants were located within a rose stand, no border plants were assigned.

The plants were treated as a standard commercial crop. Weak stems were pinched and bent down in order to maximize photosynthesizing area. Flowers were harvested at normal opening stage. Stem length, fresh mass and leaf area were measured and flower quality was evaluated on a scale of 1-4, 4 being an excellent flower. Leaf area index was visually evaluated on a weekly basis. All removed leaf area was measured. Typical daily relative growth rates of LAI were around 1.01-1.02.

Within each medium the weights of 3 plants and moisture tension of 4 containers were logged at 15-minute intervals using load cells (model SP4-30KG, HBM Co., Marlborough, Mass.) and tensiometers equipped with high-flow ceramic tips and electronic pressure transducers (Irrometer LT, 15 cm. long, Irrometer Corp. Riverside, CA). In addition to logging on-going moisture tensions, the tensiometers (inserted to a depth of 10-11 cm, 7-8 cm above the bottom of the container), were used to actuate an automated irrigation system based on tension set points. Usually, the set point for irrigation was 3 kPa. On some days higher tension was applied in order to enable STR and stomatal conductance measurements over a wider range of moisture conditions. The media surface was covered with aluminum foil to minimize evaporation. Water amount per pulse was maintained so that at each pulse some water drained out of the containers, in order to ensure homogeneity of the medium solution.

The calculations of STR vs. \(\Psi_m\) were made using data collected between 10:00 AM and 13:00 PM, Pacific daylight saving time on sunny days, only for times when no
irrigation occurred and after any water drainage from the containers had ended. During this time frame, the greenhouse temperature was always maintained between 25 and 28°C using fan and pad cooling system, resulting in a range of RH values of 50-60%. Typical photosynthetic photon flux density (PPFD) values above the plant canopy at this time are 1000-1500 µmol m⁻² sec⁻¹. Stomatal conductance and direct measurements of STR were conducted during the same time window as previously stated, using steady state porometer (Li-Cor 1600, Lincoln, NE). Only mature, fully expanded leaves were sampled. The irrigation solution consisted of half-strength Hoagland solution, using reverse-osmosis water. The electrical conductivity of the solution was 1.0 dS m⁻¹.

2.2. Physical characteristics

Physical characteristics of the media (moisture retention curve and unsaturated hydraulic conductivity as a function of moisture content) were determined as follows. The moisture retention curves for the two media were measured using the hanging column method as described by Raviv and Medina (1997) and are shown in Figure 1a. The saturated hydraulic conductivity, Kₛ, of the two media was determined using glass columns having an inner diameter of 33.1 mm and filled with 180-cm³ medium. The model of van Genuchten (1980):

\[ S_c = \left[ 1 + (\alpha h)^n \right]^m \]  

was used to fit the measured retention curves. The variable h in eq. (1) is the moisture tension (cm of water) and \( S_c = (\theta - \theta_r) / (\theta_s - \theta_r) \) is the effective saturation, where the subscripts s and r refer to the saturated and residual values of \( \theta \), respectively. The parameters \( \alpha \), m, and n are empirical and determined by a best-fit procedure using the RETC code (van Genuchten et al., 1991). The main advantage of eq. (1) is the possibility of combining it with a predictive model for the unsaturated hydraulic conductivity, thus forming the basis for a combined hydraulic model. The predicted K(h) curves agreed well with measured hydraulic conductivities for the substances examined in several studies (Wallach et al. 1992a, b and da Silva et al. 1993).

3. Results

The measured retention curves of the two media are shown in Figure 1a. The fitted values of \( \alpha \), n, and \( \theta_r \) for the UC mix are 0.066, 3.34, and 0.240 respectively, with \( R^2 = 0.997 \). In order to get a comparable fit within the relevant range of moisture tensions, the coir’s \( \theta_r \) was fixed at 0.390 and the fitted values for \( \alpha \) and n were 0.087 and 2.67, respectively, with \( R^2 = 0.983 \). The total porosity of the media was: 95.1% for coir and 76.0% for UC Mix. At tension of 1 kPa, 9.5% and 5.6% of the water are exchanged with air in the coir and UC mix, respectively, suggesting better aeration conditions in the root zone near container capacity [defined as free air space (FAS) by Bunt, 1988] of coir-grown plants. At 10 kPa, the moisture release curves are close to the asymptotic moisture content of 39.7% and 24.5% for Coir and UC mix, respectively. Available water values, as traditionally determined for container media, were almost identical, at 46%.

The Kₛ of coir is 683 cm h⁻¹ and is much higher than UC mix’s, Kₛ, 272 cm h⁻¹. Similar to the retention curves, the hydraulic conductivity of both media follows an asymptotic pattern, after an initial sharp decline with increasing moisture tension (Fig 1b). However, the different shape of the two curves results with a higher K of UC mix within the range 0.12-2.3 kPa. Above this tension, K(h) of coir is increasingly higher than that of UC mix.

Specific transpiration rates (STR) of the plants growing in the two media, as calculated using mass change by the load cells (Fig. 2) show that at both low and high tensions STR of UC mix-grown plants is low. STR of coir-grown plants is 20-30% higher.
than that of UC mix-grown plants over the entire range of moisture conditions. However, since these values were greatly affected by varying ambient climatic conditions, the actual values are very scattered so that they are not statistically significant above 1.5 kPa. Typical weights of UC mix- and coir-grown plants are shown in Fig. 3. The difference between the STR of the two media is reflected in the rate of weight change over time, which is consistently higher in coir containers, as compared to UC mix. The aeration of the root zone in UC mix containers is low during long periods of time between irrigation pulses due to the combined effect of relative low Ks, and low STR.

Direct measurement of STR and of stomatal conductance using steady-state porometer lead to similar general conclusions (Table 1). The difference in absolute values between the two data sets results from the measurement methodology: In the first case the whole canopy is involved. The individual, direct measurements are conducted using only leaves that are fully exposed to sunlight and are therefore more physiologically active than an "average" leaf. In this case, the relative difference between the media is somewhat lower. Stomatal conductance follows the same pattern as the STR and a clear difference between the two media can be found in the range 0.8 - 2.5 kPa.

All measured quality parameters of the flowers of both media were identical. However, coir-grown plants yielded 19% more than their UC mix counterparts (Table 2).

4. Discussion

The measured retention curves for both coir and UC mix (Figure 1a) are similar to curves published earlier for these media. For example, Fonteno’s (1996) moisture retention curve for coir shows θ at saturation of between 92 and 95% and 38% at 10 kPa. Kiehl et al (1992) reported a moisture release curve for UC mix that, although very similar, does deviate slightly from the observed pattern. The differences are likely to result from variations in the composition of the medium since batches vary from year to year as sources for the components vary and due to the level of accuracy used in measuring the amounts of each component. The two media vary considerably as to their FAS. When free drainage following an irrigation event stops (known as container capacity), the container bottom is at saturation (Ψm =0) while tension near the container surface is about 1.8 kPa. Since the tensiometer is located at a depth of 7-8 cm, its reading at this stage will be around 0.7- 0.8 kPa. Corresponding FAS's at the tensiometer tip are 3% for UC mix and 8% for coir. The former is considered to be a very low value (Bunt, 1988). Oxygen deficiency in the root zone may result with decreased root permeability and increased resistance to entry of soil water (Veen, 1988).

The sharp decline in K(h) values within a relatively small range of h emphasizes the large effect that the resistance of water flow from the bulk soil to the root-soil interface has on water availability in container media. K varies along the container depth (and the resulting change in θ) by approximately two orders of magnitude. In addition to the geotropic root growth habit, this is probably the reason for the common phenomenon of root mats near the bottom of the pot that was also observed in this case. In UC mix this dense root layer is subjected to oxygen deficiency for a large part of the interval between irrigation pulses as indicated by the lower STR. It can be calculated from Fig. 3 that this area of the root zone reached sufficient FAS (10%) after 6:50 hours for coir and 12:10 hours for UC mix.

The sharp decrease of container weight, soon after an irrigation event (Fig. 3) is mainly due to free drainage. The following moderate decrease in container weight is mainly due to T. The difference in the rates of weight decrease between the two media during this stage reflects the relative fluxes of transpiring water from the plants.

The calculated hydraulic conductivity pattern with increasing tension has some specific horticultural implications. The momentary tension of the medium solution together with the tension difference between the medium-root interface and medium bulk are measures for the ability of water flux from the medium bulk to the root-medium interface to replenish moisture that has been withdrawn by the roots. Taking a peak
transpirational demand of 500 cm$^3$ h$^{-1}$ plant$^{-1}$ and assuming a functional root surface area of 2000 cm$^2$ plant$^{-1}$, a minimal $K$ of 0.25 cm h$^{-1}$ is required to constantly satisfy the atmospheric demand. This $K$ value corresponds with a tension of up to 3.3 kPa in UC mix and of 6.1 kPa in coir. This suggests that coir-grown plants can cope better with moderate water stress than UC mix-grown plants. It should be noted, in this respect, that the difference in physical characteristics between UC mix and coir are small, compared to some other commonly used media such as rockwool and perlite, on the one hand, and tuff, on the other hand. Based on our results, showing that subtle differences in characteristics may lead to clear performance differences, it can be assumed that much higher differences in performance should be expected among media having larger differences in physical properties if irrigation regime is not fine-tuned to suit each medium’s individual characteristics.

The $K_s$ of coir and its higher FAS at container capacity expose the roots of coir-grown plants to much shorter periods of oxygen deficiency than that of UC mix. This resulted with STR of UC mix-grown plants that was much lower than that of coir-grown plants below 1.5 kPa (Fig. 2). Two possible explanations might be given for the fact that the STR of UC mix-grown plants was lower than that of coir-grown plants also in the range 1.5 - 2.3 kPa [where $K(h)$ of coir is higher than that of UC mix].

- A possible carry-over effect of the transient oxygen deficiency, caused at the termination of each irrigation pulse, which was given in excess in order to mimic the commercial practice where there is a need to discharge excess non-nutritional ions.
- The root distribution within the container was not even. More roots were located at the bottom of the containers than at the top. As mentioned above, those roots may be exposed to sub optimal aeration while tension at the tensiometer tip is within the optimal range.

The combined effects of these factors are consistent higher STR values of coir-grown plants (Figure 2). The fact that these differences in plant's response to $\theta$ were different between these two media while their "available water capacities" are very similar, underlines the roles of FAS and hydraulic conductivity as the main factors determining water availability to plant roots. A detailed study of physical and hydraulic characteristics of the media should be conducted so that an optimal choice of medium could be made. Then water availability can be optimized using high-flow tensiometers or moisture content measurements, using load cells, TDR or FD sensors.

References


Tables

1. Stomatal conductance and STR of fully expanded mature rose leaves grown in UC mix or coir media, as a function of tension. Different letters for observations within the same range of moisture tension denote a significant difference at p<0.05, based on t-test.

<table>
<thead>
<tr>
<th>Moisture tension range (kPa)</th>
<th>Stomatal conductance (µmol cm(^{-2}) sec(^{-1}))</th>
<th>STR (µmol m(^{-2}) sec(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UC mix</td>
<td>Coir</td>
</tr>
<tr>
<td>0.8-1.5</td>
<td>0.89 a</td>
<td>1.39 b</td>
</tr>
<tr>
<td>1.6-2.5</td>
<td>1.04 a</td>
<td>1.35 b</td>
</tr>
<tr>
<td>2.6-3.5</td>
<td>0.78 a</td>
<td>0.91 a</td>
</tr>
<tr>
<td>3.6-5.5</td>
<td>0.79 a</td>
<td>1.05 a</td>
</tr>
</tbody>
</table>

2. Yield and quality parameters of UC mix- and coir-grown rose plants.

<table>
<thead>
<tr>
<th></th>
<th>Flowers/plant</th>
<th>Ave. fl. Length (cm)</th>
<th>Ave. fl. Weight (g)</th>
<th>Quality (1-4)</th>
<th>Ave. leaf area/fl (cm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>UC mix</td>
<td>27.3</td>
<td>53.6</td>
<td>40.2</td>
<td>3.20</td>
<td>456</td>
</tr>
<tr>
<td>Coir</td>
<td>32.4</td>
<td>55.3</td>
<td>40.2</td>
<td>3.36</td>
<td>457</td>
</tr>
</tbody>
</table>
Figures

1.A. Measured water release curves and B. Predicted K(h) of UC mix and coir.
2. Specific transpiration rate (µmol H₂O m⁻² s⁻¹) of UC mix (thick line) and coir-grown rose plants (thin line) as a function of moisture tension.

3. Container weights (Kg) of UC mix- (thick line) and coir-grown rose plants (thin line) over time.