



## Deficit irrigation and transparent plastic covers can save water and improve grapevine cultivation in the tropics



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### ABSTRACT

We examined the interactive effects of deficit irrigation and transparent plastic covering (TPC) on key physiological traits in tropically grown grapevines. ‘Niagara Rosada’ grapevine (*Vitis labrusca*) was subjected to both Regulated Deficit Irrigation (RDI) and Partial Rootzone Drying (PRD) while being grown under a TPC to address the following questions: (i) Does the grapevine present anisohydric or isohydric behavior? (ii) How does deficit irrigation affect leaf water potential ( $\Psi$ )? (iii) Can RDI and PRD improve plants water use efficiency? (iv) How does deficit irrigation affect leaf photochemical and biochemical capacity? (v) What are the effects of deficit irrigation on leaf respiration and leaf carbon balance? (vi) Is it possible to save water without affecting yield and fruit quality? Three water management techniques were applied: full-irrigated (FI): 100% of the crop evapotranspiration ( $ET_c$ ) was supplied to both sides of the root system; RDI: 50% of the  $ET_c$  was supplied to both sides of the root system; and PRD: 50% of  $ET_c$  was alternately supplied to only one side of the root system. These irrigation treatments were replicated such that the two plots were either covered by a polyethylene plastic structure or remained uncovered. We found that: (i) ‘Niagara Rosada’ grapevine presented anisohydric behavior; (ii) deficit irrigation did not affect  $\Psi$ ; (iii) Neither RDI nor PRD had a significant effect on water use efficiency (iv); no limitations by the carboxylation reactions of photosynthesis or Rubisco oxygenation ( $V_o$  1500) were observed, and photochemical capacity was not inhibited; (v) Light and dark leaf respiration rates were not affected by either RDI or PRD and therefore deficit irrigation did not damage the leaf carbon balance; (vi) a

**Abbreviations:**  $\Gamma^*$ ,  $CO_2$  compensation point in the absence of respiration in the light;  $\Psi$ , leaf water potential;  $\Psi_{pd}$ , leaf water potential at predawn;  $\Psi_{md}$ , leaf water potential at midday;  $\delta^{13}C$ , C-isotope composition; ABA, abscisic acid;  $A_{net}$ , net photosynthetic rates;  $A_{net}/g_s$ , intrinsic water use efficiency;  $C_i/C_a$ , ratio of the internal to ambient  $CO_2$  concentration; CWSI, crop water stress index;  $Dl_0/CS$ , dissipation per excited cross section;  $E$ , transpiration rates;  $ET_0/ABS$ , quantum yield of electron transport;  $ET_0/TR_0$ , efficiency with which a trapped excitation energy can move an electron transport chain further than the Quinone A;  $ET_c$ , crop evapotranspiration; FI, full irrigated; FRF, far red;  $F_o/F_m$  ratio, maximum quantum yield of primary photochemistry;  $g_s$ , stomatal conductance;  $J$ , photosynthetic electron transport;  $K_c$ , Michaelis constants for carboxylation;  $K_o$ , Michaelis constants for oxygenation; LCB, leaf carbon balance; PI, performance index; PQ, plastoquinone; PRD, partial rootzone drying; PSII, photosystem II; QA, quinone A; R, leaf respiration rates;  $RC/CS_o$ , fraction of active reaction centers per excited cross-section of leaf;  $R_{dark}$ , leaf respiration rates in the dark; RDI, regulated deficit irrigation; RF, red;  $R_{light}$ , leaf respiration rates in the light; Rubisco, ribulose -1,5-bisphosphate carboxylase/oxygenase;  $S_m$ , energy needed to close all reaction centers expressed by the normalized area;  $T_{dry}$ , temperature of a leaf covered with liquid paraffin;  $T_{leaf}$ , leaf temperature;  $T_{wet}$ , temperature of a leaf sprayed with water;  $V_c$ , rates of carboxylation of Rubisco;  $V_c$  1500, rates of carboxylation of Rubisco at  $1500 \mu mol m^{-2} s^{-1}$ ;  $V_{cmax}$ , maximum rates of carboxylation of Rubisco;  $V_o$ , rates of oxygenation of Rubisco;  $V_o$  1500, rates of oxygenation of Rubisco at  $1500 \mu mol m^{-2} s^{-1}$ ;  $V_{omax}$ , maximum rates of oxygenation of Rubisco; VPD, air vapor pressure deficit;  $A_{net}/E$ , water use efficiency

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considerable volume of water was saved when deficit irrigation was used, without affecting production; (vii) TPC use can be an effective strategy for growing grapevine in tropical conditions.

## 1. Introduction

Grapevines are the most widely cultivated fruit in the world and are grown on nearly every continent (FAOSTAT, 2014). However, grapevine production is water intensive and water shortage is the most significant limiting factor of crop production worldwide (FAOSTAT 2014). The future of sustainable grapevine cultivation is likely to require expansion to more favorable locations, or a major reduction in water use (Flexas et al., 2016). While grapevines can be grown in tropical areas, such as in Brazil, the climatic conditions can be even more problematic (Permanhani et al., 2016) due to the intense irregularity of precipitation patterns. Given the requisite climatic conditions and predicted effects of global warming (IPCC, 2014), the future of grapevine cultivation is uncertain, and the use of alternative irrigation techniques such as Regulated Deficit Irrigation (RDI) and Partial Root-zone Drying (PRD) should be explored.

RDI and PRD are two specific deficit irrigation techniques that tune water availability temporally (specific timing of the application – RDI) or spatially (alternating dry–wet zones – PRD) (Chaves et al., 2010). Under RDI, the water is supplied at levels below that required for full crop evapotranspiration ( $ET_c$ ) during specific phenological stages, particularly after fruit set when fruit growth is less sensitive to reductions in water supply (Chaves et al., 2010; Tarara and Peña, 2015). This technique was designed to optimize fruit number, size and quality by balancing vegetative growth and potential for production (Poni et al., 2009; Chaves et al., 2010). By contrast, under PRD, the two sides of the grapevines' root system are alternately irrigated providing a spatial reduction in water availability. PRD can induce the synthesis of abscisic acid (ABA) by roots in the dried half of the rootzone, and lead to partial stomatal closure without reducing overall leaf water status (Stoll et al., 2000; Dry and Loveys, 1998; Antolín et al., 2006, 2008). Such reductions in stomatal conductance and transpiration are typically larger than the decrease in net photosynthesis, and thus increase water use efficiency without impairing plant development, yield or fruit quality (de Souza et al., 2005; Chaves et al., 2007; Pou et al., 2012).

Although both RDI and PRD systems can improve water use in plants, deficit irrigation responses in grapevines are dependent on specific stress 'tolerance' or 'avoidance' mechanisms (Schultz, 2003). Grapevines can have either isohydric or anisohydric behavior depending on the stomatal control strategy presented in response to changes in air vapor pressure deficit (VPD) and/or water availability in the soil (Schultz, 2003; Soar et al., 2006; Chaves et al., 2010; Tomás et al., 2014; Lavoie-Lamoureux et al., 2017). In isohydric plants, ABA accumulation in leaves promotes stomata closure early in response to either decreased water content in the soil or increased VPD, so that leaf water potential ( $\Psi$ ) remains unchanged or slightly decreases (Schultz, 2003; Poni et al., 2007; Lovisolo et al., 2010; Pou et al., 2012; Flexas, 2016; Lavoie-Lamoureux et al., 2017). However, foliar ABA can also limit leaf gas exchange over the long-term, by preventing stomatal recovery upon rewatering and resulting in the down-regulation of transpiration. Isohydricity may favor embolism repair and preserves water under conditions of fluctuating water availability and repeated drought (Tombesi et al., 2015). On the other hand, anisohydric plants have a high tolerance to reduced water availability and do not significantly modify stomatal apertures as  $\Psi$  varies (Rogiers et al., 2012; Palliotti et al., 2015; Lavoie-Lamoureux et al., 2017). It has been reported that such iso/anisohydric behavior is influenced by the specific ambient growth conditions, such as hydraulic resistances within the soil-plant system, plant age and climate (Schultz, 2003; Lovisolo et al., 2010; Chaves et al., 2010; Hochberg et al., 2013). Currently there is a demand

for knowledge about the ecophysiological responses of grapevine cultivars to a reduction in water availability (Chaves et al., 2010; Flexas et al., 2010, 2016; Lavoie-Lamoureux et al., 2017), especially under Tropical conditions.

Limitations to plant growth and crop yield imposed by water availability are mainly due to reductions in the carbon balance, and therefore dependent on the equilibrium between photosynthesis and respiration (Poni et al., 2009; Flexas et al., 2006). Viticultural methods for reducing water losses through stomata closure without resulting in concomitant reductions in  $CO_2$  uptake are desired. More specifically, improving the metabolic efficiency of photosynthesis by increasing Rubisco carboxylation capacity, could improve the growth of grapevines under limited water conditions (Flexas et al., 2016). Much less attention has been given to respiration (Flexas et al., 2006; Schultz and Stoll, 2010; Morales et al., 2016), despite the fact that leaf respiration occurs continuously and even small changes in this process can result in substantial variation in the plant carbon balance (Poni et al., 2009; Flexas et al., 2010; Griffin and Heskell, 2013; Tomás et al., 2014). It has been previously reported that grapevine leaf respiration can increase under moderate water shortage (Silva et al., 2017), and deficit irrigation could result in significant carbon losses through leaf respiration (Flexas et al., 2010; Salazar-Parra et al., 2015). Moreover, it is known that leaf respiration in the light ( $R_{light}$ ) is usually lower than in the dark ( $R_{dark}$ ), with the degree of light inhibition responding differently to environmental signals (Tcherkez et al., 2010), such as water availability (Ayub et al., 2011; Crous et al., 2012). A full understanding of the leaf carbon balance requires that the rate of respiration in both the dark ( $R_{dark}$ ) and in the light ( $R_{light}$ ) be quantified.

Parallel to deficit irrigation use, protected cultivation, using transparent plastic covering (TPC), is now becoming a common practice in table grapes (Permanhani et al., 2016). TPC has been reported to increase the water use efficiency in grapevines by creating higher humidity and lowering transpiration as compared to open field conditions (Stanghellini, 2014; Permanhani et al., 2016). Higher shoot growth rates, leaf areas and chlorophyll contents have been observed in grapevines grown under TPC (de Souza et al., 2015). TPC can also protect a grapevine canopy from adverse meteorological conditions, such as wind and rain (Roberto et al., 2011; Du et al., 2015; Permanhani et al., 2016). While rainfall increases grapevine vegetative growth, it can reduce fruit quality due to imbalances in the sink/source ratio (Monteiro and Lopes, 2007; Chaves et al., 2010). Moreover, leaf wetness caused by rainfall can trigger disease development, such as mildew and botrytis, leading to use of fungicides and other chemicals (Botelho et al., 2011; Pedro et al., 2011; de Souza et al., 2015; Permanhani et al., 2016). However, the use of specific TPC methodologies (type of plastic used and distance of canopy) can present disadvantages as well, such as excessive overheating due to inadequate air circulation (Liu et al., 2012). High temperatures can impair leaf function and alter grape cluster microclimates with a likely negative impact on yield and grape composition (Permanhani et al., 2016). The effects of TPC on grapevines in tropical settings has not been studied, but could provide more in-depth knowledge about the potential use of this technique for extending the range of grapevine cultivation.

To the best of our knowledge, this is the first work designed to analyze the effects of deficit irrigation on table grapes cultivated in tropical conditions under TPC. Studies about protected cultivation in grapevines under Tropical conditions are scarce. Moreover, the table grapevine cultivar used in the present work, 'Niagara Rosada', is poorly researched, even though it is widely accepted by consumers and therefore, widely cultivated in Brazil. Thus, we undertook an

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