THE EFFECT OF PARTIAL ROOTZONE DRYING ON THE
PARTITIONING OF DRY MATTER, CARBON, NITROGEN
AND INORGANIC IONS OF GRAPEVINES

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Declaration

I hereby declare that this thesis contains no material that has been accepted for the award of any other degree or diploma at any University. To the best of my knowledge and belief, no material described herein has been previously published or written by any other person, except where due reference is made in the text.

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Summary

Partial rootzone drying (PRD) is an irrigation management technique designed to reduce water use in grapevines without a decline in yield, thereby increasing water-use efficiency (measured as t/ML) (WUE). The principle of PRD is to keep part of the root system at a constant drying rate to produce soil-derived signals to above-ground plant organs to induce a physiological response. Major PRD effects include a reduced canopy size and greatly increased WUE with possible improvements in fruit quality. Although we have a good understanding of the hormonal physiology of PRD, little is known on the effect of PRD on partitioning of C, N and inorganic ions such as K. This thesis broadens our knowledge on the effects of PRD on grapevine field performance, growth and dry matter accumulation as well as its effects on physiology and biochemistry. In field experiments over 3 seasons, PRD reduced water use in grapevines without a significant decline in yield. PRD effects included reduced shoot growth and greatly increased WUE. Field-grown Cabernet Sauvignon, where the PRD grapevines were irrigated at half the control rate, and Shiraz where the PRD grapevines were irrigated at same rate as controls, confirmed that PRD is not simply an irrigation strategy that applies less water, rather it alters the way in which the plant responds to its environment, e.g. PRD alters the sensitivity of the stomatal response to atmospheric conditions and significantly influence enzymes that regulate nutrient accumulation and partitioning. PRD did not change the total amount of carbon and nitrogen on a whole plant basis. However, it caused a significant partitioning of carbon and nitrogen towards trunk, roots and fruit at the expense of shoot growth. This change in partitioning occurred as a result of altered activity of the enzymes controlling the assimilation of carbon and nitrogen. PRD significantly reduced nitrate reductase (NR) activity in grapevine leaves, which catalyses the first step in the assimilation of nitrate irrespective of the amount of water applied. The reduction in NR activity is correlated with the development of the PRD cycle and the associated reduction in stomatal conductance.

PRD also significantly altered grapevine sucrolytic enzyme activity that regulate source:sink relationships. PRD showed transient increases in leaf sucrose phosphate synthase (SPS) activity (formation of sucrose) compared to control, but significantly reduced leaf neutral invertase (sucrose cleavage) and leaf starch content in both field and potted experiments. This may indicate an increased photosynthetic capacity and a reduction in its sink strength for sucrose in favor of organs such as fruit and roots. This hypothesis was reinforced by the fact that berries showed significantly higher levels in glucose and fructose early in the season. Berry sugar content and Brix at harvest however was unaffected. Although PRD had no significant effect on berry characteristics at harvest such as Brix and pH, it occasionally reduced per berry K⁺ content and increased total amino acid concentration that may lead to positive outcomes for wine quality.

PRD-treated grapevine roots on the ‘wet’- and ‘drying’-sides differed greatly in enzyme activity and osmolality. PRD significantly increased osmolality in both wet and drying roots by increasing total osmolyte concentration that may facilitate the movement of water from wet to dry roots. The increases in osmolality were also associated with increased free polyamine production (spermidine and spermine) in PRD roots that may be related to increased root growth and density.
List of Abbreviations

ABA  abscisic acid
ADC  arginine decarboxylase
AI   acid invertase
GWRDC  Australian Grape and Wine Research Development Corporation
Ci  intracellular CO$_2$ concentrations
CK  cytokinins
CSIRO  Commonwealth Scientific & Industrial Research Organization
°C  degrees Celsius
ET$_0$  evapotranspiration
FAA  free amino acid
FAN  free amino nitrogen
GDD  growing degree days
GOGAT  glutamine synthase/glutamate synthase
g$_s$  stomatal conductance
GS  glutamine synthase
IRGA  infrared gas analysis instrument
LA  leaf area
NADPH  nicotinamide adenine dinucleotide phosphate
NCCs  nitrogen-containing compounds
NI  neutral invertase
NR  nitrate reductase
PAR  photosynthetic active radiation
PAs  polyamines
Pn  photosynthesis
PRD  partial rootzone drying
RH  relative humidity
RuBP  ribulose-1,5-bisphosphate
s.e.  standard error of the mean
SPS  sucrose phosphate synthase
SucSy  sucrose synthase
TDR  time domain reflectometry
TSS  total soluble solids
VSP  vertical shoot positioning
WUE  water use efficiency
Ψ$_L$  leaf water potential
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Amino acid concentration (nM/g fresh wt) in shoots of field-grown Coombe Cabernet Sauvignon grapevines at harvest in 2001. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n = 7 ± s.e.; n.d. = not detected).

Amino acid concentration (nM/g fresh wt) in leaves of field-grown Coombe Shiraz at harvest in 2001. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n = 7 ± s.e.; n.d. = not detected).

Amino acid concentration (nM/g fresh wt) in shoots of field-grown Coombe Shiraz at harvest in 2001. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n = 7 ± s.e.).

Amino acid concentration (nM/g fresh wt) in shoots of field-grown Coombe Cabernet Sauvignon grapevines at harvest in 2001. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n = 7 ± s.e.; n.d. = not detected).

Sucrolytic enzyme activity in berries of field-grown Coombe Cabernet Sauvignon grapevines (2003) measured at two different times during ripening. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n = 7 ± s.e.).

Sucrolytic enzyme activity in berries of field-grown Coombe Shiraz grapevines measured shortly after veraison in 2003. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n = 7 ± s.e.).

Sucrolytic enzyme activity in berries of field-grown Coombe Cabernet Sauvignon grapevines at harvest in 2001. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n = 7 ± s.e.).

Sucrolytic enzyme activity in berries of field-grown Nuriootpa Shiraz grapevines at harvest in 2001. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n = 7 ± s.e.).

The evolution in the concentration of free amino acids (nM/g fresh wt) in Coombe Cabernet Sauvignon berries during the ripening period in 2001 (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n = 7; a = significantly different (P<0.10); * = significantly different (P<0.05)).

The concentration of free amino acids (nM/g fresh wt) in Coombe Cabernet Sauvignon berries during veraison and harvest in 2002 (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n = 7 ± s.e.; * = significantly different (P<0.05)).

Amino acid concentration (nM/g fresh wt) in berries of field-grown Coombe Shiraz grapevines during the 2001 season. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n = 7; a = significantly different (P<0.10)).
9.12 The concentration of free amino acids (nM/g fresh wt) in Coombe Shiraz berries during veraison and at harvest in 2002. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n = 7 ± s.e.; a = significantly different (P<0.10)).

10.1 The inorganic ion concentration (μg/g dry wt) and ion content (μg/berry) in Coombe Cabernet Sauvignon berries at veraison in 2002. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n=7 ± s.e.).

10.2 The inorganic ion concentration (μg/g dry wt) and ion content (μg/berry) in Coombe Cabernet Sauvignon berries at harvest in 2002. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n=7 ± s.e.).

10.3 The inorganic ion concentration (μg/g dry wt) and ion content (μg/berry) in Coombe Shiraz berries at veraison in 2002. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n=7 ± s.e.).

10.4 The inorganic ion concentration (μg/g dry wt) and ion content (μg/berry) in Coombe Shiraz berries at harvest in 2002. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n=7 ± s.e.).

10.5 The inorganic ion concentration (μg/g dry wt) and ion content (μg/berry) of Coombe Cabernet Sauvignon berries at veraison in 2003. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n=7 ± s.e.).

10.6 The inorganic ion concentration (μg/g dry wt) and ion content (μg/berry) of Coombe Cabernet Sauvignon berries at harvest in 2003. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n=7 ± s.e.).

10.7 The inorganic ion concentration (μg/g dry wt) and ion content (μg/berry) of Coombe Shiraz berries at veraison in 2003. (PRD received the same amount of irrigation water as control on only one side at any time; control received water on both sides; means n=7 ± s.e.).

10.8 The inorganic ion concentration (μg/g dry wt) and ion content (μg/berry) of Coombe Shiraz berries at harvest in 2003. (PRD received the same amount of irrigation water as control only on one side at any time; control received water on both sides; means n=7 ± s.e.).

10.9 The Ca, K, Mg, P and S concentration (μg/g dry wt) in Nuriootpa Shiraz berries at harvest in 2001. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n=5 ± s.e.).

10.10 The Ca, K, Mg, P and S contents (μg/berry) of Nuriootpa Shiraz berries at harvest in 2001. (PRD received half the amount of irrigation water as control by irrigating on only one side at any time; control received water on both sides; means n=5 ± s.e.).

11.1 Various physiological responses of grapevines on PRD treatment (% change compared to control). (n.s. = not significant). Shaded areas = PRD effects that may be related to a degree of water stress.