

Water use efficiency in Almonds (*Prunus dulcis* (Mill.) D. A. Webb)

Vahid Rahimi Eichi

B.Sc., M.Sc.

Submitted in fulfilment of the requirements for the degree of

Master of Philosophy

School of Agriculture, Food and Wine

Faculty of Science

University of Adelaide

July 2013

Table of Contents

Table of Contents	I
Abstract	III
Declaration and Authorisation of Access to copying	V
Acknowledgments	VI
List of Abbreviations	VII
List of Figures	IX
List of Tables	XI
CHAPTER ONE	1
General introduction and literature review	1
1.1 Almonds in the world and in Australia	1
1.1.1 Almond irrigation in Australia	3
1.2 Water restrictions and solutions	4
1.3 Effects of drought stress on Almonds	5
1.4 Water use efficiency	6
1.4.1 Improving the efficiency of deficit irrigation strategies	8
1.4.2 Carbon Isotope Discrimination	9
CHAPTER TWO	12
Comparison of different water status indicators in	12
almond (<i>Prunus dulcis</i>) trees grown under two	12
deficit irrigation strategies.	12
2.1 Introduction	12
2.2 Materials & Method	17
2.2.1 Site	17
2.2.2 Irrigation treatments	17
2.2.3 Plant measurements	19
2.2.4 Statistical analysis	22
2.3 Results	22
2.3.1 Kernel yield and WUE	23
2.3.2 Plant water relations	24
2.3.2.1 Midday stem water potential (MSWP) and stomatal conductance (g_s)	24
2.3.2.2 Increment of trunk circumference (ΔTC)	25
2.3.2.3 Carbon isotope discrimination	25
2.4 Discussion	30
2.4.1 Water status indicators	30
2.4.2 Relationships between water status indicators	36
CHAPTER THREE	42
Water relations in almonds	42

3.1 Introduction.....	42
3.2 Materials and Methods.....	46
3.2.1.1 HCFM methodology	47
3.2.2.1 Visualizing the post-venous area by Scanning Electron Microscope (SEM)	49
3.3 Results.....	51
3.4 Discussion.....	56
CHAPTER FOUR.....	59
General Discussion	59
Bibliography	62

Abstract

Almond (*Prunus dulcis* (Mill) D. A. Webb) is a nut tree in the family Rosaceae, which compared to other nut crops, grown in Mediterranean climates, is relatively drought resistant. Due to the lack of, or high cost of water, almond growers are more inclined to improve gross production water use efficiency (WUE) by adopting water saving irrigation strategies. To this aim, the sensitivity and accuracy of different water status indicators need to be compared to design a suitable irrigation schedule. Meanwhile, instantaneous water use efficiency (WUE_i) that is a measure made at the leaf scale can also be used as a criterion for estimating WUE in breeding programs.

To study the effects of different deficit irrigation strategies, sustained and regulated deficit irrigations (SDI and RDI) were applied on almond trees for two consecutive seasons (2009-2010 and 2010-2011). Five levels of water amount were applied; namely, 55, 70, 85, 100 and 120% ET_c. Kernel yield, midday stem water potential (MSWP), stomatal conductance (g_s), increment in trunk circumference (Δ TC) and carbon isotope discrimination ($\Delta^{13}\text{C}$) were measured for both seasons. Results obtained in the 2009-2010 season showed that regardless of irrigation strategy, kernel yield was reduced in 70% ET_c of irrigation or less. Meanwhile kernel yield, WUE and water status indicators in this season were more sensitive to the quantity of water applied rather than to the deficit strategy (SDI or RDI). However, kernel yield was slightly lower in RDI 70% ET_c compared to SDI 70% ET_c treatments.

Although, there were high correlations between all water status indicators and the amount of water applied, g_s and $\Delta^{13}\text{C}$ showed lower sensitivity towards water deficit compared to MSWP and Δ TC, implying an anisohydric behaviour of almond trees. Meanwhile, in the first season, the observed correlation coefficients between kernel yield and Δ TC were lower than those of other water status indicators: MSWP \approx g_s \approx $\Delta^{13}\text{C}$ > Δ TC. In addition, there was only a moderate correlation (R² = 0.61) between $\Delta^{13}\text{C}$ and WUE in the first season indicating that $\Delta^{13}\text{C}$ may not be a reliable indicator of changes in WUE in almond trees. In the 2010-2011 season, there were no significant differences in kernel yields and water status indicators

between different treatments. It was probably due to the humid weather and frequent rain in the second season that negated the effects of deficit irrigation on almond trees.

To study the WUE_i in different genotypes, g_s and assimilation rate (A) in 5 mixed crosses of almond were examined. The significant correlations between g_s , A and internal concentration of CO_2 (C_i) indicated that A was probably limited by both stomatal and non-stomatal parameters that might be affected by genotype variations. Mesophyll anatomy and g_s between three almond varieties (Nonpareil, Carmel and Masbovera) were also compared. The results demonstrated that the post-venous hydraulic distance D_m and the density of mesophyll cells might indirectly affect g_s .

Declaration and Authorisation of Access to copying

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of thesis, when deposited in the University Library, being available for loan and photocopying.

Signed

Date

Acknowledgments

I acknowledge my supervisors Dr Michelle Wirthensohn, Professor Stephen Tyerman and Dr. Mark Downey. Thank you for giving me the opportunity to carry out this project in your laboratory and for your support and feedback throughout my Masters candidature. Thanks must also go to Dr. Karl Sommer for his support and valuable comments.

I want to acknowledge the following people for their contribution to my project:

Jana Kolesik, Kate Delaporte, Cathy Taylor, Cassandra Collins, Rebecca Vandeleur, Wendy Sullivan, Sigfredo Fuentes, Matthew Gilliam, Iman Lohraseb, Ehsan Tavakkoli, Esmaeil Ebrahimi, Jessica Bauschke, Richard Ratna and Maclin Dayod.

Special thanks to Nenah MacKenzie for her assistance to work with Mass Spectrometer.

Thank you to the School of Agriculture, Food and Wine.

My special regards to my parents for all their love and support.

List of Abbreviations

A	assimilation rate per unit of leaf area ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
C_a	external CO_2
C_i	Internal CO_2
D_m	post-venous hydraulic distance
E	transpiration rate per unit of leaf area ($\text{mmol m}^{-2} \text{s}^{-1}$)
E_{pan}	class A evaporation pan
ET_c	potential crop evapotranspiration
ET_o	reference crop evapotranspiration
g_c	stomatal conductance to CO_2 ($\text{mmol m}^{-2} \text{s}^{-1}$)
g_m	mesophyll conductance ($\text{mmol m}^{-2} \text{s}^{-1}$)
g_s	stomatal conductance ($\text{mmol m}^{-2} \text{s}^{-1}$)
g_w	stomatal conductance to water vapour ($\text{mmol m}^{-2} \text{s}^{-1}$)
HCFM	hydraulic conductance flow meter
k_{leaf}	leaf hydraulic conductance
K_c	crop coefficient
KF	kernel fraction
KY	kernel yield (t ha^{-1})
L_1	leaf hydraulic conductance normalized to leaf area ($\text{kg s}^{-1} \text{mpa}^{-1} \text{s}^{-2}$)
MDB	Murray-Darling River Basin
MSWP	midday stem water potential (Mpa)
PPFD	photosynthetic photon flux density $\mu\text{mol m}^{-2} \text{s}^{-1}$
RDI	regulated deficit irrigation
SDI	sustained deficit irrigation
VPD	vapour pressure deficit
W_a	external water vapour

W_i	internal water vapour
WUE	water use efficiency or gross production water use efficiency (kg mm^{-1})
WUE _i	instantaneous water use efficiency ($\mu\text{molCO}_2 \text{ mmol}^{-1} \text{H}_2\text{O}$)
$\Delta^{13}\text{C}$	carbon isotope discrimination
δ_a	carbon isotope composition in atmosphere
δ_p	carbon isotope composition in plant tissue
$\delta^{13}\text{C}$	isotope discrimination for carbon 13
ΔTC	increment in trunk circumference (mm)

List of Figures

Figure 1.1 Australia's share of global almond production in 2012.....	2
Figure 1.2 The estimated areas of almond plantings in Australia.....	2
Figure 1.3 Almond production in Australia by variety in 2012.....	3
Figure 1.4 Murray-Darling River Basin.....	4
Source: http://ramblingsdc.net/Australia/MurrayDarling.htm	4
Figure 1.5 Relationships between $\Delta^{13}\text{C}$ and C_i / C_a (A) and between $\Delta^{13}\text{C}$ and WUE (B) in the leaves of wheat.....	11
Figure 2.1 The plot plan of the field trial.....	21
Figure 2.2 Two irrigation strategies and five watering levels. Y-axis depicts the percentage full ET_c . Flowering and fruit setting times were August and September respectively with harvest in March.	21
Figure 2.4 Values of kernel yield (A), kernel fraction (kernel yield/(shell + hull)) (B), gross production water use efficiency WUE (C), midday stem water potential MSWP (D), stomatal conductance g_s (E), increment in trunk circumference ΔTC (F) and carbon isotope discrimination ($\Delta^{13}\text{C}\text{‰}$) (G) in the almond trees of eight irrigation treatments at the first (2009-2010) season. Each bar corresponds to the mean of 6 (A, B, C, E and F) and 3 (D and G). TC was measured at 22/05/2009 and 21/05/2010. $\Delta^{13}\text{C}$ was measured in the shells of fruit samples collected at the end of season (27/2/2010). Error bars are standard errors. Error Bars with the same letter are not significantly different at $P < 0.05$ (Duncan's test).	26
Figure 2.5 Relationship between the total amount of applied water, including rainfall, (mm/season) and kernel yield (A), midday stem water potential MSWP (B), trunk circumference ΔTC (C), stomatal conductance g_s (D), carbon isotope discrimination $\Delta^{13}\text{C}\text{‰}$ (E) and gross production water use efficiency WUE (F) for each deficit irrigation treatment with respect to control 100% ET_c over 2009-2010 season. Each point represents the mean of 6 (A, C, D, E and F) and 3 (B and E) replications \pm SE.	28
Figure 2.6 seasonal fluctuations in (A) midday stomatal conductance (g_s) and (B) midday stem water potential (MSWP) of almond trees grown in control and water-stressed conditions. The developmental stages (II-III: rapid vegetative growth, IV: kernel-filling, V: post-harvest) of <i>P. dulcis</i> tree are separated by dashed vertical lines.	29
Figure 2.7 Relationship between trunk circumference variations (ΔTC) with the average midday stem water potential (MSWP) (A) and stomatal conductance (g_s) (B). Data are recorded from the almond trees irrigated with eight different regimes in 2009-2010 season. Each point is the mean of 6 (g_s and ΔTC) and 3 (MSWP) replicates \pm SE, ($P < 0.001$).	35

Figure 2.8 Relationship between midday stem water potential (MSWP) and stomatal conductance (g_s) of almond trees over the same season under eight irrigation regimes. Each point is the mean of 6 (g_s) and 3 (MSWP) replicates \pm SE.....	37
Figure 2.9 Relationship between kernel yield ($t\cdot ha^{-1}$) and water status indicators over 2009-2010 season. Each point represents the mean of 6 (kernel yield, Δ TC and g_s) and 3 (MSWP and $\Delta^{13}C$) replications \pm SE. Δ TC: trunk circumference. MSWP: midday stem water potential.	40
Figure 2.10 Relationship between gross production water use efficiency (WUE) * 100 with stomatal conductance (g_s) (A) and carbon isotope discrimination ($\Delta^{13}C\%$) (B) water status indicators over 2009-2010 season. Each point represents the mean of 6 (WUE and g_s) and 3 ($\Delta^{13}C$) replications \pm SE.	41
Figure 3.1 Cross sections from the leaves of <i>Curatela americana</i> . Red arrows depict the post venous distances. “y” letters indicate the vertical distance from vascular tissue to the leaf surface (Brodrigg et al., 2007).	45
Figure 3.2 After cutting under water condition, the branch is tightly attached to the tube.	48
Figure 3.3 Transpiration rate E (A), assimilation rate A (B), stomatal conductance g_s (C), leaf hydraulic conductivity normalized to leaf area L_{shoot} (D), instantaneous water use efficiency WUE_i A/E (E) and internal concentration of CO_2 (C_i) (F) for 5 mixed crosses of almond. Each column represents the average of 4 replicates \pm SE. Different letters indicate statistical differences (Duncan’s test; $P < 0.05$).....	52
Figure 3.4 The relationships between hydraulic conductance normalised to leaf area L_{shoot} with stomatal conductance g_s (A) and carbon assimilation A (B). The relationships between carbon dioxide assimilation rate A with stomatal conductance g_s (C) and internal concentration of CO_2 (C_i) (D). Error bars represent the average of 4 replicates \pm SE for each point.	53
Figure 3.5 The variation of stomatal conductance (g_s) (A) and post venous distance (D_m) (B) for Carmel, Masbovera and Nonpareil. The means \pm SE ($n = 3$ and 8) are shown for D_m and g_s , respectively. Error Bars with the same letter are not significantly different (Duncan’s test; $P < 0.05$).....	54
Figure 3.6 Scanning electron microscope images of almond (<i>P. dulcis</i>) leaves. Horizontal (x) and vertical (y) distances of vascular bundles from stomata in Masbovera (A) and Carmel (B) varieties. The compact arrangement of mesophyll tissue in Masbovera (C).	55

List of Tables

Table 2.1 Timing of sustained (SDI) and regulated deficit irrigation (RDI), control and 'wet' irrigation treatments applied at Lake Powell for the 2009-2010 and 2010-2011 seasons. Below the line shows post harvest period.	18
Table 2.2 Irrigation treatments, irrigation, effective rain, effective rain + irrigation, reference crop evapotranspiration (ET _o) and timing of deficit in 2009-2010 and 2010-2011 seasons. ...	23
Table 2.3 Variations of kernel yield (KY) (t.ha ⁻¹), kernel fraction (KF), carbon isotope discrimination $\Delta^{13}\text{C}\text{‰}$ and midday stem water potential (MSWP) (MPa). The factors are compared between eight different irrigation treatments in almond trees in (2010-2011) season. Values are means of 3 (MSWP and $\Delta^{13}\text{C}$) and 6 (KY and KF). Mean values within a column followed by different letters were significantly different at $P < 0.05$ using Duncan's comparison test. MSWP was measured from 29/09/2010 to 10/03/2011. The shells of the fruit samples collected at the end of season (24/2/2011) were used for $\Delta^{13}\text{C}$ measurement.....	27