

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

# **Preharvest Practices Affecting Postharvest Quality of 'Hayward' Kiwifruit**

---

A thesis presented in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY  
In  
Plant Physiology and Horticultural Science

Massey University, New Zealand



Katrina Norah Buxton

November 2005

## Abstract

Repeat purchase of kiwifruit is primarily driven by consumer judgement of internal fruit quality attributes, including those affected by dry matter concentration (DMC) and mineral composition in fruit. This research investigated mechanisms affecting carbohydrate, mineral and water accumulation in 'Hayward' kiwifruit (*Actinidia deliciosa*), and related these to specific management practices. Canopy manipulation through pruning and treatments such as artificial pollination, defoliation, girdling, thinning and application of the auxin transport inhibitor TIBA, may affect fruit DMC and mineral composition.

Leaf photosynthesis and fruit dry matter concentrations (DMC) started to decline as leaf area index values increased above 3-4. In addition to reducing competition for carbohydrates between vegetative and reproductive growth, leader pruning probably increased DMCs of fruit in the leader zone by improving light interception. Photosynthesis was not affected by crop loads between 20-60 fruit m<sup>-2</sup>, but was consistently higher on non-terminating (long) shoots than on terminating (short) shoots, as were fruit DMCs. Differences in photosynthetic rate of leaves on these two shoot types were attributed to differences in shoot exposure to the sun, and also to the greater demand for carbohydrate within long shoots.

Leaves subtending fruit may increase Ca, and to a lesser extent Mg, flow into fruit, however their accumulation was not affected by leaves outside the fruiting shoot. Xylem sap Ca and Mg concentrations were higher in shoots with a high rather than a low leaf: fruit (L:F) ratio and this may, at least partially, relate to the increase in shoot transpiration that occurs as shoot L:F ratios increase. Within vine variation in fruit Ca concentrations may reflect variations in xylem sap flow rates and Ca concentrations of xylem sap reaching fruit.

Calcium translocation may occur independently of ion movement in the transpiration stream. Timing and extent of vascular differentiation in flower and fruitlet pedicels, possibly regulated by auxin, may influence fruit Ca accumulation. It is likely that early differentiation of vascular tissue in flower and fruitlet pedicels influenced cell division and subsequent (carbohydrate) sink strength of fruit by determining availability of carbohydrate for partitioning into cell walls.

While growers have the potential to induce minor changes in fruit DMC, further increases will depend on the separation of carbohydrate and water accumulation. Further research is required to elucidate the mechanisms regulating phloem transport and unloading of sucrose in kiwifruit.

## Acknowledgements

I can't believe my thesis is finished! It makes me very proud to think back four years, to when I first started, and consider all the things that I have accomplished and my own personal development during the course of my studies. This has definitely been one of the biggest and hardest challenges I have ever taken on, and it never would have been accomplished without the advice and support of the following people and organisations. It is my pleasure to acknowledge these people.

Firstly, there are my supervisors Professor Errol Hewett and Dr Ian Ferguson for their patient guidance and support throughout the course of my PhD. I recognise and greatly appreciate all the hours of time they have invested in me over the last four years, despite having hectic schedules of their own.

I would also like to say a special thanks to Drs Sandy Lang and Elspeth MacRae, who 'got the ball rolling' for me, and to Dr Mike Clearwater for the considerable quantity of information, expertise and feedback that he has provided me with over the last four years. Dr Nihal De Silva also deserves a special mention for the statistical advice he has shared with me. In addition the following people have all provided help and/or advice: Annette Richardson, Dr Jeremy Burdon, Linda Boyd, Dr Cristos Xiloyannis, Dr Mike Currie, Dr Bartelo Dichio, Dr Ian Hallet, Dr Nagin Lallu, Dr Kate Maguire, Dr Ken Marsh, Dr Denny Meyer, Alistair Mowat, Steven Owen, Dr Kevin Patterson, Paul Sutherland, Dr Grant Thorp, Dr Jens Wünsche and the orchard management team at Te Puke HortResearch.

Also I would like to thank the people I worked with at Apata Centrepac Ltd and Satara Co-operative Group Ltd, for assisting with the grading, packing and storage of fruit from my experiments; Dave Jury and staff at Muller and Associates who worked with me on the experiment reported in Chapter three; Growers Bruce Vanstone, Tom Newman, Howard Strahan and Dave Burnside who provided experimental vines.

HortResearch has provided the required facilities to complete my research and staff there, many of whom are mentioned above, have been particularly great to me over the last four years, not just providing technical assistance and advice, but often friendship as well. Generous financial assistance from the Tertiary Education Commission (formerly from the Foundation for Research, Science and Technology) and ZESPRI™ International Ltd has not only ensured that this research even 'got off the ground', but has enabled me to present papers at several international conferences (Appendix 1). ZESPRI™ International Ltd also provided me with opportunities to interact with growers and other industry personnel.

Lastly, I would like to thank my boyfriend Neil, friends and family for getting me through the tough times and for their support and understanding when I could not always be as social as I would have liked. Plenty of time to make up for that now!

# CONTENTS

---

|  |              |
|--|--------------|
| <b>ABSTRACT</b>  | <b>iii</b>   |
| <b>ACKNOWLEDGEMENTS</b>  | <b>v</b>     |
| <b>CONTENTS</b>  | <b>vii</b>   |
| <b>LIST OF FIGURES</b>   | <b>xiii</b>  |
| <b>LIST OF TABLES</b>  | <b>xix</b>   |
| <b>LIST OF ABBREVIATIONS</b>   | <b>xxiii</b> |
| <br>   |              |
| <b>CHAPTER 1. General Introduction</b>   | <b>1</b>     |
| 1.1. Internal quality in kiwifruit: importance of high Ca and DM concentrations      | 1            |
| 1.1.1. Fruit DMC and taste   |              |
| 1.1.2. Postharvest quality and fruit mineral and DM concentrations                   | 5            |
| 1.1.3. Factors affecting fruit variability   | 7            |
| 1.2. Carbohydrate, mineral nutrient and water accumulation in kiwifruit              | 10           |
| 1.2.1. Fruit growth  | 10           |
| 1.2.2. Phloem transport and carbohydrate accumulation                                | 11           |
| 1.2.3. Xylem transport, water and mineral accumulation                               | 13           |
| 1.2.4. Fruit DMC and its relationship to Ca  | 19           |
| 1.3. Canopy management and fruit quality   | 21           |
| 1.3.1. Vine description  | 21           |
| 1.3.2. Canopy management   | 23           |
| 1.4. Fruit water loss and kiwifruit internal quality                                 | 30           |
| 1.4.1. Fruit skin structure and water loss   | 32           |
| 1.4.2. Fruit surface area and water loss   | 35           |
| 1.5. Vascular tissues and their development in the fruit stalk                       | 35           |
| 1.5.1. Effects of vascular capacity on carbohydrate and mineral accumulation         | 35           |
| 1.5.2. Xylem morphology  | 36           |
| 1.5.3. Hydraulic conductance   | 37           |
| 1.5.4. Phloem morphology   | 39           |
| 1.5.5. Vascular development in the fruit stalk                                       | 39           |
| 1.5.6. Factors affecting vascular development  | 42           |
| 1.6. Auxins and fruit quality  | 43           |
| 1.6.1. Auxins and vascular differentiation   | 44           |
| 1.6.2. Auxins and cell division and elongation                                       | 45           |
| 1.6.3. Auxins and carbohydrate accumulation within the fruit                         | 45           |
| 1.6.4. Auxin application and the effect of seeds                                     | 46           |
| 1.6.5. Effect of auxin transport inhibitors on mineral and carbohydrate accumulation | 48           |

|                   |  |           |
|-------------------|--|-----------|
| 1.7.              | Problem Statement and Objectives                           | 49        |
| 1.7.1.            | Statement of the problem                                   | 49        |
| 1.7.2.            | Objectives   | 50        |
| <b>CHAPTER 2.</b> | <b>General Methods</b>                                     | <b>53</b> |
| 2.1.              | Chemicals  | 53        |
| 2.2.              | Fruit selection  | 53        |
| 2.3.              | Field preparation of fruit and fruit stalks for assessment | 53        |
| 2.4.              | Secondary vascular measurements                            | 54        |
| 2.5.              | Mineral analysis   | 56        |
| 2.6.              | Dry matter concentration                                   | 56        |
| 2.7.              | Xylem functionality  | 56        |
| 2.7.1.            | Dye infiltration   | 56        |
| 2.7.2.            | Determining xylem functionality                            | 57        |
| 2.8.              | Harvest dates  | 58        |
| 2.9.              | Fruit storage assessment                                   | 59        |
| 2.10.             | Data handling and statistics                               | 60        |
| 2.10.1.           | Data handling  | 60        |
| 2.10.2.           | Experimental design and statistical analysis               | 60        |
| <b>CHAPTER 3.</b> | <b>Kiwifruit Pruning Systems and Fruit Quality</b>         | <b>63</b> |
| 3.1.              | Introduction   | 63        |
| 3.2.              | Materials and methods                                      | 64        |
| 3.2.1             | Experimental design  | 64        |
| 3.2.2             | Pruning strategies   | 65        |
| 3.2.3.            | Seasonal analyses  | 67        |
| 3.2.4.            | Experimental problems                                      | 71        |
| 3.2.5.            | Statistical analysis                                       | 72        |
| 3.3.              | Results  | 72        |
| 3.3.1.            | Canopy attributes  | 72        |
| 3.3.2.            | Yield components   | 73        |
| 3.3.3.            | Fruit data   | 74        |
| 3.3.4.            | Storage and sensory data                                   | 80        |
| 3.4.              | Discussion   | 83        |
| 3.4.1.            | Fruit quality: physical attributes                         | 83        |
| 3.4.2.            | Fruit quality as perceived by the consumer                 | 87        |
| 3.5.              | Conclusions  | 89        |

|                   |   |            |
|-------------------|---|------------|
| <b>CHAPTER 4.</b> | <b>Crop Load Effects on Photosynthesis and Transpiration and<br/>Subsequent Effects on Fruit Quality</b>  | <b>91</b>  |
| 4.1.              | Introduction  | 91         |
| 4.2.              | Materials and methods   | 93         |
| 4.2.1.            | 2002/2003 Season  | 93         |
| 4.2.2.            | 2003/2004 Season  | 95         |
| 4.2.3.            | Statistical analysis  | 96         |
| 4.3.              | Results   | 96         |
| 4.3.1.            | Canopy density  | 96         |
| 4.3.2.            | Fruit and fruit stalk data  | 98         |
| 4.3.3.            | Photosynthesis and stomatal conductance   | 110        |
| 4.3.4.            | Storage trial results   | 114        |
| 4.4.              | Discussion  | 117        |
| 4.4.1.            | Crop load effects on photosynthesis and stomatal conductance  | 117        |
| 4.4.2.            | Crop load effects on fruit properties   | 121        |
| 4.4.3.            | Crop load effects on postharvest fruit quality  | 124        |
| 4.5.              | Conclusions   | 125        |
| <br>              |   |            |
| <b>CHAPTER 5:</b> | <b>Carbohydrate and Mineral Accumulation in Long, Non-<br/>Terminating and Short, Terminating Shoots: Effects of Girdling<br/>and Defoliation</b> | <b>127</b> |
| 5.1.              | Introduction  | 127        |
| 5.2.              | Materials and methods   | 129        |
| 5.2.1.            | Experimental design and treatments  | 129        |
| 5.2.2.            | Harvest procedure   | 130        |
| 5.2.3.            | Xylem functionality   | 130        |
| 5.2.4.            | Statistical analysis  | 131        |
| 5.3.              | Results   | 131        |
| 5.3.1.            | December harvest results  | 131        |
| 5.3.2.            | January harvest results   | 133        |
| 5.3.3.            | April harvest results   | 135        |
| 5.4.              | Discussion  | 137        |
| 5.4.1.            | Minerals  | 137        |
| 5.4.2.            | Fruit weight and dry matter concentration   | 142        |
| 5.5.              | Conclusions   | 144        |

|                   |  |            |
|-------------------|--|------------|
| <b>CHAPTER 6:</b> | <b>Fruit Transpiration, Skin Permeance, Minerals and Carbohydrate Accumulation</b>   | <b>147</b> |
| 6.1.              | Introduction   | 147        |
| 6.2.              | Materials and methods  | 149        |
| 6.2.1.            | The effect of fruit transpiration on mineral and carbohydrate accumulation in fruit from long, non-terminating and short, terminating shoots | 149        |
| 6.2.2.            | Effect of shoot type on fruit permeance  | 151        |
| 6.3.              | Results  | 156        |
| 6.3.1.            | The effect of fruit transpiration on mineral and carbohydrate accumulation in fruit from long, non-terminating and short, terminating shoots | 156        |
| 6.3.2.            | Effect of shoot type on fruit permeance  | 160        |
| 6.4.              | Discussion   | 163        |
| 6.4.1.            | Mineral accumulation and fruit transpiration   | 163        |
| 6.4.2.            | Shoot type effects   | 165        |
| 6.4.3.            | Mineral accumulation and fruit permeance   | 168        |
| 6.5.              | Conclusions  | 168        |
| <br>              |  |            |
| <b>CHAPTER 7:</b> | <b>Seasonal Trends in Vascular Development of Fruit Stalks From Long, Non-Terminating and Short, Terminating Shoots</b>                      | <b>171</b> |
| 7.1.              | Introduction   | 171        |
| 7.2.              | Materials and methods  | 172        |
| 7.2.1.            | Experimental design  | 172        |
| 7.2.2.            | Statistical analysis   | 172        |
| 7.3.              | Results and discussion   | 173        |
| 7.3.1.            | Flower and fruit stalk growth  | 173        |
| 7.3.2.            | Vascular development in the fruit stalk  | 174        |
| 7.3.3.            | Spatial distribution of phloem and xylem tissues within the fruit stalk  | 179        |
| 7.4.              | Conclusions  | 181        |
| <br>              |  |            |
| <b>CHAPTER 8:</b> | <b>TIBA and Fruit Seed Number Influences Mineral and Carbohydrate Accumulation in Kiwifruit: A Potential Role for Auxins</b>                 | <b>185</b> |
| 8.1.              | Introduction   | 185        |
| 8.2.              | Materials and methods  | 189        |
| 8.2.1.            | TIBA and fruit quality   | 189        |
| 8.2.2.            | TIBA plus girdling or defoliation and fruit quality  | 191        |
| 8.2.3.            | Seeds and fruit quality  | 193        |
| 8.3.              | Results  | 196        |



|        |   |     |
|--------|---|-----|
| 8.3.1. | TIBA and fruit quality  | 196 |
| 8.3.2. | Effects of TIBA plus girdling or defoliation on fruit quality         | 208 |
| 8.3.3. | Seeds and fruit quality   | 217 |
| 8.4.   | Discussion  | 221 |
| 8.4.1. | Mineral ion accumulation  | 221 |
| 8.4.2. | Fresh and dry weight accumulation                                     | 224 |
| 8.4.3. | Girdling and defoliation in relation to TIBA effects on fruit quality | 227 |
| 8.4.4. | TIBA and fruit quality in storage                                     | 227 |
| 8.5.   | Conclusions   | 228 |

**CHAPTER 9: Non-destructive Measurement of Mineral Concentrations in Xylem Sap of Different Kiwifruit Shoot Types Using Spittlebugs** **231**

|        |   |     |
|--------|---|-----|
| 9.1.   | Introduction  | 231 |
| 9.2.   | Materials and methods   | 232 |
| 9.2.1. | Plant material  | 232 |
| 9.2.2. | Bug collection and xylem sap feeding  | 233 |
| 9.2.3. | Collection of excreta sap   | 234 |
| 9.2.4. | Excreta sap analysis  | 234 |
| 9.2.5. | Spittlebug excreta sap and xylem sap composition  | 235 |
| 9.2.6. | Vacuum-extraction of xylem sap  | 235 |
| 9.2.7. | Axillary shoot attributes   | 236 |
| 9.2.8. | Statistical analysis  | 236 |
| 9.3.   | Results   | 237 |
| 9.3.1. | Bug feeding patterns  | 237 |
| 9.3.2. | Excreta sap ion composition   | 239 |
| 9.3.3. | The effect of axillary shoot-type on xylem sap composition  | 240 |
| 9.3.4. | Ion concentrations gradients down a cane  | 241 |
| 9.3.5. | Calibration solution results  | 242 |
| 9.4.   | Discussion  | 242 |
| 9.4.1. | Xylem sap mineral composition   | 242 |
| 9.4.2. | Insect feeding patterns   | 243 |
| 9.4.3. | Spatial variation in xylem sap mineral ion concentrations: evidence that minerals are partitioned on a demand basis | 244 |
| 9.5.   | Conclusions   | 246 |

**CHAPTER 10: General Discussion** **249**

|       |   |     |
|-------|---|-----|
| 10.1. | Thesis objective  | 249 |
| 10.2. | Factors affecting Ca and carbohydrate accumulation in kiwifruit | 250 |
| 10.3. | Factors affecting fruit DM, Mg, K and P concentrations          | 257 |

|   |            |
|---|------------|
| 10.4. Potential to manipulate fruit DM and Ca concentrations to benefit fruit quality | 258        |
| 10.5. Directions for future research  | 261        |
| 10.6. Conclusions   | 263        |
| <b>REFERENCES</b>   | <b>265</b> |
| <b>APPENDIX I. International Conference and Industry Presentations</b>                | <b>287</b> |
| <b>APPENDIX II. Chemicals Utilised in Fruit Assessment</b>                            | <b>288</b> |

## List of Figures

### Chapter 1:

|       |   |    |
|-------|---|----|
| 1.1.  | Average DMC of fruit from 24 different orchards within New Zealand, as measured in 2004 and 2005. | 7  |
| 1.2.  | Fresh and dry weight accumulation in 'Hayward' kiwifruit.   | 10 |
| 1.3.  | Starch and soluble sugar accumulation in 'Hayward' kiwifruit.                                     | 12 |
| 1.4.  | Soluble sugar accumulation in 'Hayward' fruit.  | 12 |
| 1.5.  | Mineral accumulation in different organs within kiwifruit vines.                                  | 16 |
| 1.6.  | Fruit Ca contents and concentrations in 'Hayward' kiwifruit                                       | 17 |
| 1.7.  | Fruit P, Mg and K contents and concentrations in 'Hayward' kiwifruit.                             | 18 |
| 1.8.  | Seasonal changes in DMC in 'Hayward' kiwifruit.   | 20 |
| 1.9.  | Kiwifruit vine trained on pergola trellis.  | 21 |
| 1.10. | A kiwifruit stalk and cross-section of the stalk of a mature fruit.                               | 40 |

### Chapter 2:

|      |  |    |
|------|--|----|
| 2.1. | Wind tunnel design for measuring xylem functionality.  | 57 |
| 2.2. | A transverse kiwifruit section illustrating the stained and unstained ventromedian carpellary (VMC) bundles. | 58 |

### Chapter 3:

|      |  |    |
|------|--|----|
| 3.1. | Design of the pruning systems experiment.  | 65 |
| 3.2. | A digital hemispherical photo taken from underneath the canopy of a kiwifruit vine.                                  | 70 |
| 3.3. | Flowering and yield in monitored leader and conventionally pruned (LP and CP) vines, as measured over three seasons. | 74 |
| 3.4. | Yield per area in LP and CP vines.   | 75 |
| 3.5. | DMC of fruit from LP and CP vines, as measured over three seasons.   | 76 |
| 3.6. | Relationship between crop load and fruit DMC with canopy openness and LAI values illustrated.                        | 77 |
| 3.7. | Relationship between crop load and fruit DW per m <sup>2</sup> .   | 78 |
| 3.8. | Fruit Ca, Mg, K and P concentrations in LP and CP vines, as measured over three seasons.                             | 79 |

## Chapter 4:

|       |  |     |
|-------|--|-----|
| 4.1.  | Canopy light transmission in high and low crop load, pruned and unpruned vines.  | 97  |
| 4.2.  | Canopy openness and LAI, as measured at three different crop loads.  | 97  |
| 4.3.  | Canopy openness and LAI in high and low crop load, pruned and unpruned vines.  | 98  |
| 4.4.  | Fresh weight and DMC of fruit harvested from pruned and unpruned long, non-terminating (long) and short, terminating (short) shoots.           | 99  |
| 4.5.  | Fresh weight and DMC of fruit from long and short shoots, as measured at three different crop loads.   | 100 |
| 4.6.  | Relationship between crop load and fruit dry weight.   | 101 |
| 4.7.  | Potassium, P, Ca and Mg concentrations in fruit from high and low crop load, pruned and unpruned vines.  | 102 |
| 4.8.  | Potassium, P, Ca and Mg concentrations in fruit harvested from pruned and unpruned long and short shoots from high and low crop load vines.    | 103 |
| 4.9.  | Xylem and phloem area and estimated secondary xylem conductance in the stalks of fruit from high and low crop load pruned and unpruned vines.  | 105 |
| 4.10. | Phloem and xylem area in stalks of fruit from pruned and unpruned long and short shoots.   | 106 |
| 4.11. | Estimated secondary xylem conductance in stalks of fruit from pruned and unpruned long and short shoots.                                       | 107 |
| 4.12. | Relationship between fruit fresh weight, dry weight, DMC and fruit stalk phloem and xylem area.  | 108 |
| 4.13. | Relationship between fruit Ca, Mg, K and P and fruit stalk xylem area.   | 109 |
| 4.14. | Relationship between estimated fruit stalk secondary xylem conductance and fruit Ca concentration.   | 109 |
| 4.15. | Relationship between leaf stomatal conductance and net assimilation rate.  | 110 |
| 4.16. | Photosynthesis and stomatal conductance in leaves from high crop load, pruned and unpruned vines and low crop load, pruned and unpruned vines. | 111 |
| 4.17. | Photosynthesis and stomatal conductance in leaves from long, pruned and unpruned shoots and short pruned and unpruned shoots.                  | 112 |
| 4.18. | Relationship between leaf photosynthetic rates, canopy openness and LAI.   | 113 |
| 4.19. | Relationship between leaf stomatal conductance and fruit Ca, Mg, K and P concentrations.   | 114 |
| 4.20. | Relationship between leaf photosynthetic rates and fruit DMC in short and long shoots.   | 115 |

|       |  |     |
|-------|--|-----|
| 4.21. | Fruit firmness and ripe soluble solids concentration in high and low crop load, pruned and unpruned vines after 24 weeks at 1-3°C. | 116 |
| 4.22. | Relationship between LTB incidence and blemish incidence.  | 116 |

### **Chapter 5:**

|      |   |     |
|------|---|-----|
| 5.1. | Xylem functionality of VMC bundles in kiwifruit following spring defoliation of long and short shoots, as measured on 21 December 2001.           | 133 |
| 5.2. | Xylem functionality of VMC bundles in kiwifruit following spring and summer defoliation of long and short shoots, as measured on 20 January 2002. | 134 |
| 5.3. | Xylem functionality of VMC bundles in kiwifruit following spring and summer defoliation of long and short shoots, as measured on 27 April 2002.   | 136 |

### **Chapter 6:**

|      |  |     |
|------|--|-----|
| 6.1. | Fan treatment design.  | 150 |
| 6.2. | Relationship between fruit weight and surface area.                                  | 154 |
| 6.3. | Seasonal changes in permeance and surface area of fruit from long and short shoots.  | 161 |
| 6.4. | Relationship between permeance and surface area of fruit from long and short shoots. | 162 |
| 6.5. | Trichome density in “Hayward” kiwifruit.   | 162 |

### **Chapter 7:**

|      |  |     |
|------|--|-----|
| 7.1. | Flower and fruit stalk length and diameter development in stalks from long and short shoots.   | 173 |
| 7.2. | Cross-sections of kiwifruit pedicels two and twenty-one weeks after anthesis.  | 174 |
| 7.3. | Secondary phloem, xylem and pith development in flower and fruit stalks from long and short shoots.                                    | 175 |
| 7.4. | Seasonal changes in secondary xylem vessel number and estimated conductance in stalks from flowers and fruit on long and short shoots. | 176 |
| 7.5. | Relationship between flower and fruit stalk diameter, phloem and xylem areas and estimated secondary xylem conductance.                | 178 |
| 7.6. | Spatial distribution in pith, xylem and phloem areas down a fruit stalk.   | 179 |
| 7.7. | Spatial distribution in xylem vessel number and estimated conductance down a fruit stalk.  | 180 |

## Chapter 8:

|       |  |     |
|-------|--|-----|
| 8.1.  | Diagrammatic representation of one vine replicate.   | 192 |
| 8.2.  | Relationship between actual and estimated fruit seed numbers and, between the pollen solution concentration and estimated fruit seed numbers.          | 195 |
| 8.3.  | Vascular discolouration in TIBA-treated fruit.   | 196 |
| 8.4.  | Fruit fresh weight, DM and Ca concentrations, as measured on 7 January 2003 and 5 May 2003, following TIBA application.                                | 200 |
| 8.5.  | Xylem and phloem area, xylem vessel number and estimated conductance, as measured on 10 January 2003, following TIBA application.                      | 201 |
| 8.6.  | Fruit Ca, Mg, K and P concentrations, as measured on 10 January 2003, following TIBA application.  | 202 |
| 8.7.  | Xylem and phloem area, xylem vessel number and estimated conductance, as measured on 21 April 2003, following TIBA application.                        | 203 |
| 8.8.  | Fresh weight and DMC, as measured on 21 April 2003, following TIBA application.  | 204 |
| 8.9.  | Fruit Ca, Mg, K and P concentrations, as measured on 21 April 2003, following TIBA application.  | 205 |
| 8.10. | Functionality of the xylem vessels in the VMC bundles, as measured on 10-11 January 2003, following TIBA application.                                  | 206 |
| 8.11. | Relationship between xylem and phloem area and fruit FW.   | 206 |
| 8.12. | Relationship between estimated secondary xylem conductance and fruit Ca, Mg, K and P concentrations.   | 207 |
| 8.13. | Calcium concentrations in TIBA-treated fruit from short control, defoliated and girdled shoots.  | 211 |
| 8.14. | DMC in TIBA-treated fruit from long control, defoliated and girdled shoots.  | 214 |
| 8.15. | Relationship between estimated fruit seed number, FW, DW and fruit DMC.  | 217 |
| 8.16. | Relationship between estimated fruit seed number and fruit Ca, Mg, K and P concentrations.   | 218 |
| 8.17. | Relationship between estimated fruit seed number, phloem and xylem areas, and the phloem: xylem ratio.   | 219 |
| 8.18. | Relationship between the estimated fruit seed number and secondary xylem vessel number and estimated conductance.                                      | 219 |
| 8.19. | Percentage of small, medium and large diameter vessels contributing to the estimated secondary xylem conductance in fruit with different seed numbers. | 220 |
| 8.20. | Concentrations of Ca, Mg, K and P in relation to estimated secondary xylem conductance in fruit stalks.  | 220 |

|       |   |     |
|-------|---|-----|
| 8.21. | Diagrammatic representation of the proposed effects of TIBA on Ca and DM concentrations in kiwifruit. | 222 |
| 8.22. | Proposed rate of DW increase in fruit with low and high cell numbers.                                 | 225 |

### **Chapter 9:**

|      |   |     |
|------|---|-----|
| 9.1. | Cages used to contain the spittlebugs whilst feeding on kiwifruit fruit stalks and leaves.          | 233 |
| 9.2. | Rate of excreta sap production throughout the day.  | 237 |
| 9.3. | Seasonal changes in the volume of excreta sap produced per insect per day.                          | 238 |
| 9.4. | Relationship between Ca, Mg and K concentrations in the xylem sap.                                  | 239 |
| 9.5. | Seasonal changes in excreta sap mineral ion concentrations.   | 240 |
| 9.6. | Mean ratio of excreta sap ion concentrations verses that in the corresponding calibration solution. | 242 |

### **Chapter 10:**

|       |   |     |
|-------|---|-----|
| 10.1. | Diagrammatic representation of the factors that may affect carbohydrate, mineral and water accumulation in 'Hayward' kiwifruit. | 251 |
|-------|---|-----|

## List of Tables

### Chapter 1:

|      |  |    |
|------|--|----|
| 1.1. | Concentration of soluble and insoluble carbohydrates in kiwifruit.   | 3  |
| 1.2. | Incidence of storage disorders in 'Hayward' kiwifruit from six different growing regions after 24 weeks storage at 0°C.              | 5  |
| 1.3. | Average fruit mineral and DM concentrations in 'Hayward' kiwifruit from six different growing regions after 24 weeks storage at 0°C. | 8  |
| 1.4. | Vine characteristics affected by different orchard management strategies.  | 9  |
| 1.5. | Cell types of the secondary xylem of kiwifruit.  | 37 |
| 1.6. | Cell types of the secondary phloem of kiwifruit.   | 39 |

### Chapter 3:

|      |   |    |
|------|---|----|
| 3.1. | Canopy light transmission in the leader and fruiting zones of leader and conventionally pruned (LP and CP) vines. | 73 |
| 3.2. | Canopy openness and leaf area index in LP and CP vines.   | 73 |
| 3.3. | Fresh weight of fruit from the leader and fruiting zones of LP and CP vines.                                      | 75 |
| 3.4. | DMC in fruit from the leader and fruiting zones of LP and CP vines.   | 76 |
| 3.5. | Ripe soluble solids content of fruit from the leader and fruiting zones of LP and CP vines.                       | 81 |
| 3.6. | Firmness of fruit from three different count sizes, from LP and CP vines after 26 weeks in storage at 0°C.        | 82 |
| 3.7. | Storage disorder incidence in fruit from three different count sizes from LP and CP vines.                        | 83 |
| 3.8. | Attributes of LP and CP vines.  | 85 |

### Chapter 4:

|      |  |     |
|------|--|-----|
| 4.1. | Attributes of leaves, fruit stalks and fruit on long, non-terminating (long) and short terminating (short) shoots. | 101 |
|------|--|-----|



## Chapter 5:

- 5.1. Several quality attributes of fruit from long and short axillary kiwifruit shoots, as measured on 19 December 2001, following shoot defoliation or girdling on 24 November 2001. 132
- 5.2. Several quality attributes of fruit from long and short axillary kiwifruit shoots, as measured on 25 January 2002, following shoot defoliation on 24 November 2001 and 5 January 2002, or shoot girdling on 24 November 2002. 134
- 5.3. Several quality attributes of fruit from long and short axillary kiwifruit shoots, as measured on 25 April 2002, following shoot defoliation on 24 November 2001 and 5 January 2002, or shoot girdling on 24 November 2002 and 1 February 2002. 135

## Chapter 6:

- 6.1. Attributes of kiwifruit from long and short axillary shoots harvested 46 days after full bloom (DAFB) following the application of control, fan and bag treatments at petal fall. 157
- 6.2. Attributes of fruit stalks from fruit on long and short axillary shoots harvested 46 DAFB following the application of control, fan and bag treatments at petal fall. 158
- 6.3. Attributes of kiwifruit from long and short axillary shoots harvested 144 DAFB following the application of control, fan and bag treatments at petal fall. 159
- 6.4. Attributes of fruit stalks from fruit on long and short axillary shoots harvested 144 DAFB following the application of control, fan and bag treatments at petal fall. 160

## Chapter 7:

- 7.1. Percentage of small, medium and large secondary xylem vessels and their contribution to the total estimated secondary xylem conductance in fruit stalks from long and short shoots. 177

## Chapter 8:

- 8.1. Several fruit quality attributes, measured on 7 January 2003, following application of TIBA, at 50 and 100 mg L<sup>-1</sup> on 5 December 2002, 8 DAFB. 198

|      |  |     |
|------|--|-----|
| 8.2. | Several fruit quality attributes, measured on 5 May 2003, following application of TIBA, at 50 and 100 mg L <sup>-1</sup> on 5 December 2002, 8 DAFB.                            | 199 |
| 8.3. | Several fruit quality attributes, measured on 14 January 2003, following TIBA application to fruit on girdled, defoliated or control (untreated) long and short axillary shoots. | 209 |
| 8.4. | Several fruit quality attributes, measured on 30 April 2003, following TIBA application to fruit on girdled, defoliated or control long and short axillary shoots.               | 212 |
| 8.5. | Xylem functionality and corresponding fruit fresh weights in untreated and TIBA-treated fruit from long and short control, defoliated or girdled shoots.                         | 215 |
| 8.6. | Postharvest attributes of untreated and TIBA-treated fruit from long and short control, defoliated and girdled axillary shoots, as measured after 24 weeks in storage at 0°C.    | 216 |

### **Chapter 9:**

|      |  |     |
|------|--|-----|
| 9.1. | Attributes of long and short axillary shoots.      | 241 |
| 9.2. | Mineral concentration gradient in sap down a cane. | 242 |

### **Chapter 10:**

|       |  |     |
|-------|--|-----|
| 10.1. | Evidence that auxin may indirectly affect carbohydrate and Ca accumulation in kiwifruit by regulating vascular differentiation in flower/ fruit stalks and/or fruit cell division. | 254 |
|-------|--|-----|

## List of Abbreviations

|       |                                       |
|-------|---------------------------------------|
| ABA   | abscisic acid                         |
| ANOVA | analysis of variance                  |
| AuG   | autumn girdling                       |
| $a_w$ | water activity                        |
| BER   | blossom end rot                       |
| CME   | chloroflurenolmethylester             |
| CP    | conventionally-pruned                 |
| CPPU  | N1-(2-chloro-4-pyridyl)-N3-phenylurea |
| CSA   | cross-sectional area                  |
| DAFB  | days after full bloom                 |
| DM    | dry matter                            |
| DMC   | dry matter concentration              |
| DPFB  | days prior to full bloom              |
| DW    | dry weight                            |
| FB    | full bloom                            |
| FW    | fresh weight                          |
| FZ    | fruiting zone                         |
| GLA   | gap light analyser                    |
| GLM   | general linear model                  |
| Gs    | stomatal conductance                  |
| HP    | high crop load, pruned (vines)        |
| HUP   | high crop load, unpruned (vines)      |
| IAA   | indole-3-acetic acid                  |
| $K_h$ | hydraulic conductivity                |
| LAI   | leaf area index                       |
| L:F   | leaf: fruit (ratio)                   |
| LP    | leader-pruned                         |
| LSD   | least significant difference          |
| LTB   | low temperature breakdown             |
| LUP   | low crop load, unpruned (vines)       |
| LwP   | low crop load, pruned (vines)         |
| LZ    | leader zone                           |
| NAA   | naphthalene acetic acid               |
| NPA   | 1-N-naphthylphthalamic acid           |
| NPQ   | non-photochemical quenching           |

|      |   |
|------|---|
| PAR  | photosynthetically active radiation       |
| PC   | personal computer                         |
| PGR  | plant growth regulator                    |
| PIX  | 1,1-dimethyl-piperidinium                 |
| Pn   | Net photosynthesis                        |
| RH   | relative humidity                         |
| rSSC | ripe soluble solids concentration         |
| SA   | surface area                              |
| SB   | short-base (proximal cane end)            |
| SE   | short-end (distal cane end)               |
| SLW  | specific leaf weight                      |
| SmD  | summer defoliation                        |
| SpD  | spring defoliation                        |
| SpG  | spring girdling                           |
| SSC  | soluble solids content                    |
| TIBA | 2,3,5-triiodobenzoic acid                 |
| VMC  | ventromedian carpellary (vascular bundle) |
| VPD  | vapour pressure deficit                   |
| WAFB | weeks after full bloom                    |