Whole Canopy versus Single Leaf Gas Exchange Responses to Water Stress in Cabernet Sauvignon Grapevines

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Abstract

Responses of single leaf photosynthesis and whole canopy net CO_2 exchange (NCE) to a range of water deficits were compared in three-year-old, fruiting, potted 'Cabernet Sauvignon'/5C grapevines by withholding irrigation to groups of plants for differing time periods, then measuring stem water potential, single leaf gas exchange and whole plant gas exchange rapidly in a short period. Measurements were done in the sun in the late morning, then repeated in the dark after a two hour equilibration period. In general, water stress-induced reductions were similar for single leaf photosynthesis and whole canopy NCE. Respiration in the dark was reduced for both leaves and whole canopies, but reductions were much less severe than for gas exchange in the light. The ratio of photosynthesis or NCE to respiration declined linearly for both leaves and whole canopies with increasing stress. Whole canopy gas exchange appeared to be dominated by leaf gas exchange, thus leaf response data may be useful in estimating whole canopy gas exchange responses with adjustments made for leaf area and for fruit and stem respiration.

Introduction

There have been many studies of water relations using single leaf gas exchange measurements (Smart et al., 1983; Williams et al., 1994; Williams et al., 1990). Single leaf measurements, however, may not necessarily predict whole canopy net CO_2 exchange (NCE) responses to environmental stress such as water deficits since many different organs are involved, and each may have its own responses to water deficits. There may also be many indirect effects on whole canopy gas exchange (e.g. reductions in growth rates of shoots or fruits may affect growth respiration). Both scales of measurements are needed to determine if leaf measurements can be directly scaled up to estimate whole canopy physiology. The objectives of this study were to measure concurrently both single leaf and whole canopy NCE responses to short-term water deficits in potted grapevines.

Materials and methods

Three-year-old 'Cabernet Sauvignon'/3309 (*Vitis vinifera* L.) fruiting grapevines, grown in 20-liter pots outside were used for the study conducted in late July. Water deficits of differing intensities were induced by withholding irrigation to two groups of eight vines for differing time periods before measurement. Eight control vines were well-watered. After stress developed, stem water potential, single leaf and whole canopy NCE were rapidly measured by a team in a short period on a uniformly clear day.

Single leaf gas exchange was measured with a CIRAS-1 Gas Analysis System (PP Systems, Haverhill, MA) with two different leaf chambers: a 2.5 cm^2 broad leaf chamber for measuring photosynthesis, and a 35 cm^2 cylindrical conifer chamber for respiration. Measurements were made in saturating sunlight for photosynthesis, then in the afternoon after >2 hours of darkness for respiration.

Whole canopy gas exchange was measured in a flow-through whole canopy "balioon-type" chamber of clear Mylar® plastic (modified from Corelli Grappadelli et al., 1993) that enclosed full canopies in the chamber, and was secured around the stem. Air from a fan passed through the chamber at about 1.5 volumes/minute, and the CO_2 differential across the chamber was measured with an ADC LCA-2 CO_2 analyzer (ADC, Hoddesdon, Herts., UK). Temperatures, humidity and light were monitored. For dark respiration readings, the entire system was moved into a dark concrete building, but outside air was utilized.

Vine water status was estimated with stem water potentials measured by enclosing representative leaves inside foil-covered plastic bags covered with aluminum foil for at least 30 minutes to stop transpiration. Bagged leaves were excised and immediately placed in a pressure chamber (Soil Moisture Corp., Santa Barbara, CA) to measure stem water potential. In order to get representative samples for the tree stem water potential, measured leaves were selected from the upper part of the lower half of the vine.

Results and discussion

The whole canopy mean net gas exchange rates per unit leaf area in the light were approximately 65% of the exposed single leaf rates (Fig. 1). This was due to the inclusion of shaded leaves, clusters and stems within the gas exchange chamber. Since the proportion of shaded-to-exposed leaves varies so much, along with the amount of fruit and structural wood, the ratio of single leaf NCE rates to mean canopy NCE rates would vary and need to be determined for each situation.

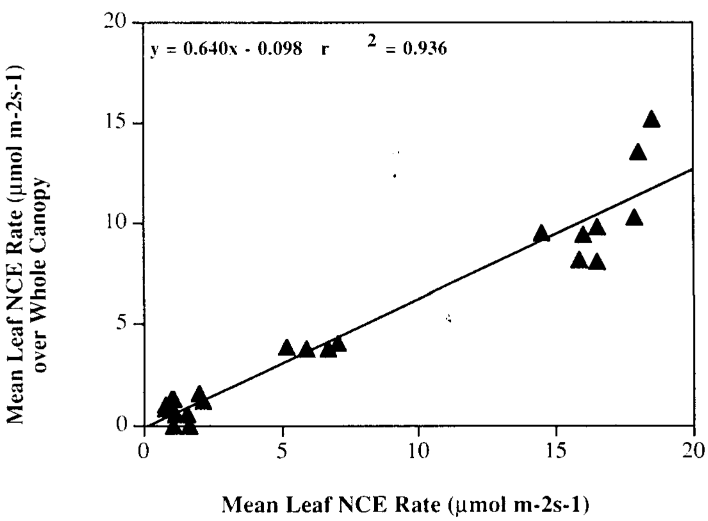

Figure 1. The correlation between single leaf and mean canopy NCE rates in potted 'Cabernet' grapevines exposed to varying periods without watering. Meaf leaf NCE rate for the whole canopy was calculated by canopy NCE/canopy leaf area.

Table 1. Regressions of the responses to short term water deficits of 'Cabernet' grape leaf and mean whole canopy light and dark NCE rates to vine water status as stem water potentials (StemPot in -MPa). NCE rates are in positive µmol CO_2 m^{-2} leaf area s^{-1} for both light and dark (canopy rate is canopy NCE divided by total leaf area per vine).

	Regression	r^2
Leaf Light NCE	= 13.5 (StemPot)+ 24.2	0.88
Canopy Light NCE	= 8.8 (StemPot)+ 15.6	0.85
Leaf Dark NCE	= 0.34 (StemPot) + 1.1	0.74
Canopy Dark NCE	= 0.19 (StemPot) + 1.0	0.20

Water stress-induced reductions in single leaf and whole canopy NCE in the light were linear, similar and both well correlated to the stem potentials (Table 1). Leaf respiration in the dark declined with increasing water stress similar to the leaf photosynthetic response. Leaf respiration rates were generally about 5-10% of the photosynthetic rates in the well-watered vines, but increased to about 15-20% when water stress reduced the photosynthetic rates by about 80%. Unlike leaf responses whole canopy respiration rates were not well correlated to water stress (Table 1). For well-watered vines canopy respiration rates were about 8-15% of the photosynthesis rates. But since the canopy respiration rate did not decline much with water stress, the respiration became a greater proportion of the gas exchange as the photosynthesis declined.

Whole canopy gas exchange was dominated by leaf gas exchange in these young vines that had open canopies, relatively few clusters and little shoot and trunk weight. Therefore, leaf response data may be useful in predicting whole canopy gas exchange responses once adjustments for leaf area, and fruit and stem respiration are made. The short-term water stress used in this study caused direct reductions in both photosynthesis and respiration that may not necessarily represent long-term responses to water stress that develop more slowly and may affect growth and cropping patterns over the season. Thus the next step is to repeat this type of study under field conditions to evaluate long-term responses.

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