

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.

**STUDIES OF THE FACTORS AFFECTING THE
YIELD AND QUALITY OF SINGLE TRUSS TOMATOES**

Lynette Stella Morgan

1996

**A thesis presented in partial
fulfilment of the requirements
for the degree
of Doctorate of Philosophy in
Horticultural Science at
Massey University**

ABSTRACT

This research was conducted to evaluate the potential of the single truss system of tomato production to produce high yields of quality fruit under New Zealand conditions. The NFT hydroponic system was used to grow the plants so that nutrient solution conductivity could be maintained close to predetermined levels.

In the first experiment three cultivars were compared. At the time of fruit set of the first truss four conductivity treatments (2, 4, 6 and 8 mS cm⁻¹) were applied. Yield and fruit quality data was obtained from each of six crops over an 18 month period. Yield (fruit size) decreased with increasing conductivity for all three cultivars. Season also had a significant effect on yield, with an April harvested crop having the highest yield. Both fruit brix and titratable acidity were increased at the higher conductivity levels. There were also cultivar and seasonal differences in fruit quality, with the cherry cultivar 'Cherita' consistently producing the highest brix and titratable acidity levels. Brix levels were found to be low in the December harvested crop, while acidity was highest in the December, April and July harvested crops. Season, solution conductivity and cultivar influenced plant leaf area and leaf area index. Solution conductivity also effected foliar mineral levels, as did cultivar.

Three successive multi truss crops were grown in a pumice media system to provide fruit quality data for sensory evaluation and comparison with single truss and commercial compositional fruit quality. The same three cultivars as were compared in the single truss crop experiment were grown at three conductivity levels (2, 4 and 6 mS cm⁻¹) applied at the time of fruit set of the first truss. Fruit samples were taken from the 5th and 6th trusses for quality evaluation. Season and solution conductivity had an effect on fruit dry matter percentage and brix. Fruit shelf life was affected by season, conductivity and cultivar, with a longer shelf life obtained from fruit grown at the higher conductivity levels. The December harvested crop had the lowest overall shelf life. Fruit firmness was only affected by solution conductivity, with the fruit from the higher

conductivity treatments being firmest. Sensory evaluation of Rondello fruit on three separate occasions showed that the higher conductivity treatment scored highest for most attributes, and that these sensory scores correlated well with brix and titratable acidity levels.

A second single truss crop experiment focused on manipulation of the source/sink relationship (fruit and leaf number combinations) of three successional crops and the effect of spring and winter CO₂ enrichment on two of the three crops. The summer crop also evaluated the effect of crop shading and source/sink relationship on fruit yield, as high fruit temperatures were suspected to have reduced yield in the previous summer single truss crops. Yield and fruit quality data was collected from all three crops, along with fruit and environmental temperature recordings from the summer crop. It was found that season and fruit number effected yield, with the 8 fruit per plant treatment resulting in the greatest yield. Leaf number (either 2 or 3) and season affected fruit dry matter percentage, brix and leaf area, while fruit number influenced brix levels. CO₂ enrichment (1000 ppm) had no effect on either spring or winter fruit yield, but did advance crop maturity allowing an extra crop per year to be produced. Thus yearly yield was increased by CO₂ enrichment. CO₂ enrichment improved fruit quality in the spring crop, but had no effect on the winter crop. Shading of the summer crop resulted in an increase of 10% in total fruit yield and 19% in marketable fruit yield, due to the presence of smaller fruit and heat induced ripening disorders in the unshaded crop. Both leaf number and shading treatments affected titratable acidity, with unshaded fruit having greater percent citric acid levels. Shelf life and fruit firmness was greater in the shaded crop. Air, canopy and fruit temperatures were reduced under shade, with exposed fruit often reaching extreme temperatures (above 40°C).

Having established that leaf and fruit temperatures were reaching extreme levels during the summer in a single truss cropping situation, the effect of these temperatures on photosynthesis and fruit respiration was examined. The effect of leaf age on photosynthesis was also examined as single truss plants do not continue to produce young foliage to maintain photosynthesis levels. After harvest, net photosynthesis and the light compensation point, which had been increasing began to fall rapidly at all light

levels. It was found that after an initial drop as leaves matured, leaf age did not effect net photosynthesis. Plants exposed to 800 PAR showed maximum net photosynthesis at temperatures between 25 - 27°C. Net photosynthesis ceased at 43°C.

Fruit truss respiration rates were determined at 4 temperatures (25, 30, 35 and 40°C), on 3 occasions (18, 26, 36 and 40 days after fruit set). 5 different tissue sample combinations were assessed comprising, the whole truss with sealed and unsealed cut surfaces, fruit only with sealed and unsealed calyx scar and calyx, peduncles and plant stem only. It was found that temperature, truss portion assessed and stage of fruit maturity all affect fruit respiration rate, with the fruit only (calyx scar unsealed) resulting in the greatest CO₂ efflux. It was concluded that while the fruit epidermis is relatively impermeable to gas escape, the main route for CO₂ is through the calyx scar. Mature green fruit had the greatest response of increased CO₂ production with increasing temperature, while temperatures above 25°C disrupted the climacteric pattern of CO₂ evolution. It was concluded that in single truss plants, when temperatures were above 30°C, net photosynthesis is reduced, while fruit respiration begins to increase rapidly, both responses having a detrimental effect on yield.

The single truss system was shown to produce yields and fruit quality equal to those of good multi truss commercial tomato producers in New Zealand. This was achieved by CO₂ enrichment for crop advancement and summer crop shading, while moderate levels of solution conductivity produced good quality fruit. However, there is the possibility of further improving these yields by utilisation of other technologies such as a movable bench system and manipulation of plant density, timing of conductivity application, and different cultivars. The potential of this system for high quality, high yielding tomato fruit production warrants commercial evaluation.

ACKNOWLEDGEMENTS

I would like to thank the following people for their support, input and encouragement during the research and preparation of this thesis:

my supervisors Dr Keith Fisher and Dr Mike Nichols for their guidance and patience, their sharing of knowledge and never ending supply of ideas.

Professor Errol Hewitt, Dr Nigel Banks, Chris Rawlingson and Suzie Newman for their advice, interest and assistance with the postharvest component of this research.

Dr David Woolley for his input into the design of the photosynthesis and respiration experimentation and subsequent discussion.

the staff of the Plant Growth Unit, particularly Bryan Sturgess, Ray Johnstone and Charlie Forbes who provided valuable assistance with the NFT systems, growth cabinets, respiration chambers, greenhouse environment and who always managed to fix those things that broke down.

my panel of trained tomato tasters and all those staff and students who participated in numerous panel selections, whose enthusiasm and interest was greatly valued.

the Packhouse association of NZ (PANZ) who provided industry information and commercial fruit samples for quality assessment.

the Vice Chancellors study grant fund, C Alma Baker trust and the Helen Alkers trust whose financial support was greatly appreciated.

the staff and students of the Plant Science department for their interest, support and friendship during the last 4 years.

my parents, Pam and Keith Morgan for their encouragement, financial support, and insistence that I get a higher education.

my husband Simon for his technical assistance, emotional support, hours of proof reading and for not ever letting me give up.

CONTENTS	PAGE
ABSTRACT	ii
ACKNOWLEDGEMENTS	v
CONTENTS	vi
LIST OF TABLES	xx
LIST OF FIGURES	xxv
LIST OF PLATES	xxvix
INTRODUCTION	xxvxx
1 REVIEW OF LITERATURE	1
1.1 Tomato production	1
1.1.1 Introduction	1
1.1.2 New Zealand greenhouse tomato industry	1
1.2 Physiology of the tomato crop	2
1.2.1 Growth form	2
1.2.2 Nutrient uptake	3
1.2.3 Distribution of nutrients	5
1.2.4 Flowering	5
1.2.5 Pollination	8
1.3 Photosynthesis	9
1.3.1 Introduction	9
1.3.2 Effect of radiation levels	9
1.3.3 Light compensation point and saturation levels	10
1.3.4 Effect of leaf age on crop photosynthesis	13
1.3.5 Effect and availability of CO ₂	14
1.3.6 CO ₂ fixation and carbohydrate translocation	16
1.4 Temperature	17
1.4.1 Effects of temperature on tomato crop photosynthesis	17
1.4.2 The effect of solution temperature on tomato plant growth and development	18

2.3.2.2	Effect of solution conductivity on fruit firmness	...91
2.3.3	Effect of planting date and solution conductivity on sensory evaluation	...92
2.3.3.1	Introduction	...92
2.3.3.2	Effect of planting date and solution conductivity on sensory evaluation	...92
2.3.3.3	Correlation between analytical compositional analysis and sensory evaluation scores	...94
2.3.4	Effect of solution conductivity on leaf mineral levels	...95
2.4	Discussion	...97
2.4.1	Effect of planting date, solution conductivity and cultivar on fruit quality	...97
2.4.1.1	Effect of planting date on compositional quality	...97
2.4.1.2	Effect of solution conductivity on compositional fruit quality	...97
2.4.1.3	Effect of cultivar on compositional fruit quality	...98
2.4.2	Effect of planting date, solution conductivity and cultivar on fruit shelf life and firmness	...98
2.4.2.1	Effect of solution conductivity on fruit shelf life and firmness	...98
2.4.2.2	Effect of planting date and cultivar on shelf life	...99
2.4.3	Effect of planting date and solution conductivity on fruit sensory evaluation	...99
2.4.4	Effect of solution conductivity on foliar mineral levels	...101
3	THE EFFECT OF SEASON, SOLUTION CONDUCTIVITY AND CULTIVAR ON THE YIELD AND QUALITY OF SINGLE TRUSS TOMATO CROPS	...103
3.1	Introduction	...103

3.3.2.2	Titrateable acidity	...	...	...	...	...	...	...	119
3.3.2.2.1	Effect of season and conductivity on fruit titrateable acidity levels								119
3.3.2.2.2	Effect of season and cultivar on fruit titrateable acidity levels								120
3.3.3	Effect of season, solution conductivity and cultivar on leaf growth	...	...	...	...	...	...	...	121
3.3.3.1	Leaf area and leaf area index				...	...			121
3.3.3.1.1	Effect of solution conductivity on leaf area and leaf area index								121
3.3.3.1.2	Effect of season and cultivar on leaf area and leaf area index								123
3.3.4	Effect of season, solution conductivity and cultivar on leaf mineral levels	...	...	...	...	...	...	...	124
3.4	Discussion	...	...	...	...	...	...	...	127
3.4.1	Yield, size and number of fruit				...	...	...		127
3.4.1.1	Effect of season and cultivar on yield, size and number of fruit				...	...	...		127
3.4.1.1.1	Effect of season and cultivar on fruit yield				...	...	...		127
3.4.1.1.2	Effect of season and cultivar on fruit size				...	...	...		129
3.4.1.1.3	Effect of season and cultivar on fruit number				...	...	...		129
3.4.1.2	Effect of solution conductivity on yield, size and number of fruit				...	...	...		130
3.4.1.2.1	Effect of solution conductivity on fruit yield				...	...	...		130
3.4.1.2.2	Effect of solution conductivity on fruit size				...	...	...		131

	4.2.2.2	Source sink strengths	...	...	...	...	142
	4.2.2.3	Carbon dioxide enrichment	...	...	...	...	142
	4.2.2.4	Crop shading	...	...	...	...	143
	4.2.2.5	Greenhouse compartments	...	...	...	...	143
	4.2.3	Experimental design	...	...	...	...	143
	4.2.4	Data collection	...	...	...	...	143
	4.2.4.1	Yield and fruit quality	...	...	...	...	143
	4.2.4.2	Plant measurements	...	...	...	...	144
	4.2.4.3	Temperature measurements	...	...	...	...	144
	4.2.5	Data analysis	...	...	...	...	145
4.3	Results	...	...	...	...	...	146
	4.3.1	Introduction	...	...	...	...	146
	4.3.2	Effect of season and source/sink treatment on the performance of the spring, summer and winter crops					146
	4.3.2.1	Effect of season and source/sink treatment on yield and fruit size	...	...	...	...	146
	4.3.2.2	Effect of season and source/sink treatment on fruit quality	...	...	...	...	148
	4.3.2.3	Effect of season and source/sink treatment on leaf area (cm ²) and leaf area index	...	...	...	...	149
	4.3.3	Effect of season, CO ₂ enrichment and source/sink treatment on the performance of the spring and winter crops					150
	4.3.3.1	Introduction	...	...	...	...	150
	4.3.3.2	Effect of season and CO ₂ enrichment on fruit yield	...	...	...	...	150
	4.3.3.3	Effect of season, CO ₂ enrichment and source sink treatment on fruit quality	...	...	...	...	151
	4.3.3.4	Effect of season, CO ₂ enrichment and source sink treatment on plant leaf area and leaf area index	...	...	...	...	155
	4.3.3.5	Effect of CO ₂ on crop timing	...	...	...	...	157

				5.2.3.1.4	Fruit respiration experiments	...	178
5.3	Results	...	...	...	...	...	182
5.3.1	Photosynthesis experiments	...	...	...	...	...	182
	5.3.1.1	The effect of leaf age and light intensity on					
		net photosynthesis	...	...	...	...	182
	5.3.1.2	Effect of leaf temperature on net photosynthesis					183
5.3.2	Fruit truss respiration experiments	...	...	...	...	...	184
	5.3.2.1	Introduction	...	...	...	...	184
	5.3.2.2	Fruit truss respiration during fruit development					184
	5.3.2.3	Effect of fruit maturity and temperature on					
		respiration rate	...	...	...	...	187
	5.3.2.4	Effect of temperature on leaf net photosynthesis					
		and fruit truss respiration	...	...	...	...	188
5.4	Discussion	...	...	...	...	...	190
5.4.1	Photosynthesis experiments	...	...	...	...	...	190
	5.4.1.1	Effect of leaf age and light intensity on					
		net photosynthesis	...	...	...	...	190
	5.4.1.2	Effect of leaf temperature on net photosynthesis					194
5.4.2	Respiration experiments	...	...	...	...	...	195
	5.4.2.1	Effect of temperature on fruit truss					
		respiration rates	...	...	...	...	195
	5.4.2.2	Effect of truss portion on respiration rate	...				196
	5.4.2.3	Effect of fruit maturity and temperature on					
		mature tomato fruit respiration	...	...			198
	5.4.2.4	Effect of temperature on photosynthesis,					
		respiration and final fruit size	...	...			199

Table 4.2	The effect of season and source/sink treatment on yield, fruit size, percentage dry matter, brix, percent citric acid and leaf area	...147
Table 4.3	Effect of season and fruit number on yield (g/plant) and fruit size (g/plant)	...148
Table 4.4	Effect of leaf and fruit number on fruit percentage dry matter and brix levels	...149
Table 4.5	Effect of season and leaf number on leaf area (cm ²) and leaf area index	...150
Table 4.6	Effect of CO ₂ enrichment on spring and winter yield and fruit size.	151
Table 4.7	Effect of season, CO ₂ enrichment and source/sink treatment on spring and winter crops	...152
Table 4.8	Effect of season, fruit number and CO ₂ enrichment on fruit percentage dry matter	...153
Table 4.9	Effect of season, CO ₂ enrichment and source/sink treatment on fruit brix levels and titratable acidity expressed as percent citric acid	...154
Table 4.10	Effect of season, source/sink treatment and CO ₂ enrichment on plant leaf area (cm ²) and leaf area index	...156
Table 4.11	Effect of CO ₂ on crop timing (days)	...157
Table 4.12	Effect of source/sink treatment on crops shading on the summer crop	...158

Table 4.13	Effect of crop shading on total and marketable crop yields and fruit size ... ..	...158
Table 4.14	Effect of shading, leaf and fruit number on percent citric acid	...159
Table 4.15	Effect of shading on fruit shelf life (days) ... ..	...159
Table 4.16	Effect of shading and leaf number on leaf area (cm ²) and leaf area index ... ..	...160
Table 5.1	Plant developmental stages ... ..	...176
Table 5.2	Photosynthesis x temperature treatments - 10 weeks after sowing...	177
Table 5.3	Respiration treatments ... ..	...177
Table 5.4	Fruit respiration determinations ... ..	...181
Table 5.5	Effect of temperature, fruit truss portion, date of assessment and fruit colour (for the final assessment) on fruit truss respiration rates	...184
Table 6.1	Crop timing - number of days from planting to crop removal	...203
Table 6.2	Highest yields obtained at a density of 13.5 plants/m ² (cultivar Rondello) ... ..	...205
Table 6.3	Expected yearly yields utilising different percentage growing areas.	205
Table 6.4	Comparison of single truss and commercial fruit sample quality	...206

Table 6.5	Effect of conductivity on yield, brix and percent citric acid levels in single truss crops	...	...	...	...	...	...	...207
Table A1.1	Bark additives - Seed Germination Media	...	...	...	...	...	...	...238
Table A2.1	Bark additives - Growing on Media	...	...	...	...	...	...	...239
Table A3.1	NFT stock solution	...	...	...	...	...	...	...240
Table A4.1	Commercially produced packhouse fruit quality ranges	...	...	...	...	...	...	...246

LIST OF FIGURES

	PAGE
Figure 2.1 Taste panel score sheet ... ..	...83
Figure 2.2 Effect of planting date on fruit dry matter percentage ...	...86
Figure 2.3 Effect of solution conductivity on fruit dry matter percentage	...86
Figure 2.4 Effect of cultivar on fruit dry matter percentage ... ..	...87
Figure 2.5 Effect of planting date and conductivity on fruit brix levels	...87
Figure 2.6 Effect of planting date and cultivar on fruit brix ... ..	...88
Figure 2.7 Effect of cultivar on fruit titratable acidity levels (% citric acid)	...89
Figure 2.8 Effect of planting date and conductivity on fruit shelf life	...90
Figure 2.9 Effect of planting date and cultivar on shelf life ... ..	...91
Figure 2.10 Effect of solution conductivity on Rondello fruit firmness (March harvest only) ... ..	...91
Figure 2.11 Effect of solution conductivity on fruit sensory evaluation scores for the October (a), December (b) and March (c) harvested crops	...93
Figure 2.12 Correlation between the effects of solution conductivity on brix levels and sweetness sensory evaluation scores ... ..	...94
Figure 2.13 Correlation between the effect of solution conductivity on fruit titratable acidity levels (% citric acid) and acidity sensory evaluation score	...95

Figure 2.14	Effect of solution conductivity on foliar N (a), K (b) and Ca (c) levels ... ..	...96
Figure 3.1	Example of an NFT bench ... ..	...106
Figure 3.2	Effect of season, conductivity and cultivar on yield (g/plant) ...	...112
Figure 3.3	Effect of solution conductivity on yield (mean of 3 cultivars and 6 plantings) ... ..	...114
Figure 3.4	Effect of solution conductivity on fruit size (mean of 3 cultivars and 6 plantings) ... ..	...114
Figure 3.5	Effect of season on yield for the cultivars Rondello, Ophir and Cherita ... ..	...115
Figure 3.6	Effect of season on fruit number for the cultivars Rondello, Ophir and Cherita ... ..	...116
Figure 3.7	Effect of season on fruit size for three cultivars ... ..	...117
Figure 3.8	Effect of season on brix levels for the cultivars Rondello, Ophir and Cherita ... ..	...118
Figure 3.9	Effect of solution conductivity on fruit brix levels ... ..	...119
Figure 3.10	Effect of season on leaf area for all cultivars ... ..	...123
Figure 3.11	Effect of solution conductivity on foliar N levels (5 planting dates averaged with the July crop presented separately) ... ..	...124

Figure 3.12	Effect of solution conductivity on foliar P levels (5 planting dates averaged with the July crop presented separately) ... ..	...125
Figure 3.13	Effect of solution conductivity on foliar K levels (5 planting dates averaged with the July crop presented separately) ... ..	...125
Figure 3.14	Effect of solution conductivity on foliar Ca levels (5 planting dates averaged with the July crop presented separately) ... ..	...126
Figure 3.15	Cultivar differences in foliar N, P, K, Ca and Mg levels ... ..	...126
Figure 4.1	Example of a bench layout ... ..	...144
Figure 4.2	Air temperature of unshaded and shaded crops ... ..	...160
Figure 4.3	Canopy temperature of unshaded and shaded crops ... ..	...161
Figure 4.4	Fruit skin and air temperature of unshaded and shaded crops ... ..	...161
Figure 4.5	Temperature of exposed surface, fruit centre and shaded surface of an exposed fruit on a day with high solar radiation ... ..	...162
Figure 4.6	Temperature on exposed surface, fruit centre and shaded surface of an exposed fruit on a day with low solar radiation ... ..	...162
Figure 5.1	Respiration chamber ... ..	...179
Figure 5.2	Diagram of truss, stalk and portion of plant stem which was severed from each plant and placed in the fruit respiration chamber ... ..	...180

LIST OF PLATES

				PAGE
Plate 3.1	Seedlings 1 day after planting into the NFT gullies	...		...105
Plate 3.2	Single truss crop at the 50% fruit set stage	...	...	...105
Plate 3.3	Single truss crop showing bench system and nutrient lines			...108
Plate 3.4	Plants at the time of conductivity treatment application	...		...108
Plate 4.1	Seedlings 1 day after planting into the NFT system (CO ₂ enriched crop)	...	... ..	...141
Plate 4.2	Source sink treatment fruit nearing maturity (CO ₂ enriched crop)	...	... ..	...141