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SOIL–ROOT INTERFACE WATER POTENTIAL IN *Prunus*×*cistena* GROWN IN DIFFERENT ARTIFICIAL MIXES

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Xu H. L., Caron J., Bernier P. Y., Gauthier L. and Gosselin A. *Soil–root interface water potential in Prunus×cistena grown in different artificial mixes.* BIOTRONICS **24**, 35–43, 1995. The water potential at soil–root interface ($\Psi_{s\text{-}r}$), indicates soil water availability at the point of contact between the root and the soil. It is important in the pathway of water flow from the soil through the plant to the air. In this study, relations of $\Psi_{s\text{-}r}$ with bulk soil water potential (Ψ_{soil}), xylem water potential (Ψ_{xylem}), and stomatal conductance (g_s) were established to estimate the value of $\Psi_{s\text{-}r}$ and elucidate its response to soil texture. Three soil mixes made of composted bark, peat and sand (Mix–1), peat, bark, sand and compost (Mix–2), and peat, sawdust and sand (Mix–3), were used with *Prunus*×*cistena*, an ornamental shrub. After soil water was depleted to different levels, Ψ_{soil}, Ψ_{xylem}, g_s as well as transpiration rate (Tr) were measured. $\Psi_{s\text{-}r}$ was calculated from these measured data. Plants grown in Mix–2 maintained higher $\Psi_{s\text{-}r}$ until Ψ_{soil} decreased to -24 kPa, while $\Psi_{s\text{-}r}$ in the plants grown in Mix–1 began to decrease at -5 kPa of Ψ_{soil}. Mix–3 showed a medium critical Ψ_{soil} for $\Psi_{s\text{-}r}$ to decrease. Since there was a better soil water availability, plants in Mix–2 also showed a higher Ψ_{xylem} as well as higher g_s and Tr as consequences. Plants in Mix–2 maintained better plant water status mainly by avoiding water stress. Plants in Mix–3 also avoided water stress, but it was, at least in part, attributed to less leaf area.

Key words: Drought resistance; *Prunus*×*cistena*; Soil–root interface water potential; Stomatal conductance; Water potential

INTRODUCTION

In the soil–plant–atmosphere continuum, water moves from soil in response to water potential gradients across a series of resistances (*2, 4, 10, 12, 13*). Hydraulic properties of a soil, which depend on the soil components and

Abbreviations: $\Psi_{s\text{-}r}$, water potential at soil–root interface, MPa; Ψ_{soil}, soil water potential, kPa; Ψ_{xylem}, plant xylem water potential, MPa; Tr, transpiration rate, 10^{-5} Kg m^{-2} s^{-1}; g_s, stomatal conductance, 10^{-2} m s^{-1}.

texture, affect the characteristics of the soil-plant water flow continuum and water status inside plant. Soil texture affects plant water status in two ways. The first is static effect and the second is dynamic one (*5, 6*). The static effect on plant water potential is due to the direct control of soil texture on soil water potential (Ψ_{soil}). At a given level of soil water content, fine soils such as clays have lower Ψ_{soil} than coarse soils such as loam and fine sands. In order for water to move from the soil into the plant, the energy level of the water (expressed as water potential) inside the plant must be lower than that in the soil as in a pumping system. Therefore, the fine soils having lower water potential produce lower water status inside the plant. The second effect of soil texture on plant water potential involves feedback from the plant to the soil. As a root extracts water from the surrounding soil, the water content in the soil at or near the soil-root interface drops, resulting in a corresponding decrease in water potential of that near-root zone ($\Psi_{s\text{-}r}$). $\Psi_{s\text{-}r}$ depends on water uptake by the root and also on the ability of the soil farther from the root to replenish the lost soil water around that root. In the pathway of water flow, water potential at the soil-root interface is the most important and appears to be a good indicator of soil water availability to the plants. However, it is difficult to measure it routinely. Plant water status might be more convenient to manage from Ψ_{soil} determination if a good relationship between Ψ_{soil} and $\Psi_{s\text{-}r}$ can be established. Therefore, one of the objectives in the present research is to find a relationship between Ψ_{soil} and $\Psi_{s\text{-}r}$ and elucidate the effects of soil texture on this relationship. It is also importance to develop a method to determine these parameters.

On the other hand, different plants, or the same kind of plants with different water status experience, have different feedback effect on the soil-plant-water relations (*14*) For example, at the soil-root interface of the plant with high root activity, the soil water potential at the near-root zone is lower, if water content and hydraulic properties of the soil are at a given level. In this case, higher hydraulic conductance is needed to keep the soil-root interface water potential from decreasing. The plants which have been hardened with water stress possess higher root activity and consequent higher water uptake ability, resulting in higher plant water potential and consequent higher physiological activity under the same drought condition as the unhardened plants. Plants adapt to drought conditions by drought avoidance and drought tolerance (*9*). A plant with drought avoidance can maintain a higher tissue water potential than non-avoidant one even under the same soil water deficit condition. The plant with drought tolerance is able to perform physiological function better than the non-tolerant one even with the same low plant water potential. Different soil mixture makes plants undergo different water experience even under the same irrigation system. Therefore, the feedback effect of plant water status on the soil-root interface water potential and their relationship were also discussed in terms of drought resistance, drought avoidance and drought tolerance.

MATERIALS AND METHODS

Plant materials and soil mixes

An ornamental shrub, *Prunus × cistena*, was used as plant material. The following three soil mixes were used as substrates.

Mix-1···composted bark, peat and sand;

Mix-2···peat, bark, sand and compost;

Mix-3···peat, sawdust and sand.

Hard cuttings with leaves and bare roots were planted to plastic pots filled with abovementioned soil mixes in June, 1991 and grown in the field. Slow releasing fertilizer (Nutricote®–180 days) was applied on the surface of the soil. Fertilization with soluble 20–20–20 (N–P–K) was made once a week. The first pruning was made in June 1991 and the 2nd pruning was in October 1991. Weeds were removed by hand. Geotexile plus white polyethylene was used to wrap the plants in November 1991, in order to prevent from winter cold damage. The wrapping material was removed in April, 1992. In August 1992, the pots were moved to a greenhouse, where the air temperature and relative humidity were controlled at 20℃ and 50%, respectively. For each soil mixture treatment, the pots were divided into three plots and placed in Latin Square design. Every plot included seven pots. Soil water was depleted to different levels with one plot as control (sufficiently watered). Soil water potential, xylem water potential, and transpiration rate as well as stomatal conductance were measured using these plants in different soil water conditions.

Measurements

Soil water potential was directly monitored by tensiometers. Xylem water potential was measured according to Turner (*15*) with a pressure chamber (Model 3000, Soilmoisture Equipment Corp., Santa Barbara, CA, 93105, USA) using three branches at different positions on a plant to estimate the water potential of the whole plant. A whole branch was cut from the main shoot, immediately put into a polyvinyl bag, and then placed into the pressure chamber. Some wet tissue paper was placed on the bottom of the pressure chamber to maintain the air humidity at saturation and consequently prevent transpirational water loss. The speed of pressure application was fast at beginning. When the imposed pressure was closed to the level of plant water potential, the speed was then lowered down to 0.01 MPa s^{-1}. When water exuded from the xylem and saturated the cut end of the branch, pressure application was stopped. The negative value of the balanced pressure was then assumed to be the xylem water potential. Transpiration rate and stomatal conductance were measured using a Licor transpiration measurement system (Licor-600). Five leaves at different position of a plant were measured to estimate the average transpiration rate and stomatal conductance. Then, leaf area of the whole plant was measured using a leaf area meter (Licor Model 3000). Soil water potential at soil-root interface ($\Psi_{s\text{-}r}$) was calculated from the data of xylem water potential (Ψ_{xylem}), stomatal conductance (g_s), and leaf area (A) as follows.

$$\Psi_{s-r}=\Psi^{d}_{xylem}-\frac{\Psi_{xylem}\Sigma(g_s^d A^d)}{\Sigma(g_s^i A^i)}$$

Here, the superscripts i and d mean irrigated and drought conditions respectively (7).

Concept and calculation of drought resistance, avoidance and tolerance

Drought resistance is contributed by the mechanisms of drought avoidance and drought tolerance (9). Drought avoidance means that the plant can avoid or reduce tissue water loss even under soil water deficit conditions. A drought tolerant plant can perform its physiological function better than non-tolerant ones even the plant tissue loses water under drought conditions. Drought resistance (R_d) is calculated as follows.

$$R_d=\Psi^{0}_{soil}-\Psi^{50}_{soil}=-\Psi^{50}_{soil}$$

Here, Ψ^{0}_{soil} is the soil water potential under well watered condition and considered as zero; Ψ^{50}_{soil} is the soil water potential at 50% depression of the indicator of physiological function. In the present work the transpiration rate is considered as the physiological indicator. Drought tolerance (T_d) was calculated as follows.

$$T_d=\Psi^{0}_{xylem}-\Psi^{50}_{xylem}$$

Ψ^{0}_{xylem} is the leaf water potential without any water stress and here defined as that at -1 kPa of Ψ_{soil} (Table 1). Ψ^{50}_{xylem} is the xylem water potential at 50% depression of the indicator of physiological function. Drought avoidance (A_d) was defined as the ratio of drought resistance against drought tolerance.

$$A_d=R_d/T_d$$

Table 1. Soil-root interface water potential (Ψ_{s-r}), xylem water potential (Ψ_{xylem}), transpiration rate (Tr) and stomatal conductance (g_s) in *Prunus* × *cistena* plants grown in three different soil mixes at saturated (−1 kPa) and unsaturated (−20 kPa) soil water conditions.

Parameter	At −1 KPa Ψ_{soil}			At −20 KPa Ψ_{soil}		
	Mix-1	Mix-2	Mix-3	Mix-1	Mix-2	Mix-3
Ψ_{s-r} (MPa)	−0.28	−0.17	−0.56	−1.39	−0.64	−0.98
Ψ_{xylem} (MPa)	−0.93	−0.83	−1.02	−1.76	−1.32	−1.17
Tr (10^{-8} m^3 m^{-3} s^{-1})	7.69	8.23	7.94	2.18	3.16	4.90
g_s (10^2 s m^{-1})	1.65	1.63	1.90	0.18	0.25	0.39

The data are derived from regressions of the variables with Ψ_{soil} as shown in Figure 1.

RESULTS AND DISCUSSION

Water potential at soil–root interface

Plants grown in Mix–2 maintained high soil–root interface water potential ($\Psi_{s\text{-}r}$) until bulk soil water potential (Ψ_{soil}) decreased to -24 kPa while $\Psi_{s\text{-}r}$ in Mix–1 began to decrease at -5 kPa of Ψ_{soil} and Mix–3 showed a medium critical Ψ_{soil} for $\Psi_{s\text{-}r}$ to begin to decrease (Fig. 1). At the Ψ_{soil} level of -1 kPa, $\Psi_{s\text{-}r}$ was lower in Mix–3 than in the other two mixes (Table 1). This might be due to soil texture or the component. When the soil is saturated, all of pores are filled with water and the hydraulic conductivity is high. In this case, the hydraulic conductivity is affected by soil texture. A coarse soil has a high hydraulic conductivity because the connected pore space is larger and

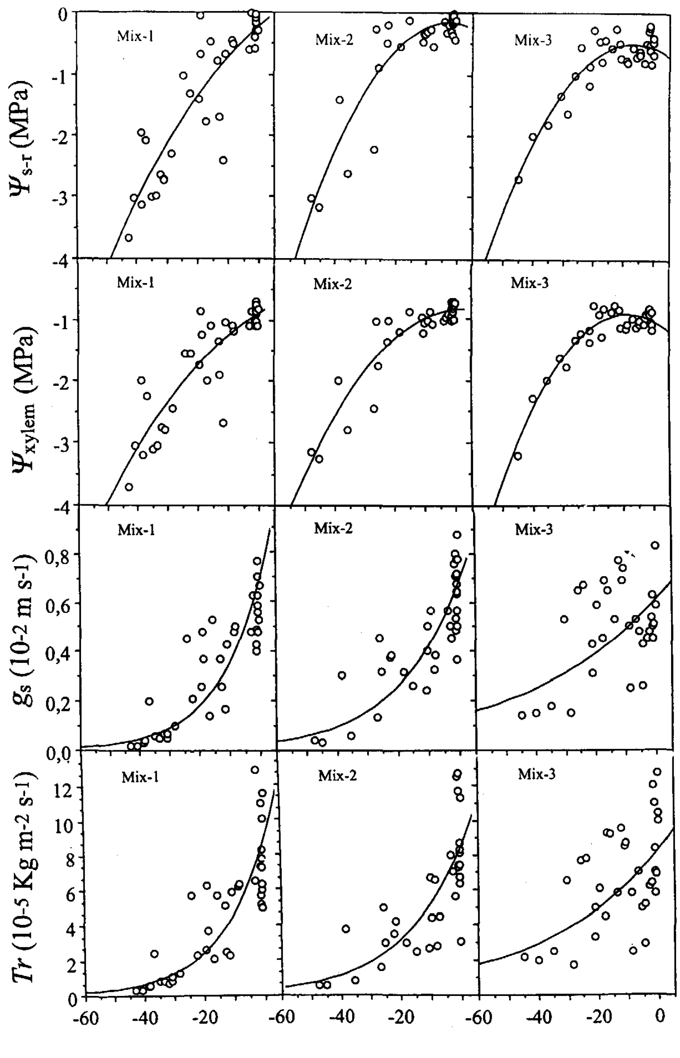

Fig. 1. Changes of soil–root interface water potential ($\Psi_{s\text{-}r}$), xylem water potential (Ψ_{xylem}), stomatal conductance (g_s), and transpiration rate (Tr) in response to changes in bulk soil water potential (Ψ_{soil}).

the large soil particles hold water more loosely than those in a fine soil (*1, 3, 6*). Therefore, water availability is higher at the soil–root interface in the coarse soil. However, at the Ψ_{soil} level of -20 kPa, $\Psi_{s\text{-}r}$ in Mix–1, -2 and -3 were very different from each other and show a $\Psi_{s\text{-}r}$ value of -1.39, -0.64 and -0.98 MPa, respectively (Table 1). The tendency of $\Psi_{s\text{-}r}$ values was not consistent with that in saturated soils. The tightness of the water held by the soil was greater in Mix–1 than in Mix–2. $\Psi_{s\text{-}r}$ in Mix–3 at the Ψ_{soil} of -20 kPa is lower than in Mix–2, but the decrement (from -0.56 to -0.98) is not larger than that in Mix–2 (from -0.17 to -0.64). This means that soil water availability is also stable in Mix–3. As the soil water content decreases, some of the pores become air filled and conductivity for water flow decreases. Furthermore, as suction develops, larger pores are first filled with air, leaving water to flow through the smaller pores and circumvent the large empty pores. Therefore, in a coarse soil or an aggregated soil, the large interparticle or interaggregate pore spaces, which confer high conductivity at saturation, become barriers to water flow (*6*). Our result is in agreement with the above –mentioned hypothesis.

Xylem water potential

The plants grown in Mix–2 maintained high Ψ_{xylem} under unsaturated soil water conditions (Fig. 1, Table 1). This was due to the high $\Psi_{s\text{-}r}$ which indicates soil water availability to the plants. The plants grown in Mix–3 also maintained higher Ψ_{xylem}. Ψ_{xylem} indicates the water status of the plant and is not only determined by soil water availability indicated by $\Psi_{s\text{-}r}$, but also related to the transpirational water consumption. The transpiration, especially under soil water deficit condictions, is positively proportional to Ψ_{xylem} and determined by the stomatal conductance. Usually, high Ψ_{xylem} results in a high transpiration. However, if the transpiration is very high and the soil water availability cannot balance the transpirational water loss, Ψ_{xylem} decreases in response to the high transpiration (*8*). The total leaf area was less in the plants grown in Mix–3 (not shown). Less leaf area caused less water consumption. The better plant water status in the plants grown in Mix–3 was, at least in part, attributed to the less transpirational water consumption.

Transpiration and stomatal conductance

Transpiration rate per unit leaf area was considered as an indicator of physiological activity in the present experiment. The plants grown in Mix–2 and Mix–3 showed a higher transpiration rate (*Tr*) and a higher stomatal conductance (g_s) under unsaturated soil water conditions (Fig. 1, Table 1). Tr is positively related to plant water potential and ultimately proportional to the soil water availability shown by $\Psi_{s\text{-}r}$. The results of Tr and g_s are in agreement with those of $\Psi_{s\text{-}r}$ and Ψ_{xylem}. However, total transpiration has a feedback effect on the plant water potential. If the total transpiration is very high, soil water will be depleted earlier and consequently plant water potential decreases. Under well watered conditions in the present experiment, the total

Table 2. Drought resistance (R_d), *tolerance* (T_d) *and avoidance* (A_d) based on transpiration maintenance in *Prunus* × *cistena* plants grown in different soil mixes

Soil mix	R_d (*kPa*)	T_d (*MPa*)	A_d
Mix-1	10.5	0.49	0.021
Mix-2	17.0	0.65	0.026
Mix-3	32.0	0.42	0.076

transpiration of the plants in Mix-3 was much less than in other two mixes due to the less total leaf area. This caused less water loss and maintained better plant water status.

Drought resistance, tolerance, and avoidance based on transpration maintenance

Dought resistance was higher in the plants grown in Mix-2 (17.0) and especially in Mix-3 (32.0) than in Mix-1 (10.5) (Table 2). High drought resistance of the plants in Mix-2 was mainly contributed by drought tolerance and in part by drought avoidance. This means that even at a low plant water status, plants in Mix-2 can perform transpiration better than the plants in other mixes. Many reports have shown that drought tolerant plants can maintain complete or partial stomatal opening by osmotic adjustment or turgor regulation in response to lowering plant water potential (*11*). However, the drought resistance of the plants in Mix-3 was contributed only by drought avoidance. This means plants in Mix-3 maintain higher plant water potential than plants in other mixes even at the same soil water conditions. The mechanism accounting for this phenomenon in the present experiment is not clear. The less total leaf area might be one of the reasons since less total leaf area results in less water loss from the plants. In some cases, plants show smaller leaves and less total leaf area than normal by changing cell size and/ or reducing leaf number in response to water deficit conditions (*9*). This is a result of plant adaptation to water stress. Less leaf area observed in plants of Mix-3 in the present study might be, at least in part, attributed to this kind of adaptation.

CONCLUSION

In the pathway of water flow from the soil through plant to air, one of the most important factors is the water potential at soil-root interface, which shows the soil water availability to the plants. In methodology, soil-root interface water potential can be estimated from the relation between bulk soil water potential and plant water status. Soil texture or the component of the soil mixes affected the soil-root interface water potential. Soil Mix-2 showed a higher soil-root water potential and consequent better plant water status under dry soil conditions.. Soil Mix-3 also showed a higher soil-root interface water potential under drought conditions, but it was partly due to the less leaf area that caused less water consumption. The analysis based on drought resistance, tolerance and avoidance was consistent with the above-mentioned suggestion. It is also suggested that soil water availability was controlled not only by soil hydraulic properties (through static effect) but also by plant characteristics, such as plant xylem water potential, xylem resistance, stomatal resistance and transpiration.

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