Final Report

Increasing productivity and extending seasonality in soil grown vegetables using capsicum as a candidate

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Summary

Two long term productivity trials were established at the DAF Gatton research Facility over the course of this project. The trials investigated the value of rootstocks, varieties, ratooning and shading. A formal literature review of plant material, production techniques and technological advances in capsicum and chilli was undertaken as a first step in determining the project work program.

In trial number one at Gatton, all five graft treatments were based on the commercial variety Warlock as the scion. The rootstock treatments evaluated were; Warlock self-grafted (to evaluate grafting impact), non-grafted Warlock, a commercial chilli line Caysan known for its resilience under a range of conditions, a newly released commercial capsicum rootstock Capsifort and Wild Malay Eggplant (WME). Three other varieties, a new variety SV6947 and two older heirloom lines were included in planting 1. The new Monsanto variety SV6947 produced the highest total marketable yield – though this yield was only significantly higher than the chilli graft (Caysan) and the two older varieties, Yolo Wonder and Green Giant. The new variety SV6947 displayed a beneficial, more uniform flowering and fruit position pattern within the plant.

Following harvest, all plants were cut back by hand (May 2014) and ratoon crop regrowth was assessed. Regrowth was equal across all treatments however the cold weather resulted in both small plant and fruit size. Marketable yield of the May ratooned crop was poor. Timing was the issue the ratooning treatment should have been delayed until mid-July, allowing the ratoon crop to grow into the warm spring. Root health of all graft and variety treatments was assessed 482 days after initial planting. Analysis of root dry weight revealed that new crop Warlock had the healthiest root system, while grafted Warlock had a healthier root system than the commercial rootstock and new variety SV6947. Standard Warlock and grafted chilli had a similar root health rating to grafted Warlock. The chilli graft reduced canopy height and increased density but did not reduce fruit sunburn. Sunburn is a major cause of marketable fruit and income loss. Crop 3 grown through the November 2014 period had a mean fruit sunburn incidence of 34%. Local commercial growers experienced severe production losses with 40 to 60% of marketable yield lost to sunburn in the November / December harvest period of 2014. Trial number 2 at Gatton in October 2015 evaluated 3 different graft combinations, one older variety and another new capsicum variety. Crop 5 data showed Plato, new line SV9699, SV6947 (scion) grafted to Warlock and Warlock grafted to Hungarian Hot Wax to be the highest yielding treatments. This crop was mechanically cut back in February 2016 and a sixth crop harvested in May 2016. Planting 2 was grown under a cheap prototype protective net cover. This reduced summer sunburn levels from the 34% in crop 3 to around 4% in crop 5. Fruit quality under the protective net was exceptional with one local capsicum grower who visited the trial area commenting that fruit being harvested was similar to glass house quality. This was a result of slightly increased humidity in a hot dry growing environment and an average temperature reduction of 4^{o}C between 1 and 3 pm recorded under the protective net. Capsicum fruit harvested from under the net were shiny with smooth skin and looked as though they had been polished.

A third trial was establisedat Bowen compared the same treatments utilised in planting 1 at Gatton in a conventional (intensive) tillage and permanent bed system. Data though not conclusive showed a trend to improved production under conventional tillage. Yield in the intensive tillage blocks revealed no significant differences between treatments though SV6947 tended to produce a higher number of slightly smaller medium marketable fruit. The Giru protected cropping observation planting cannot be analysed, though the fruit quality of all treatments, was very good, new variety SV6947 tended to pick more uniformly and for longer than the other material.

Grafting treatments had no adverse effect on plant stem diameter or flowering pattern. The commercially available rootstock Capsifort grafted to Warlock, self-grafted Warlock and the chilli (Caysan) grafted to Warlock produced similar marketable yield to Warlock. The chilli graft altered plant architecture (reduced canopy height with a more dense plant canopy). The new variety SV6947 produced more marketable fruit and a slightly higher total fruit weight than Warlock – though this difference was not statistically significant. Planting 2 revealed the chilli (inferno) graft reduced Warlock plant height significantly but also reduced yield. Hungarian Hot Wax (chilli graft) yielded as well as Warlock, exhibited considerably less root scarring and had similar dry root weight to Warlock. Plato the new variety SV9699 and SV6947 (grafted to Warlock roots) yielded best.

The protective net utilised in trial 2, increased marketable yield by 30% when compared to planting 1 yield. This was a direct result of reduced fruit sunburn. Fruit quality of all treatments in planting 2 at Gatton under the protective net was vastly superior to previous crops. Fruit gloss quality and lustre rivalled glasshouse quality product

Keywords

Capsicum, grafting, rootstocks, productivity, root health, capsicum varieties, chilli, hail net, protective cover.

Introduction

Australian capsicum production is concentrated in Queensland, accounting for around 80% of national value according to publically available statistics. The latest Queensland Government AgTrends Update (April 2015), reported that the value of capsicums and chilli grown in Queensland was $153 million dollars (Ref; https://publications.qld.gov.au/dataset/f3dc0525-a23a-4486-8841-f8b16743895a/resource/d9ecec3b-1f6d-45a7-952e-cb33a12c7c59/download/agtrends2015.pdf). Capsicums and chilli are grown year round in Queensland with production centred in the Bowen, and Bundaberg regions in the winter and the Lockyer Valley and Stanthorpe regions in the summer.

Production, crop establishment and harvesting costs are high and increasing, forcing growers to seek efficiencies and productivity gains. Growers are becoming more specialized with only high quality product accepted by the markets. A literature review of current world capsicum research findings and trends was completed in September 2013. This document provided direction and insight that informed the projects future work focus. Multinational seed companies market dominant hybridised plant material coupled with the decline in publicly funded selection and breeding worldwide over the last ten to fifteen years, somewhat limits avenues for industry lead variety and breeding research. Two areas identified as worth further investigation were plant grafting and ratooning. Grafting was identified in the literature as an alternate method of improving plant performance, resilience and disease resistance. Ratooning has potential to increase plant yield by providing the opportunity to harvest a second crop from an existing planting – maximizing use of and return from existing plants and infrastructure. There is little published Australian information available on either grafting or ratooning capsicum plants under Australian conditions. This project evaluated several new capsicum varieties, some older historic material and a number of unique grafted rootstock combinations. Commercially available rootstock material was evaluated along with four chilli lines trialed as rootstocks and several novel rootstocks – Kangaroo Apple and Wild Malay Eggplant.

The number of commercial capsicum growers operating in the Locker Valley has declined markedly over the last 10 years. There are a number of reasons for this decline but one major driver has been the impact of increasing summer maximum temperatures. Growers in all production regions report that sunburn damage accounts for a large percentage of their marketable yield loss.

Performance of the grafted material was also evaluated in Bowen as an observation trial in a protective cropping structure in Giru.

Methodology

Trial Design

The two long term Gatton trials (planting 1 January 2014 and planting 2 October 2015) each treatment had four replicates of each trial treatment arranged in a randomised complete block design. The outer bed on either side of the four treatment beds was a buffer row, and a 5 meter buffer was included at either end of the four treatment beds. Individual treatment plantings were 5 m long double rows with 30 plants per plot - the centre 20 plants of each treatment plot contained the buffer rows. Refer to Appendix 3 for trial plans of the two Gatton and one Bowen field trials. Due to the planned long term nature of the Gatton trial work – custom made thick plastic film (40 micron instead of the usual 18 micron) was sourced and used when setting up beds for the trial. This silver reflective plastic film was chosen as a means of minimising aphid and sucking pest activity (and potential virus transmission) during the plant establishment phase of the cropping cycle. The irrigation system for both plantings was a set up using Netafim® thick wall, high quality pressure compensating drip line designed for long term crops. Irrigation frequency was determined using two sets of tensiometers at either end of the cropped area. Each tensiometer set consisted of a shallow (20cm) and a deep (35 cm) sampling depth. Irrigation was applied to ensure plant stress was minimized throughout the cropping cycle, with water applied when the shallow tensiometer recorded a root suction reading between 20 and 45 kPa. Irrigation was automated but checked daily.

The Bowen field trial design was a randomised block design with six capsicum productivity treatments replicated 3 times, thirty plants per treatment with the 20 plants in the centre of each plot use as datum plants. The trial treatments were planted within two main tillage systems: 1/ a permanent bed system with beds that were formed once (in 2011), with a buried drip irrigation tape that had not had a complete soil disturbance since 2011. The minimal soil disturbance in the permanent bed system was produced by zone tillage with a pair of wavy discs. Beds were covered with a black biodegradable film mulch (Mater-Bi Novamont®) and 2/ an intensive tillage system, where planting beds had been formed every year after multiple soil tillage operations and with annual use and disposal of polyethylene drip irrigation tape and polyethylene film mulch. Irrigation was applied according to plant need and weather conditions and assessed daily.

Nutrition

Nutrition and plant protection practices in the Gatton trials were based on local industry best practice. The same nutrition regime was utilized for all plantings and crops grown on the Gatton site. This balanced weekly fertigation program delivered 200 units of nitrogen, 24 units of phosphorous and 240 units of potassium per hectare as well as a balanced prescriptive application of micronutrients over the cropping period of each crop. When cut back a maintenance nutrition program was applied until such time as the ratoon plants had recovered, reshot, begun to regrow – when again they were treated as a growing crop.

The Bowen crop was grown according to local nutrition practices as advised by a local researcher. The standard tillage and permanent bed systems both received a total of 125 Kg/ha of nitrogen in total as part of a balanced nutrition program. (Nutrition detail program for Gatton in appendix 4)

Pest & Disease Management

Trial areas were monitored weekly and crop protection products applied as required in accordance with local industry best practice and weather events. Bacterial leaf spot was not an issue in the Bowen trial and surprisingly caused very little damage in the Gatton trials – even planting 1 which was cut back twice, produced 4 separate crops and was in ground for a total of 15 months and 27 days did not develop any significant bacterial leaf spot (BLS) outbreaks. A new variety in this trial claimed improved resistance BLS but this remained untested in any meaningful way.

Graft and Variety Treatments

Planting 1 at Gatton consisted of 6 treatments. (Planting in ground 482 days)

1. Chilli "Caysan" (South Pacific Seeds) used as rootstock grafted to Warlock
2. Commercial rootstock "Capsifort" (Monsanto) grafted on to Warlock
3. Warlock ungrafted (standard)
4. SV6947 (Monsanto) ungrafted - new trial variety
5. Wild Malay Eggplant used as rootstock grafted to Warlock (Monsanto). Unfortunately this graft union was found to be physically incompatible as a rootstock material for *capsicum annum*.
6. Warlock grafted to Warlock – to determine the impact of the grafting process and stress of grafting on stem diameter and plant productivity.

Planting 2 at Gatton consisted of 8 treatments. (Planting in ground 224 days)

1. Plato (Monsanto vegetables)
2. SV SV6947 (Monsanto vegetables) new trial line
3. SV6947 (Monsanto) <u>grafted as scion</u> onto Warlock roots
4. Warlock on Tree Chilli
5. Warlock self-grafted
6. Warlock on Hungarian Hot Wax
7. Warlock self - grafted (a repeated treatment as the Kangaroo Apple graft was incompatible)
8. Warlock on Inferno

Bowen field trial and Bowen protected cropping observation (5 treatments).

1. Chilli "Caysan" (South Pacific Seeds) used as rootstock grafted to Warlock

2. Commercial rootstock "Capsifort" (Monsanto) grafted on to Warlock

3. Warlock ungrafted (standard)

4. SV6947 (Monsanto) ungrafted - new trial variety

5. Warlock grafted to Warlock – to determine the impact of the grafting process

Plant and Yield Measurement

Stem diameter measurements for transplants of planting 1 crop 1 at Gatton were taken to determine if grafting or rootstock combinations altered stem (early plant vigour) diameter.

Flower percentage measurements for transplants of planting 1 crop 1 at Gatton were taken to determine if grafting or rootstock combinations altered flowering pattern.

Fruit from all treatments in all trial crops were sorted in accordance with commercial practice. Fully mature fruit was harvested and assessed at each picking date. Misshapen, damaged, sunburnt or insect damaged fruit was not considered marketable and was graded out and recorded. Only commercially marketable fruit as defined in Woolworths Capsicum (Green Blocky) product. specifications was recorded as marketable yield. (Note: Giru protective cropping observation trial fruit were graded according to glasshouse fruit quality specifications - observation trial only due to small plant numbers in this environment).

Sunburn fruit damage for all treatments in all trial crops were sorted and recorded.

Plant cutback and ratoon regrowth for all treatments was assessed in planting 1 crop 1 to measure the impact of the position of the ratoon cut on subsequent ratoon growth.

Light and temperature and humidity readings were taken in planting 2 (crop 5 and 6) to determine the impact protective netting had on the plant growing environment.

Outputs

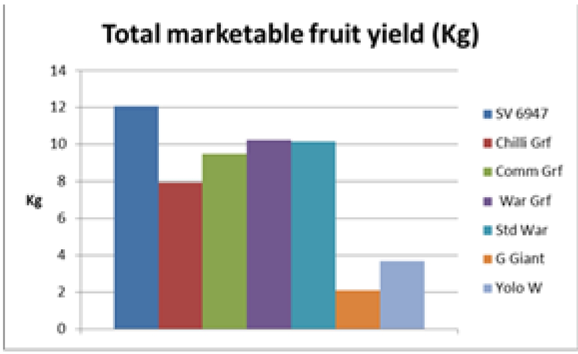
- Literature review completed and submitted to Hort Innovation 30th September 2013
- Gatton trial site visited by interstate executive members of the National Horticultural Research Network - presentation given and discussions in March 2014
- Planting 1 Gatton research results presented at Maroochy Research Facility plant breeders meeting in June 2015
- Grower field walks conducted at Gatton trial site, March 2014, February 2015, and December 2016.
- Chilli (variety Caysan (South Pacific Seeds)) when grafted to Warlock scion reduces canopy height, improves canopy density and intensifies leaf colour.
- Identified graft incompatibility with capsicum – Wild Malay Eggplant and Kangaroo Apple.
- Identified capsicum graft compatibility with chilli – Inferno, Hungarian Hot Wax, and Caysan.
- Grafted Capsifort and Hungarian Hot Wax yields were as good as Warlock in at least the first harvest.
- Yield data and potential of new lines SV6947 and SV9699 identified and documented.
- Beneficial fruiting pattern and non-clustering (less deformed fruit) trait of SV6947 and SV9699 identified.
- Root health comparison data for all treatment material compiled and documented.
- Effective mechanized ratooning of Warlock capsicum was demonstrated and documented.
- Impact of suspended protective crop cover measured, with beneficial reduction in temperature and increase in humidity documented and reported. Fruit quality and marketable yield increase from protective netting documented and measured.

Outcomes

Individual Treatments

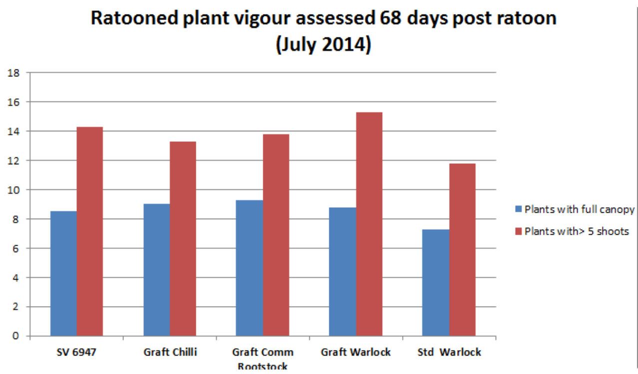
Planting 1 crop 1. Analysis of first season plant stem diameter, flower production and growth results make it apparent that the act of grafting did not significantly alter the plant stem diameter, flowering pattern or plant vigour. Marketable fruit yield was highest (and statistically similar) in Warlock, Warlock self-grafted, and Warlock grafted to Capsifort (commercial rootstock). The new Monsanto variety SV6947 produced the highest total marketable yield – though statistically this yield was only significantly higher than the chilli graft (Caysan) and the two older varieties, Yolo Wonder and Green Giant. The new variety SV6947 displayed a beneficial, more uniform flowering and fruit position pattern within the plant structure.

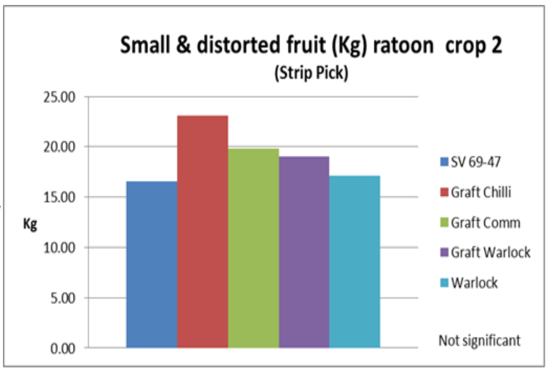
It was noticeable that SV6947 set one flower (with the potential to develop fruit) at each leaf axil on the main stem – resulting in less deformed fruit as a result of reduced fruit bunching, a common problem with Warlock. The older varieties Yolo Wonder and Green Giant produced less marketable yield as well as a high number of small fruit, and are of no commercial interest. The Warlock on chilli (Caysan) graft reduced plant canopy height and increased density. This graft induced alteration of plant architecture did not improve marketable yield by reducing fruit sunburn, though it should be noted that November 2014 daily maximum temperatures were exceptionally high. The yield of Caysan chilli graft was trending lower (though not significant) than Warlock self-grafted and un-grafted, Capsifort graft and new variety SV6947. The two older varieties exhibited a more consistent fruit harvest over four picks but fruit size was small and unacceptable in today's market.



Crop 1 mean marketable yield (Kg) from 20 plants and at right mature trial area prior to harvest.

Ratoon crop regrowth data for crop 2 (after crop 1 was cut back) indicates that in fact the position of the ratoon cut seemed to have negligible impact on plant recovery and growth, with all treatments reshooting in similar fashion. Mean plant number with full canopy and plants with more than 5 shoots (from 20 plants) is graphed below at left – with no significant difference detected. Good plant protection practices and an appropriate background nutrition program play an important role in plant growth and recovery after ratooning. When cutting back a summer harvested crop going into autumn, cutting off should be delayed until the peak of the cold winter temperatures. This will allow both plant material from the previous crop and fruit developed in cool weather to be cut off together – minimizing labour input. The first ratoon crop at Gatton (cut off in May) reshot and grew on into June and July and re-flowered, producing undersized fruit in the prevailing cold temperatures. Trial results below indicate these initial crop plants should have been left and held in situ through the winter and cut back in mid - August.





Left: Ratoon crop regrowth (20 plants) was uniform across all treatments when cut off 1 node above main fork

Right: Unmarketable small squat fruit yield as ratoon crop grew into cooling winter weather

Comparing the medium marketable fruit weight of all treatments from planting 1 crop 1 to those obtained in crop 4 reveals a severe decline in productive fruit output. Marketable yield in crop 4 had declined between 70 and 90% when compared to crop 1. Growing the long term trial crop through for a little over 14 months (4 separate crops) was done to test the graft and varietal root systems health and resilience.

Root health being assessed (left) and an example of a mechanically cut back ratoon crop.

Planting 2 in October in Gatton which produced crop 5 and crop 6 in the Gatton series included a total of 8 treatments, one new variety and several different graft combinations.

The Warlock on Kangaroo Apple graft was incompatible and discontinued, though several straight Kangaroo Apple plants were grown on in another area for observation and revealed that this plant has a formidable root system. The Warlock on Tree Chilli graft reduced plant height, but plant vigour was also noticeably less than other treatments in the trial. These plants were smaller in stature than the chilli graft (Caysan) grown in planting 1 and had fruit that was more exposed. Plato, new variety SV9699 and SV6947 grafted onto Warlock had the highest marketable yields. Warlock grafted on to Hungarian Hot Wax, performed as well as self-grafted Warlock and non-grafted Warlock. Grafting Warlock onto the chilli variety, Inferno, and onto Tree Chilli resulted in decreased yield and a higher incidence of deformed fruit.

A broad mite infestation impacted crop 6 yield results. Crop 6 should have showcased further the productivity gains achieved in crop 5 attributed largely to the protective netting, improved plant health and reduction in sunburn loss. Unfortunately mite damage at the early fruit development and flowering stage caused plant growing tip damage, flower and young fruit abortion and heavy fruit scarring on a large percentage of fruit. This pest outbreak represents the only mentionable pest or disease problem encountered over the 706 continuous days we had capsicums in the ground at Gatton.

No significant differences occurred in overall marketable fruit yield in the Bowen trial. Tillage method did not significantly impact final yield (though fruit yield from all intensive treatments seemed to indicate a trend toward outperforming the old permanent beds). The Bowen field trial data revealed that the new variety SV6947 and the chilli graft (Caysan) treatments produced a significantly higher number of marketable fruit than the standard Warlock treatment. However mean individual medium fruit weight of SV6947 was less than Warlock resulting in no significant marketable yield difference being detected.

Plant Height

Ratooning did not reduce subsequent plant height potential. This is borne out by both measurement and observation (refer to photographs of crop 3 and crop 4 trellised plants in this report).

Root Health

Planting 1 root health assessment 482 days after planting identified root health differences. Grafted Warlock had a significantly higher dry root weight than the chilli graft and standard Warlock, while SV6947 and Capsifort had the lowest mean dry root weight. It should be noted that based on yield data crop 4 plants were in biological decline. A root assessment after ratoon crop 2 or 3 when the whole plant was biologically younger may have highlighted more relevant differences. Root health assessment in planting 2 (many different treatments to planting 1) revealed Warlock to have the highest dry root weight but had lesions on the roots. Interestingly Hungarian Hot Wax, Inferno and the new variety SV9699 had no root disease. Warlock had many lesions on the feeder roots but still had the heaviest root system. The cause of lesions remains undiagnosed (at the time of report preparation) – despite pathological examination.

Root health results of the graft treatments Capsifort and Hungarian Hot Wax along with the new varieties SV6947 and SV9699 reveal a lower root dry weight than standard Warlock. Marketable fruit yield of the above treatments was as good as, and in some instances slightly better than standard Warlock. These results indicate that in order to use root health measurement as an indicator of yield potential, root system health assessments should be carried out at the conclusion of each harvest. Assessment of root health at the end of planting 1 (482 days) and planting 2 (224 days) allowed comparison of relative root health at that time but was not the best indicator of relative yield potential.

Protective Netting

The protective netting (Appendix 6) cover reduced sunburn impact on marketable fruit by 30%, made a huge difference to fruit quality as well as size and reduced plant deaths. Fruit quality under this structure was exceptional – experienced local farmers and project staff who picked and graded all fruit in all crops remarked upon how this protective net boosted both fruit quality and plant productivity.

Evaluation and Discussion

The initial literature review provided the opportunity to review and consider relevant capsicum research carried out over recent years around the world. The research material selected and documented had relevance to capsicum (bell pepper) crop productivity in the Australian context. The aim of the review was to inform and prioritise the initial field trial work program. Small productivity improvements based on precise implementation of existing agronomic techniques e.g., irrigation, nutrition, foliar disease control, was not the focus.

This review of international research highlights the lack of documented Australian work in the area of graft suitability compatibility and impact on yield in the Australian environment. International research while interesting and potentially informative is of limited value as the varieties used are often coded numbers (not available in Australia) and the environment is very different. Cheap and plentiful labour, limited land, harsh environmental conditions or disease issues combine to make grafting more viable and necessary internationally. With the advent of automated grafting machines grafting cost will in future not be an impediment to Australian adoption. Specialist Australian tomato growers are currently buying hand grafted material as they have access to well researched beneficial rootstocks

Testing locally available potential rootstock material and rootstock/scion interactions in Australia's unique climate, soils and production systems provides local information to enhance industry productivity potential. Soil health in Australian capsicum growing regions has been highlighted as a major issue, nematodes and soil disease reduce yield potential in intensively farmed soils.

Ratooning as a technique in a dry climate has the potential to extend plant yield or target early production periods. While results in this trial series confirm the ability to cut back mature capsicum plants and produce a ratoon crop plant with equal size and vigour to that of the first crop, weather and timing issues prevented full marketable yield potential from being attained in planting 1 crop 2, while mite damage impacted results in crop 6. The potential of a single ratoon crop produced after the initial harvest should be investigated further.

This research has delivered the following information and data;

- Field tested and evaluated six capsicum graft combinations under Australian growing conditions using Warlock as the scion in five of these combinations and Warlock as a rootstock in one combination.
- Documented and analysed the performance of a commercially available capsicum rootstock in Queensland conditions.
- Identified two root systems that are not compatible with *Capsicum annum* and six that can be grafted as well as documenting yield outcomes.
- The Bowen field trial compared the same rootstock material as grown in Gatton planting 1 but across an intensive (normal ground preparation) and permanent bed system. The permanent bed system was in it's third year and marketable yield of all treatments were statistically the same across both production systems though the new variety SV6947 produced the greatest fruit weight and statistically the greatest fruit number.
- Identified and field tested two new varieties (available in Australia) that have claimed improved resistance to bacterial dry leaf spot - at the very early stages of limited commercial trials prior to their potential release in Australia.
- The project demonstrated that cutting off mature capsicum plants at the first node above the plant main fork facilitates ratoon growth and achieves a plant of equal height to the initial planting.
- Mechanical plant ratooning (hedger) was as effective as careful hand trimming of mature capsicums.
- Visually assessed root health and measured and compared root dry weight for all material included in the Gatton long term field trials – documenting relative root system performance under Australian conditions in Australian soils.
- The project demonstrated an effective cheap retractable protective net cover that greatly increased marketable yield by reducing sunburn loss by 30 %. This demonstrated productivity gain has major implications for summer capsicum producers.

- Fruit quality under the protective net was enhanced and plant death due to plant stress greatly reduced.

Feedback

The work program benefited as a result of comment from local experienced producers, site visits to compare the crop to nearby commercial crops and from a nearby local producer provided valuable feedback. Discussions with researchers in the Northern Territory lead to the initial inclusion of Wild Malay Eggplant. Discussions with local seed companies lead to the selection, access and inclusion of emerging new trial material.

Learnings

- The act of grafting had no adverse effect on capsicum plant stem diameter or flowering pattern.
- This project has field trialed, documented and reported on a number of unique capsicum graft combinations. The following rootstocks grafted to Warlock were as good as Warlock for marketable weight in at least the first harvest - commercial graft variety “Capsifort”, and chilli Hungarian Hot Wax graft.
- Chilli graft Caysan caused a 15% reduction Warlock canopy height and denser darker leaved canopy – the ability to alter canopy height and colour could be useful in automation systems
- New variety SV 6947 and SV9699 have an improved fruit setting pattern, less fruit clumping and in our trials marketable yield was as good as if not better than Warlock
- Chilli roots and SV 9699 had considerably less root disease scarring than other lines in Gatton planting 2 root assessment –this is worth further investigation
- The project has documented relative root health score and dry weights of two new varieties and a number of rootstocks.
- The project has documented temperature, and relative humidity, differences produced by a retractable protective net installed over a summer above capsicum crop in the Lockyer Valley
- The project has demonstrated the potential to increase summer field grown capsicum productivity by 30 %. Decreasing sunburn loss can be easily quantified, however the accompanying increase in fruit quality, gloss and marketability will also enhance grower $ return and fruit demand.

  Cutting back mature plants after final harvest and growing a viable ratoon crop plant is possible, though correct timing and pest management is crucial if more value is to be extracted from existing plants, and growing infrastructure. Time of ratooning should be managed when autumn cropped plants are growing into the cold. After final harvest of the initial crop plants should not be cut back until late winter, thus removing plant tops and any late flower derived (flat) cold affected fruit from plants just before spring when the ratoon crop will regrow and set new fruit.
- The use of shade structures has the potential to greatly improve the yield and quality of capsicum crops in the Lockyer Valley and potentially other hot dry capsicum growing areas in Australia by:
  - Reducing yield losses due to sunburn damaged fruit;

- Improving fruit quality with respect to appearance;
- Improving fruit quality with respect to shape and reducing marketable yield losses associated with fruit deformity (internode length effect);
- Increasing the length of the stem internode to influence fruit spacing thus minimising crowding of the fruit resulting in less deformity and improved fruit shape. These elongated internodes have the potential to improve the efficiency of any robotic harvesting technology which may become available in the future; and
- Regulating light levels to improve the capability of automated harvesting technologies which are under development by reducing variation in visible and UV light, so enhancing automated vision systems fruit detection accuracy.

Recommendations

1. Varietal screening trial.

New varieties SV6947 and SV9699 exhibited an improved fruit setting pattern, less fruit clumping and better s marketable than Warlock. A follow up variety screening trial could compare SV6947 and SV9699 and other new varieties to Warlock. A recent review of overseas results indicates both SV9699 and SV6947 have some resistance to nematodes.

2. Rootstock trial under high disease pressure.

Hungarian Hot Wax and Capsifort (used as rootstocks) performed well from a yield and root system perspective and warrant further research under high disease pressures. Hungarian Hot Wax had unscarred roots in the root health assessment carried out after crop 6. The commercial rootstock Capsifort has documented disease resistance. Root health assessment of crop 6 showed that Warlock root systems had noticeable scarring and nodulation compared to the chilli (Hungarian Hot Wax) and SV9699 roots. Further research is required to determine how well these different rootstocks perform under significant disease pressure. The new variety SV6947 should also be included in any disease or nematode screening trial because in Planting 2 at Gatton when the root scarring was evident this variety was grafted to Warlock roots.

3. Ratoon crop timing.

Cutting back mature plants after final harvest and getting a viable ratoon plant is possible. Further investigation into time of cutting back and assessment of ratoon crop yield potential is warranted.

4. Graft compatibility.

A comprehensive pot trial screening project would be beneficial to rapidly identify other compatible capsicum graft candidate rootstocks.

5. Crop architecture management.

The chilli graft Caysan caused a 15% reduction Warlock canopy height and denser darker leaved canopy. The chilli graft Inferno reduced Warlock plant height by 40 %. This should be noted and considered in any future work to investigate how plant architecture manipulation could assist machine and automated harvest research.

6 Economics of low cost protective structures.

The use of shade structures has the potential to greatly improve the yield and quality of field grown capsicum fruit in the Lockyer Valley and potentially other hot dry capsicum growing areas in Australia. Further research into the economics and best low cost architecture is warranted.

Scientific Refereed Publications

No publications at this stage

Intellectual Property/Commercialisation

No commercial IP generated

Acknowledgements

Special thanks to Mary Firrell at Gatton Research Facility for her dedication, data recording and organizational skills displayed through three years of field trials. Her contribution to the final report has been invaluable – Thanks.

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Thanks Gatton Research Station staff for general assistance helping lay plastic, spraying, checking on irrigation when requested and allowed the author to borrow tools from the workshop. Thanks to Gavin and Kev– contract post drivers who helped install the protective net main support posts. Ron for hard work input and help picking and grading fruit. Special thanks to Kev, his patience and sense of humour as we ran wire, home-made baler twine rope and threaded many Zip Ties to install and tension the protective net.

Thanks to the Qld Dept of Agriculture and Fisheries biometricians who assisted with statistical analysis.

Appendices

1. Field trial crop methodology and detailed results by crop 1 – 6 plus Bowen
2. Research trial time line – all crops
3. Trial plans planting 1 & 2 Gatton and Bowen field trial
4. Nutrition regime - Gatton
5. Woolworths capsicum quality specification
6. Hale net (protective net) specification

Appendix – 1

Individual Crop Results

Explanatory Note: Individual detailed crop results are listed on the following pages.

Gatton planting one and two (crops 1 – 6) are reported in the first section of this document with addition data and results associated with these crops. The Bowen field and protective cropping trial at Giru are reported towards the end of this document. The North Queensland work in Bowen and Giru occurred from June to December 2014, between planting 1 crop 2 and crop 3 at Gatton.

In order to aid the readers understanding and follow the thread and development of the long term capsicum research trials at the Gatton site the author has reported on the Gatton work in the initial part of this document.

Gatton-Planting 1 Crop 1

Transplanted 8th of January 2014

Harvested 24th of March – 16 April 2014

Summary

The initial Gatton capsicum productivity trial was established at the Department of Agriculture & Fisheries (Qld) Gatton Research Facility, and harvested 4 times.

This trial consisted of five treatments with 4 replicates in a randomised complete block design, compared and evaluated for their impact on crop productivity. All graft treatments were based on the current industry standard commercial variety Warlock as the scion. The grafted rootstock treatments chosen for evaluation were; current commercial capsicum variety Warlock grafted onto itself (to evaluate grafting impact), non-grafted commercial capsicum standard Warlock, a commercially available chilli line Caysan (South Pacific Seeds) known for its resilience under a range of conditions, a newly released commercial capsicum rootstock Capsifort (Monsanto) available in international markets and Wild Malay Eggplant (WME), known for its soil disease resistant properties.

Materials and Methods

Treatment Detail

1. Chilli "Caysan" (South Pacific Seeds) used as rootstock grafted to Warlock
2. Commercial rootstock "Capsifort" (Monsanto) grafted on to Warlock
3. Warlock ungrafted (standard)
4. SV6947 (Monsanto) ungrafted - newly available trial variety
5. Wild Malay Eggplant used as rootstock grafted to Warlock (Monsanto). A Northern Territory tomato grower found that a yellow fruited "Wild Malay Eggplant" (WME) was a better bacterial wilt resistant rootstock for tomatoes than some other commercial tomato rootstocks (B. Conde (NT DPI) – pers comm). The Solanaceae family of vegetables include potatoes, tomatoes, eggplant, capsicum and chillies. Seed of Wild Malay Eggplant was sourced so that we could ascertain if this rootstock could be utilised to combat soil diseases in capsicum - a solanaceous crop related to tomato. Unfortunately the graft union failed and Wild Malay Eggplant was found to be physically incompatible as a rootstock material for *capsicum annum* – despite considerable effort and grafting expertise. The graft union did not fully take (knit) - was not sound and unsuitable for commercial field planting. This graft treatment was replaced with a newly available trial variety Sv6947. This new variety is reported to have improved foliar disease resistance against Bacterial leafspot a serious disease found in all commercial production regions and caused by a bacterium (*Xanthomonas campestris pv. vesicatoria*).

6. Warlock grafted to Warlock – to determine the impact t of the grafting process and stress of grafting.

All graft treatments were based on the current industry standard commercial field capsicum variety Warlock which was used as the scion material.

Trial Design

In the Gatton trial area (planting 1, 2014 and planting 2, 2015) each treatment had four replicates in a randomised complete block trial design. The outer bed on either side of the trial was a buffer row, with a 5 meter buffer at either end of the treatment plots. Individual treatment plantings were 5 m long double rows with 30 plants per plot - the centre 20 plants of each treatment plot were harvested and assessed. Refer to trial plan – planting 1 and planting 2 in appendix 3. The trial was established in the field on the 8th of January 2014. Due to the planned long term nature of this work – custom made thick plastic film (40 micron instead of the usual 18 micron) was sourced and used when setting up beds for the trial. This silver reflective plastic film was chosen as a means of minimising aphid and sucking pest activity (and potential virus transmission) during the plant establishment phase of the cropping cycle. The irrigation system was a set up using Netafim® thick wall, high quality pressure compensating drip line designed for long term crops. Nutrition and plant protection practices were based on industry best practice. Good nutrition management together with the use of drip irrigation, tensiometers for irrigation scheduling and a preventative copper fungicide program resulted in no incidence of bacterial leaf spot.

Crop Nutrition

The same nutrition regime was utilised for all plantings and crops grown on the Gatton site. This balanced weekly fertigation program delivered 200 units of nitrogen, 24 units of phosphorous and 240 units of potassium per hectare as well as a balanced prescriptive application of micronutrients over the cropping period of each crop. (Appendix 4)

The initial trial planting established well in spite of the record heat experienced at Gatton in January 2014. (Figure 1 - 4)

Figure 1 Trial Establishment

Figure 2 Crop Growth

Figure 3 Crop Maturity

Figure 4 Crop Harvest

Planting 1 Crop 1 Results

Assessment of grafting impact on Warlock capsicum early growth using plant stem diameter as a measure.

To measure and assess any impact on early plant establishment and plant vigour caused by any of the grafting treatments, plant stem diameter was measured three times during the initial plant establishment phase, on the 29th of January, the 5th of February and the 12th of February, 21, 29 and 36 days after transplanting. Mean stem diameter was measured 5 mm above the cotyledon node of each plant 36 days after transplanting (12 plants measured per replicate) Results appear in Table 1 below .

Table 1- Grafted treatment stem diameter 5 mm above cotyledon node 36 days after transplant

Treatment	SV 6947	Chilli Graft	Capsifort Graft	Warlock Graft	Warlock Standard	Green Giant	Yolo Wonder	LSD
Mean Stem Diam (mm)	14.49	14.11	14.63	15.73	15.02	14.26	14.18	0.741

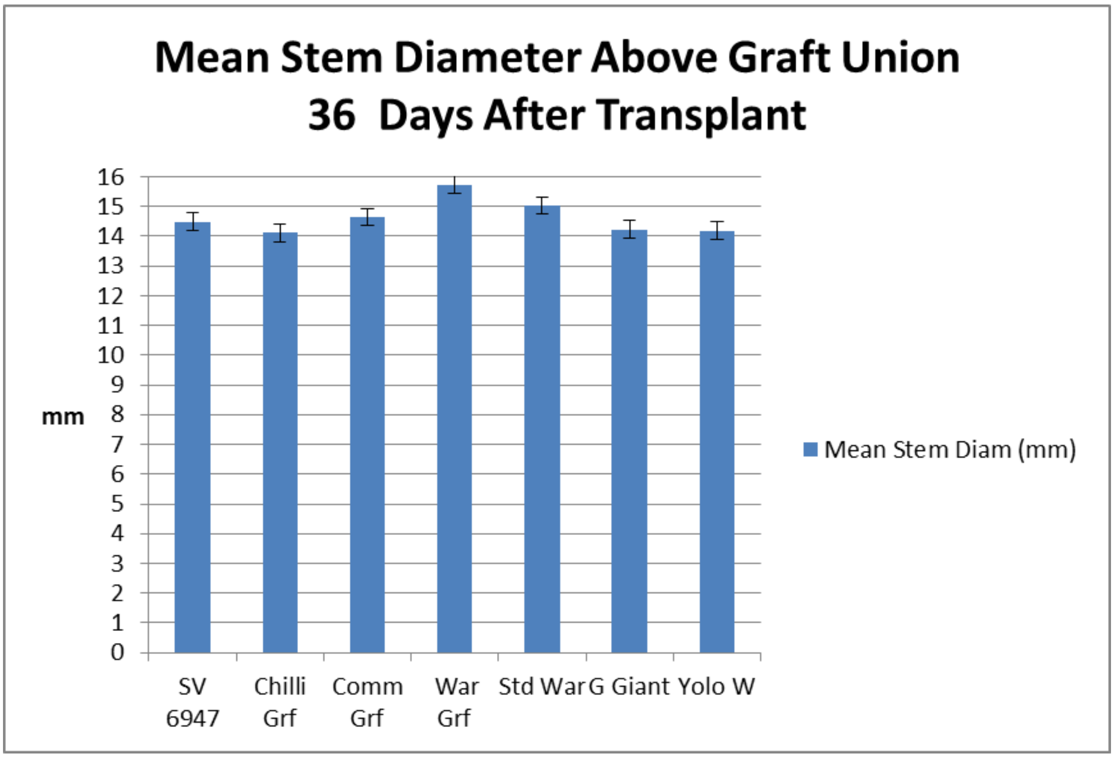


Figure 5 Grafted material stem diameter 5 mm above cotyledon node

Results in Figure 5 above indicate that grafting treatments and the act of grafting alone has not reduced plant vigour. Self-grafted Warlock (Warlock on Warlock) has a similar stem diameter to ungrafted Warlock 36 days after transplant. The mean stem diameter of the grafted commercial capsicum rootstock (Capsifort) was the same as ungrafted Warlock, while the Chilli (Caysan) rootstock graft treatment has slightly reduced plant stem diameter 36 days after transplant. All material whether grafted or ungrafted including the older lines Yolo Wonder and Green Giant exhibited similar stem diameters which gives confidence in the success of the grafting technique. The fact that Seminis line SV6947 stem diameter was not statistically different to that of ungrafted Warlock and grafted Capsifort is interesting, as this replacement treatment was planted 7 days later than all other treatments. The new commercial trial line SV6947 appeared vigorous and established well.

Assessment of grafting impact on Warlock capsicum early growth using flower development as a measure.

Table 2 below presents mean percentage of all treatment plants with open flowers present 28 days after transplant

Table 2 Mean flower percentage on each treatment 28 days after transplant

Treatment	SV 6947	Chilli Graft	Capsifort Graft	Warlock Graft	Warlock Standard	Green Giant	Yolo Wonder	LSD
Open flowers per 20 plants	1.3	73.8	63.8	43.8	45	69.9	40	22.7
Ranking	d	a	ab	bc	bc	a	c	

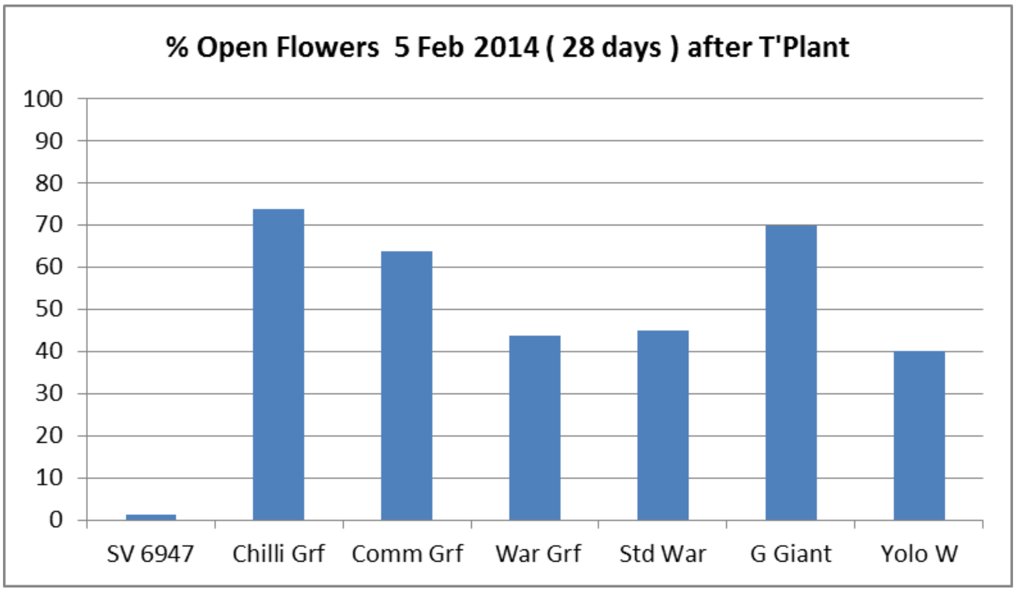


Figure 6 Mean percentage of open flowers 28 days after transplant

The Chilli graft treatment had significantly more open flowers than both Warlock and the self- grafted Warlock treatment 28 days after transplant, with 73% of plants having open flowers (Table 2 & Figure 6). The commercial graft (Capsifort) material exhibited the next highest number of open flowers per plant but this was not significantly different to standard Warlock or the self-grafted Warlock treatments. It is notable that the new Monsanto line SV6947 had very few open flowers by comparison to the rest of the treatments. This line was physically taller and slower to begin flowering though it must be remembered that these plants were planted 7 days later so are actually 21 days after transplant (not 28). This is an interesting point to remember when examining the marketable fruit harvest data below where line SV6947 yielded as well as, or better than other treatments at first harvest on the 24th of March 2014.

Grafted rootstock impact on Warlock capsicum marketable fruit yield.

In accordance with commercial practice fully mature green fruit was harvested and assessed at each picking date. Misshapen, damaged, sunburnt or insect damaged fruit was not considered marketable and was graded out and recorded. Only commercially marketable fruit as defined in Woolworths Capsicum (Green Blocky) product specifications (Appendix 5) was recorded as marketable yield. We decided to slightly modify the medium sized fruit length specification 95-110 mm to include fruit 85-110mm in length. This was done as a result of discussion with growers and the thick-walled nature and size of these blocky Warlock fruit. Thick walled blocky mature green fruit 85 mm long was considered marketable as medium fruit by local growers. Only blemish free well-formed fruit were considered marketable and included in the marketable medium fruit count. Only a few large fruit (110 – 130 mm long) were harvested and were combined with medium fruit. Growing conditions and temperature are the key drivers that influence how a capsicum plant will develop, flower and size up fruit and this varies from season to season. Harvested marketable fruit were graded into small and medium sizes, with only medium fruit deemed marketable (Figure 7). Warlock capsicum fruit are known as a blocky (square) fruit, favoured by growers and resellers having fruit width similar to their length, an appearance currently preferred by consumers. The two older varieties (Green Giant and Yolo Wonder) included in this first trial planting produced relatively small fruit as evidenced by the low medium fruit yield. These two older lines were included to assess their relative disease resistance, fruit yield, and fruiting pattern in comparison to Warlock, a modern hybridised variety, grown widely throughout Australia for the last fifteen years. These two older lines produced a large number of small fruit unsuited to modern supermarket demands.

Figure 7 an example of small and medium mature green fruit from crop 1

Table 3 Mean weight (Kg) of marketable fruit harvested 75 to 98 days after transplant.

Harvest Date	SV 6947	Chilli Graft	Capsifort Graft	Warlock Graft	Warlock Standard	Green Giant	Yolo Wonder	LSD
24/03/2014	8.17	4.89	6.96	6.59	6.15	0.67	1.47	
01/04/2014	2.42	1.46	1.73	2.17	1.33	0.53	1.38	
08/04/2014	0.78	1.1	0.67	1.69	0.95	0.72	0.67	
16/04/2014	0.7	0.49	0.11	0.61	0.74	0.17	0.17	
Total Marketable Fruit Weight (Kg)	12.07	7.94	9.47	10.22	10.16	2.09	3.69	
	a	ab	a	a	a	c	bc	4.69

Table 3 shows marketable yield for each picking date and overall total number of kilograms of marketable fruit harvested for each treatment. The older lines Yolo Wonder and Green Giant were poor producers of marketable fruit both producing significantly less saleable fruit than all other treatments except the chilli graft which was not significantly different from Yolo Wonder. Marketable fruit yield from all the new and grafted material was similar with no statistical difference between treatments. Interestingly SV6947 marketable fruit yield was comparable and seemed to trend higher than Warlock though this difference was not significant. It is worth comparing fruit weight at first pick (above) of all treatments, especially SV6947 and while referring back to Figure 6 above, where the younger SV6947 plants appeared to be slower to flower. At first harvest SV6947 plants appeared vigorous and yielded well with marketable fruit picking at the same time as all other material.

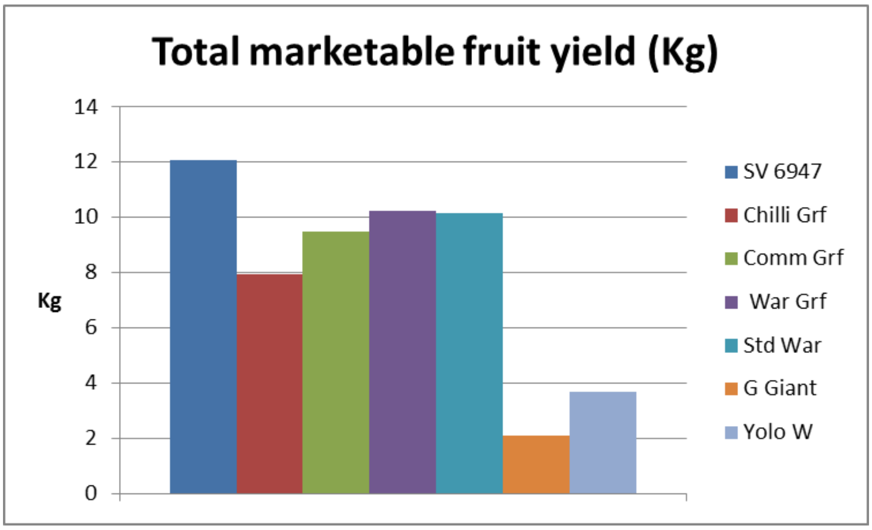


Figure 8 Total marketable fruit yield for each treatment

The lower yield (though not significantly lower compared to other graft treatments) of the Chilli (Caysan) graft material in Table 3 and Figure 8 above can be somewhat explained by the impact of sunburn on fruit classification as a result of our need to trellis all treatments when semi-mature fruit was on the plants. Trellising was needed due to the good leaf canopy and heavy fruit load on plants which began to cause plant stem splitting (at branching forks) – endangering the long term health and viability of all treatments and plants. In this summer crop we aimed to grow a large leaf canopy in order to maximise fruit shading in an effort to minimise sunburn impact.

Figure 9 Example of stem splitting as a result of large fruit load in large canopied crop that necessitated trellising prior to harvest.

The plant stem cracking threat due to crop load and large leaf canopy size necessitated action late in the cropping cycle and this late trellising altered the leaf canopy structure and exposed some semi-mature fruit to hot summer sun impacts.

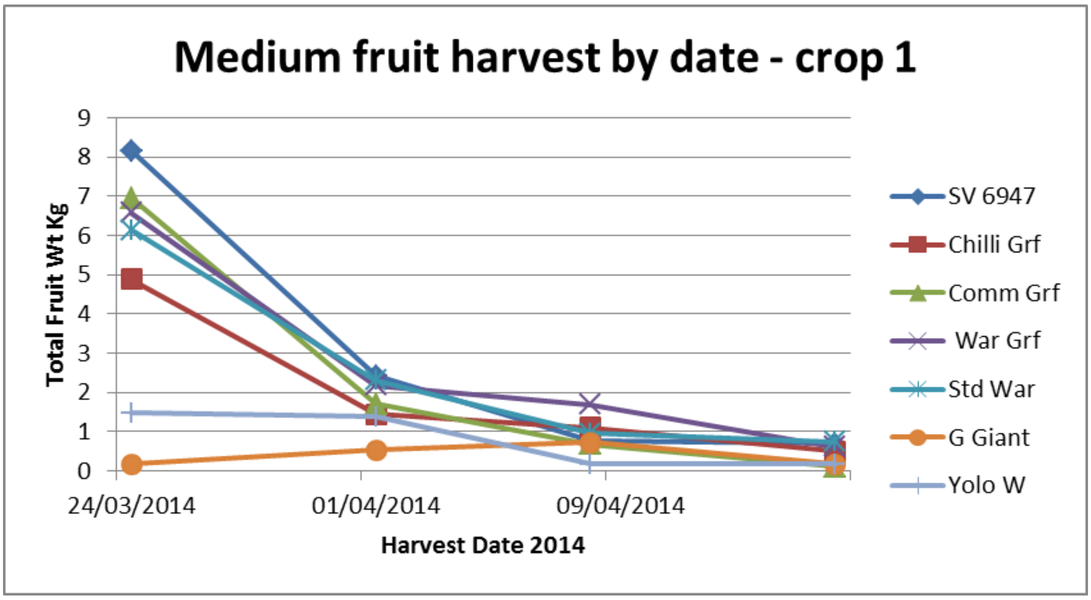


Figure 10 Mean marketable fruit weight harvested from each treatment

None of the grafted rootstock material significantly altered the fruiting production trend line of the Warlock scion, with all lines producing significantly less fruit in the second and subsequent harvests compared to the first harvest (Figure 10). In fact except for the occurrence of good fruit prices in early 2014, plants would not normally have been picked the fourth time - due to the relatively low remaining yield. Considering the impact of sunburn and fruit fly damage to fruit at first harvest (second pick and subsequent harvests were unaffected) as outlined later in this report it is evident that Warlock (scion material) is a heavy early cropper, with on average 60% of total medium fruit yield taken at first harvest and around 20% of total yield on the second pick.

Grafted rootstock impact on Warlock capsicum undersized (small) fruit yield.

The older lines Yolo Wonder and Green Giant produced a large percentage of small under sized fruit throughout the harvest period. This underlines the improved fruit characteristics of the newer hybridised commercial material currently used by Australian growers. Ungrafted Warlock and Warlock self-grafted produced the least number of small fruit, though this was not significantly lower than chilli graft or SV6947.

Table 4 -Mean weight (Kg) of small fruit (<75 mm long) harvested 75 to 98 days after transplant.

Harvest Date	SV 6947	Chilli Graft	Capsifort Graft	Warlock Graft	Warlock Standard	Green Giant	Yolo Wonder	LSD
24/03/2014	2.19	5.33	4.79	2.26	2.63	5.41	7.69	
01/04/2014	2.89	2.09	2.80	1.92	1.62	2.18	4.08	
08/04/2014	1.23	1.39	1.56	1.11	1.75	3.04	2.69	
16/04/2014	2.35	1.55	2.19	2.14	1.95	3.39	1.68	
Total Marketable Fruit Weight (Kg)	8.66	10.36	11.34	7.434	7.95	14.02	16.14	
Rank	cd	cd	bc	d	d	ab	a	2.98

The older capsicum lines Yolo Wonder and Green Giant were much more consistent fruit producers throughout the harvest period (Table 4); however the smaller fruit size means they are of no value in the modern commercial supply chain.

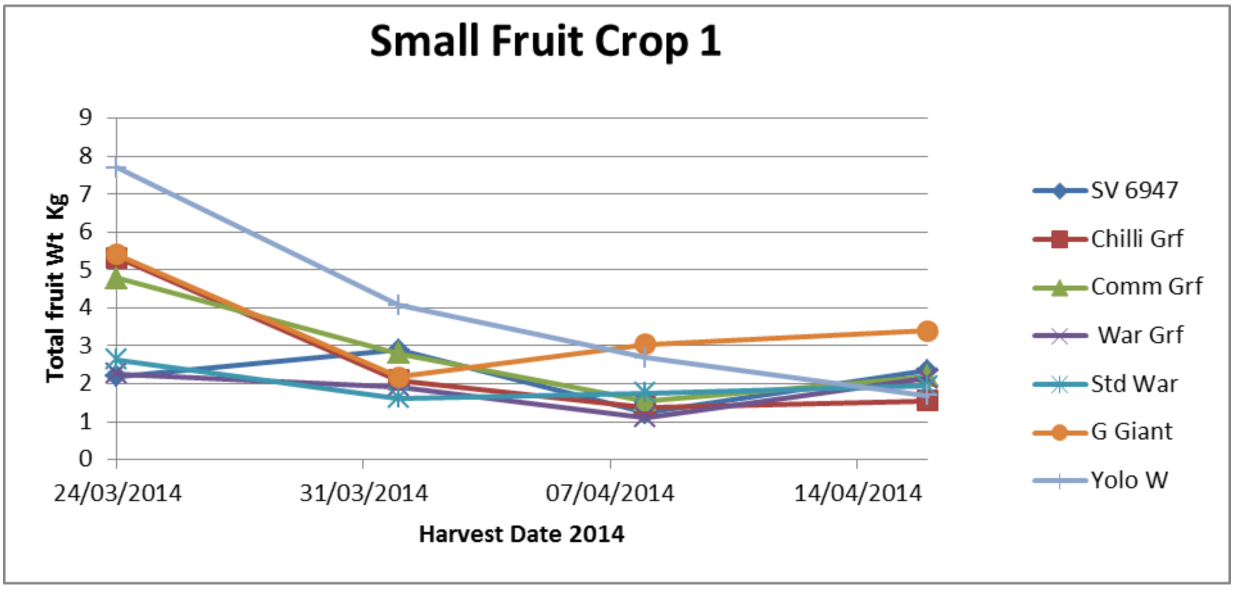


Figure 11 Mean weight of small fruit harvested at each pick from each treatment

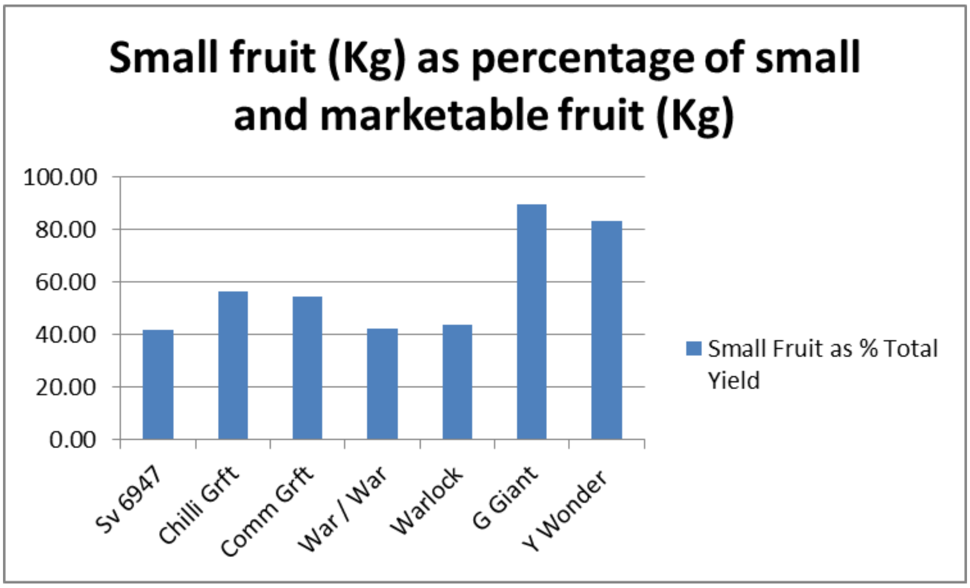


Figure 12 Small fruit total Kg as a percentage of treatment total sound fruit

Yield data presented in Figure 12 above documents that the older varieties Green Giant and Yolo Wonder produced mostly small sized fruit – unsuited to the modern commercial market which demands large blocky fruit.

Graft impact on total number of marketable fruit from 20 plants

Table 5 Total number of marketable fruit from 20 plants

Harvest Date	SV 6947	Chilli Graft	Capsifort Graft	Warlock Graft	Warlock Standard	Green Giant	Yolo Wonder	LSD
24/03/2014	38.75	21.5	32.25	24.33	25.25	2.56	8.52	
01/04/2014	11.5	6.3	7.5	9.5	10	2.54	7.53	
08/04/2014	4	5	2.7	5.75	4.25	3.54	0.57	
16/04/2014	3.25	2	0.5	2.75	3.5	1.	0.57	
Total marketable fruit number	57.5	34.8	43.2	42.1	43	9.7	19.7	
Ranking	a	bc	ab	ab	ab	d	cd	19.45

Results for the number of marketable fruit harvested from crop 1 tabulated above (Table 5) demonstrates that the new variety SV6947 yielded well though statistically no different to grafted

Warlock, standard Warlock or the commercial rootstock Capsifort. Warlock grafted to the chilli rootstock (Caysan) produced statistically less marketable fruit than SV6947, while the older lines Yolo Wonder and Green Giant produced the least number of marketable fruit. Chilli rootstock (Caysan) graft treatment suffered the most sunburn impact as a result of late crop trellising (and it's reduced plant height) which was carried out to avoid plant stem splitting and potential subsequent plant death. This sunburn impact was exacerbated by the fact that the chilli graft (Caysan) material had a lower canopy – so when trellised tended to expose more fruit. Sunburn data appears below along with an explanation of the need for crop trellising.

Graft impact on marketable fruit weight

Table 6 Mean marketable fruit size (Kg)

Treatment	SV 6947	Chilli Graft	Capsifort (Comm) Graft	Warlock Graft	Warlock Standard	Green Giant	Yolo Wonder	LSD
Marketable fruit average size (Kg)	0.209	0.228	0.219	0.239	0.234	0.187	0.169	0.0124
	c	ab	bc	a	a	d	e	

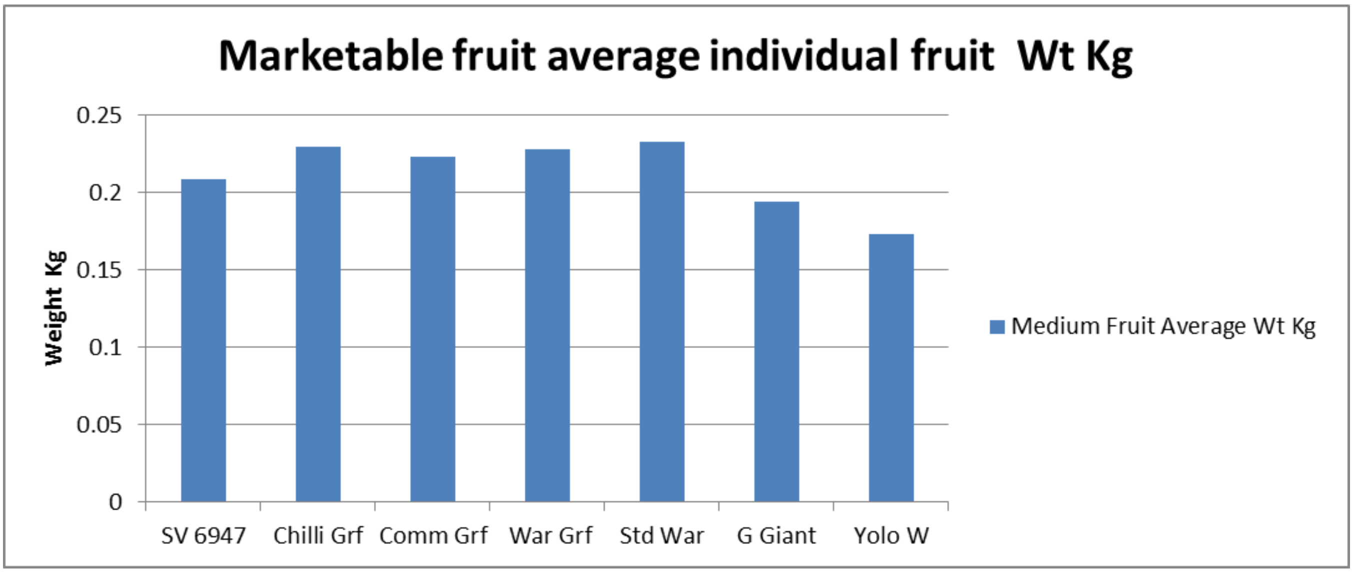


Figure 13 Mean marketable fruit weight

A comparison of average marketable fruit weight reveals that Warlock self-grafted, ungrafted Warlock and the chilli (Caysan) graft produced the heaviest mature green fruit. The new variety SV6947 and the Capsifort graft treatments produced slightly smaller fruit while the few marketable fruit from the older varieties Green Giant and Yolo Wonder were significantly smaller in weight. Even though the new variety SV6947 produced slightly smaller fruit, the total marketable fruit yield was higher (Table 5) than any other graft treatment.

Impact of sunburn on total yield - small and medium fruit

Table 7 Mean total sunburnt fruit weight (small and marketable)

Harvest Date	SV 6947	Chilli Graft	Capsifort Graft	Warlock Graft	Warlock Standard	Green Giant	Yolo Wonder	
24/03/2014	5	8	6.25	6.33	4.25	3.08	5.08	
01/04/2014	5.75	4	1.5	4.5	3	1.1	4.08	
08/04/2014	3.25	5.5	4.75	6.25	6	3.08	4.08	
16/04/2014	2.75	1.5	1.75	2.25	2.25	2.09	1.11	
Total sunburnt fruit number	16.75	19	14.25	19.33	15.5	9.35	14.35	
Mean	4.19	4.75	3.56	4.83	3.87	2.34	3.59	Not significant

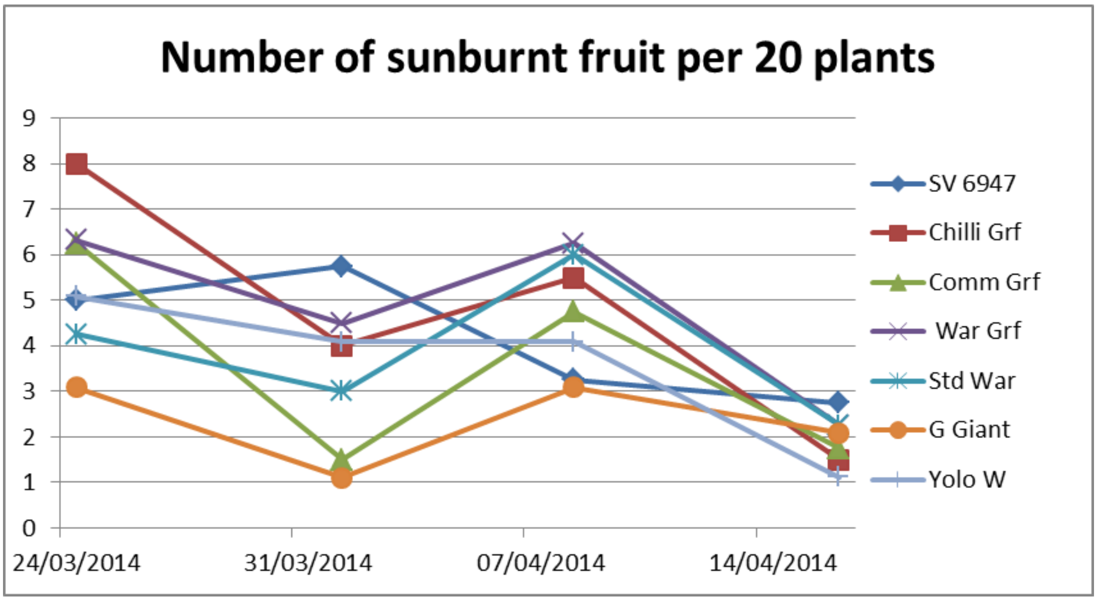


Figure 14 Mean number of sunburnt fruit per treatment at each harvest date

All treatments produced plants with good canopy and leaf cover which protected developing fruit. However two weeks prior to first harvest in hot summer conditions some plant stem splitting and crop lodging, as a result of wind and crop load was observed. This necessitated trellising the crop in order to prevent plants splitting at branching points (central branch) as mature fruit finished filling and smaller fruits sized up. This late trellising on the 11th of March (13 days prior to first harvest) altered the leaf canopy structure slightly and exposed semi-mature fruit (older fruit) to extreme sun impacts. Sunburn losses in the Lockyer Valley summer capsicum cropping season causes substantial losses and growers rely on above average returns to offset this impact (B Fisher, pers comm) Higher sunburn levels evident in the table above can be explained by the impact of sunburn on older fruit as a result of the need to trellis all treatments when semi-mature fruit was on the plants. During planning and establishment we planned not to trellis in an effort to mimic common growing practice (untrellised), to minimise production costs and facilitate better crop and machine access for pest and disease control. However once the full fruit load and windy weather caused some crop lodging and plant splitting, intervention was essential. We devised and installed a low cost trellis system based on self-supporting small plastic posts and cheap baler twine. This system proved effective in supporting the mature crop, however it did alter the lower plant leaf canopy exposing some semi-mature fruit two weeks prior to first harvest.

The chilli (Caysan) graft treatment did noticeably alter the height of the plant canopy in that graft treatment (Figure 16) the image below is from the ratoon crop (planting 1 crop2) and the slightly shorter darker plant canopy is visible in this image. Unfortunately we noted but did not measure and document this difference in canopy structure. This was a conscious decision as it was discussed and decided that if the altered canopy structure was of commercial benefit it would be evident in reduced fruit sunburn levels. The Chilli grafted plot is clearly visible below, flanked by graft treatments that did not impact plant colour or architecture.

Figure 15 Grafted chilli rootstock, left of picture with standard Warlock to the right

Figure 16 Crop prior to trellising 3rd March (left) and after trellising (right) 11th March 2014

Crop establishment, growth, fruit maturation and sunburn in record summer heat.

The weather during crop establishment growth and fruiting in the summer 2014 needs to be put into context. Below is a graph of upper and lower 25% of maximum and minimum as well as mean temperatures from 1984 to 2013 (30 Years) at Gatton during the January to March period as well as monthly mean temperatures for 2014.

We grew a good healthy vigorous crop despite these conditions with no plant loss during the crop establishment phase. There is no doubt that these high temperature and UV light conditions contributed to sunburn losses exacerbated by late (but necessary) crop trellising. The graph below gives some context to the fruit sunburn losses reported above and on reflection highlights how relatively small those losses were thanks to appropriate crop irrigation, management and robust well supported crop leaf canopy.

Gatton Temperature Data (30 year average and monthly mean for 2014)

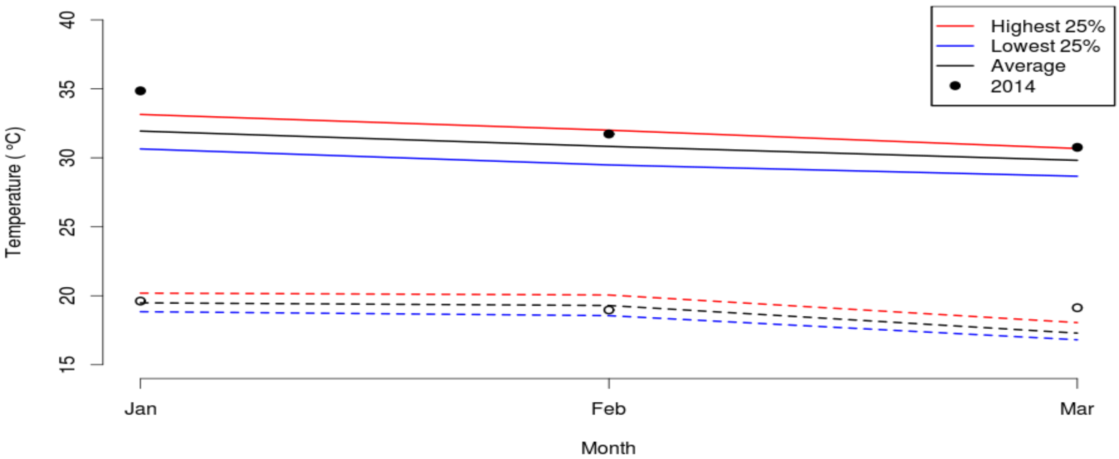


Figure 17 Upper and lower 25% of maximum and minimum temperatures and mean maximum and minimum at Gatton in January, February & March from 1984 to 2014

Sunburn Impact on crop 1 harvest period 24th March to 14th April 2014

At each harvest date all fully mature fruit were picked, graded and assessed. Harvested fruit were either fully mature large green or fruit that were fully mature and were starting to colour - fruit had reached maximum weight in the prevailing environmental conditions and had begun to colour. Harvest data from each plot was recorded for all small, and marketable (medium & large) fruit. The number and weight of any sunburn affected fruit in these categories was also recorded.

Figure 18 Sunburn damage on a fruit as result of summer heat photo taken 19th February of crop 1, almost a month prior to first pick

Sunburn is a major cause of yield loss in summer capsicum crops in the Lockyer Valley, plants planted in late August are harvested in late October, November and December. The Autumn crop – planted in late February or early March and harvested in Late April or May suffers less sunburn impact as the weather is cooling as fruit matures on the plant. Fruit lost to sunburn is a major impost on potential crop profitability as all the effort and expense involved in getting mature fruit on the plant, crop establishment, nutrition, irrigation and plant protection is wasted as sunburn damage renders fruit unsaleable – even to the processing market. The impact of sunburn on crop 1 for all treatments is documented below (Table 8).

Table 8 The impact of fruit sunburn on crop 1 for all treatments

Total fruit harvested by category	Sv 6947	Chilli Grft (Caysan)	Comm Grft (Capsifort)	Warlock self grafted	Warlock	Green Giant	Yolo Wonder
Small fruit (Kg)	8.66	10.36	11.34	8.15	7.95	13.58	15.70
Marketable fruit (Kg)	12.07	7.93	9.45	11.06	10.15	1.59	3.16
Sunburn damaged fruit (Kg)	2.42	2.83	2.08	3.08	2.39	1.09	1.31
Sunburn as % of small and marketable fruit	10.47	13.42	9.10	13.82	11.66	6.69	6.48

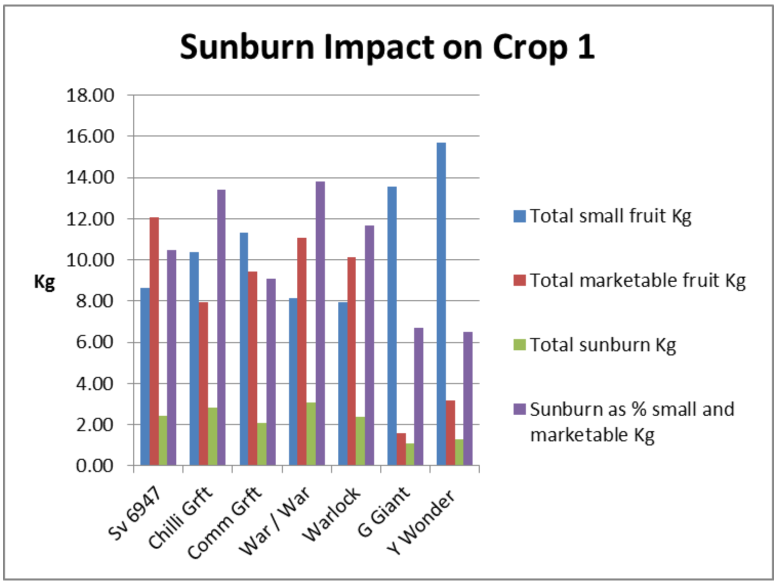


Figure 19 Fruit category weight in Kg and sunburn for all treatments

Leaving aside the older varieties Yolo Wonder and Green Giant which have predominantly small fruit (by today's standards) the average loss of small medium and large fruit in crop 1 from the 5 other treatments was 11.6%. It should be remembered that when picking any fruit (even if small) that has any sign of sunburn was harvested. Commercially sun damaged this fruit is removed from the plant so as to stop the plant wasting energy filling out damaged fruit and dropped on the ground. Sunburn in the Autumn – crop planted in February March is usually less of an issue than the spring crop which is filling out fruit in November as daily maximum temperatures are rising

The combined mean sunburn impact on yield of small and marketable fruit categories averaged across all trial treatments is depicted in the figure below.

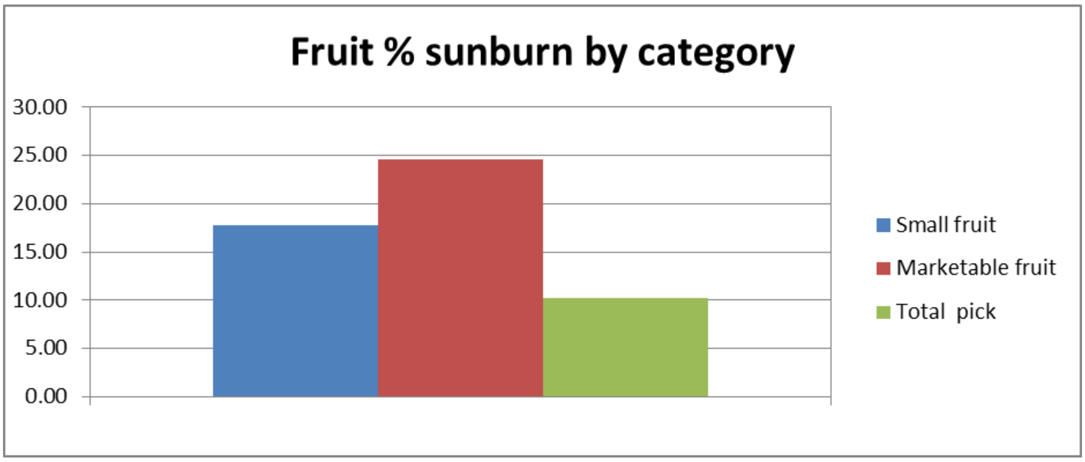


Figure 20 Sunburnt fruit percentage loss of total crop yield

Sunburn damage caused almost 25% of marketable fruit picked to be discarded.

Ratooning treatment

On the 6th of May 2014, twenty days after final harvest all treatments and buffer areas were ratooned. This involved topping (hand pruning) all plants back to the second node above the main plant fork, approximately 10 centimeters above ground level. All top material and trimmings were removed from the trial site and the ratooned plants were sprayed with a copper and mancozeb mixture to aid plant recovery and protect against disease infection.

One week later the trial area was again sprayed with a copper and mancozeb mixture to assist with plant recovery. The area was then left to recover and managed through the winter months. Disease management decisions were based on daily plant observations and irrigation decisions on tensiometer readings.

Observations of plant regrowth rate characteristics for all graft treatments were recorded. This data is analysed and reported in the ratooning section of this report.

Conclusion

Planting 1 crop 1 at Gatton provided a range of information. First season plant stem diameter, flower production and growth results have been analysed and it is apparent that the act of grafting did not alter plant stem diameter, flowering or vigour during establishment. Marketable fruit yield was highest and statistically similar for Warlock, Warlock self-grafted, and Warlock grafted to Capsifort (commercial rootstock). The new Monsanto variety SV6947 produced the highest total marketable yield – though this yield was only significantly higher than the chilli graft (Caysan) and the two older varieties, Yolo Wonder and Green Giant. The new variety SV6947 displayed a beneficial, more uniform flowering and fruit position pattern within the plant structure. It was noticeable that SV6947 set one flower (with potential to develop into fruit) at each leaf axil on the main stem – resulting in less deformed fruit as a result of fruit bunching – a common issue with Warlock plants. The older varieties Yolo Wonder and Green Giant produced statistically less marketable yield as well as a high number of small fruit. Some differences in plant canopy height (chilli graft) were observed and noted in the initial trial, however these difference did not improve marketable yield by reducing fruit sunburn.

Individual fruit weight was impacted by grafting and variety treatments with SV6947, Capsifort graft (commercial graft) and the older lines Green Giant and Yolo Wonder producing smaller fruit than the rest of the material. The two older varieties exhibited a more consistent fruit harvest over the four harvest times; however fruit size was unacceptable in today's modern market. Sunburn damage has the potential to greatly reduce marketable yield but the altered canopy structure invoked by the chilli graft (Caysan) did not reduce sunburn damage in this trial in an extremely hot November period (Refer protective netting effects).

Gatton-Planting 1 Crop 2.

Crop 1 ratooned 8th of May 2014.

Harvested 24th of September 2014

Ratooning Treatment to Extend Productive Crop Life.

On the 8th of May 2014, twenty days after final harvest of the first Gatton trial crop, all treatments were ratooned. This involved cutting (hand pruning) all plants back to the second node above the main plant fork, approximately 10 centimetres above ground level. To assess the impact of the position of the ratoon cut on subsequent growth we observed measured and monitored each treatment regularly. Individual plant branching structure also impacted how the plant could be ratooned – some plants having a more branching structure than others.

Once ratooned the trial area nutrition regime was altered to a maintenance fertilizer regime until the crop had reshot and begun to regrow and had 3 to 4 new leaves at each shoot. The maintenance fertilizer program was begun 1 week after plant cut back and consisted of 1 Kg of Nutrafeed 20 +TE in week 2, 1 Kg of calcium nitrate and ¾ Kg of potassium nitrate in week 3. Observations of plant regrowth rates after ratooning were made, measured and documented. We observed all datum plants in each replicated treatment with a final assessment of plant vigor and plant canopy development being carried out on the 15th of July 2014, some 68 days after crop ratooning (Figure 21).

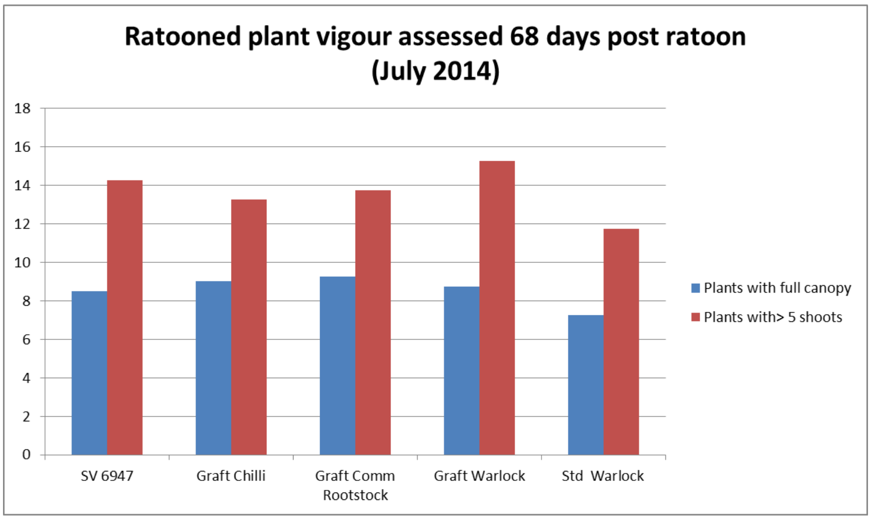


Figure 21 Mean rating of 20 plants per treatment, assessing plant canopy development and number of plants with more than five new shoots.

This data indicates that in fact the position of the ratoon cut seemed to have negligible impact on plant recovery and growth, with all treatments reshooting in similar fashion. Good plant protection practices and appropriate background nutrition practices no doubt play an important role in plant growth and recovery after ratooning. Ratooned plants were sprayed weekly for the first few weeks with copper to assist cut tissue to heal and ward off infection. The cooler winter weather and a low input plant nutrition regime assisted plant recovery.

A factor that impacted on ratoon survival after the initial crop was the structural integrity of the plants main stems. A small number of heavily laden plants did suffer from main trunk and main stem cracking as a result of heavy crop load on lateral branches in crop 1. This was only an issue if the crack was below the ratoon height (Figure 22)

Figure 22 Ratooned plants 8th May 2104 and at right an example of structural cracking due to fruit load in crop 1.

Two weeks after ratooning plants had begun to recover and re-shoot; this was aided by a mild beginning to winter with warm soil temperatures aiding plant recovery (Figure 23)

Figure 23 New shoots visible on centre plant 14 days after ratooning – tagged plants were used to measure plant regrowth rate after being cut back

In any long lived system natural plant variability, plant vigour, soil temperature, plant root health and environmental factors such as soil variability will interact to create variability amongst a study population. Ratooning saw individual plant vigour expressed (Figure 24) but as outlined above the majority of plants compensated and soon produced good growth from multiple new shoots.

Figure 24 Example of individual plant vigour differences 45 days after ratooning

This ratoon crop was maintained throughout the winter period to enable a comparison of the yield from this ratoon crop to a newly planted (September 2014) summer crop. An unseasonal warm early and mid-winter period (June, July) encouraged early regrowth and early flower formation on all ratooned plants. The following late colder weather in August 2014 resulted in poor fruit size and shape as well as some sunburn damage as maximum daily temperatures then flipped to extreme highs in mid-September 2014.

If given the opportunity again we would in retrospect delay ratooning and hold mature plants longer after harvesting crop 1. Ratooning in mid-August may have delayed flowering, but in any case would have avoided the need to strip pick fruit that developed over the cooler months. This fruit would have been removed by the late ratooning process – saving manpower. In crop 2 harvest all ratooned plants and buffer areas were strip picked to remove any fruit that had developed over the winter season. This strip pick to remove all fruit that developed during cool weather was carried out on the 24th of September 2014. All fruit from this harvest was graded and assessed for commercial acceptability.

Planting 1 Crop 2 - Harvested 24th September 2014.

In the cool Gatton winter period all ratooned plants exhibited rolled outer mature leaves (Figure 25). This symptom was not nutritional and as the temperatures warmed in late August and early September rapid leaf and plant growth occurred as the plants developed the third crop. On the 24th of September 2014 a strip pick of all over-wintered ratoon fruit was carried out, with fruit from all treatments assessed for commercial acceptability. The cool temperatures of late July and early August resulted in small squat fruit that failed to meet commercial specifications. The reduced bush size of the over winter ratoon crop also resulted in exposing the undersized fruit to sun impact and subsequent sunburn (Figure 25). There was no significant difference between treatments, with a very low number of marketable medium fruit produced by all treatments and a high number of undersized and distorted fruit.

Figure 25 Overview of ratoon crop area on 9th of September, 7 day old new warlock planting replicates visible

Figure 26 Grafted Warlock plot in foreground, some curled leaf, shows small plant size and visible mature fruit

Crop 2 Harvest Results

Yield details of crop 2 the ratoon treatment initiated at the conclusion of crop 1 (harvested in March and April 2014) occurred over winter appear below in table (Table 9). A warm early winter and cool late winter period saw plants reshoot and flower and then grow into a cool late winter period. The harvest yield data and categories highlight the effect of cool temperatures on plant fruit shape and weight – as a result of stunted plant size. The older varieties Yolo winder and Green Giant plant yield data is not presented, though plots were ratooned and harvested. Crop 1 results indicated poor commercial performance of these two older lines (Table 5).

Table 9 Mean fruit yield (Kg) category for crop 2 at Gatton – a ratooned plant treatment.

Treatment	Market (Kg)	Small & deformed (Kg)	Sunburn (Kg)
SV 69-47	0.79	16.55	0.78
Grafted Chilli (caysan)	0.18	23.06	0.35
Grafted Capsifort (comm)	0.90	19.85	0.77
Grafted Warlock	1.11	19.06	0.57
Warlock	0.62	17.09	0.36

Figure 27 Ratooned plants with mature fruit on the 25th of August 2014 (crop 2). Note fruit exposure due to fruit fill during low temperature conditions.

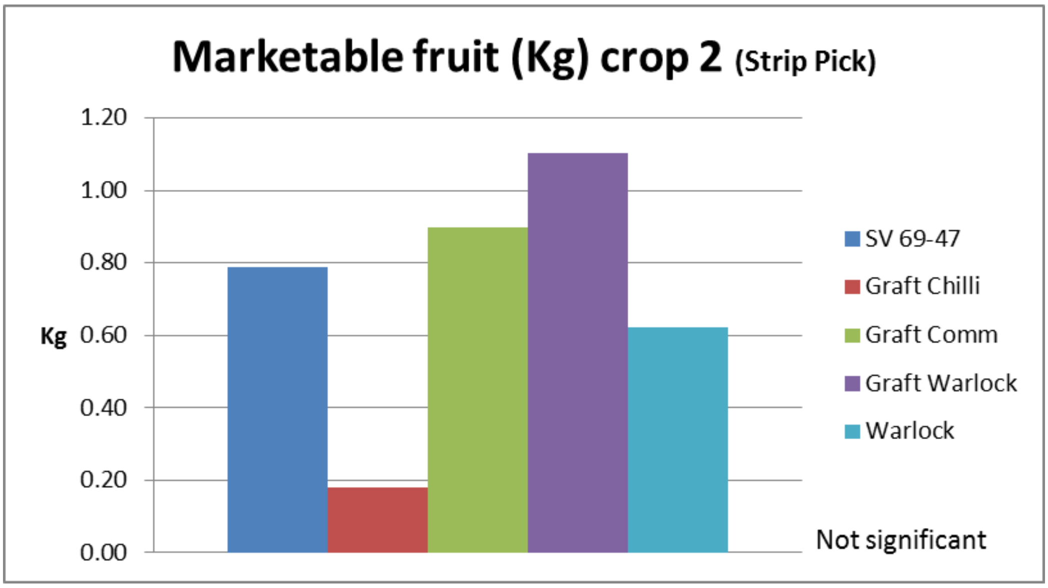


Figure 28 Marketable fruit yield from all treatments

Low temperatures produced a high number of undersized small fruit that was squat and distorted – a known result of cool temperatures when capsicum fruit are forming and filling. In retrospect and after the experience gained in this project it would have been best to delay ratooning until very late in winter. This would have avoided the need to strip pick exposed fruit off the cold affected plants as fruit would have been removed with ratoon material. Later ratooning in say mid-August would have seen plants regrow into a warming environment.

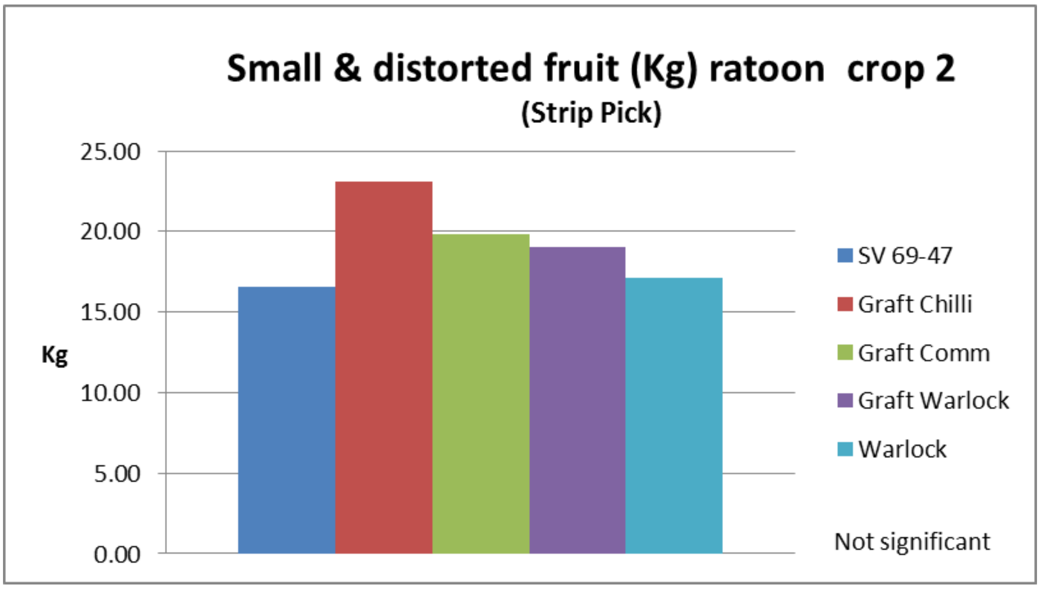


Figure 29 Small distorted fruit weight for all treatments in crop 2.

Figure 30 Squat flat fruit shape of crop 2 (ratooned 8th May 2014 strip picked 24th September 2014).

The other unusual fruit trait besides a flattening of the fruit (failure to elongate in cool weather) was a protrusion growth from the base end of the fruit (Figure 31). This seems associated with cool weather as it was not evident in fruit picked off the same plants in any previous or subsequent crop.

Figure 31 Showing protrusion from fruit base and the flattened fruit shape observed in fruit harvested in this cool season crop. The squat nature of most of this cooler ratoon crop fruit is visible above.

Marketable yield from all ratoon treatments grown over winter was poor, totalling only 3.6 Kg of fruit, while small and deformed fruit totalled 95.6Kg for all treatments. This was due to the impact of cool temperatures on plant canopy size and fruit development in this crop ratooned in May 2014.

Figure 32 Fruit picked from the buffer rows in this bin reinforce that fruit shape was the issue not biological potential yield

Conclusion

Cool temperatures in late winter saw plants that had been ratooned in May regrow, flower and set fruit before the onset of coolest part of winter. Although a reasonable amount of fruit was produced, slowed plant growth in cool temperatures saw plants set and develop a small flat unmarketable fruit. In retrospect and after the experience gained in this project it would have been best to delay ratooning until very late in winter. This would have avoided the need to strip pick exposed fruit off the cold affected plants (crop 2) as fruit would have been removed with ratoon material. Later ratooning in mid- August would have seen plants regrow into a warming environment.

New Crop Warlock Comparison Planting for Crop 3

On the 2nd of September a new replicated treatment of ungrafted Warlock was transplanted in the trial area. This replicated planting was performed to allow a comparison of the ratooned (over wintered) crop fruit yield with that of newly established Warlock plants transplanted in the local traditional summer capsicum planting timeslot (early September). These new plants along with a third fruit set (crop 3) on the May ratooned treatment plants were harvested and assessed on the 25th of November 2014

Figure 33 Crop 3 plants 15 days prior to harvest, two of the four new crop Warlock treatment plots have been highlighted.

Gatton-Planting 1 Crop 3

Crop 2 strip picked 24th of September 2014 (same plants grown on and re-flowered)

Crop 3 Harvested 25th of November 2014

Planting 1 Crop 3

Harvest of crop 3 was conducted on the 25th of November 2014, a once over harvest of mature green and fully coloured fruit from all datum plants. Throughout the trial mature fruit has been harvested from the 20 datum plants in the centre of each plot from a total of 30 plants in each treatment replicate. Where a plant death or obvious sickness prevented this fruit were harvested from the nearest adjoining datum plant in the same row. A new planned replicated planting of Warlock capsicum was transplanted in previously unused plots within the existing trial area on the 2nd of September 2014. This was designed to allow comparison of yield and plant performance with the existing ratooned plants first planted in January 2014. Due to the volume of fruit harvested from crop 3 it was decided that for fruit grading and assessment purposes a subsampling technique would be employed .Yield results for crop 3 are based on grading and assessing one quarter of the total number of fruit harvested from each plot. To check the validity of each subsample, total fruit weight per plot was recorded and compared to subsample weight per plot as a means of verifying this commonly used subsampling technique.

Maximum daily temperatures in November 2014 in Gatton were extreme and this resulted in sunburn damage to both mature and maturing fruit. Though the chilli graft treatment resulted in a more stocky plant with visibly darker foliage (Figure 37), there was no marketable yield benefit. The extreme heat experienced in November 2014 as fruit was maturing caused plant leaf wilting (though soil moisture levels were more than adequate) exposing fruit in all treatments to high temperature, and high levels of ultra violet (UV) light. Sunburn damage was inevitable in the extreme conditions. To cope and survive plants shut down in the peak heat of the day and wilting foliage partially exposed fruit usually shaded and protected by plant foliage. Two local commercial capsicum experienced severe losses as a result of the weather, one reported a 70% decrease in marketable yield and vowed never again to grow a summer capsicum crop, another grower lost about 40 % of expected marketable yield. (B Fisher, pers comm). The high temperatures in this cropping period also caused the smaller fruit size and consequently fruit weights recorded in all treatments in this summer crop.

Figure 34 Crop 3 Warlock plants (left of pink peg) 7 days prior to harvest at 2pm note slight plant wilt although moisture in soil visible outside plastic bed to left of white trellis peg. Note sunburn visible on exposed fruit (just right of yellow marker).

Crop 3 Harvest Results.

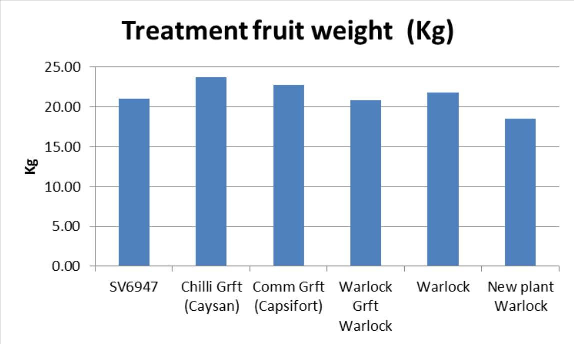
High daily maximum temperatures impacted plant growth, sunburn damage and fruit size in this crop which resulted in virtually no marketable fruit being produced. The majority of fruit were in the small fruit category, less than 75 mm long and the few medium fruit harvested were included in the small fruit category. The "new plant" Warlock comparison treatment also produced only small fruit with an average fruit weight of only 148 grams. Average marketable fruit weight in a non-heat affected crop should produce a piece of fruit weighing 180 to 200g.

Mean fruit yield per treatment.

There was no significant difference in the small (not medium – so no marketable) fruit yield produced by any treatment in crop 3 with fruit yield on average being 21.44Kg from 20 plants (1.07 Kg per plant). Results are presented in table (Table 10) below along with the graphed yield data. Interestingly the "new plant" Warlock crop (84 days old) produced a crop of small fruit weighing 18.52 Kg from 20 plants while the original Warlock (323 days old) and producing its' third fruit crop produced 21.75 Kg of small fruit from 20 plants. These figures are not significantly different – indicating the small fruit yield from the older ratooned treatments were not significantly different to the younger planting in this extreme heat.

Table 10 Comparison of mean small fruit yield (Kg) for all treatments including "new crop warlock"

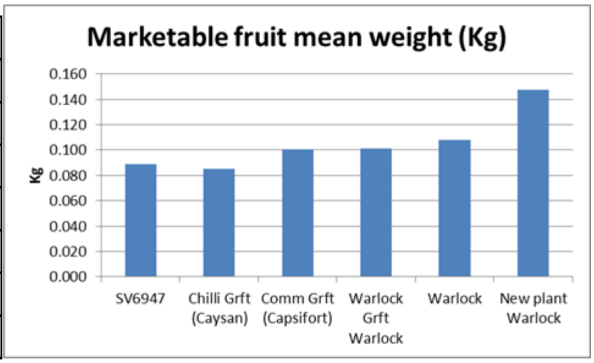
Treatment	Total fruit yield (Kg)
SV6947	21.05
Chilli Grft (Caysan)	23.75
Comm Grft (Capsifort)	22.76
Warlock Grft Warlock	20.80
Warlock	21.75
New plant Warlock	18.52
	Not significant



There was no significant difference in small fruit yield as a result of variety or rootstock in crop 3 as can be seen above. There was significant difference in individual small fruit size as measured by weight (g) between different treatments. New crop Warlock had the largest mean fruit weight (148 grams) while Warlock was slightly smaller (108 grams) the other graft treatments and SV6947 were of similar size.

Table 11 Comparison of individual mean fruit weight of all treatments

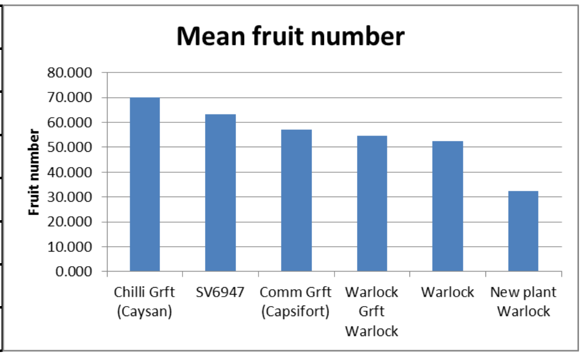
Treatment	Mean individual fruit weight (Kg)	
New plant Warlock	0.148	a
Warlock	0.108	b
Warlock Grft Warlock	0.101	bc
Comm Grft (Capsifort)	0.100	bc
SV6947	0.089	bc
Chilli Grft (Caysan)	0.085	c
	LSD 0.02051	



Mean individual fruit weight of new crop Warlock was significantly heavier than other treatments. The mean small fruit weight of new crop Warlock was some 40g heavier than the best of the older ratooned treatments, standard Warlock. New crop Warlock small fruit was 46g heavier than the grafted Warlock, 47g heavier than Warlock grafted on a commercial rootstock and 62g heavier than the small fruit of SV6947.These ratooned plants were 11 months old when crop 3 was harvested and assessed.

Table 12 Mean fruit number for each treatment

Treatment	Mean fruit number	
Chilli Grft (Caysan)	70.000	a
SV6947	63.250	ab
Comm Grft (Capsifort)	57.000	ab
Warlock Grft Warlock	54.500	ab
Warlock	52.500	b
New plant Warlock	32.250	c
	LSD 15.9	



The grafted chilli treatment produced the highest number of small fruit compared to new crop Warlock and standard Warlock, though as highlighted in the previous table mean individual fruit weight was significantly lower. The grafted commercial rootstock and grafted Warlock treatments produced similar small fruit numbers to standard Warlock and the new variety SV6947.

Sunburn Impact on Marketable Yield.

Local commercial growers of many crop types reported high impact from sunburn and heat stress in crops harvested in mid to late November 2014. One local grower of a late spring (maturing in late November) capsicum crop who had the ability to apply overhead irrigation as well as standard drip, reported using overhead irrigation to cool plant foliage (with limited success) to reduce heat and sunburn impact, on crop yield. The crop suffered severe marketable yield loss due to an extended period of high maximum daily temperatures. This October and November 2014 heat event should be put into context and compared with the historical "norm". Data below sourced from the Bureau of Meteorology (BoM) records gives an idea of the extreme temperatures which impacted the capsicum trial crop 3 at a time when fruit was fully formed and maturing in late November 2014.

During October and November 2014 very high daily maximum temperatures in the Gatton (Qld) horticultural region had significant impact on crop yields and profitability in a range of high value horticultural crops. The graph below compares the October and November maximum daily temperatures to the long term mean maximum temperature (blue line) for these months.

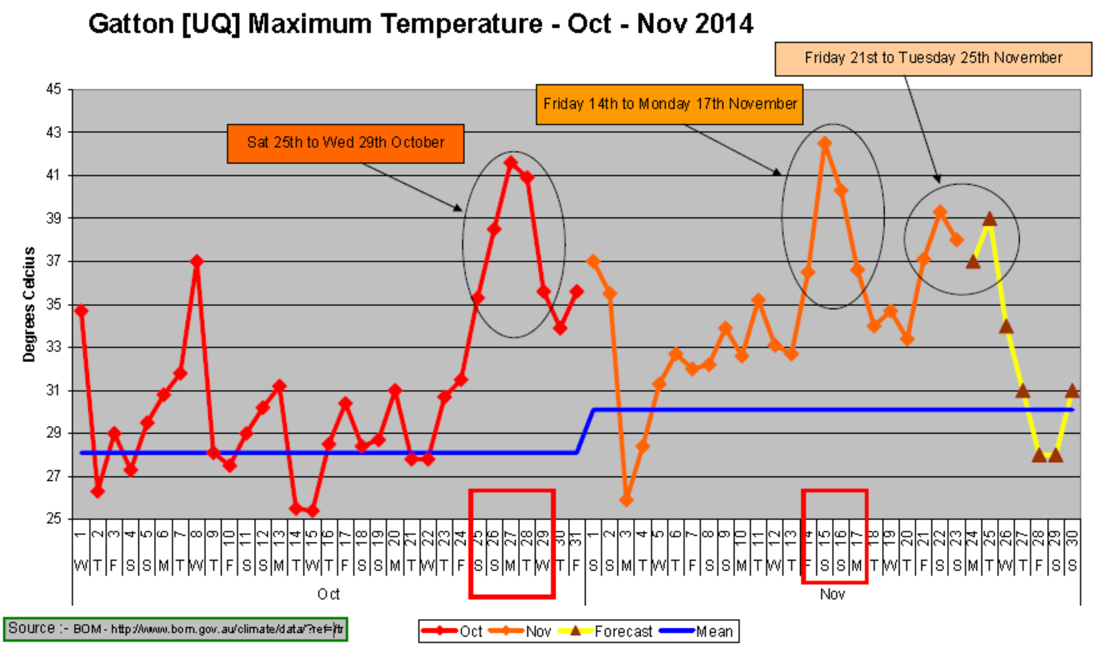


Figure 35 Maximum daily temperature at Gatton capsicum trial site in October and November 2014 – blue line indicates long term daily maximum for Gatton in October and November

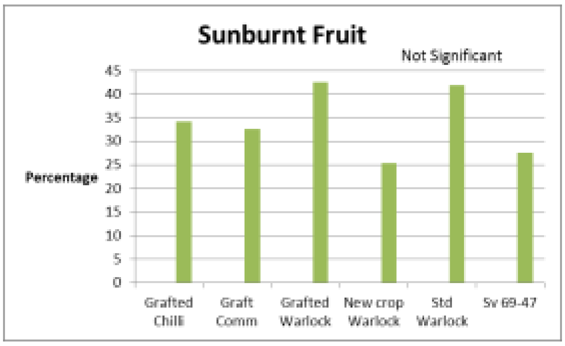
Extreme maximum daily temperatures resulted in significant trial crop impacts and loss of marketable yield potential. Extreme heat over many days had a number of impacts on the trial crop area, capsicum plants aborted flowers and the heat caused a significant reduction in fruit size. Mature plants wilted in the heat of the day as leaves shut down and this partial wilting during the hottest part of the day exposed mature fruit to high heat and ultraviolet light – causing sunburn. These extreme maximum daily temperatures (exceeding a daily maximum of 35^{C}) during October and November 2014 resulted in plant stress and fruit yield impacts - well irrigated plants just could not cope.

Even though the graft trial area was well watered and managed, trellised to minimise fruit exposure, fruit load, plant canopy wilting and drooping (a natural plant response under high temperatures) the heat of November 2014 resulted in severe sunburn impact on all treatments (Table 13). A visual inspection of the mature crop by walking through the treatments prior to harvest of crop 3 indicated a disturbingly high incidence of sunburn. The eye is drawn to the outer most, high fruit on the plants – this visual assessment indicated 70% of visible fruit being sunburn affected. The overall sunburn impact on small fruit across all treatments was in fact around 34% (Table 13) a devastating impact. This highlights the importance of good canopy cover, leaf turgor, plant architecture and fruit position on yield potential in capsicum – a highly perishable warm weather fresh market crop.

No variety or graft treatment showed any significant differences in terms of reduced sunburn impact on small fruit yield. The growing environment was simply too challenging as a result of this period of extreme summer heat.

Table 13 Sunburn percentage tabulated and graphed – crop 3

Percentage Sunburnt Fruit			%
Grafted Chilli			34.22
Graft Comm			32.57
Grafted Warlock			42.52
New crop Warlock			25.30
Std Warlock			42.00
Sv 69-47			27.61



Grafted rootstock altered plant architecture

There was a noticeable difference in the plant architecture of the Warlock plants that were grafted onto chilli rootstock (a shortening of plant height) both in the initial crop and after the ratooning treatment (Figure 36). This more compact plant canopy did not however reduce fruit sunburn percentages observed in the trial. No other graft treatment altered final plant height or architecture. Unfortunately this plant architecture impact was not measured directly as it was thought that sunburnt fruit percentage would reflect any meaningful plant changes induced by the rootstock treatments. When ratooning after crop 1 while removing ratooned canopy bulk we did note increased weight and volume being removed from each chilli graft treatment. The fact that no reduction in measured sunburn impact was evident means that in this temperature regime such plant architecture changes did not alter the effect of severe maximum temperatures.

It is interesting to ponder if a reduced sunburn impact would have been measured had summer maximums been less severe in November 2014. The Warlock grafted to a chilli (Caysan) rootstock plot is highlighted in the image below - a noticeable difference in the Warlock scion height and colour is visible when compared to surrounding treatments.

Figure 36 Grafted chilli (Caysan) rootstock, left of picture with standard Warlock to the right

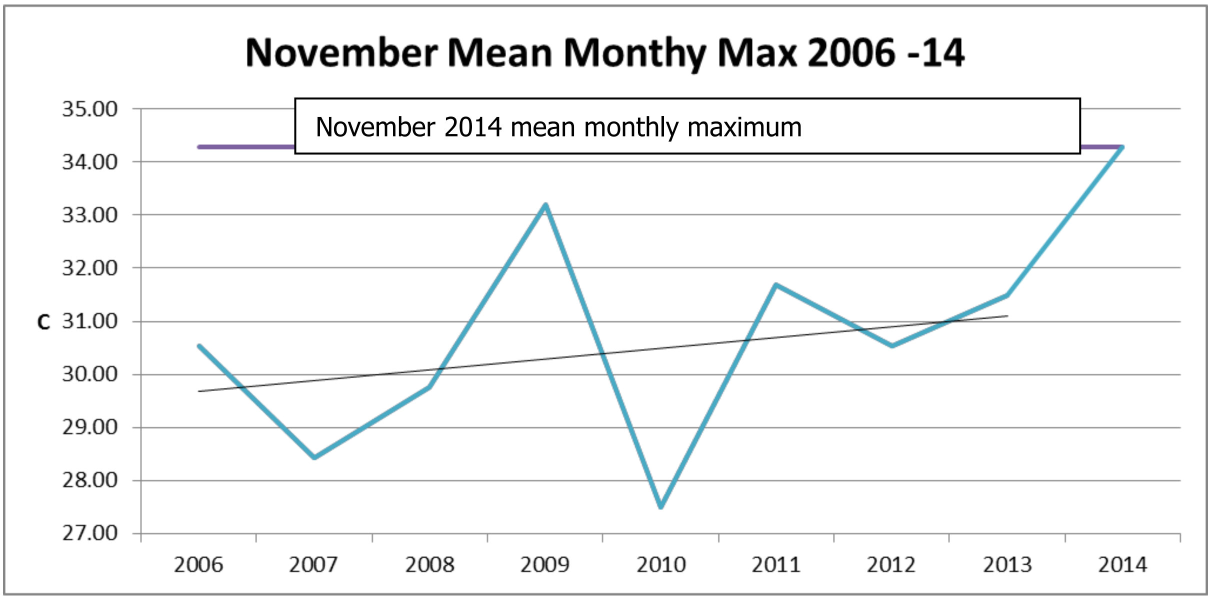


Figure 37 Maximum mean monthly temperatures for Gatton 2006-2014 with trend line fitted (grey), data source: BOM.gov.au / UQ Gatton

Conclusion

Extreme maximum summer temperatures in November as capsicum fruit was sizing and maturing resulted in a high proportion of small fruit in addition to high levels of fruit sunburn in all graft and variety treatments. Though the chilli (Caysan) graft treatment did shorten the warlock plant canopy and produced a denser and darker canopy – excessive November heat negated any potential to reduce sun impacts. Crop 1 results indicate that the chilli graft treatment produces poor marketable yield potential compared to SV6947, self-grafted Warlock and standard Warlock. Sunburn impact at time of year when price has potential to be most lucrative. Growers need a method of coping with high maximum late spring early summer maximum temperature effects - given above maximum temperature data and increasing trend.

Gatton-Planting 1 Crop 4

Crop 3 ratooned 15th of January 2015 (mechanically)

Crop 4 Harvested 1st of April 2015

After the third commercial crop harvest the trial area was maintained until the 15th of January 2015 when all treatments and buffer area plants were ratooned for a second time. It was decided to ratoon mechanically (using a mechanical hedge trimmer) to simulate conditions mimicking a commercial operation. The initial ratooning treatment (after crop 1) was carried out by hand (using secateurs), ratooning plants just above the first node, beyond the main plant branching fork. The impact of this treatment was measured assessed and documented previously (Figure 21).

Observation and plant growth recovery data from the first ratooning treatment gave us confidence to mechanically ratoon the plants after crop 3. The opportunity to test mechanical ratooning that mimic's commercial reality where a flail could be utilised to remove top growth and allow plants to reshoot was crucial. We used a commercial reciprocating hedge trimmer and for ease of operation cut all plants off just below trellis height.

Figure 38 Ratooning crop 3 plants mechanically with a hedge trimmer

Figure 39 Mechanically ratooned plants (above) at Gatton on the 15th of January 2015 with plants on right about to be ratooned

Once ratooned the trial area was sprayed weekly with copper and mancozeb at label rates to aid stem healing and prevent infection. This action protected cut plant stems from disease and dried out any plant trimmings left behind in the crop area. On the 21st of January a second replicated Warlock comparison crop was planted in order to compare plant growth and yield to that of the original ratoon treatments (planted January 2014) and now ratooned, first new comparison crop Warlock planted on the 2nd of September 2014. Unfortunately this new planting did not establish despite concerted effort and replanting some poorly growing plants with retained spares (from the same plant batch). Some transplant production issue is suspected as the cause of this new planting failure – all new seedlings in all plots performed poorlyly. This was characterised by the transplant root ball not putting roots out into the surrounding soil. These young plants grew poorly and began to wilt, yellow and set flowers within days of planting. This second new comparison crop treatment was not able to be successfully established despite a concerted effort so the decision was taken to discontinue this second comparison crop.

Figure 40 Second new crop Warlock planted 21 January 2015 for comparison with crop 4 failed to establish properly. Every plant in all replicates suffering severe leaf yellowing and apical growing point disfiguration and subsequent premature flowering.

Figure 41 Crop 4 regrowth on 3rd of February 2015 (19 days after crop 3 plants were ratooned)

Crop 4 was grown according to the trial standard crop nutrition program which was utilized for all individual crops throughout this trial series (planting 1 crop 1,2,3 & 4 and planting 2 crop 5 & 6) (Appendix 4).

Crop 4 Harvest Results

Harvest of crop 4 was carried out on the 1st of April 2015. A once over mature green fruit harvest (common industry practice) was carried out, harvesting all mature green and all slightly coloured (more advanced) fruit from all datum plants. Fruit size across all treatments was smaller in crop 4 than in crop 3. The original plant material had now been ratooned twice, produced a full crop on three previous occasions, and in the ground for a total of fifteen months. It should be noted that growing and plant protection practices were similar for all crops. An identical nutrition program was implemented for all crops and an early examination by means of a complete plant leaf analysis indicated this program supplied a balanced plant nutrient profile meeting the planed application of all minor and macro nutrients while providing the equivalent of 200 units of nitrogen, 24 units of phosphorous and 240 units of potassium per hectare as well as a balanced prescriptive application of micronutrients through each cropping cycle.

Medium fruit weight and number declined further in this harvest across all treatments with no significant differences between treatments. It is interesting that both the original standard Warlock and the self-grafted Warlock treatment were on the upper end of the results spread for medium fruit number and weight, as was SV6947.

Table 14 Medium fruit per treatment in crop 4

Medium Fruit Number	
Grafted Chilli	4.3
Grafted commercial	5.5
Grafted Warlock	10.2
Std Warlock	15.5
SV6947	14.5
Warlock Sept 2014	6

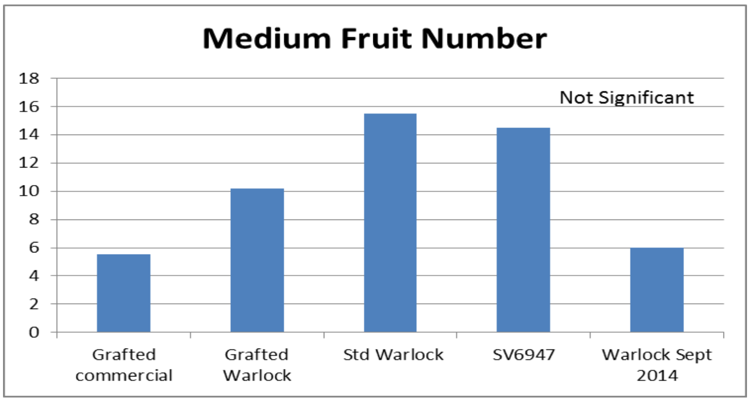
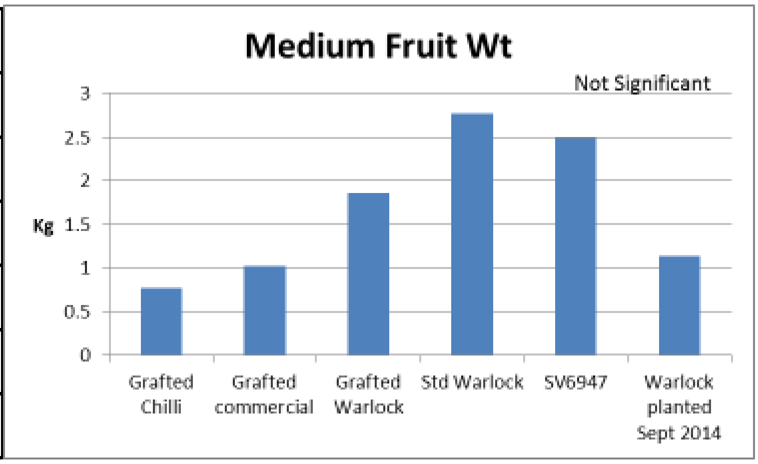


Table 15 Medium fruit weight crop 4

Medium Fruit Wt	Kg
Grafted Chilli	0.76
Grafted commercial	1.02
Grafted Warlock	1.86
Std Warlock	2.77
SV6947	2.49
Warlock Sept 2014	1.13



There was no significant difference in medium fruit weight between treatments with all treatments yielding poorly in this harvest

Marketable Fruit Weight – Crop 4

All treatment material except the Warlock comparison treatments planted in September were 448 days old (1 year 2 months and 24 days) when harvest on April 1st 2015. These plants have been in situ in a plasticulture production situation in the same soil in an open field situation since they were planted on the 8th of January 2014. Comparing the medium marketable fruit weight from the initial crop to those obtained in crop 4 reveals a severe decline in productive fruit output in this period as documented below. Growing the long term trial crop through for a little over 14 months (4 separate crops) was done to test the graft and varietal material plant and root system health and resilience.

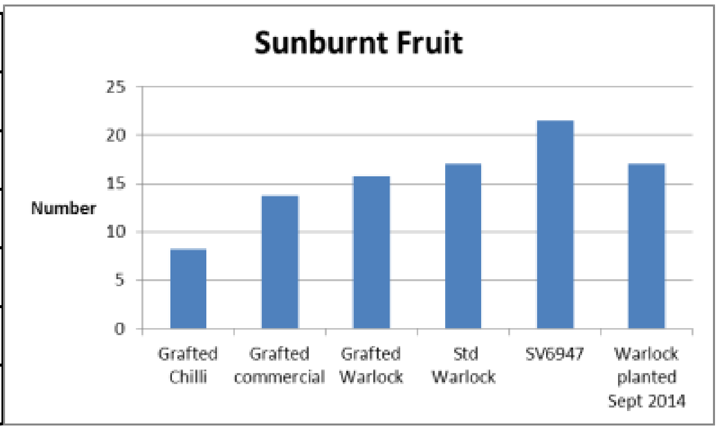
Table 16 Calculated change in marketable fruit yield between crop 1 and crop 4

Treatment	Marketable fruit (Kg) crop 1 16th April 2014	Marketable fruit (Kg) crop 4 1st April 2015	Yield decline % crop 1 to crop4
Grafted Chilli (Caysan)	7.94	0.76	90.5
Grafted commercial (Capsifort)	9.47	1.02	89.3
Grafted Warlock	10.22	1.86	81.81
Std Warlock	10.16	2.77	72.8
SV6947	12.07	2.49	79.40

New crop Warlock marketable yield in crop 4 is not compared above – though results show it yielded poorly (1.13 Kg marketable fruit), though the plant material is considerably younger (211 days) has produced only two crops and been ratooned once. A possible explanation for this may be that it performed poorly due to "sour" soil that had been bedded up and under plastic for 9 months (6th January- 2 September 2014 (239 days) prior to planting. Nutritional differences are not the answer as no irrigation was supplied to the new crop Warlock plots until they were planted in September 2014 when they received the same standard fertilizer applications as the rest of crop 4 (Appendix 4). The plastic covered beds had visibly sunk since first bedded up and had no active plant root system to keep the soil cool and aerated so compaction, soil solarisation (heat under plastic) and lack of aeration may be partly explain this yield result.

Table 17 Sunburnt fruit number per treatment in crop 4 – no significant difference

Sunburnt Fruit Number	
Grafted Chilli	8.2
Grafted commercial	13.8
Grafted Warlock	15.8
Std Warlock	17
SV6947	21.5
Warlock Sept 2014	17

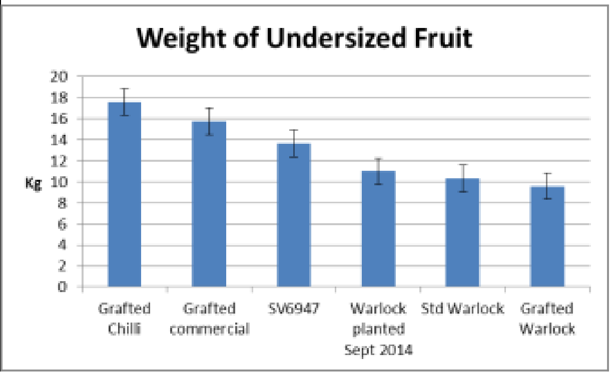


There was no significant difference in number of sunburnt fruit between treatments. A high percentage of fruit from all treatments in this trial was classified as undersized – being less than

75mm in length and unsuitable for sale. There were however significant differences in the weight of undersized fruit harvested from each treatment.

Table 18 Weight of undersized fruit with significant differences between some treatments

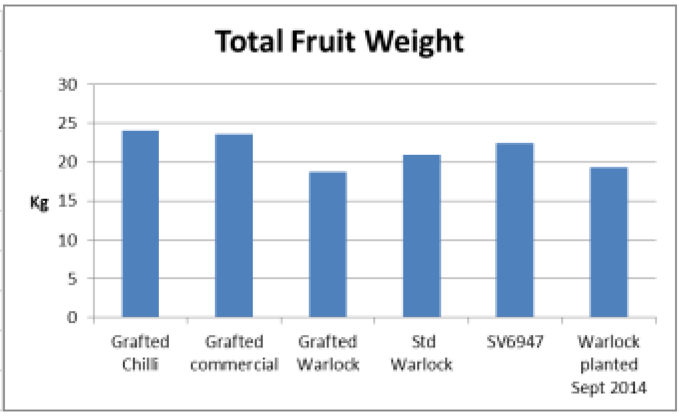
Weight of Undersize	Kg	
Grafted Chilli	17.58	a
Grafted commercial	15.71	ab
SV6947	13.65	bc
Warlock planted Sept	10.99	cd
Std Warlock	10.32	cd
Grafted Warlock	9.59	d
LSD	3.825	



Grafted Chilli (Caysan) and grafted commercial (Capsifort) rootstock produced a greater weight of undersized fruit than new crop Warlock, grafted Warlock, and standard Warlock. The grafted chilli and commercial graft treatments increased the proportion of undersized fruit compared to the Warlock root systems.

Table 19 Total fruit weight – small and medium fruit.

Total Fruit Weight	Kg
Grafted Chilli	24.04
Grafted commercial	23.55
Grafted Warlock	18.76
Std Warlock	20.95
SV6947	22.41
Warlock planted Sept	19.27
LSD	5.462



Marketable fruit yield was poor in all treatments and undersized fruit make up a large percentage of total fruit harvested. There was no significant difference between treatments when comparing total fruit weight harvested from crop 4.

Conclusion

Crop 4 yield results for all treatments indicate a steep decline in marketable yield potential. A high number of small undersize fruit were produced, possibly indicating treatments plants are too old and in severe biological decline. The yield decline documented in crop 4 was not unexpected – the plant is simply too old. A single ratoon treatment – allowing two crops from the one batch of plant material may well maximise yield potential. The crop beds originally bedded up in January 2014 had visible sunk and compacted further exacerbating growing conditions and this too may have contributed to poor yield and may somewhat explain the poor performance of the younger Warlock plants that were newly planted in September 2014 (crop 3).

Root Health Assessment

On the 5th of April 2015, four days after crop 4 was harvested and assessed the root system of 5 plants in each replicate were dug and assessed. This assessment was carried out by carefully using a digging fork to dig 5 consecutive central datum plants from the western row of each treatment replicate.

Sampling procedure

After removing the plastic mulch from the section to be sampled one person operated from either side of the row to be sampled. In a co-ordinated manner, digging forks were used to loosed a section of soil 30 cm either side of the plant stem about 15 cm in front of the stem of the plant. Once loosened the digging forks were placed either side of the plant stem and the plant supported by holding the stem as it was carefully levered from the ground. This was done for 5 consecutive plants, excess soil was scraped off carefully by hand in the field then each plant was carried to the edge of the field and the roots triple washed in detergent water before being hosed off carefully to remove all soil and fully expose plant roots.

After discussion and comparison each root system was then rated visually for root health on a scale of 1 – 5 (5 was very white and healthy with a high number of fine feeder roots, while 1 was discoloured with no small feeder roots and short root length) This assessment scale rated root visual colour density for each of the five individual root systems. The scores from the 5 plants by 4 replicates were then combined to provide an overall root health score – to allow comparison between treatments. We also measured root width from either side of the plant stem and root depth below original ground level. Then as a final step all root systems were photographed.

Once all plants were assessed visually for root health we carefully trimmed and bagged all large and feeder roots from the central stem. This was done by carefully removing all root material at the point where it was joined to the central plant stem below ground level- making sure that no central stem was removed. This root material was bagged by replicate and oven dried to obtain a replicated sample for weighing and statistical analysis.

Figure 42 Photo of standardised root trimming method used to collect roots for weight analysis

Root Health Assessment Results.

Table 20 Root health score

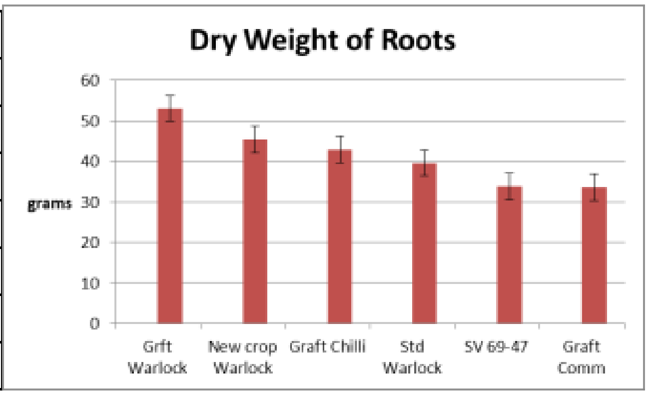
Treatment	Mean Root Health Score (1-5)	
New Crop Warlock	3.150	a
Graft Warlock	2.700	ab
Std Warlock	2.350	bc
Graft Chilli	2.100	bc
Graft Comm	1.975	c
SV 69-47	1.900	c
LSD	0.670	

Statistical analysis of the above root health score determined that new crop Warlock had the healthiest root system, while grafted Warlock had healthier root systems than the grafted commercial rootstock and new variety SV69-47. Standard Warlock and grafted chilli had a similar root health rating to grafted Warlock.

Root dry weight.

Table 21 Root dry weight of each treatment (grams)

Treatment	Mean Dry Root Weight	
Grft Warlock	53.06	a
New crop Warlock	45.36	ab
Graft Chilli (Caysan)	42.85	bc
Std Warlock	39.56	bc
SV 69-47	33.82	c
Graft Comm (Capsifort)	33.55	c
	LSD	9.673



Statistical analysis of trimmed roots from all treatments fifteen months after initial planting of the Gatton long term trial shows that grafted Warlock and new crop Warlock (planted 2nd September 2104 - so 7 months old) had the highest dry root weights (therefore largest root system)of all treatments (**Error! Reference source not found.**Table 21).The grafted commercial rootstock (Capsifort) and the new variety SV6947 had the lowest root dried weight (smallest root system). Grafted chilli rootstock (Caysan) and standard Warlock had similar root dry weights to that of new crop Warlock. Significant differences in root system dry weight have been measured with Warlock roots (as measured by root dry weight) having a greater weight than the commercial rootstock Capsifort and trending to outperforming SV6947.

A review of crop 1 marketable yield data and general yield trends for SV6947 reveals it yields as well, if not better than Warlock material and has the added advantage of setting a single fruit on a leaf node – reducing loss from deformed fruit and simplifying harvesting.

Selected images of root health assessment

Figure 43 Grafted commercial roots after 15 months in soil

Figure 44 Standard Warlock roots after 15 months in soil

Figure 45 Chilli graft (Caysan) roots after 15 months in soil

Figure 46 Variety SV6947 roots after 15 months in soil

Figure 47 Green Giant (older variety) roots after 15 months in soil

Figure 48 Yolo Wonder (older variety) roots after 15 months in soil

Conclusion - Root Health of Planting 1

When dug and assessed for root health all treatments had been growing continuously for 482 days (one year, three months and 27 days). This provided a unique opportunity to observe plant root structure and plant root health differences. There were marked differences visible when the different roots were dug and assessed. The visual assessment score gives a very good quantitative measure of visible differences in root health. Grafted Warlock had a significantly higher dry root weight than the chilli graft, standard Warlock, while root dry weight of new crop warlock was similar – though as detailed above total fruit weight (Table 19) significantly lower. SV6947 and Capsifort had the lowest mean dry root weight. If this data is considered in conjunction with the lack of any marketable medium fruit from crop 4 – it reinforces the hypothesis that all treatment plant material was in biological decline.

Sample size may have also contributed to the inherent variability of these results- though carefully digging 5 plants from each of 4 replicates of 6 treatments is a time consuming task – a larger sample size may have been beneficial. However it is cautionary to consider that Warlock dry root weight from standard warlock is significantly lower than Warlock self-grafted. No doubt small soil differences within the replicates play a part but after such a long time in the soil and producing 4 complete harvests all plant material may simply have been in decline. Given the big difference in dry root weight between Warlock and SV6947, it is interesting to ponder what effect a more robust disease resistant root system may have on yield of SV6947.

Gatton Planting 1 Crop - 5

A second planting of capsicum grafting and ratooning trials was established for the summer of 2015/2016. Treatments for planting 2 were selected based on results from the previous planting (crop 1 – 4), availability of new varieties and to investigate root vigour by grafting to other solanum species.

Project staff were aware of several commercial rootstocks available overseas and tried to obtain seed of this material. Although two potential rootstock varieties were identified while planning this second trial, accessing seed from overseas proved impossible due to seed testing protocols (for contamination by potato tuber spindle virus) required as part of importation of seed from the solanaceae family. The seed testing regime was sighted as a barrier to accessing material not currently available in Australia by international seed supply companies. Australia is still largely unaffected by this virus, quarantine measures are essential in an effort to safeguard Australian agriculture – this overseas material was ruled out

Notes on grafting material

A number of possibilities in the Solanum family were explored as potential alternative rootstocks on which to graft the standard variety "Warlock". When considering and reviewing potential candidate material a number of factors needed to be considered including, availability of seed, knowledge of graft compatibility, potential toxicity and of course weed potential of rootstock material (as if useful seed needs to be produced)

Potential candidates:

Giant Devils Fig;

Wild seed of Giant Devils Fig was collected and sown but germination was slow and poor (15 plants germinated from 200 seeds) and toxicity potential was unknown. Therefore this treatment was not used.

Kangaroo apple (*Solanum laciniatum*)

Key points

Native plant

Has edible fruit when fully ripe

Seed readily available from "Southern Harvest" Tasmania.

Seed was obtained and sown at Withcott Seedlings; 1 full tray for grafting and 20 plants extra to look at the ungrafted plant and for seed collection if necessary. The germination rate was good and seedlings were grafted onto the Warlock scion by specialist grafting staff at Withcott Seedlings. The grafts were slow to take and this graft treatment was held back fourteen days (in the hope the tissue would knit) and only delivered on the the 20th of October 2015. Upon inspection it was clear that the Kangaroo apple grafts had not taken, the Warlock scion was at best weakly attached to the rootstock which had put out new shoots and grown from below the graft. This graft material was obviously incompatible and dropped from field planting. Three partially knitted plants were planted in a trial guard row on the 27th October but ultimately didn't survive. Four ungrafted Kangaroo Apple plants were planted on the southern end of one trial guard row for observation purposes and to obtain fresh seed.

Figure 49 Kangaroo Apple rootstock with failed Warlock scion visible. The graft was unsuccessful and the rootstock has grown on.

Tree Chilli/Rocoto (*Capsicum pubescens*).

Key points

Capsicum genus therefore grafting has increased chance of success

Robust tree growing to 2m therefore must have a well-developed root system

Has edible fruit

Seed readily available from "Southern Harvest" Tasmania

Seed was obtained and sown at Withcott seedlings, the germination rate was good and the seedlings were grafted to Warlock scion by specialist grafting staff. The grafting was successful and the plants were delivered to GRF and planted on the 13th October. A few extra ungrafted plants were planted in the southern end of eastern and western guard row of the trial – to observe canopy morphology and in an effort to obtain fresh local seed.

Figure 50 Warlock grafted onto Tree Chilli rootstock (grafting clip visible)

Naranjilla (*Solanum quitoense*).

Key points

Solanum family

Edible fruit

Seed was available

On inspection of the material we had seeded at the nursery (8th of September2015) germination Naranjilla seed was found to be very poor and as a result of low plant numbers this potential graft treatment was discontinued.

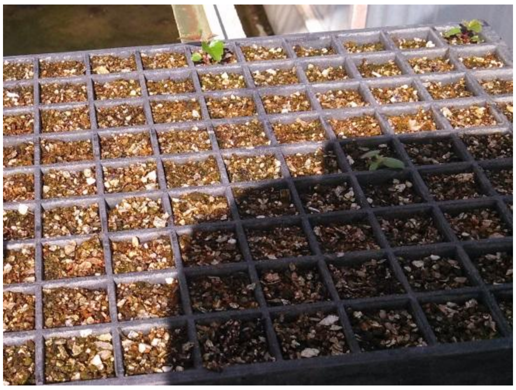


Figure 51 Poor germination of Naranjilla seed

Chilli lines Hungarian Hot Wax and Inferno.

Key points

Same species as capsicum – C. annum

Seed available from "Southern Harvest" Tasmania.

On discussion, the owner of the above company advised these lines were versatile and Hungarian Hot Wax was a robust plant with a good root system. Inferno chilli was also worth considering.

New Varieties SV6947, SV 4856 and SV9699 (Monsanto Australia).

The trial variety SV6947 yielded well in previous trials but upon root system assessment was categorised as having a "poor" root system compared to Warlock plants of similar age (482 days old). Because of the performance of SV6947 in planting 1 it was grafted on to Warlock which after 482 days in the soil had a better root system to examine if this would enhance yields further or impact fruit size.

SV9699 a new (Monsanto) commercial trial line was initially difficult to obtain but eventually a small quantity was obtained for use.

SV4856 another new commercial (Monsanto) trial variety was initially scheduled for inclusion in the trial but at seeding time was not available for use

Gatton-Planting 2 Crop 5

Transplanted 6th and 20th October 2015.

Harvested 22rd of December to 3rd February 2015

Summary

The second Gatton capsicum productivity trial was established at the Department of Agriculture & Fisheries (Qld) Gatton Research Facility, and harvested 3 times from late December 2015 to mid-February 2016.

This trial consisted of 7 treatments with 4 replicates and 1 extra treatment with 2 replicates arranged in a randomised block design and compared and evaluated for their impact on crop productivity. All graft treatments were based on the current industry standard commercial variety Warlock as the scion. The grafted rootstock treatments chosen for evaluation were; Warlock self-grafted (grafted onto itself, Warlock grafted to a chilli plant sold as Hungarian hot wax, Warlock grafted to a chilli plant known as Inferno, non-grafted Warlock, and ungrafted comparison varieties Plato an older established line, a new trial variety SV6947 (both from Monsanto). After the reviewing the results of the high yielding SV6947 from planting 1, we included one extra treatment- SV6947 was kept as the scion and grafted with Warlock as the root stock.

Materials and Methods

Treatments;

1. Plato
2. SV9699 (Monsanto) new trial line
3. SV6947 (Monsanto) grafted but with Warlock as rootstock
4. Warlock on Tree Chilli
5. Warlock self-grafted

6. Warlock on Hungarian Hot Wax

7. Warlock self - grafted (a second treatment as the Kangaroo Apple graft was incompatible)

8. Warlock on Inferno

All graft treatments were based on the current industry standard commercial field capsicum variety Warlock which was used as the scion material, except treatment 3 above which was included to explore the yield potential of SV6947 with a Warlock rootstock. A newly available trial variety, SV9699 was sourced and included in the trial. This new variety is reported to have improved foliar disease resistance against Bacterial leafspot. Bacterial leafspot is caused by a bacterium (*Xanthomonas campestris pv. Vesicatoria).* Unfortunately the Kangaroo Apple rootstock grafts did not take and this treatment was replaced with a duplicate self-grafted Warlock). Each treatment had four replicates as shown on the trial plan. The new trial was established in the field in October 2015 using the same techniques, spacing, plastic beds, dedicated irrigation system, nutrition plan, pest and disease control equipment and procedures utilised throughout planting 1.

Refer to trial plan – planting 1 and planting 2 (Appendix 3)

Harvest

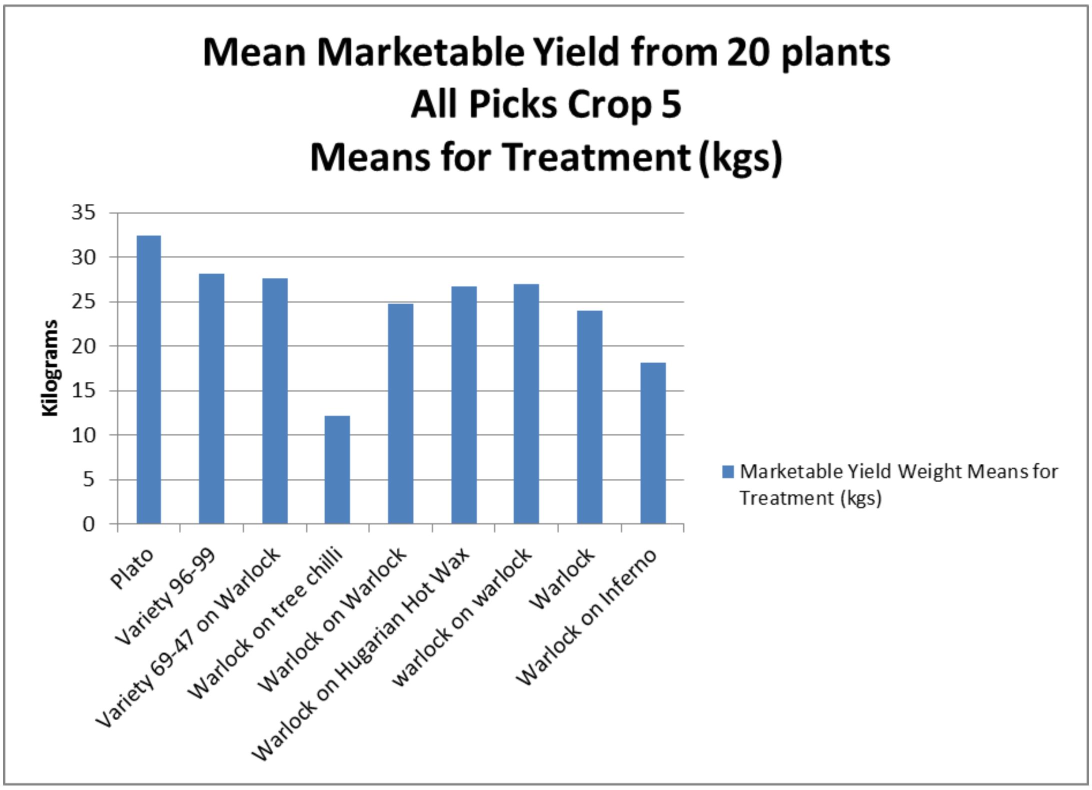
The trial treatments were harvested a total of 3 times as fruit reached the green fully mature stage. The time to first pick was complicated by the fact that two of the treatments planted were held back for 14 days at the seedling supplier in order to harden plants and maximise graft strength. The initial field planting occurred on the 6th of October (treatments 1,2,4,6 and 8) while the final treatments (3,5 and 7) were planted in the field on the 20th of October 2015. The first pick was conducted on the 22nd December 2015 which was 77 days after transplant (DAT) of the first seedlings. The second pick was conducted on the 13th January 99 DAT and the third on the 3rd February 120DAT. Mature green fruit was harvested from the middle twenty data plants of each plot (30 plants). All fruit was graded and sized according to Woolworths specifications for blocky green capsicum (Appendix 5).

The weight/count of medium and large sized fruit was combined to give the category of “Marketable Yield”. The data from each of the 3 picks was combined to give an overall yield for crop 5 and this spaced harvest period was deemed sufficient to account for differences in planting date.

Yield data was analysed by ANOVA using Genstat version 16. Results below are presented as pairwise tests between means using the LSD procedure

Table 22 Mean marketable yield for all 3 picks

Treatment	Mean Marketable Yield (Kgs) from 20 plants	
Plato	32.42	*a*
Variety 96-99	28.1	*ab*
Variety 69-47 on Warlock	27.6	*ab*
Warlock on Hungarian Hot Wax	26.7	*b*
Warlock on Warlock	25.89	*b*
Warlock	23.98	*b*
Warlock on Inferno	18.33	*c*
Warlock on tree chilli	12.1	*d*
Means with same subscript are not significantly different at the P = 0.050 level		



The commercial variety Plato produced the highest mean yield of all the treatments although this was not significantly higher than the new variety SV9699 or variety SV6947grafted onto a Warlock rootstock. These latter treatments were also not significantly different from Warlock grafted onto Hungarian Hot Wax self-grafted Warlock or ungrafted Warlock. Warlock grafted onto Inferno and Warlock onto Tree Chilli yielded significantly less than all the other treatments.

Table 23 Side by side comparison of Large, Medium and Small fruit yields across for all 3 harvests.

Combined Yield from 20 plants All Harvests								
Treatment Yield for Large Fruit			Treatment Yield for Medium Fruit			Treatment Yield for Small Fruit		
Treatment	Mean Kgs		Treatment	Mean Kgs		Treatment	Mean Kgs	
Plato	19.28	a	Variety 69-47 on Warlock	17.71	a	Warlock on Inferno	5.82	a
Warlock on Warlock	10.84	b	Variety 96-99	17.68	a	Variety 96-99	5.66	a
Variety 96-99	10.42	bc	Warlock on Hungarian Hot Wax	16.38	ab	Variety 69-47 on Warlock	5.21	ab
Warlock on Hungarian Hot Wax	10.32	bc	Warlock on Warlock	15.05	bc	Warlock on Hungarian Hot Wax	4.83	abc
Variety 69-47 on Warlock	9.89	bc	Warlock	14.44	bcd	Warlock on tree chilli	4.30	bc
Warlock	9.54	bc	Plato	13.15	cd	Warlock	4.23	bc
Warlock on Inferno	6.27	cd	Warlock on Inferno	12.06	de	Warlock on Warlock	4.00	c
Warlock on tree chilli	2.59	d	Warlock on tree chilli	9.5	e	Plato	3.81	c

The tabulated data above gives a comparison of fruit yield by size category. Plato produced significantly more large fruit than any other treatment, while yield of medium sized fruit was similar to Warlock and self-grafted Warlock; additionally Plato had a low proportion of small fruit. Ungrafted Warlock, a standard industry variety, yielded significantly less than the highest yielding treatment in both the large and medium categories in crop 5.

Continued Harvest Potential before Ratooning

After the third pick in February the plants were cut back to allow adequate time for the plants to regrow in the autumn and before the onset of cold weather.

With the exception of Warlock on Tree Chilli, the plants were still very healthy and vigorous after the third harvest with flowers and small fruit still plentiful. An indication of ongoing harvest potential can be seen in the following table which records the mean number of undersized fruit for each treatment which were below the harvest specifications at the date of the third harvest but would have developed into marketable fruit within the next 21 days had plants not been ratooned. Time constraints required that we ratoon crop 5 prior to a 4th potential fruit harvest, with cool weather approaching we wanted to allow time for plants to regrow and be able to harvest this ratooned material within the project time frame.

Table 24 Undersized fruit number not harvested in the third pick of crop 5

Fruit categorised as undersized from third harvest	
Treatment	Mean Undersize Count for 20 plants
Plato	5
Variety 96-99	14.75
Variety 69-47 on Warlock	14.75
Warlock on tree chilli	13.75
Warlock on Warlock	8.375
Warlock on Hungarian Hot Wax	11.75
Warlock	6.75
Warlock on Inferno	13.06

Deformed Fruit

Fruit deformity was defined as misshapen or out of proportion in either length or width compared to accepted marketable fruit. The highest incidence of fruit deformity was recorded in Warlock grafted onto inferno and Tree Chilli. Many of the fruit harvested from the Warlock on tree chilli treatment were small and flat and more lobbed compared to commercial varieties

Table 25 Deformed fruit number for each treatment

Deformed Fruit Count		
Treatment	Mean number per 20 plants	
Warlock on Inferno	31.67	a
Warlock on tree chilli	30.75	a
Warlock on Hungarian Hot Wax	14.75	b
Plato	13.75	b
Warlock on Warlock	12.50	b
Warlock	11.75	b
Variety 96-99	10.75	b
Variety 69-47 on Warlock	7.50	b
Means with same subscript are not significantly different at the P = 0.050 level		

Figure 52 Warlock on inferno fruit with deformed fruit clearly visible crop 5 pick 3

Figure 53 Warlock on Tree Chilli showing squat fruit crop 5 pick 3

Sunburn

The incidence of sunburn was greatly reduced in this summer crop as a result of the slight shading effect of hail netting which was installed over the crop in early December. The white hail netting was rated as giving between 18- 20% shade and was installed to quantify it's potential to reduce the temperature and direct sunlight impacts on fruit. See separate section -protective netting effects (Appendix 6).

While Warlock on Inferno had a significantly higher number of sunburn damaged fruit, this is understandable as in an effort to maximise the number of graft treatments tested these plots were located on the outer rows of the trial block and therefore had greater potential to suffer sunburn as the netting cover edge hung down 50cm from the wire support cable but did not ameliorate early morning or late afternoon sunlight impacts on the outside row of the Warlock/ Inferno plot. It should be noted that the hail netting was not installed until the 3rd of December 2015 (3 weeks prior to first harvest – hence the majority of sunburn recorded here can largely be attributed to pre-existing sun damage prior to protective net installation.

Table 26 Sunburnt fruit number as a percentage of total count

Number of sunburnt fruit as a % of total count - Crop 5		
Treatment	mean %	
Warlock on Inferno	10.63	a
Warlock on Hungarian Hot Wax	5.47	b
Plato	5.04	bc
Variety 96-99	3.57	bc
Warlock on Warlock	2.78	bc
Variety 69-47 on Warlock	2.62	bc
Warlock	2.25	bc
Warlock on tree chilli	0.85	c
NB: Means with same subscript are not significantly different at the P = 0.050 level		

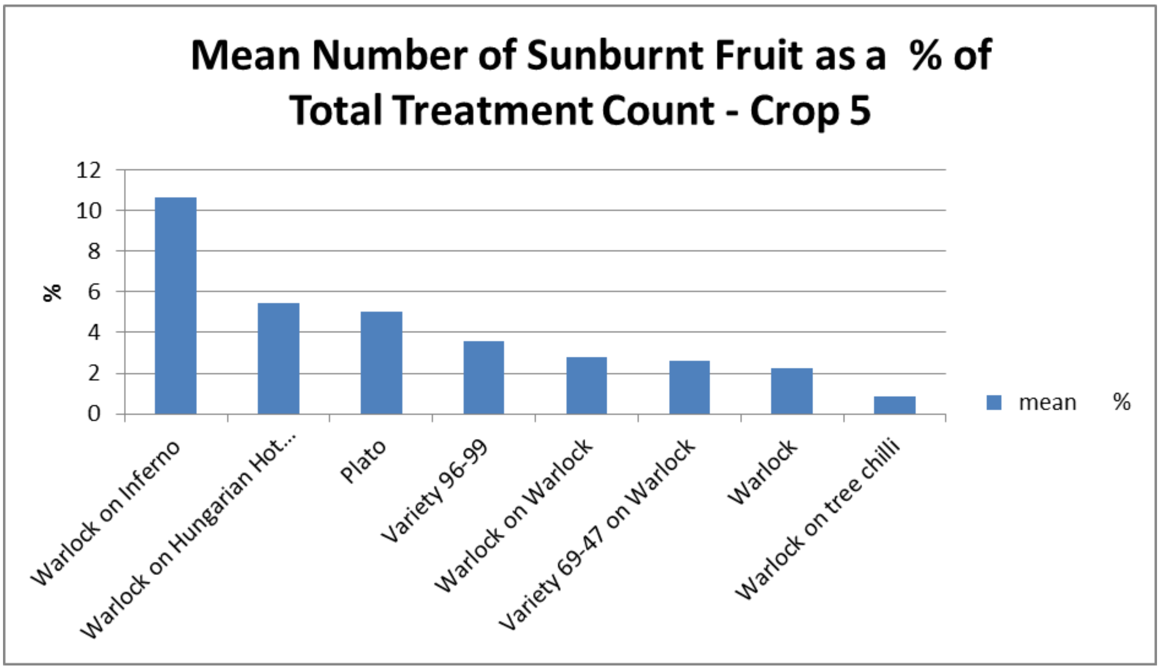


Figure 54 Graph of mean number of sunburnt fruit recorded under the protective netting

Fruit Quality

Fruit quality in crop 5 was consistent across treatments and exceptionally good. The lustrous fruit characteristic was difficult to quantify and unable to be rated - all fruit under the netting was equally good. A local grower who visited and inspected the trial site just after the third harvest and prior to crop ratooning commented on the high quality of the fruit produced by this crop under net in the Gatton summer compared to his field grown fruit of similar maturity. Brian Fisher commented "I can't get over the gloss and shine on the fruit they are more like glasshouse quality". This effect may be due not only to both reduced sunlight and UV light impacts combined with the slightly increased humidity under the hail net cover, resulting in a less "stressed fruit"

Figure 55 In field photo of capsicum fruit showing fruit shine and quality.

Plant size and quality was markedly improved, plants had better colour in under the protective net and this reduced heat stress translated through to better quality fruit and very minimal plant loss during crop 5 and crop 6 when compared to the first four crops.

Plant internode length was also lengthened by the protective net and this is highlighted in images below – but discussed in the Netting Effects section.

Conclusion

The impact of grafting differed depending on rootstock material. Some of the more novel potential rootstock candidates seemed incompatible with the Warlock scion and thus the graft was unsuccessful. The Warlock on Kangaroo Apple graft seemed totally incompatible and resulted in no viable seedlings. The graft union did not knit, the Warlock scion material in the majority of grafted seedlings withered and died and the rootstock which was very vigorous tended to reshoot below the graft. The Warlock on Tree Chilli graft was successful and the plants survived and fruited however the height and vigour of the plants was noticeably less than other treatments in the trial. These plants were smaller in stature than the chilli graft (Caysan) grown in planting 1 and had fruit that was more exposed. The older variety Plato, new variety SV9699 and SV6947 grafted onto Warlock had the highest marketable yields. Warlock grafted on to Hungarian Hot Wax, performed as well as self-grafted Warlock and ungrafted Warlock.

Grafting Warlock onto the chilli variety, Inferno, and onto Tree Chilli resulted in decreased yield and a higher incidence of deformed fruit. When comparing the ungrafted Tree Chilli plants to all other capsicum plants in the trial the aforementioned seemed initially smaller, slower growing and later in setting fruit. At the conclusion of the trial however Tree Chilli plants were taller than all the others.

Figure 56 Ungrafted Tree Chilli plant; centre of photo in an outer buffer row

The incidence of sunburn was greatly reduced in this crop and if the results of Warlock on Inferno are excluded as some of these plants (1 row in each replicate) were on the outside edges of the plots. This meant that direct sunlight fell on fruit in the early morning and late afternoon as the edge of the outer row was directly below the edge of the protective net (no overhang). Results show that the overall mean marketable fruit loss to sunburn is 3.23% markedly less than in crops 1 – 4. A more detailed discussion of these results is presented towards the end of this document in the "Protective Netting Effects" section.

Fruit quality was extremely high in crop 5 with fruit having a noticeably glossy appearance and shine; this is further discussed in the section on protective netting effects.

Figure 57 In field photo illustrating fruit gloss and spacing of fruit on stems under protective net

Gatton-Planting 2 Crop 6

Plants from Crop 5 Ratooned 16th February 2016

Harvested 10th May 2016

The previous crop, Crop 5, was harvested in February 2016 and the plants then ratooned (cut back) mechanically cutting all plants back to around the second node above the main plant fork, approximately 10 centimetres above ground level. Individual plant branching structure also impacted how the plant could be ratooned – some plants having a more branching structure than others.

Figure 58 Mechanical cut back of capsicum plants after the final pick of crop 5

All plants were then allowed to regrow, flower and fruit as outlined in previous crop ratooning discussions. A once over harvest was conducted on the 10th May 2016 when the majority of fruit had attained the green mature fruit stage.

Harvested fruit was size and defect graded to meet Woolworth's specifications as previously outlined (Appendix 5).

Mite Damage

This crop was severely affected by a broad mite infestation in late February/March with serious consequences to crop and fruit development. New and developing leaf and flower buds were damaged, thus some fruit failed to develop, and some fruit which had already formed was scarred and fruit growth inhibited, preventing normal fruit fill and development.

At harvest in addition to normal size grading, fruit was also classified as undamaged, cosmetically damaged or severely damaged. The damage to the fruit in this latter category was deemed to be so severe that fruit shape and size were affected and thus the fruit was counted but not weighed as this weight data would not have been accurate. Fruit development and expansion was inhibited by severe mite damage scarring – preventing fruit epidermis tissue expansion – limiting fruit potential (mite damaged fruit develop an almost corky scarred outer skin)

Marketable fruit yield data was thus compromised as the first fruit on plants was mite affected – though fruit that developed slightly later once the broad mite outbreak had been controlled developed normally. The issue was that the yield potential of the initial fruit set on plants in the affected parts of the trial plot quality was confounded. In order to assess yield potential (after discussion with statisticians) the assumption was made that the proportion of fruit in each size category would have been the same regardless of damage and the mite impacted yield data was adjusted so that the ratio of small, medium, and large fruit that was measured in the undamaged and cosmetically damaged fruit category harvested from each plot was applied to the severely damaged category. The adjusted weight of medium and large sized fruit was then combined to give the category of "Adjusted Marketable Yield".

Figure 59 Example of broad mite damage to side of mature fruit – a result of early damage to young fruit

Figure 60 Severe mite damage affecting fruit size and shape

Figure 61 Developing flower buds affected by broad mite.

Figure 62 Examples of post–harvest grading into the categories "cosmetic" (left) and "severe" (right) mite damage

Crop 6 Yield Results

Table 27 Adjusted marketable yield results

Adjusted Marketable Yield Crop 6		
Treatment	Mean Weight for Treatment (Kgs)	
Warlock	9.03	a
Plato	8.37	ab
SV69-47 on Warlock	7.87	abc
Variety 96-99	6.02	abcd
Warlock on Warlock	5.99	bcd
Warlock on Hungarian Hot Wax	5.70	bcd
Warlock on tree chilli	5.03	cd
Warlock on Inferno	3.26	d
NB: Means with same subscript are not significantly different at the P = 0.050 level		

Whilst the ungrafted Warlock treatment had the highest yield in Crop 6, it wasn't significantly different from Plato, SV6947 on Warlock and the other new variety SV9699. These latter treatments were also not significantly different from Warlock on Warlock and from Warlock on Hungarian Hot Wax. Warlock on Inferno was the lowest yielding treatment significantly lower than ungrafted Warlock.

Sunburn

Table 28 below shows marketable yield weight results for all treatments and it is interesting to note that of all fruit harvested from crop 6 (45.57 Kg in total) only 1 piece of fruit was assessed as affected by sunburn.

Table 28 Marketable yield pick 1 crop 5 for comparison

Marketable Yield from 20 plants; crop 5 pick 1		
Treatment	mean weight (kilograms)	
Plato	15.72	a
Variety 96-99	15.58	a
Warlock on Hungarian Hot Wax	15.25	ab
Variety 69-47 on Warlock	11.63	bc
Warlock on Warlock	11.34	c
Warlock on tree chilli	9.17	cd
Warlock on Inferno	7.49	d
Warlock	6.85	d
NB: Means with same subscript are not significantly different at the P = 0.050 level		

When the yield results from crop 5 pick 1 above are compared with the results from crop 6 where only 1 pick was done, the ratooned crop yields are noticeably less. No purpose is served in attempting to compare these yields between crops 5 and 6 in this instance. There is no doubt that crop 6 lost considerable yield potential because of flower buds and young fruit that were aborted due to severe mite damage suffered at the flowering and early fruit set stage. Crop 5 pick 1 yield is presented here simply to highlight the impact broad mites can have on capsicum yield.

The Effect of Ratooning on Plant Height

Plant Height was measured before the 3rd harvest of crop 5, as well as before ratooning and then again after ratooning and just prior to harvest of crop 6. Thus plants were measured just before harvest February 2016 and just before harvest in May 2016. Ten treatment plants from each plot were measured from ground level to the tip of the apical growing point. As the plants were quite variable in height with some leaning to one side these sets of measurements had a large degree of inaccuracy but were taken in an effort to compare the effect of ratooning on plant height at a similar stage of growth.

Table 29 Plant mean height (mm) for each treatment – comparison of ratoon crop height to first crop height (mm)

Treatment!	Mean Plant Height Dec 2015	Mean Plant Height May 2016
Plato	678	563
Variety 69-47 on Warlock	646	538
Variety 96-99	637	507
Warlock on Hungarian Hot Wax	587	534
Warlock on Tree Chilli	307	447
Warlock on Warlock	508	520
Warlock on Warlock	503	454

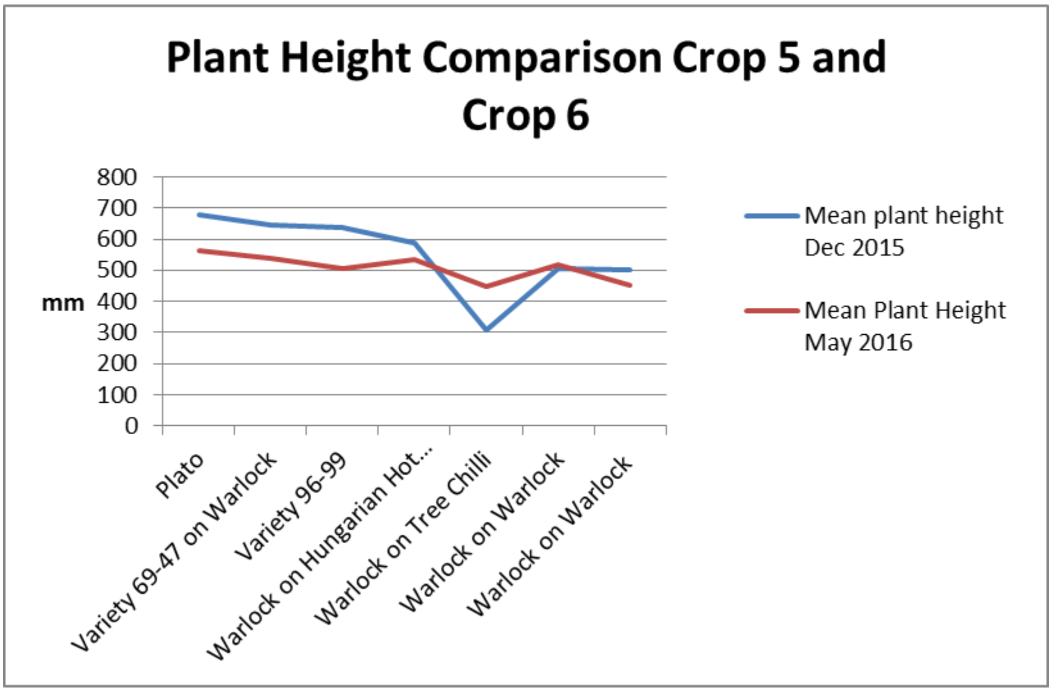


Figure 63 Mature plant height of crop 5 at harvest compared to ratoon plant height at harvest (crop 6)

The graphic above shows some difference in plant heights between crop 5 and crop 6 however the overall height means for crops 5 and 6 of 552mm and 509mm respectively are not significantly different (p=0.106) given the amount of variability in the data. Therefore the assumption is that following ratooning plants regained their pre-ratooning height. Ratooning does not significantly influence plant height potential if temperature, water availability, plant nutrition and pest and disease impacts are similar in the primary and ratooned crop. This is borne out by observation (refer to photographs of crop 3 and crop 4 trellised plants in this report)

Root Health Assessment

After completion of the crop 6 harvest an assessment was conducted to try to quantify any differences in root health between treatments. This assessment was carried out by carefully using a digging fork to dig 5 consecutive central datum plants from the western row of each treatment replicate (20 plants total).

Sampling Procedure

After removing the plastic mulch from the section to be sampled one person operated from either side of the row to be sampled. In a co-ordinated manner, digging forks were used to loosen a section of soil 30 cm either side of the plant stem and 15 cm in front of the stem of the plant. Once loosened the digging forks were placed either side of the plant stem and the plant supported by holding the stem as it was carefully levered from the ground. This was done for 5 consecutive plants, excess soil was carefully shaken off by hand in the field then each plant was carried to the edge of the field and the roots soaked then triple washed in detergent water before being hosed off carefully to remove all soil to fully expose plant roots.

After discussion and comparison each root system was then rated visually for root health on a scale of 1 – 5 (5 being very white and healthy with a high number of fine feeder roots, while 1 was discoloured with no small feeder roots and short root length) This assessment scale rated root visual colour density for each of the five individual root systems. The scores from the 5 plants by 4 replicates were then combined to provide an overall root health score – to allow comparison between treatments. Then as a final step all root systems were photographed.

Table 30 Crop 6 mean plant health visual rating results

Mean Root Health Score		
Treatment	mean rating (1 - 5)	
Warlock on Inferno	3.49	a
Inferno	3.48	a
Plato	3.35	ab
Warlock on Hungarian Hot Wax	3.35	ab
Warlock	3.2	abc
Warlock on Warlock	2.9	bcd
Variety 96-99	2.9	bcd
Hungarian Hot Wax	2.69	cd
69-47 on Warlock	2.55	d
Warlock on tree chilli	1.9	e
NB: Means with same subscript are not significantly different at the P = 0.050 level		

Warlock on Inferno and ungrafted Inferno rated highly for root health but were not significantly different from Plato, Warlock on Hungarian Hot Wax or Warlock. This improved root health was not reflected in yield data from the Warlock on Inferno treatment in fact this treatment had the poorest yield of all treatments. Interestingly Warlock on Hungarian Hot Wax achieved a higher score than ungrafted Hungarian Hot Wax. Warlock on Tree Chilli scored only 1.9 for root health and was significantly poorer than all other treatments which, from observations of its above ground plant mass and yield results, was not unexpected. A limited number of ungrafted Tree chili plants were grown in this trial and the roots also scored, however as only 6 plants were assessed and the root style was quite different to the grafted Tree Chilli roots data cannot be compared. The observation was that the roots were very healthy with more tap and side roots and less fine feeder roots. Due to the size and volume of the root mass, it is probable that a large proportion of roots remained in the ground after the plant was dug up.

Figure 64 Ungrafted Tree Chilli roots on the left and Tree Chilli roots grafted to Warlock on left

Figure 65 Ungrafted Inferno Root System on left with Warlock grafted to Hungarian Hot Wax on right

Table 31 Mean dry weight of treatment root systems – a comparative measure of root mass

Mean Dry Weight of Assessed Plant Roots		
Treatment	Mean (Kgs)	
Warlock	0.043	a
Warlock on Inferno	0.035	b
Warlock on Warlock	0.032	b
Plato	0.031	b
Warlock on Hungarian Hot Wax	0.030	b
Variety 96-99	0.023	c
69-47 on Warlock	0.023	c
Hungarian Hot Wax	0.020	c
Inferno	0.020	c
Warlock on tree chilli	0.020	c
NB: Means with same subscript are not significantly different at the P = 0.050 level		

Warlock had the largest mean root mass with around twice that of variety SV 9699, SV6947 on Warlock, Hungarian Hot Wax, Inferno and Warlock on Tree Chilli. As seen in the root health score means, Warlock on Hungarian Hot Wax performed better than ungrafted Hungarian Hot Wax and Warlock on Inferno had a greater root mass than ungrafted Inferno. This leads to the question – does grafting confer increased vigour on a plant and although this was not the case for Warlock and Warlock on Warlock in this instance. The observation was made that the root system of the ungrafted Tree Chilli plants was very robust and had more major and lateral roots than plants from the Warlock on Tree Chilli plots, and this is reflected in the non- reportable observation data. The mean root dry weight of 5 ungrafted Tree Chilli plants was 0.074 Kgs.

When washing and assessing treatment root systems the observation was made that some treatments had increased scarring and nodulation of plant feeder roots compared to others. This observation lead to all treatments being rated for root scarring, with the results are presented below.

Table 32 Results of rating mean scarred feeder severity

Treatment	Plots with root scarring on some plants (%)
Hungarian Hot Wax	0
Inferno	0
Variety 96-99	0
Warlock on Hungarian Hot Wax	0
Warlock on Inferno	0
Plato	25
Warlock on tree chilli	25
69-47 on Warlock	75
Warlock	75
Warlock on Warlock	100
Warlock on Warlock	100

The scarring was observed more frequently in plants where Warlock was either the rootstock or growing on its own roots. Warlock on Tree Chilli and Plato had only slight scarring in one replicate.

This scarring was thought to be caused by infection by either *Pythium spp.* or *Rhizoctonia spp* and was investigated as its occurrence did not seem random across plots.

Figure 66 Warlock on Warlock with roots displaying scarring and nodulation (left) and Hungarian Hot Wax with unscarred roots (right).

Figure 67 Warlock on Warlock roots, sample of 5 plants from one replicate

Samples were taken from the butts (below ground level) of 5 plants from replicate 4 only and disease isolations were performed in the DAF Gatton plant pathology laboratory. The following pathogens were isolated using a range of techniques - 6 plates from each of 5 treatment plants were cultured except in the case of Pythium where only 2 plates from each of 5 treatment plants were cultured. Results indicated that the Fusarium species was either *F. oxysporum* or *F. solani* while the Pythium spp was possibly *P. myriotylum*.

Table 33 Pathogen sampling results to try and identify root scarring causal organism

	Pathogen Incidence- number of plates					Plots with root scarring on some plants (%)
Treatment	Fusarium (from 30 plates)	Trichoderma (from 30 plates)	Pythium (from 10 plates)	Cladosporium (from 30 plates)	unknown/other	
Warlock on Warlock	0	7	2	1	0	100
Warlock on Tree Chilli	10	0	0	1	0	25
Warlock on Warlock	5	1	1	1	0	100
69-47 on Warlock	5	0	0	2	2	75
Warlock on Hungarian Hot Wax	15	0	0	1	1	0
Variety 69-99	20	0	0	5	1	0
Plato	9	1	0	7	6	25
New Warlock	3	0	0	0	4	
Hot Wax	26	0	5	0	1	0
Inferno (4 plants)	7	0	1	2	3	0
Tree Chilli	19	present	7	0	0	0

Table 34 Incidence of Fusarium and root scarring

Treatment	Fusarium	Scarring
Warlock on Warlock	0	100
Warlock on Tree Chilli	10	25
Warlock on Warlock	5	100
69-47 on Warlock	5	75
Warlock on Hungarian Hot Wax	15	0
Variety 69-99	20	0
Plato	9	25
New Warlock	3	
Hot Wax	26	0
Inferno (4 plants)	7	0
Tree Chilli	19	0

Table 34 appears to show little correlation between pathogen prevalence and root scarring, in fact if anything it is an inverse correlation with the highest incidence of Fusarium present in ungrafted Hungarian Hot Wax, SV9699 and Warlock on Hungarian Hot Wax all of which had no scarring observed during root assessment. A very low incidence of Pythium was found but under severe disease pressure would the plants with no scarring be more tolerant / resistant to infection and thus outperform Warlock and Warlock grafts in survival and yield.

Conclusion

Crop 5 was cut back in February the ratoon regrowth of crop 6 was rapid and lush with the plants returning to an at similar plant size to that of crop 5 as indicated by the mean plant height data obtained prior to the last harvest of crop 5 and the first harvest of crop 6.

Adjusted marketable yield of crop 6 (once over harvest) was less than that of crop 5 pick 1. Warlock, Plato, SV6947 on Warlock and SV9699 were the highest yielding treatments in crop 6. Broad mite damage severely limited the yield potential of this crop – a timely reminder of the impact pest (in this case) and disease outbreaks can cause. This pest infestation severely limited marketable yield – fruit size, number and quality – a blow to productivity.

Results of assessing all treatment roots at the conclusion of the trial gave root health scores ranging from 1.9 and 3.5. This visual assessment system seems informative and representative with the Warlock on Tree Chilli graft treatment which was visually quite poor also returning the lowest score. The roots of ungrafted Tree Chilli however were robust and had twice the dry weight of most of the other treatments – one possible explanation for this difference is a graft/ scion effect conferring a dwarfing effect to the root system. The chilli variety Inferno rated highly for root health as both a rootstock and an ungrafted plant and as a rootstock had the second largest mean root dry weight. Hungarian Hot Wax performed moderately well in both the root health and weight assessment

The observation was made that Warlock as both a rootstock and ungrafted plant had noticeable scarring and nodulation of the roots compared to the chilli and SV9699 roots. While this scarring was thought to be a result of Pythium infection, laboratory isolations showed this was not the case. However this scarring is likely to be the result of an infection at some stage during crop growth which has not affected the roots sufficiently to impact plant growth. Further research may be useful to determine how well these different rootstocks performed under significant disease pressure and whether those roots without evidence of scarring would have greater tolerance or resistance to disease. In light of the performance of Hungarian Hot Wax as a rootstock with a Warlock scion it’s marketable yield, good score for root assessment and lack of root scarring, future opportunities to assess it as a rootstock with a Plato ,SV9699 or SV6947, or another scion would be valuable.

Protective Netting Effects

Sunburn damage to capsicum crops in the Lockyer Valley summer capsicum cropping season results in substantial plant productivity losses and local growers rely on above average summer capsicum prices to offset this impact (B Fisher, pers comm). Due to the high incidence of sunburn and subsequent loss of marketable fruit experienced and documented in planting 1 crop 1 and 3 (2014) and detailed below, options and techniques for minimising damage were investigated in planting 2.

A number of potential possibilities were investigated and evaluated including floating row covers, shade cloth, and sprayed on sunburn protection products. The disadvantages of floating row covers in a research situation included difficulty in accessing plants for measurement and monitoring and uncertainty as to how they would affect growth and normal plant development. The use of floating row covers in a commercial crop presented similar practical challenges; accessing the crop for pest and disease monitoring and control, keeping individual row covers fixed and in place, as well as a handling system to deploy and remove row covers (initially and at each pick). Protective sunburn coating products have given differing results, with some products difficult to remove from fruit prior to harvest, making them less marketable. The most practical and commercially adaptable option for protecting summer crop plants and fruit from sun impacts was to develop and install a low cost crop shade structure that allowed good crop access, and good air movement. The low cost structure needed to be structurally sound but affordable and practical. Initially commercial shade cloth was considered, however shade percentage, product width (4 m cloth width meant high manufacturing cost to cover a large area) and product weight made this option unsuitable. Further investigation revealed hail net to be a viable option with a 10 - 15 % shade factor (manufacturer advised would be 10%) and 21% UV reduction (dependant on how much the material was stretched when erected (stretch%), wider material width (6.5m allowed reduced fabrication cost) and a lower product weight of 75 g/m^2 (compared to 90 g/m^2 for shade cloth) – meaning less weight in a cover designed to be 50m long and 9m wide. The shade canopy was designed in two pieces, so that it could be retracted (half to either end) when harvesting – then re-joined at the centre and tensioned to protect the crop between picks. White hail netting was installed above the trial crop utilising a low cost structure to quantify its potential to reduce high temperature impacts and lost productivity caused by fruit sunburn. Koppers® log posts (two corner posts at either end and one post in the middle on each side 25 m from either end) were used to support the finished structure that was approximately 1.64 metres above ground level and fully covering the trial plot. Supply and manufacturing delays (two 6.5 m wide strips had to be cut and sewn together to form the 50 m long by 9 m wide protective cover) meant the protective cover was installed over the maturing crop on the 3rd of December 58 days after the first seedlings were transplanted and 19 days prior to the first harvest.

Figure 68 Shade structure being built – Koppers® logs and stay posts installed.

Figure 69 Baler twine rope was used to support the weight of the net.

Figure 70 Edge of netting showing attachment with loose zip ties to support wire allowing for easy cover retraction.

Figure 71 Netting retracted to the ends of the trial area to enable harvest

Figure 72 Netting sections being re-joined after harvest

Sunburn Reduction

The purpose of installing the hail netting was as a protective net structure to reduce marketable yield loss due to sunburn and improve crop productivity. Recorded rates of fruit sunburn were extremely high in previous crops as can be seen below in tables 35 & 36. Crop 1 which was grown through the period January – April 2014 had a mean fruit sunburn incidence of 10.23% and Crop 3 grown through the September – late November 2014 period had a mean fruit sunburn incidence of 34%.

Table 35 Mean sunburn damage for each treatment in crop1

Percentage Sunburnt Marketable and Small; Crop 1	
Treatment	**Mean % Sunburn**
Warlock / Warlock	**13.82**
Grafted Chilli	**13.42**
Warlock	**11.66**
SV 6947	**10.47**
Graft Comm	**9.10**
G Giant	**6.69**
Y Wonder	**6.48**
Mean	**10.23**

Table 36 Mean sunburn damage for each treatment in crop 3

Percentage Sunburnt Fruit; Crop 3	
Treatment	Mean % Sunburn
Warlock / Warlock	42.52
Warlock	42.00
Grafted Chilli	34.22
Graft Comm	32.57
SV 69-47	27.61
New crop Warlock	25.30
Mean	34.04

Crop 5 was grown without the protective netting for the initial 58 days of the crops life with the protective netting installed on the 3rd December 2015. The crop was then harvested in three picks on the 22nd December 2014, 13th January and the 3rd February 2015. The mean loss of marketable fruit due to fruit sunburn for crop 5 pick 1 (grown through the period 6th October to 22nd December 2015) was 7.7%. The fact that the protective net was installed only 3 weeks before the first harvest when mature fruit were filling on the plants meant that in the first pick there was an expectation that there would still be some sunburn.

It is informative to compare the mean sunburn damage % in pick 1 to the overall mean sunburn incidence for the 3 combined picks of harvest 1. The overall loss of marketable fruit to sunburn in crop 5 was 4.15% with an extremely low incidence of sunburn in pick 2 and 3 of crop 5

Table 37 Mean sunburn damage for each treatment in crop 5 pick 1 under protective net

Percentage Sunburnt Fruit Pick 1; Crop 5	
Treatment	Mean Sunburn as % of total count
Warlock on Inferno	29.72
Plato	11.34
Warlock on Hungarian Hot Wax	8.64
warlock on warlock	8.26
Variety 96-99	5.63
Variety 69-47 on Warlock	2.15
Warlock on Warlock	1.47
Warlock on tree chilli	1.19
Warlock	0.93
Mean	7.70

Table 38 Mean sunburn damage for each treatment in crop 5 all picks under protective net

Percentage Sunburnt Fruit (% of 3 combined picks) - Crop 5	
Treatment	Mean % Sunburn
Warlock on Inferno	10.631
Warlock on Hungarian Hot Wax	5.471
Plato	5.041
Variety 96-99	3.57
Warlock on Warlock	2.779
Variety 69-47 on Warlock	2.615
Warlock	2.245
Warlock on tree chilli	0.848
Mean	4.15

When comparing the overall mean of 34.4% fruit sunburn in crop 3 and 4.15% fruit sunburn in crop 5, both crops that were grown at similar times of the year, (growing period; September – late November 2014 and October – late December 2015 respectively), it is clear that there is a dramatic decrease in yield loss due to sunburnt fruit. This result combined with the drop in sunburn between the first pick and the two subsequent picks carried out in crop 5 support the hypothesis that the protective netting would decrease fruit sunburn.

Figure 73 Fruit under netting which, although exposed on the bush, shows no sign of sunburn.

Temperature Differences

Temperature and humidity logging iButton® sensors (web reference: www.maximintegrated.com/en/products/ibutton/ibuttons/thermochron.cfm) were placed in the trial area at a standardised height of 0.5m above ground level in the same inter row (bare soil walkway between the same crop rows). Each sensor station consisted of two individual iButtons® with one station under the protective netting and the other outside in direct sunlight. Each logger station consisted of two iButtons®, suspended within a cardboard cup to prevent direct sunlight hitting the metal logger bodies (similar to a Stevenson Screen however the cups were closed at one end preventing uninterrupted airflow). This may have confounded the readings slightly as some warm air could be trapped against the closed end of the cup (preventing a fair comparison of site data with BoM temperature data) however a direct comparison of under net and outside net readings is still relevant and informative. Both temperature and humidity were logged automatically every hour from the 24th of December 2015 until the 15th of February 2016. The data was then downloaded to a computer at the conclusion of the recording period and data from the two iButtons® at the under net and outside net stations were each averaged to give a mean under net and outside net data set for comparison.

A large amount of data was generated using this methodology throughout this experiment. In order to compare and analyse the temperature and humidity data to quantify the impact of the protective net, it was decided to compare daily readings under and outside the protective net based on each days hourly readings taken at 1, 2 & 3 pm in the afternoon. Hourly temperature and humidity varies daily depending on a range of factors so in order to allow a fair comparison of long term impacts of the protective cover on maturing capsicum fruit this standard time window comparison was employed. The graph below represents a standard time at which to compare readings, 1pm, 2 pm and 3pm daily. This time window may not represent the highest maximum temperature or humidity difference under and outside the protective net but was chosen as a standardised comparison window.

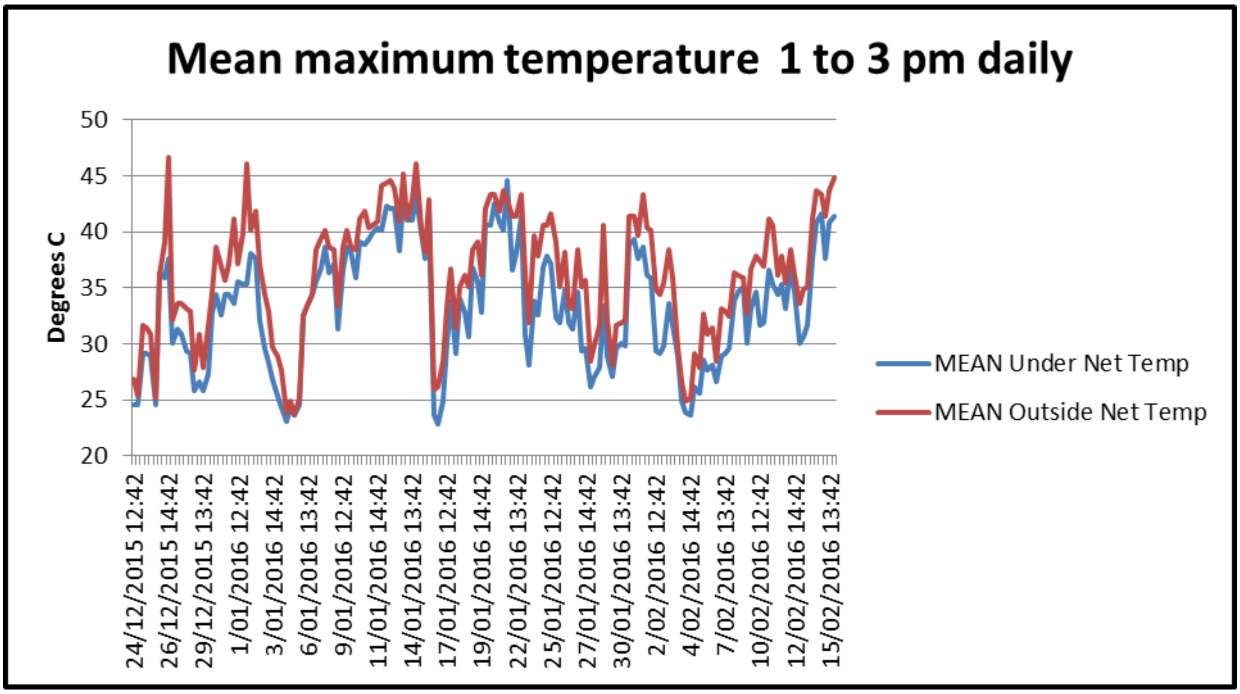


Figure 74 Mean daily temperature (1 - 3 pm) crop 5 and 6 under protective net and outside protective net

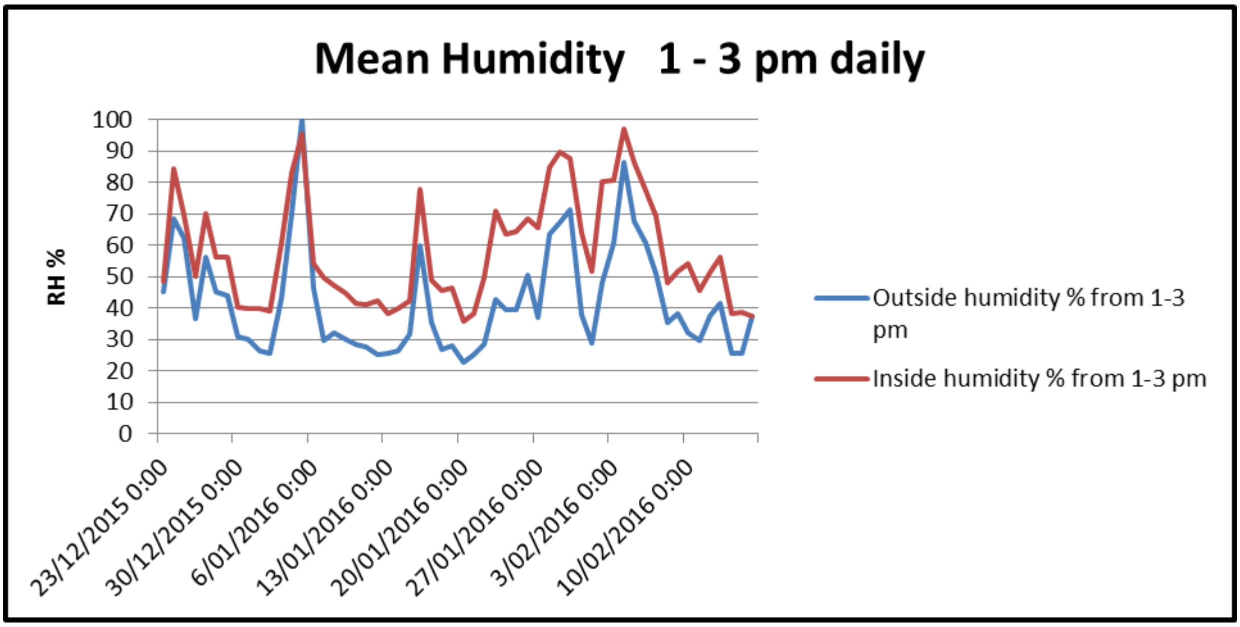


Figure 75 Mean daily humidity (1 - 3 pm) crop 5 and 6 under protective net and outside protective net

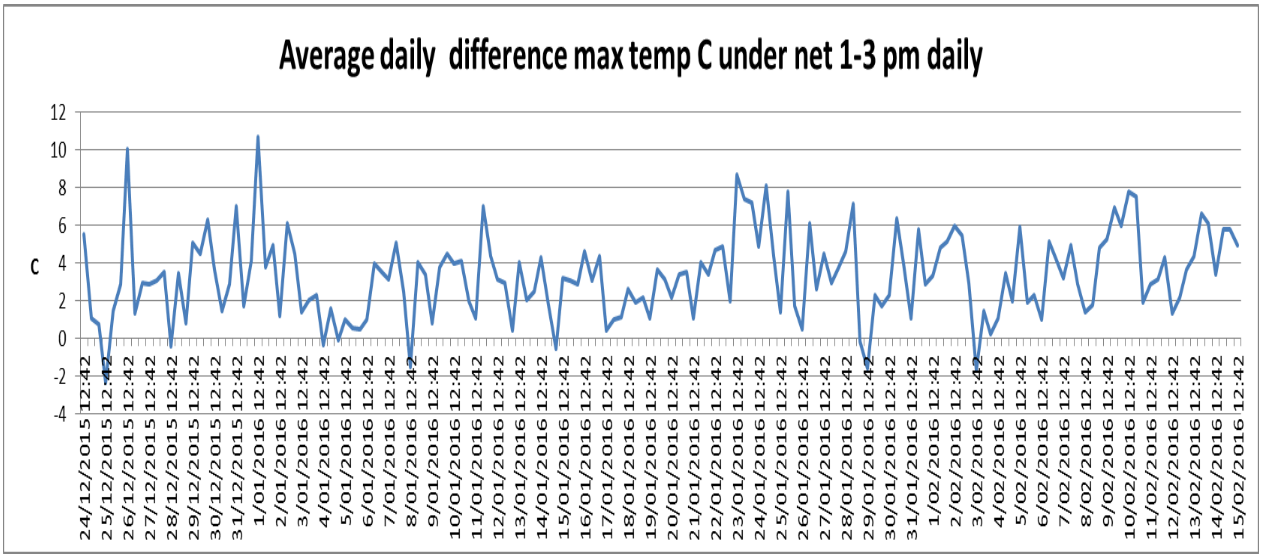


Figure 76 Mean daily temperature difference (1 - 3 pm) crop 5 and 6 under protective net and outside protective net

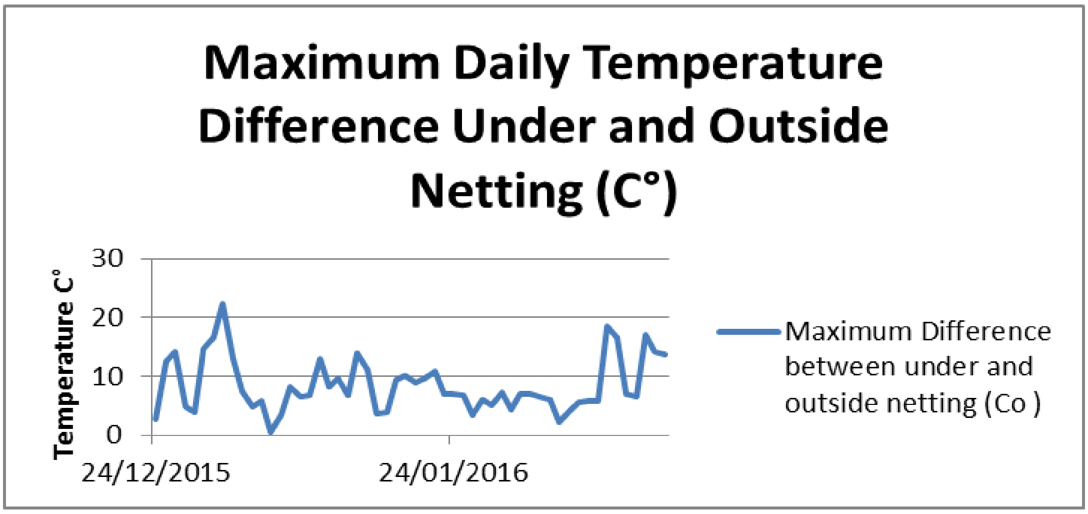


Figure 77 Maximum daily temperature differences (10am and 2 pm) crop 5 and 6 under and outside net

The above graph illustrates the variability and maximum temperature difference fluctuations experienced under the protective net compared to outside the protective net between 10 am and 5 pm daily from the 24th of December 2015 until the 15th of February 2016. The protective netting ameliorated the high temperature periods as illustrated in the previous graph.

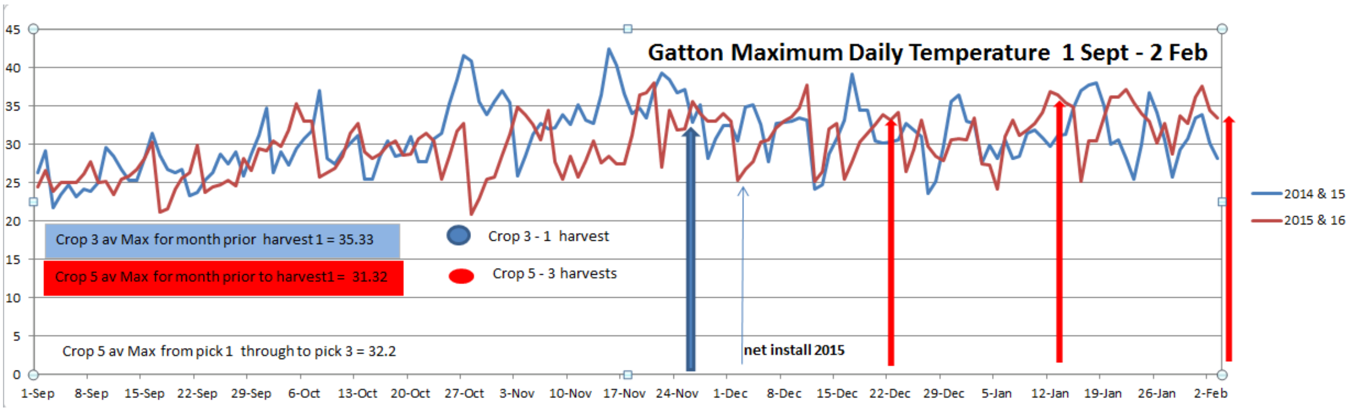


Figure 78 Maximum daily temperatures at Gatton (BoM site) comparing crop 3 and crop 5 daily maximums

The above graph displays the daily maximum temperatures at the BoM University of Qld site – approximately 1 Km south east of the Gatton trial site. Maximum temperatures experienced for Crop 3 harvested in one pick on 25 November 2014 are indicated in blue – as is the harvest date. Crop 5 grown from December 2015 to February 2016 maximum daily growing temperatures and harvest dates are indicated in red. Though it was not as abnormally hot when crop 5 was picking compared to crop 3 – local growers still suffered significant fruit loss due to sunburn. The impact of the protective net on reducing the maximum air temperature under the net compared to outside the net is represented graphically above. The data reveals that the mean temperature reduction under the protective net was 3.97° C between 1 and 3 pm in the cropping period from the 24th of December until the 15th of February 2016.

The impact of the protective net on humidity around the crop canopy under the protective net compared to outside the net is represented graphically above. The data reveals that the mean humidity difference under the protective net was an increase of 10.39 % between 1 and 3 pm in the cropping period from the 24th of December until the 15th of February 2016

This data reveals the major impact a simple protective net structure can have on field grown crop productivity. Marketable fruit loss to sunburn was reduced from 34% in crop 3 to below 4% in crop 5 a significant 30 % reduction.

Measured Light Level Outside and Under Protective Net.

Light (LUX) transmission readings were taken on 4 different days at a standardised height of 450 mm above ground level under protective netting and outside the netting using a Digitech QM1587 light (lux) meter. Data is presented below to document findings. Mean light transmission reduction was in the order of 25 % compared to prevailing light levels.

Table 39 Light transmission measurements

Date	Time	Outside net	Under protective net	Difference %
11 Feb 2016	8.00 am	47000	35200	25.1
	1.00 pm	97800	72600	25.7
16 Feb 2016	10.45 am	93200	68500	26.5
	11.30 am	99000	74600	24.6
17 Feb 2016	9.30 am	84500	52500	37.8
	1.00 pm	90000	68700	23.6
	11.00am	74500	60600	18.6
5 March 2016	1.00 pm	86000	66600	22.5
Mean light reading difference				25.55 %

Figure 79 Digitech QM1587 light (lux) meter

Plant Internode Length.

An unanticipated positive outcome of the use of the netting was an increased plant stem internode length. This outcome is reported as an observation only in these results as it was not measured effectively but noted and documented in the following photos. Measurement of internode length was carried out but is not reported here due to the large variability between plants and treatment (sample size of 10 plants from 4 replicates not sufficient) and there were no plants grown in the open field to facilitate a direct effect comparison. The slight plant etiolation is hypothesised to be a direct result of less light inception and UV radiation under the net causing the plants to elongate slightly

Due to the elongated stem internodes, fruit spacing was ideal for optimal fruit development, unlike in earlier crops there were very few deformed fruit recorded at harvest. This deformed fruit is the result of fruit clustering and impaction between closely spaced fruit and plant stems and branches. This is a common issue mentioned by growers and was an observation from planting 1.

This observation of the effect of a protective net on internode length could be useful to examine in the context of the development of automated harvesting methods, as fruit spaced along a stem would be easier for a robotic device to both identify and harvest.

Figure 80 Photos above showing elongated internodes and well-spaced fruit and flowers of protective net treatments

Fruit Quality

Another unexpected outcome of installing the netting was the improvement of the visual appearance of all fruit. Capsicum fruit harvested from under the netting were shiny with smooth skin and looked as though they had been polished. Such lustrous fruit was not seen in previous crops and was quite different from fruit on other plants with no net covering we had assessed and graded from previous non-netted crops. Fruit quality and finish were greatly improved with crop 5 marketable fruit having a distinctive lustrous shine and full firm fruit appearance. The increased humidity under the protective net countered the prevailing hot dry open field environment nearby resulting in noticeably fruit quality improvement.

We were not able to measure this improved quality but a local grower who visited the crop was very impressed with the quality and commented that it was what he would have expected form glasshouse grown fruit. This fruit quality effect may be due to the reduced sunlight and high UV light impacts as well as slightly increased humidity under the protective net cover, resulting in a less "stressed" fruit.

Figure 81 Large fruit from protected net crop – note gloss on all fruit

Figure 82 In field photo illustrating fruit quality.

Conclusion - Protective Netting Effects

The results of installing the protective net structure with a nominal 12% light and 21% UV reduction factor proved that sunburn damage could be reduced to very low levels under the high temperature growing conditions encountered during the summer of 2015/2016. From a productivity and marketable yield perspective this was arguably one of the more interesting and widely applicable findings of the trial series. Protective net could be adopted by growers to mitigate the effects of fruit sunburn and thus has the potential to markedly improve the viability of capsicum production in the Lockyer Valley and other high temperature growing locations. This technique also has the potential to extend the production window in north Queensland capsicum areas. Further trials could validate these results, investigate different types of netting (e.g. colours) and utilise a high clearance post structure so picking can occur without retracting the protective netting.

The quality of fruit grown under the netting compared to earlier r capsicum crops which were grown without netting was visibly improved. Although the fruit bloom was unable to be quantified the positive feedback given by a grower and by other GRF staff supports the concept that netting deserves further investigation as a means of improving both quality and marketable yield.

Apparent lengthening of the stem internode seemed to influence fruit spacing thus minimising crowding of the fruit resulting in less deformity and improved fruit shape. This trait warrants further investigation as it has the potential to improve the efficiency of any robotic harvesting technology which may become available in the future. Robotic harvesting operations would benefit not only from better spaced fruit of higher gloss (easier to detect robotically) but also potentially from a reduction in light reflection and refraction under the protective net.

The use of shade structures has the potential to improve the yield and quality of marketable capsicum fruit in the Lockyer Valley and potentially other capsicum growing areas in Queensland.

- Thus further trials are warranted with respect to;
- Structure design and optimisation,
- Cost effectiveness,
- Suitability under varying environmental conditions,
- Potential negative outcomes,
- Impact of reduced light on plant architecture, resulting fruit quality improvement and potential for easier mechanical harvesting.

Note to reader

The North Queensland capsicum productivity trial was grown in Bowen in the winter of 2014. It is reported here separately and last as the above Gatton long term trials represent a continuous production run that shows how the capsicum productivity trial process developed and evolved when coping with high temperature summer production challenges.

The Bowen work reported below includes a small observation trial carried out in a protective cropping structure in Giru.

Bowen Trial Summary.

Transplanted; 25th June 2014

Harvested; 8th October 2014

The Bowen capsicum productivity trial was planted on the twenty fifth of June 2014 Department of Agriculture, Fisheries Bowen Research Station and harvested in a once over pick on the eighth of October 2014. The trial consisted of 6 treatments with 3 replicates arranged in a randomised block design. To facilitate a once over harvest fully mature fruit were allowed to achieve full red colouration prior to harvest.

Treatments;

1. Chilli "Caysan" (South Pacific Seeds) used as rootstock grafted to Warlock
2. Commercial rootstock "Capsifort" (Monsanto) grafted on to Warlock
3. Warlock ungrafted (standard)
4. SV6947 (Monsanto) ungrafted newly available trial variety
5. Wild Malay Eggplant used as rootstock grafted to Warlock (Monsanto). A Northern Territory tomato grower found that a yellow fruited "Wild Malay Eggplant" (WME) was a better bacterial wilt resistant rootstock for tomatoes than some other commercial tomato rootstocks.(B. Conde (NT DPI) – pers comm). The Solanaceae family of vegetables include potatoes, tomatoes, eggplant, capsicum and chillies. Seed of Wild Malay Eggplant was sourced so that we could test if this rootstock could be utilised to combat soil diseases in capsicum - a solanaceous crop related to tomato. Unfortunately despite considerable effort and expertise this graft union was found to be physically incompatible as a rootstock material for *capsicum annum* –. The graft union did not fully take (knit) - was not sound and unsuitable for commercial field planting. The WME graft treatment was unable to be planted and was replaced with spare plants of the new trial variety giving a second treatment of the new variety SV6947 at the Bowen site
6. Warlock grafted to Warlock – to determine the effect of the process and stress of grafting

All graft treatments were based on the current industry standard commercial field capsicum variety Warlock which was used as the scion material.

Overview of Bowen productivity treatments.

Chilli rootstock - there has been some limited previous work examining the differences in architecture of chilli root systems. Commercial chilli growers reported some variation in the performance of chilli varieties after flooding and crop stress (Auschilli- Pers comm). **Caysan** chilli was suggested as a very robust chilli line that out - performed other commercial varieties after floods and in periods of crop stress.

Capsifort a commercial rootstock (Monsanto) originating overseas but available in Australia has claimed advantages of more fruit of first quality and gives possibility of growing under nematode and phytophtora pressure.

Wild Malay Eggplant, a Northern Territory tomato grower found that a yellow fruited "Wild Malay Eggplant" (WME) was a better bacterial wilt resistant rootstock for tomatoes than some other commercial tomato rootstocks.(B. Conde (Northern Territory DPI&F) – pers comm). Unfortunately this graft union was found to be physically incompatible as a rootstock material for *capsicum annum* – despite considerable effort and expertise. The graft union was not sound and unsuitable for commercial planting. This graft option was eliminated in subsequent trials**.**

New material, variety SV6947 (Monsanto) available as a new trial line improved bacterial leaf spot resistance and improved fruit quality claims

Warlock grafted to Warlock – to quantify any impact of the graft process on plant performance

The Bowen trial site offered a unique trial opportunity in June 2014 to examine root system performance in both a conventionally prepared cropping system and a permanent bed system – managed as one trial site in one location. In addition to examining graft impact on yield in a standard cropping system, we were able to compare and contrast yield outcomes in an established permanent bed cropping system where the permanent beds were entering their third year of cropping.

The six productivity treatments were replicated three times in both the freshly prepared "conventional beds" and in the existing permanent bed system.

The Bowen trial site grafting treatments mirrored the DAF (Qld) Gatton Research Facility planting treatments. Six treatments were compared and evaluated for their impact on productivity. All graft treatments were based on the current industry standard commercial variety Warlock as the grafted scion.

Methodology - Bowen Field Trial.

The Bowen capsicum productivity trial was setup within a 6,000-m^2 minimum tillage field trial area at the Department of Agriculture, Fisheries Bowen Research Station.

The trial design was a randomised block design with six capsicum productivity treatments replicated 3 times, thirty plants per treatment with the 20 plants in the centre of each plot use as datum plants. The trial treatments were planted within two main tillage systems tested: 1/ a permanent bed system with beds that were formed once (in 2011), with a buried drip irrigation tape, and that had not have a complete soil disturbance in since 2011 but which had a black biodegradable film mulch (Mater-Bi Novamont®) and 2/ an intensive tillage system, where planting beds had been formed every year after multiple soil tillage operations and with annual use and disposal of polyethylene drip irrigation tape and polyethylene film mulch (the industry standard production regime -known as 'plasticulture'). The minimal soil disturbance in the permanent bed system was produced by zone tillage with a pair of wavy discs. A detailed explanation of the agronomical practices used in the trial can be found in the project report by Pattison et al. (2013).

In the standard tillage system, base fertilisers were incorporated into the soil when bed forming just prior to laying plastic and post planting via fertigation through drip irrigation. In the permanent bed system fertigation was used to apply fertilisers throughout the cropping cycle. The standard tillage and permanent bed systems both received a total of 125 Kg / ha of nitrogen in total as part of a balanced nutrition program. Pest and disease control and irrigation were carried out in accordance and standard industry practice for a Bowen winter capsicum crop.

The trial was planted on the 25th of June 2014 using a conventional water-wheel transplanter. Plants were transplanted as per standard practice, two rows per bed with an intra-row plant spacing of 39 cm (plant density: 32,050 plants/ha). The trial area was harvested in a once over harvest on the 8th of October 2014, 105 days after transplanting (Figure 83). Harvest was timed so as to maximise commercial yield, with approximately 80% of fruit at the red colour stage. Twenty central datum plants (30 plants per plot) were harvested from each treatment - the same procedure and fruit quality standards used for all Gatton trial harvests. Harvested fruit were size and quality graded as "marketable" or "unmarketable" using commercial fruit quality guidelines. Weights for all harvested material was recorded –and a record kept of any "rotten" fruit left behind in each plot

Figure 83 Bowen capsicum trial area overview at left and Bowen trial ready for harvest 8th Oct 2014

Results

Analysis of all marketable fruit harvested from all capsicum productivity treatments across the entire trial area – both standard and permanent bed treatments revealed no significant differences attributable to cultivation method (Table 40). Though at first glance there seems to be a trend toward the standard cultivation practice producing higher fruit yield.

Table 40 Marketable weight (Kg) for each capsicum treatment in two cultivation types (no significant difference)

Cultivation Type	Chilli Grft	Comm Grft	Std War	SV6947	SV6947 #2	War on W
Permanent Bed	14.07	11.82	11.14	14.57	15.65	12.32
Std Cultivation	16.58	16.52	12.86	15.74	16.77	18.86

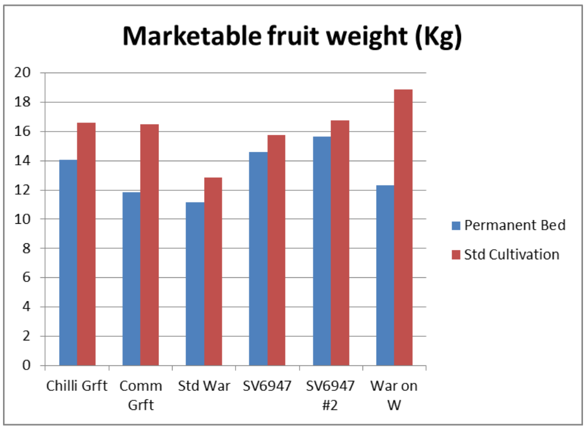


Figure 84 Marketable fruit weight for each capsicum treatment in two cultivation types (not significant)

When marketable fruit number for the entire trial area, permanent and standard cultivation was analysed in a split plot design there were significant differences between treatments common to both production systems.(Figure 85) Analysis reveals that SV6947and the chilli graft treatments produced more fruit than the standard Warlock treatment. Warlock on warlock and Capsifort grafted material (labelled Comm Grft) yielded similar fruit number to warlock while the chilli graft (Caysan) produced more fruit than Warlock but less than the new variety SV6947.

Table 41 Marketable fruit number for productivity treatment across standard cultivation and permanent beds

Treatment	mean	rank
SV6947 #2	64.17	a
SV6947	60.83	ab
Chilli Grft	53.17	b
War on W	51.67	bc
Comm Grft	51.5	bc
Std War	42.67	c
		LSD=9.847

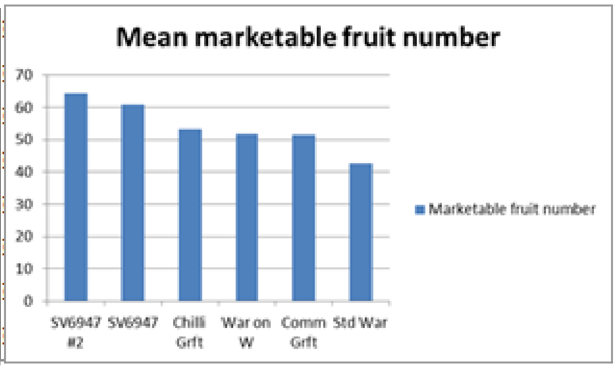


Figure 85 at right marketable fruit number for productivity treatments

Analysis of individual fruit size data indicates that warlock on warlock, chilli graft and standard warlock produced similar sized fruit, with SV6947 having slightly smaller fruit size. The fruit size of commercial rootstock Capsifort (commercial graft) was similar to Warlock but smaller than grafted Warlock.

Table 42 Mean weight of marketable fruit (grams) across standard cultivation and permanent beds

Treatment	Mean fruit weight (g)	rank
War on Warlock	299.6	a
Chilli Grft	288	ab
Std Warlock	279.5	ab
Comm Grft	275.3	b
SV6947 #2	251.7	c
SV6947	250	c
		LSD=22.87

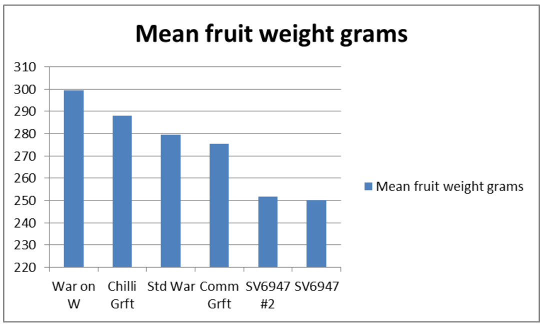


Figure 86 at right mean marketable fruit weight (grams), standard cultivation and permanent beds

Evaluation of plant size (above ground biomass)

At the conclusion of the Bowen harvest it was decided to sample all treatments to determine if there was any significant difference in plant size that was related to tillage method or productivity treatment.

Methodology

On the 22nd of October 2014 plant biomass was sampled. Two plants were taken from each data plot in the trial area, giving a total of 6 plants per productivity treatment in both the standard and permanent tillage treatment areas. Fresh weight for each sample was recorded prior to placement in in a drying oven, and sample dry weight was recorded when dried material was removed from the oven and is presented below.

Sampled plants were cut off in a standardised manner - at ground level, see image below

Figure 87 Standard method used to sample above ground biomass

Plant dried biomass analysis.

The standard practice tillage treatment plants had significantly higher plant dry weights than the permanent bed treatments as indicated below (Table 43).

Table 43 Mean plant dried weight for standard cultivation and permanent beds

Tillage	Mean Wt (kg)	
Std tillage	0.1507	a
Permanent tillage.	0.1188	b
	LSD =	0.01793

Significant differences were detected when graft treatment plant dry weights were compared across both the standard cultivation and permanent bed plots.

The plant dry weight of SV6947, Warlock on Caysan, Warlock on Capsifort were significantly heavier than Warlock on Warlock and ungrafted Warlock as seen in (Table 44) below. This plant size difference was not reflected in total marketable fruit weight, where no significant yield difference occurred (Table 44). Note: a duplicate treatment of SV6947-2 was grown in the Bowen field trial, as trial was planned and Wild Malay Eggplant graft was not planted due to graft incompatibility (poor graft success and adventitious rooting of scion to soil – see Gatton crop 1 treatment list for a detailed explanation).

Table 44 Mean Graft treatment plant top dried weight for standard cultivation and permanent beds

Treatment	Mean Wt (Kg)	Rank
2-Seminis SV69-47	0.1465	a
War on chilli (Caysan)	0.141	a
War on comm (Capsifort)	0.14	ab
1-Seminis SV69-47	0.1332	abc
War on Warlock	0.1258	bc
War no Graft	0.122	c
		LSD = 0.01507

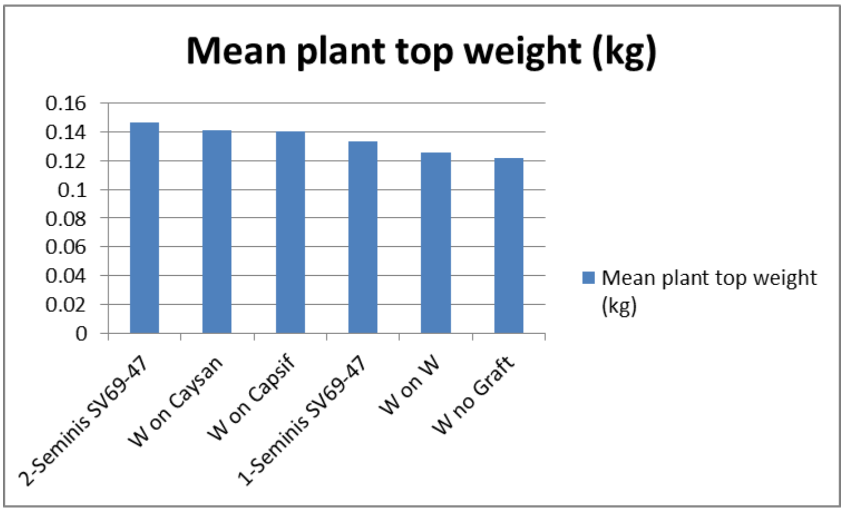


Figure 88 Mean graft treatment plant top dry weight across standard and permanent bed tillage systems

Conclusion

Marketable fruit number of treatments whether grown in intensive or permanent cultivation were not significantly different. Though at first glance there seems to be a trend toward standard cultivation producing higher fruit yield. There was however a significant difference in fruit number. Analysis reveals that SV6947and the chilli graft treatments produced more fruit than the standard Warlock treatment. Warlock on Warlock and Capsifort grafted material (labelled Comm Graft) yielded similar fruit number to Warlock while the chilli graft (Caysan) produced more fruit than Warlock but less than the new variety SV6947.

Plant top biomass was samples (plants cut off at ground level and top weight compared revealed the standard practice tillage treatment plants had significantly higher plant dry weights than the permanent bed treatments .New variety SV6947, Warlock on Caysan chilli and Warlock on Capsifort produced larger plant top weight than Warlock.

Giru Protected Crop Observation Trial Summary.

Transplanted; 26th June 2014

Harvested; 16th October 2014 – 8th December 2014

Methodology

The opportunity was taken to compare yield potential and plant performance of all grated rootstock material in a protective cropping structure in Giru (Nth Qld). This observation trial (space availability prevented replication) was planted on the twenty sixth of June 2014 and allowed comparison of "field varieties" grafted material within a specialist greenhouse structure producing glasshouse capsicum lines. Five plants of each treatment were included in the observation trial, with mature fruit harvested eight times between the middle of October and the middle of December 2014. This observation trial planting received the same fertilizer and watering regime being applied to the glasshouse capsicum crop (Figure 89).

The protective structure was a commercial double-bay tunnel (12-m wide x 50-m long) with an arched roof (centre height: 4 m) and vertical sidewalls (height: 2.5 m). Side walls were ventilated and covered with a screen mesh (50% shade protection). The roof cover was a semi-transparent, light white, woven polyethylene film.

The plant growing system and capsicum plots are shown below (Figure 89). All plants were grown in 11-L polyethylene pots, aligned as a single row over a gutter that collected the drainage solution from the plant containers. The separation between plant rows was 1.45 m and the in-row plant distance was 0.25 m. This plant arrangement created a plant density of 2.8 plants/m^2. Seedlings grown by Withcott Seedlings and were transplanted into plant containers filled with volcanic rock (pumice particle size 1-4 mm diam.) as the soilless media. Plants were fertigated daily with a complete nutrient solution. Nitrogen concentration level started at 100 mg/L at transplanting and was increased to 154 mg/L two weeks after transplanting. All other nutrients were kept at the same concentration level during the cropping season. The target nutrient concentration levels were: (in mg/L) P:51; K:172; Ca:148; Mg:47; Fe:2.8; S:65.3; Zn:0.3; B:0.7; Cu:0.2; Mo:0.1, and Mn: 0.9. During most of the crop cycle the solution had a pH of 6.2 and electrical conductivity (EC) of 2.1 dS/m. Fertigation were scheduled on a time basis, with an irrigation event every hour, starting at 6 am and with a total of 12 irrigation events/day. The volume of irrigation events increased from 100 to 280 mL per plant during the cropping season. Targeted irrigation drainage from the containers was 20% but reached up to 40% with warmer weather and increased irrigation after September.

Plots were harvested when fruits ripened to red colour. Marketable fruit were weighed, counted, and graded by size following a diameter scale used for imported greenhouse-grown bell peppers. Marketable fruit reported as Class-1 included fruits with diameter over 5.6 cm (Medium, Large and Extra-large) with no blemishes and with even blocky shape.

Because this was simply an observation trial, comments are based on average marketable yields of five plants expressed as weight per unit of cropped area. Crop harvests commenced 112 days after transplanting and crops were terminated 175 days after transplanting. The harvest period was 63 days with 8 picks; on average one harvest per week from the 16th of October until the 18th of December 2014. There was no evidence of any trending yield differences between ungrafted Warlock and any of the grafted Warlock treatments, though the new variety SV6947 performed well (Table 44). The low-cost protected cropping system has demonstrated the potential to increase yield by allowing multiple picks and improving fruit appearance at harvest. The ability to control weather impacts on the crop – at a cost of increased infrastructure, inputs and management expertise does lead to increased fruit quality and yield per unit area.

Figure 89 Grafted capsicum rootstock material in foreground with specialist protective cropping varieties visible behind

Observed Plant Yield (Kg)

Table 45 Mean marketable fruit count and weight in protective cropping structure – from 5 plants

Treatment	Plants / m2	Fruit number	Marketable Wt (Kg)	Average fruit weight (Kg)
Warlock on Warlock	2.8	24.08	5.25	0.218
Std Warlock	2.8	19.6	4.77	0.244
SV-6947	2.8	25.76	4.84	0.188
Warlock on Chilli Caysan	2.8	20.16	4.48	0.223
Warlock on Capsifort	2.8	21.28	4.44	0.209
Wild Malay Eggplant (failed graft)	2.8	17.36	3.90	0.224

Table 45 above summarises yields of the field variety trial material in a protective cropping structure. Though no conclusions can be drawn from this observation trial there are some intriguing trends. A number of yield and fruit size results throughout the data sets presented in this report show a trend where grafted Warlock has seemed to slightly outperform ungrafted Warlock. Warlock and SV6947 performed well in this environment producing good marketable yield weight and a review of the data shows that SV6947 picked more continuously over the eight harvests, while the other lines seemed to have reached peak fruit production by the third pick. The Wild Malay Eggplant data is presented above for review and to illustrate the ability of plants to survive and adapt. This graft treatment is incompatible and commercially non-viable due to incompatibility (see introduction). Plant growth and survival was due to adventitious rooting initiated from above the graft point, so not attributable to the Wild Malay Eggplant grafted rootstock. This reduced restricted adventitious root system architecture is reflected in comparative plant productivity in table 45 above.

Table 46 Marketable fruit harvested at each pick for eight harvests – observational data – not replicated

	War / War	War / Chilli	War / Capsic	Std Warlock	SV6947
16/10/2014	2	7	8	1	9
24/10/2014	10	10	11	13	6
30/10/2014	7	6	4	7	4
6/11/2014	2	0	1	3	4
28/11/2014	1	1	0	1	2
5/12/2014	3	5	1	1	0
13/12/2014	9	2	2	2	5
18/12/2014	3	7	3	4	1

In summary, the observations from this protected cropping example and comparisons to yield outcomes from field trials conducted at the same time (in different locations but within the vegetable production area of the dry tropics) could support the following comments:

Because this was a non-replicated observation trial, no significant yield trends can be identified – though the marketable yield results for warlock grafted to itself and the new line SV6947 seem to indicate potential for improved yield.

The observation trial in a low-cost protective structure shows the potential for yield increases compared to field production.

Figure 90 Grading fruit from Bowen trial - Warlock on Capsifort and Warlock fruit

Appendix – 2 Capsicum Productivity Trial – Activity Time line

	Planted	Activity Date / Action	Comment
Planting 1			
GRF Crop 1	8th January 2014	24th March to 16th April 2014	Harvest & fruit assessed in 4 picks
Ratooned 8th May 2014 – ratooned by hand (secateurs)			
GRF Crop 2	Ratooned crop regrown as over winter crop	24th September 2014	Strip pick all small fruit – fruit assessed
Bowen Field Crop	25th June 2104	8th October 2014	Once over harvest
		22nd October 2014	Plant size assessed
Bowen crop not ratooned – deemed too hot over summer			
Bowen Protected Crop	26th June 2014	16th October to 18th December	Mature fruit picked as ready (8 picks)
GRF Crop 3	2nd September 2014	New plant comparison replicates planted	New crop Warlock established
	Original plants re-flowered	25th November 2014	Harvest & fruit assessed
Ratooned 15th January 2015 – ratooned mechanically (hedge trimmer)			
GRF Crop 4	Ratooned crop regrown	1st April 2015	Harvest & fruit assessed
		5th May 2015	Root system assessment
Crop in for 15 months & 27 days (482 days)			
Planting 2	**New trial area set up.**		
GRF Crop 5	Planted 6th and 20th October 2015	Graft order muddled and caused 14 day delay to planting two treatments	New replicated trial set up at Gatton research facility – identical design to Planting 1 but new graft treatments.
GRF Crop 5	3rd December	Retractable shade installed over crop	High temperatures last summer crop (crop 3) caused high fruit loss. Prototype easy shade cover installed to determine if this would increase marketable yield
		22nd December to 3rd February 2016	Harvest & fruit assess (3 picks)
Ratooned 16th February 2016 – ratooned mechanically (hedge trimmer)			
GRF Crop 6	Ratooned crop regrown	10th May 2016	Harvest & fruit assessed
		17th May 2016	Root system assessment
Crop in ground for 7 Months 11 days (224 days)			

Appendix - 3.0 Planting 1 Trial Plan – Gatton

Head Pipe on Creek end (Nth) of trial

		REP 1	REP 2	REP 3	REP 4		
Road	Guard	Guard Plot	Warlock 5plants / Green Giant-	Yolo Wonder	Guard Plot	Guard	Road
	Row	STD WAR	Unwatered Second crop	GRF CHI	GRF WAR	Row	
	Each plot **1.5 m wide**	GRF WAR	SV6947	Unwatered First crop	GRF CHI		
		Unwatered First crop	GRF CHI	GRF COM	Unwatered Second crop		
	Each plot **5 m long**	GRF COM	STD WAR	SV6947	SV69471		
		Unwatered Second crop	GRF COM	GRF WAR	STD WAR		
		GRF CHI	Unwatered First crop	Unwatered Second crop	GRF COM		
		SV6947	GRF WAR	STD WAR	Unwatered First crop		
	Guard	Guard Plot	Green Giant	Yolo Wonder	Guard Plot	Guard	

Treatment list:

T1 – grafted eggplant -substituted with **new capsicum variety** SV6947
T2 - grafted chilli (Red stickers)
T3 - grafted commercial rootstock (Yellow stickers)
T4 – grafted Warlock (Pink stickers)
T5 – standard Warlock. (Green Stickers)

Appendix - 3.1 Planting 2 Trial Plan – Gatton

Trial Plan for Planting 2: 2015-2016

Batch # 1 Seedling Transplant Date; 6th October 2015
Treatments 1, 2, 4, 6
Batch #2 Seedling Transplant Date; 20th October 2015
Treatments 3, 5, 7 and all guard plots

Head Pipe on Creek end (Nth) of trial

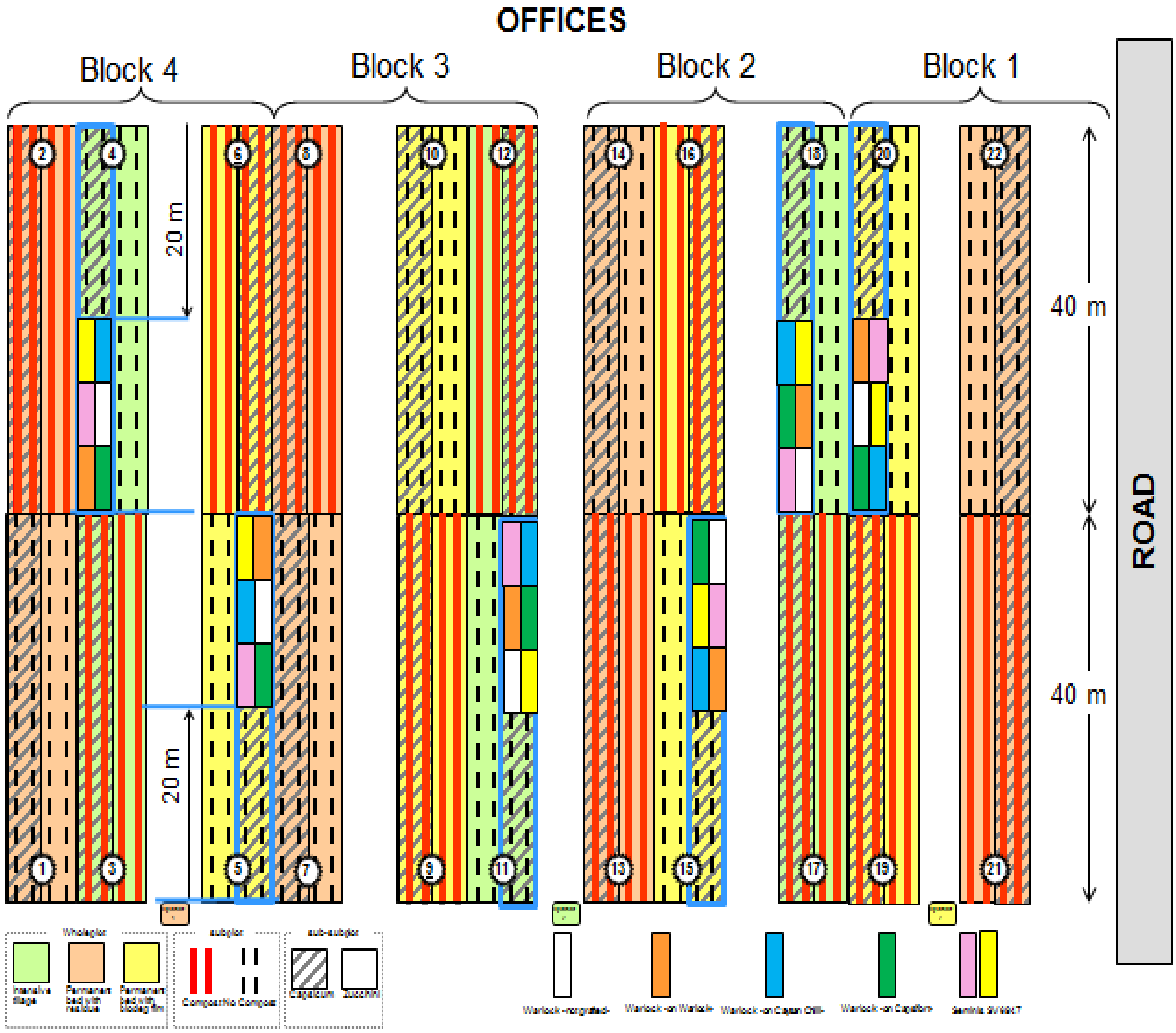
N

		REP 1	REP 2	REP 3	REP 4		
Road and Wind break	Guard	Guard Plot	Guard Plot	Guard Plot	Guard Plot	Guard	Road and Wind break
	Row	1	3	2	7	Row	
		2	7	5	4		
	H	3	1	6	5	I	
	I/W	4	5	7	3	I/W	
	I	5	2	1	6	H	
		6	4	3	2		
	KA	7	6	4	1	TC	
	TC	Guard Plot	Guard Plot	Guard Plot	Guard Plot	KA	

Plot size 1.5 m x 5m = **30 plants per plot** (twin row) (20 Datum plants per plot).
Planted area will be 6 *rows wide* = *9m x 45m long* = 405m^2 = 0.040 Ha.

Abbreviations and Extra Plantings
H = Hungarian Hot wax; 9 plants western row and 9 plants eastern row
I/W= Inferno rootstock/ Warlock scion 18 plants western row and 20 plants eastern row
I = Inferno; 4 plants western row and 6 plants eastern row
KA = Kangaroo Apple 4 plants western row and 4 plants eastern row
TC = Tree Chilli 6 plants western row and 6 plants eastern row

Appendix - 3.2 Trial Plan – Bowen



Appendix – 4 Nutrition -Cropping and Holding program–Gatton

Pre and Post Ratooning Fertiliser Program

Pre Ratooning Fertiliser Program								
		Kg fertiliser applied to trial						
Week		Flow feed 19	KNO3	Ca(NO3)2	Boron		Fertiliser N analysis	
1		3					Flow feed 19 20%N	20%
							KNO3 13.3%N	13.30%
2		4	3.5		10		CaNO3 15.5%N	15.50%
3				5			BMX and liberal Ca added	
4			5		10			
5				5				
6			5		10			
7			2.5		10			
7				4				
8			2		10			
8			2					
9				1				
	total Kg of fertiliser	7	20	15				
	Kg of N from each fertiliser	1.4	2.66	2.325				
Total N that will be applied by fertigation (Kgs)		**6.385**						
N applied in Basal pre plant		**2.56**						
Grand Total N applied for crop		**8.945**						

Authors note: Flow fee d 19 referred to here should be read as Nutrifeed 20+TE in these nutrition tables.

Fertiliser Program Post Ratooning												
Week		**Kg fertiliser applied to trial**					**N kg**	**Equiv N**				
							Applied	**kg per ha**		Fertiliser N analysis		
	Flowfeed 19	**KNO3**	**Ca(NO3)2**	**Boron**	**BMX**	**Magnesium**				Flowfeed 19	20% N	
	Kg	**Kg**	**Kg**	**Grams**	**Micro**	**Sulphate**				KNO3	13.3% N	
1	3						0.6	14.81		Ca(NO3)2	15.5% N	
										CK 77S	16 % N	
2	4	3.5		10g	10g		1.2655	31.25				
3			5			10 g	0.775	19.14				
4		5		10g	10g		0.665	16.42				
5			5			10 g	0.775	19.14				
6		5		10 g	10 g		0.665	16.42				
7		1.5	1.5			10 g	0.2325	5.74				
8		4		10 g	10 g		0.532	13.14				
9		0	1				0.155					
Total N applied by Fertigation				Subtotal			**5.665**	136.05				
N applied in Basal fertiliser							**2.56**	64				
Grand Total N applied (Kgs)							**8.225**					

Appendix – 5 Woolworths Green Blocky Capsicum Specification – No 1 Grade

Woolworths the fresh food people

Produce Specifications

PRODUCT :	**CAPSICUM**
TYPE :	**Block**
VARIETY :	**Green**
GRADE :	**One**

GENERAL APPEARANCE CRITERIA	
COLOUR	*Mid to dark green skin; bright green calyx.*
VISUAL APPEARANCE	*With smooth, glossy skin; intact calyx; sound seed cavity; free from foreign matter.*
SENSORY	*Firm, crisp, juicy flesh; peppery, slightly sweet flavour; no foreign odours or tastes.*
SHAPE	*Approximately square to oblong, slightly tapered at the blossom end; may be twisted slightly off centre; none with bends >45° from vertical or horizontal; no fruit with a twisted or deformed shape or with a very pointed blossom end.*
SIZE	*In pre-ordered size range only, per Woolworths requirements. Length : medium 90 - 110mm; large 110 - 130mm (a 10% size overlap between size grades is allowable).*
MATURITY	*None <90 mm long or <160 g weight; none >130 mm long; none with red colouration or >2 sq cm of surface with brownish tinge (overmature).*
MAJOR DEFECTS	
INSECTS	*With evidence of live insects (eg fruit fly larvae, scale).*
DISEASES	*With fungal or bacterial rots (Anthracnose, Alternaria rot, bacterial soft rot).*
	With distortion or mottling due to virus infection.
PHYSICAL / PEST DAMAGE	*With cuts, holes, or pest damage that breaks the skin.*
	With soft areas or deep-seated bruises.
TEMPERATURE INJURY	*With obvious bleached, flattened areas (sunburn).*
	With soft flesh or wrinkled skin (dehydration).
	With pitted skin and dark, soft underlying flesh (chilling injury).
PHYSIOLOGICAL DISORDER	*With open growth or stem end cracks, or with superficial skin cracking (excess moisture).*
	With softening or rotting evident at the fruit blossom end (calcium deficiency).
	With dark green /brownish spots over fruit surface (Yolo spot)
MINOR DEFECTS	
PHYSICAL / PEST DAMAGE	*With superficial dark rub marks or bruising (<1 mm deep) affecting in aggregate >1 sq cm.*
SKIN MARKS / BLEMISHES	*With >3 dark, dry spots, >1 mm diameter.*
	With scattered, superficial light brown marks affecting in aggregate >4 sq cm.

Appendix - 6 White Hail Net – Specification

NetPro
PROTECTIVE CANOPIES

HAIL NET PRODUCT SPECIFICATIONS

"PITCH HAIL NET"
HAIL & SHADE NET

Recommended for hail protection, overhead wind protection, overhead shade, overhead bird protection, reduction of evaporation and transpiration, microclimate adjustments, and reduction of sunburn.

Keywords: hail net, hail netting, hail protection, crop protection, bird exclusion, wind protection, wind shelters, micro-climate, nets, shade.

Colours:	White, Red, Grey
Construction:	Raschel Warp Knitted
Width:	Standard 6.5m; other widths available on request
Material:	HDPE Monofilament
Shade:	White 10%, Red TBA, Grey TBA (± 2%)
U/V Block:	White 21%, Red TBA, Grey TBA (± 2%)
Weight:	75g/m² ± 5g/m²
Hole Size:	10mm x 4mm (± 0.2mm), triangular
Burst Strength:	TBA
Selvedge:	Reinforced

Abbreviations Used:
m - metre
mm - millimetre (0.001m)
g/m² - grams per square metre
kPa - Kilo-Pascal, unit of pressure and stress - a measure of force per unit area
HDPE - High Density Poly-Ethylene
TBA - to be ascertained; N/A - not applicable

Warranty: *10 Year Pro Rata U/V Stability.*
Warranty covers only replacement of defective goods & does not cover or compensate the purchaser for any expense associated with installation or removal of the goods from any supporting structure.
This Warranty is given to the original purchaser only.