Horticulture Innovation Australia

Final Report

Earlier yields and better establishment of strawberry runners

Scott Mattner
Victorian Strawberry Industry
Certification Authority

Project Number: BS13002

BS13002

This project has been funded by Horticulture Innovation Australia Limited with co-investment from Toolangi Certified Strawberry Runner Growers Co-operative, Victorian Strawberry Industry Certification Authority, Strawberry Growers Association of Western Australia Inc. and funds from the Australian Government.

ISBN 0 7341 3806 7

Published and distributed by:
Horticulture Innovation Australia Limited
Level 8, 1 Chifley Square
Sydney NSW 2000
Tel: (02) 8295 2300
Fax: (02) 8295 2399

Contents

Summary

Strawberry fruit can attract high prices for growers early and late in the season, when supply is scarce. One of the key constraints to early fruit yields in specific regions of Australia (e.g. north of Perth, Western Australia and southern Queensland) is the availability and maturity of strawberry runners (bare-rooted transplants) for planting in March.

Runners are prone to poor establishment and survival in the fruit industry if they are planted when they are too immature. Seasonal issues in the strawberry nursery industry are increasingly affecting the maturity of freshly dug runners in March. In 2013, establishment of some leaf-on cultivars of runners in the Western Australian fruit industry was poor, with plant losses of around 18%.

The objective of this project was to develop strategies to improve runner establishment in the fruit industry and achieve earlier yields. The project evaluated the use of day-neutral cultivars of cold-stored runners (runners stored at -2°C), different agronomic practices, and plug plants (containerised transplants) in field trials in the strawberry fruit (mostly at Wanneroo, WA) and nursery (at Toolangi, Vic) industries.

Results showed that the use of cold-stored runners of day-neutral cultivars (Portola and San Andreas) could increase early (April/May) and late (October/November) season fruit yields at Wanneroo WA, compared with traditional leaf-on runners of short-day cultivars, such as Fortuna. Over the whole season, cold-stored runners produced up to 50% more fruit and resulted in 45% higher revenues ($2.40 more per plant) than leaf-on runners. Cold-stored runners did not produce significant amounts of fruit during the middle of the season (July-August), when leaf-on runners were fruiting heavily. Therefore, co-ordinated plantings of cold-stored runners and leaf-on runners offer growers north of Perth WA with the prospect of more even fruit production and income through an extended growing season (April-November).

An advantage of cold-stored runners is that they can be dug in the nurseries in late autumn / early winter when they are fully mature, and then cold-stored until planting in the fruit industry the following year. This reduces the impact of seasonal effects at harvest, and makes the industry more resilient to climate variability.

Research identified several factors associated with poor establishment of leaf-on runners in the fruit industry, including runner architecture (e.g. small crowns), low starch concentrations in runners, runner immaturity, soil-borne pathogens in the fruit industry, variable fumigation practices in the fruit industry, and others. To reduce the risk of poor establishment of leaf-on runners, fruit growers can: consider cultivars that are less susceptible to losses and produce higher fruit yields (e.g. Benicia), fumigate soils strictly following label recommendations, design and schedule overhead irrigation to reduce stress on establishing plants, and not expose runners to harsh environmental conditions at planting and plant them to correct soil depths. Nursery growers at Toolangi, Vic can reduce the risk of poor establishment of leaf-on runners in the fruit industry by: application of P fertilisers in the nursery industry to a threshold of 500 mg P / kg soil at planting, cut runners to a height of 20 cm two weeks before harvest, widen mother plant spacings of Fortuna to 1.3 m, grade runners to large crown sizes (above 7.5 mm),

and dig runners only when they are mature.

By the end of this project, the incidence of plant losses of establishing leaf-on runners in trials at Wanneroo WA had reduced from 18% in 2013 to 3% in 2015.

Fruit yields from plug plants were highly variable (ranging from 30% less to 30% higher than runners), and further research is required on their physiology to achieve more consistent yields. Analysis showed that the cost of plug plants (c. 2-4 times more expensive than runners) does not yet warrant their widespread commercial adoption.

Research outcomes from the project were communicated to growers through field days, trial walks, on-farm visits, newsletter articles, and flyers produced in English and Vietnamese. Outcomes were communicated to scientific colleagues through conference presentations and refereed publications.

This project has demonstrated that great gains in industry productivity and resilience can occur at a regional level. The new funding structure of HIA Limited may present a challenge in the future because there is no longer a clear pathway to fund industry-specific research through matched voluntary contributions, especially at a regional level. The future funding arrangements for research and development projects that have regional significance, but wider impacts, requires further consideration by the strawberry industry and HIA Limited.

Keywords

Strawberry; Nursery; Runner; Cold-Store Runner; Plug Plant; Runner Establishment Stress Syndrome; Plant Maturity; Day-neutral Plant; Short-day Plant; Protected Cropping.

Introduction

This project was conducted under Horticulture Australia Limited's R&D Strategic Investment Call for 2013/14 on methods for horticultural industries to manage and adapt to climate variability.

Early fruit production attracts a premium price and higher profits for strawberry growers. In Western Australia and Queensland, planting leaf-on runners in March is one of the key factors that can influence early fruit yields (e.g. Menzel & Smith, 2011; Menzel & Smith, 2012a). However, strawberry runners dug in the nursery industry in March can be immature, contain low non-structural carbohydrate levels (Menzel & Smith, 2012b) and be prone to a condition called 'runner establishment stress syndrome' (RESS) (Greer et al., 2005). In 2013, establishment of some leaf-on runners in the Western Australian and Queensland fruit industries was poor, with 10-30% losses of plants due to RESS, depending on the region and cultivar (George Weda, Toolangi Certified Strawberry Runner Growers Co-operative, personal communication). Seasonal issues and climate variability in the strawberry nursery industry are increasingly affecting planting times in August, the maturity of freshly dug runners in March, and their subsequent susceptibility to RESS in the fruit industry.

The best way to prevent RESS is to dig strawberry runners when they are fully mature (Greer et al., 2005), but this strategy may not allow fruit growers to achieve earlier yields. There are few published papers in the scientific literature specifically on the management of RESS in strawberries. However, personal communication with researchers and industry representatives in the USA and EU suggests that RESS in runners can be minimised through use of:

(1) *Cold-stored runners:* In California, fruit growers achieve earlier yields by planting cold-stored runners (-2°C) of day-neutral cultivars in summer / early autumn (Dr Doug Shaw, UC, personal communication). This strategy allows the nursery industry to dig runners in late autumn / winter when they are fully mature, and then cool-store them until the following summer / early autumn. It avoids the influence of climate variability on the maturity of runner transplants and may reduce their susceptibility to RESS.

(2) *Modified agronomic practices:* The use of correct nutrition, planting densities, and mowing regimes in the nursery industry are important to achieve desired petiole lengths and crown diameters of leaf-on runners. In Australia, recommendations for crown sizes of leaf-on runners are well defined for improved establishment and fruit yields (Menzle & Smith, 2011; Menzel & Smith, 2012a), but appropriate agronomic techniques to achieve these specifications for individual cultivars and growing regions are not known.

(3) *Plug transplants:* In Europe (reviewed by Lieten, 2013) and south-eastern US (reviewed by Durner et al., 2002), specific cultivars of plug plants (containerised transplants) produced in protected cropping systems have shown better establishment and yields than bare-rooted runners. In contrast, previous research conducted in Australia (BS04009; Menzel & Toldi, 2010) has shown that plug plants do not produce significantly greater fruit yields than bare-rooted runners. However, Australian researchers concluded that better conditioning of plug plants may improve their capacity to produce earlier and/or higher fruit yields.

Project Objectives:

This project aimed to develop strategies to reduce the incidence of RESS and achieve earlier yields in the strawberry fruit industry. The strategies evaluated included:

(1) The use of cold-stored runners of day-neutral cultivars planted in summer/early autumn,

(2) Improved nutrient (e.g. phosphorus) and agronomic (planting density, and mowing timing) regimes in the nursery industry for short-day cultivars of leaf-on runners, and

(3) Plug transplants of short-day and day-neutral cultivars produced under protected and outdoor environments in the nursery industry.

Methodology

This project conducted field trials in the Victorian strawberry nursery, and the Western Australian, Queensland, and Victorian strawberry fruit industries on strategies to achieve better establishment of runners and earlier yields in the fruit industry. Field days were regularly held at trial sites to communicate research outcomes to growers.

Field Trials:

(1) Cold-Stored Runner Trials

Runners of day-neutral cultivars (Albion, Portola, San Andreas, and Monterey) were grown and produced at Toolangi, Victoria under commercial conditions. Runners were dug in late autumn / early winter and placed in cold storage (-2°C). Two field trials (2014 and 2015) were conducted with cold-stored runners in the Western Australian fruit industry at Wanneroo. Runners were transplanted in January, February and March into soils covered with black or white plastic mulch. Vegetative growth of plants was encouraged by regularly removing flowers until March. The experimental controls were freshly dug runners of day-neutral cultivars (Albion, Portola, San Andreas and Monterey) and a traditional leaf-on cultivar (Fortuna) planted in March. Plant survival, cumulative fruit yields (picked 1-2 times per week), and cumulative gross revenues (using weekly wholesale prices for strawberry fruit for Perth (FreshLogic, Hawthorn, Vic)) were calculated through the season. The trials were conducted as randomised split-plot designs, with four blocks.

Similar commercial trials with cold-store runners were conducted in the Queensland fruit industry at Caboolture in 2014 (see Appendix I).

(2) Leaf-on Runner Trials

A series of field trials (see below) were conducted in the strawberry nursery industry at Toolangi, Victoria on agronomic practices to improve the production (runners per m^2) and quality (crown diameter, leaf area, petiole length, root length) of leaf-on runners (cv. Fortuna). The concentration of starch in the roots and crowns of harvested runners was also measured in selected trials using the α-amylase / amyloglucosidase technique (McCleary et al., 1997). Runners from nursery trials were then dug and planted in field trials in the strawberry fruit industry at Wanneroo, Western Australia. The performance of strawberry runners was measured in fruit trials, including runner survival, cumulative fruit yields, and cumulative gross revenues.

Plant spacing: Two trials (2013/14 and 2014/15) evaluated different mother plant spacings in the nursery industry for optimum runner production and quality. Treatments included mother plants spaced 4, 2, 1.3, 1, and 0.8 m apart (see Appendix I).

Phosphorus nutrition: Two separate trials (on a Red & Brown Ferrosol, 2013/14) investigated different phosphorus inputs in the nursery industry for optimum runner production and quality. Treatments

included 0, 50, 150, 200, and 300 kg/ha of P (as mono-ammonium phosphate), applied with standard rates of N (150 kg/ha), K (150 kg/ha) and S (250 kg/ha). Total application of treatments was made at planting and two subsequent top-dressings through the season (see Appendix I).

Runner maturity: In 2014/15, a trial was completed to investigate the effect of runner maturity on the subsequent establishment and yields of transplants in the fruit industry. First (most mature), second, third, and fourth (least mature) daughter runners of the cultivar Fortuna were harvested from mother plants in the nursery industry. Runners were planted-out in a trial in the fruit industry at Wanneroo, Western Australia.

Mowing timing: Also in 2014/15, a trial was conducted to evaluate different mowing timing in the nursery industry on the quality and subsequent performance of leaf-on runners of the cultivar Fortuna in the fruit industry at Wanneroo, Western Australia. Treatments included runners mown to ground level or 20 cm above ground level at 4 or 2 weeks before harvest.

All trials with leaf-on runners were conducted as randomised complete block designs, with four blocks.

(3) Plug Plant Trials

Two trials (2013/14 and 2014/15) were conducted at Toolangi, Victoria on methods to produce runner tips (stolon nodes) and plug plants using soil-less culture. The trials compared protected (screenhouse) and outdoor production systems. Mother plants of the strawberry cultivars Albion, Monterey, Festival, Camarosa and San Andreas were planted into substrate bags (coco-peat, Nature's Soil, Silvan, Victoria) mounted on raised gutters. All mother plants received standard irrigation and hydroponic nutrient inputs, as determined in previous research (BS06029; BS09019). Stolons were allowed to hang down from the mother plant, until they produced 5-10 nodes. Runner tips (nodes) were harvested from stolons and planted into transplant trays (250 cm^3 cells) containing soil-less media (coir and composted pine bark, Debco, Tyabb, Victoria), and misted for four weeks. The production of tips and plug plants per mother plant was determined.

The subsequent performance of plug plants (establishment, fruit yields and gross revenues) was evaluated compared with bare-rooted runners in strawberry fruit trials at Wanneroo, Western Australia and in commercial trials at Millgrove, Victoria.

Data were analysed using ANOVA as performed on Genstat v 16 (VSN International). Homogeneity of variance was determined by examining plots of fitted values versus residuals, while histograms of residuals were examined for normality of distribution. Data transformations were made where appropriate. Fisher's least significant difference test was used to identify differences between treatment means. The level of significance use was $p < 0.05$.

Technology Transfer:

Annual field days were held for strawberry nursery (Victoria) and fruit growers (Western Australia), agronomists, and scientists at the trial sites. Field days allowed attendees to review the results and outcomes from trials at oral presentations, and assess the performance of treatments in the field. Translators (Vietnamese) were used at field days in Western Australia, since a high proportion of fruit growers have English as a second language. In addition, members of the project team visited fruit growers on their properties in Western Australia and Queensland to inspect plants and communicate

project outcomes first hand.

Growers were also informed of project results and outcomes through best-practice flyers (English and Vietnamese) distributed at field days, and through articles in industry newsletters and conferences (see 'Outputs').

Outputs

Field Days, Workshops, Demonstrations, Meetings, and Presentations for Growers:

Mattner S.W., Milinkovic M. et al. 2013. Project BS13002 Update. Victorian Strawberry Runner Meeting, 26/11/13 Toolangi, Vic.
(18 attendees).

Runner Nutrition for Leaf-On Plants. Grower Workshop. Guest speakers: Rohan Davies and Graeme McIntyre, Incitec Pivot. 14/1/14 Toolangi, Vic.
(15 attendees).

Vacuum Cooling for Leaf-On Runners. Field Demonstration. Guest demonstrator: Jason Koenders, Alltech Refrigeration. 29/1/14 Toolangi, Vic.
(11 attendees).

Mattner S.W. Verheyen, G. 2014. Earlier Yields and Better Establishment of Strawberry Runners. Oral Presentation and Field Day (translated into Vietnamese). 18/2/14 Wanneroo, WA.
(29 attendees).

Plug Plants and Cold-store Runners. Trial inspections. 11/3/14, Caboolture, Qld (3 farms).
(17 attendees).

Verheyen G., Reid A. 2014. BS13002 Project Update. Oral Presentation and Trial Inspection. WA Strawberry Growers AGM, 5/11/14, Wanneroo WA.

Mattner S.W., Milinkovic M. et al. 2014. VSICA RD&E Update: Improving the Quality of Leaf-On Runners. Oral Presentation. Victorian Strawberry Runner Meeting, 27/11/14, Toolangi, Vic.
(15 attendees)

Milinkovic M., Mattner S.W. 2014. Soil-less Production of Strawberry Plug Plants. Trial Inspection. Victorian Strawberry Runner Meeting, 27/11/14 Toolangi, Vic.
(15 attendees)

Mattner S.W., Verheyen G. et al. 2015. Yield Potential of Cold Store Runners in WA. Oral Presentation. WA Strawberry Fruit Growers Meeting, 6/3/15, Wanneroo WA.
(19 attendees)

Runner Maturity and Cold-Store Runners. Trial inspections and farm visits. 23-25/7/15 Northern Perth, WA (12 farms).
(28 attendees)

Verheyen G., Reid A. 2015. BS13002 Project Update. Oral Presentation and Trial Inspection. WA Strawberry Growers AGM, 26/8/15, Wanneroo WA.

Mattner S.W., Greenhalgh F. et al. 2015. Technical and Economic Feasibility of Strawberry Plug Plants Production. Department of the Environment Meeting, 16/9/15, Tullamarine, Vic.
(9 attendees)

Mattner S.W., Milinkovic M. et al. 2015. BS13002 Research Update. Oral Presentation. Victorian Strawberry Runner Meeting, 24/11/15, Toolangi, Vic.
(15 attendees)

Milinkovic M., Mattner S.W. 2015. Production of Strawberry Plug Plants using Soil-less Culture. Trial Inspection. Victorian Strawberry Runner Meeting, 24/11/15, Toolangi, Vic.
(15 attendees)

Milinkovic M., Mattner S.W. et al. 2016. Soil-less Production of Certified Strawberry Transplants. Field Day. Australasian Plant Pathology Society, 16/2/16, Toolangi, Vic.
(38 attendees)

Conference Presentations / Papers:

Mattner S.W., Milinkovic M., et al. 2014 Critical challenges for the phaseout of methyl bromide in the Australian strawberry industry: Economics of soil-less production of transplants. Seventh International Symposium on Chemical and Non-Chemical Soil and Substrate Disinfestation. Torino, Italy, July 13-17 2014.

Mattner S.W., Milinkovic M., et al. 2015. Evaluation of soil-less systems for strawberry transplant production. International Convention & Exhibition on Soil-less Culture: Hydroponics & Aeroponics, Gold Coast, 5-8 July 2015.

Milinkovic M., Mattner S.W., et al. 2016. Development and performance of soil-less systems for strawberry transplant production in Australia. Eighth International Strawberry Symposium, Quebec City, August 2016.

Grower Newsletter Articles:

Mattner S.W. et al. 2014. Earlier yields and better establishment of strawberry runners. Strawberry Industry Advisor Committee Annual Report 2013/14, p 4.

Reid A., Mattner S.W., et al. 2015. Fumigation survey in Western Australia. *Simply Red*, Queensland Strawberry Industry Newsletter 37, p 8, March 2015.

Mattner, S.W., Milinkovic M. et al. (2015) Performance of strawberry plug plants. *VicStrawberries*, Victorian Strawberry Industry Newsletter, May Edition.

Best-Practice Flyers (printed in English and Vietnamese):

Mattner S.W., Verheyen G. et al. (2014) Earlier yields and better establishment of strawberry runners (BS13002). VSICA Flyer. (Distributed to WA fruit growers at AGM (5/11/14) and field day (6/3/15)).

Mattner S.W., Verheyen G. et al. (2015) Cold-store runners and plug plants. VSICA Flyer. (Distributed to WA fruit growers at AGM (26/8/15)).

Mattner S.W., Verheyen G. et al. (2015) Runner maturity and earlier yields. VSICA Flyer. (Distributed to WA fruit growers at AGM (26/8/15)).

Scientific Reports:

Mattner S.W., Verheyen, G. et al. (2014) BS13002 Earlier yields and better establishment of strawberry runners. Summary report of research. VSICA Report.

Mattner S.W., Verheyen, G. et al. (2015) Northern Perth strawberry pathogen survey. VSICA Report.

Outcomes

Results:

(1) Cold-Stored Runner Trials

Wanneroo, Western Australia: Cold-stored runners of the day-neutral cultivars San Andreas and Portola consistently produced earlier fruit yields than freshly dug bare-rooted runners, and traditional leaf-on runners of short-day cultivars (e.g. Fortuna). When cold-store runners were planted in January and February they required heavy irrigation inputs until March and the use of white plastic on soil (rather than black) for successful establishment and early yields in April (see Appendix I). When cold-store runners were planted in March they did not require white plastic for successful establishment and early yields in May (e.g. Table 1). The production of early fruit from cold-stored runners (cultivars San Andreas and Portola) provided revenue for growers when bare-rooted runners were not fruiting, and the price for fruit was relatively high. Cold-store runners of the day-neutral cultivars Monterey and Albion did not establish well when planted in January and February, and/or did not produce early fruit (Appendix I).

Table 1. *Cumulative marketable fruit yields (g/plant) of different strawberry planting material in a field trial at Wanneroo, WA in 2015. Runners were planted in late March (30/3/15). Values in each column followed by different letters are significantly different, where p < 0.05. (SD = short-day cultivar, DN = day-neutral cultivar).*

Planting Material	Cumulative Fruit Yield (g/plant)						
	May	June	July	August	September	October	November
'Fortuna' (SD) freshly dug leaf-on	0.0 a	31.8 a	127.6 d	261.9 c	539.3 d	787.0 c	818.9 bc
'San Andreas' (DN) freshly dug leaf-off	0.8 a	31.5 a	106.6 c	197.0 b	309.1 b	529.4 a	562.3 a
'San Andreas' (DN) cold-store leaf-off	32.1 c	70.7 c	71.3 b	71.3 a	224.2 a	781.7 c	850.5 c
'Portola' (DN) freshly dug leaf-off	3.9 a	51.2 b	136.6 d	242.0 c	432.8 c	708.7 b	758.6 b
Portola (DN) cold-store leaf-off	15.9 b	46.5 ab	50.0 a	50.0 a	295.3 b	1147.4 d	1233.4 d

Fruit yields of day-neutral cultivars of cold-store runners declined mid-season, compared with traditional leaf-on cultivars (e.g. Table 1). However, cold-store runners produced high fruit yields late in the season (October / November), when fruit yields of traditional leaf-on cultivars were in decline, and wholesale prices for fruit were again high. Over the whole season, cold-store runners of Portola and San Andreas produced up to 50% more fruit and resulted in 45% higher revenue (up to $2.40 more per plant) than traditional leaf-on cultivars, such as Fortuna (e.g. Table 1 & 2).

Table 2. *Cumulative revenue ($/plant) from strawberry fruit derived from different planting material in a field trial at Wanneroo, WA in 2015. Runners were planted in late March (30/3/15). Revenue was calculated from marketable fruit yields and wholesale fruit prices from the Perth market (FreshLogic, 2015). Values in each column followed by different letters are significantly different, where p < 0.05. (SD = short-day cultivar, DN = day-neutral cultivar).*

Planting Material	Cumulative Revenue ($/plant)						
	May	June	July	August	September	October	November
'Fortuna' (SD) freshly dug leaf-on	0.00 a	0.35 a	1.12 cd	2.00 d	3.46 d	4.88 b	5.16 bc
'San Andreas' (DN) freshly dug leaf-off	0.01 a	0.35 a	0.95 bc	1.55 c	2.13 b	3.40 a	3.69 a
'San Andreas' (DN) cold-store leaf-off	0.43 c	0.86 c	0.86 b	0.86 b	1.67 a	4.87 b	5.48 c
'Portola' (DN) freshly dug leaf-off	0.05 a	0.57 b	1.26 d	1.95 d	2.95 c	4.54 b	4.98 b
Portola (DN) cold-store leaf-off	0.21 b	0.55 b	0.58 a	0.58 a	1.87 ab	6.77 c	7.53 d

Caboolture Queensland: In Queensland, commercial trials showed that day-neutral cultivars of cold-store runners (Albion, Monterey, San Andreas and Portola) did not yield earlier than traditional leaf-on runners of short-day cultivars (Fortuna, Festival). Cold-store runners produced high yields late in the season when prices for fruit were low (Appendix I).

(2) Leaf-on Runner Trials

Plant spacing: Trials at Toolangi, Victoria showed that the architecture of harvested runners of the leaf-on cultivar Fortuna was highly responsive to mother plant spacing. Nursery growers aim to produce runners with crown diameters greater than 7.5 mm and petiole lengths below 20 cm. Trials showed the optimum plant spacing for mother plants of Fortuna in the strawberry nursery industry at Toolangi was

1.3 m. Currently the standard plant spacing for the cultivar Fortuna is 40 inches (c. 1.0 m). Trials showed increasing plant spacing from 1.0 m to 1.3 m could increase marketable yield of runners by up to 7% (since a greater proportion were above 7.5 mm), crown diameters by up to 15%, and reduce petiole lengths by up to 10% (see Appendix I).

Phosphorus nutrition: In trials in the nursery industry at Toolangi Victoria, strawberry runners yields showed a positive, linear response to P inputs (up to 300 kg P/ha). As such, trials did not show an optimum level of P for maximising runner yields. However, the early growth of strawberry mother plants reached a maximum level at soil concentrations of 500 mg/kg of P (see Appendix I).

Leaf-on runners of Fortuna containing high concentrations of P tended to have lower survival rates when planted in the fruit industry at Wanneroo, Western Australia (see Appendix I).

Runner maturity: A trial in the nursery industry at Toolangi showed that the crown diameters, petiole lengths, root lengths, leaf numbers, leaf areas and starch concentrations of harvested runners of the cultivar Fortuna increased, as their maturity increased (Table 3). For example, starch concentrations in the roots of first daughter runners (most mature) were 2.9%, compared with 1.5% in fourth daughter runners (least mature). Furthermore, mature runners survived (Table 3) and produced earlier and greater yields (Table 4) in the fruit industry at Wanneroo Western Australia, than less mature runners. For example, first daughter runners (most mature) yielded 15% more fruit (Table 4) and returned 22% greater revenue ($1.30 more per plant) (Table 5) than fourth daughter runners (least mature).

Table 3. *The effect of maturity on the architecture, starch concentration, and subsequent survival in the fruit industry (Wanneroo, WA) of leaf-on runners of the cultivar Fortuna harvested from a trial in the nursery industry at Toolangi, Victoria (2014/15). First daughters are the most mature runners, and fourth daughters the least mature. Mother plants were planted in the nursery industry on 11/9/14 and harvested on 24/3/15. Values followed by different letters in each column are significantly different where $p < 0.05$.*

Runners	Crown Diameter (mm)	Petiole Length (cm)	Root Length (cm)	Number of Leaves	Leaf Area (cm^2)	Crown Starch (%)	Root Starch (%)	Survival (%)
First Daughters	12.43 d	29.6 c	21.6 c	2.8 c	136.2 d	1.7 c	2.9 c	99.6 b
Second Daughters	9.62 c	28.7 c	19.5 c	2.4 b	85.8 c	1.6 b	2.6 b	99.0 b
Third Daughters	7.86 b	19.3 b	15.4 b	2.2 b	63.8 b	1.5 b	2.5 b	98.6 ab
Fourth Daughters (rejects)	4.75 a	11.0 a	9.0 a	1.8 a	30.0 a	1.1 a	1.5 a	93.9 a

Mowing timing: Mowing Fortuna runners grown at Toolangi, Victoria prior to harvest tended to reduce their crown diameters, petiole lengths, leaf areas, and leaf numbers (Table 6). Mowing runners to a height of 20 cm, 2 weeks before harvest or to ground level at 4 weeks before harvest increased their subsequent fruit yield and revenue from fruit at Wanneroo, Western Australia by up to 7% ($0.46 more per plant), compared with un-cut runners (Table 7 & 8).

Table 4. *Cumulative marketable fruit yields (g/plant) from leaf-on runners of the cultivar Fortuna with different levels of maturity in a field trial at Wanneroo, WA (2015). First daughters are the most mature runners, and fourth daughters the least mature. Runners were planted in late March (30/3/15). Values followed by different letters in each column are significantly different where p < 0.05.*

Runners	Cumulative Fruit Yield (g/plant)						
	May	June	July	August	September	October	November
First Daughters	1.1 b	51.7 b	181.6 c	364.5 c	715.0 c	1094.6 c	1147.1 c
Second Daughters	0.1 a	30.2 a	150.5 b	317.4 b	667.8 b	1020.7 b	1058.3 b
Third Daughters	0.5 ab	22.5 a	129.2 b	307.8 b	688.8 bc	1043.1 b	1078.9 b
Fourth Daughters (reject)	0.0 a	18.8 a	97.0 a	245.8 a	556.8 a	933.9 a	978.1 a

Table 5. *Cumulative revenue ($/plant) from strawberry fruit derived from leaf-on runners of the cultivar Fortuna with different levels of maturity in a field trial at Wanneroo, WA (2015). First daughters are the most mature runners, and fourth daughters the least mature. Runners were planted in late March (30/3/15). Revenue was calculated from marketable fruit yields and wholesale fruit prices from the Perth market (FreshLogic, 2015). Values in each column followed by different letters are significantly different, where p < 0.05.*

Runners	Cumulative Revenue ($/plant)						
	May	June	July	August	September	October	November
First Daughters	0.01 a	0.58 c	1.62 c	2.82 c	4.66 c	6.84 c	7.30 c
Second Daughters	0.00 a	0.34 b	1.30 b	2.39 b	4.23 b	6.26 b	6.59 b
Third Daughters	0.01 a	0.25 a	1.11 b	2.28 b	4.27 b	6.31 b	6.63 b
Fourth Daughters (rejects)	0.00 a	0.20 a	0.84 a	1.81 a	3.44 a	5.61 a	6.00 a

Table 6. *The effect of mowing before harvest on the architecture and subsequent survival in the fruit industry (Wanneroo, WA) of leaf-on runners of the cultivar Fortuna harvested from a trial in the nursery industry at Toolangi, Victoria (2014/15). Mother plants were planted in the nursery industry on 11/9/14 and harvested on 24/3/15. Values followed by different letters in each column are significantly different where p < 0.05.*

Runners	Crown Diameter (mm)	Petiole Length (cm)	Root Length (cm)	Number of Leaves	Leaf Area (cm^2)	Survival (%)
Not Cut (control)	10.5 b	28.2 d	21.7 b	3.5 c	80.1 d	97.2 a
Cut to 20 cm 4 wks before harvest	10.0 ab	21.6 c	20.5 ab	3.2 c	60.6 cd	98.6 a
Cut to 20 cm 2 wks before harvest	9.2 a	15.8 b	23.0 b	2.5 b	48.0 b	100.0 a
Cut to ground level 4 wks before harvest	9.4 a	14.2 b	18.7 a	2.1 b	51.1 bc	98.6 a
Cut to ground level 2 wks before harvest	9.2 a	8.7 a	19.1 a	0.9 a	17.2 a	94.4 a

Table 7. *Cumulative marketable fruit yields (g/plant) in a field trial at Wanneroo, WA (2015) from leaf-on runners of the cultivar Fortuna with different levels of mowing treatment in the nursery industry. Runners were planted in late March (30/3/15). Values followed by different letters in each column are significantly different where p < 0.05.*

Runners	Cumulative Fruit Yield (g/plant)						
	May	June	July	August	September	October	November
Not Cut (control)	1.3 a	42.5 b	153.0 b	329.9 b	646.3 bc	930.4 b	985.1 b
Cut to 20 cm 4 wks before harvest	3.5 a	53.0 b	165.9 b	327.1 b	616.2 ab	876.3 a	925.6 a
Cut to 20 cm 2 wks before harvest	1.9 a	41.7 b	150.6 b	332.9 b	678.1 c	986.1 c	1058.5 c
Cut to ground level 4 wks before harvest	0.9 a	39.2 ab	152.6 b	349.9 b	683.1 c	969.4 bc	1038.2 c
Cut to ground level 2 wks before harvest	0.6 a	25.9 a	105.0 a	274.7 a	596.8 a	883.8 a	952.4 ab

Table 8. *Cumulative revenue ($/plant) in a field trial at Wanneroo, WA (2015) from leaf-on runners of the cultivar Fortuna with different levels of mowing treatment in the nursery industry. Runners were planted in late March (30/3/15). Revenue was calculated from marketable fruit yields and wholesale fruit prices from the Perth market (FreshLogic, 2015). Values in each column followed by different letters are significantly different, where p < 0.05.*

Runners	Cumulative Revenue ($/plant)						
	May	June	July	August	September	October	November
Not Cut (control)	0.01 a	0.47 bc	1.36 b	2.52 b	4.18 bc	5.81 bc	6.30 ab
Cut to 20 cm 4 wks before harvest	0.05 a	0.60 c	1.51 b	2.56 b	4.07 b	5.57 ab	6.01 a
Cut to 20 cm 2 wks before harvest	0.02 a	0.47 bc	1.34 b	2.54 b	4.35 bc	6.11 c	6.76 c
Cut to ground level 4 wks before harvest	0.01 a	0.44 ab	1.35 b	2.64 b	4.39 c	6.03 c	6.64 bc
Cut to ground level 2 wks before harvest	0.01 a	0.29 a	0.92 a	2.04 a	3.72 a	5.37 a	5.98 a

(3) Plug Plant Trials

Overall, production of runner tips and plug plants in protected environments produced 60 - 200% greater yields, depending on the cultivar, than outdoor production (e.g. Table 9).

In Western Australia, plug plants planted in March consistently yielded less fruit (an average of 30% less, Table 10) and produced less revenue (an average of 30% less, or $1.40 less per plant, Table 11) than bare-rooted runners. At Millgrove Victoria, however, plug plants planted in May yielded 30% more fruit than bare-rooted runners (Appendix II). Analysis showed that plug plants would cost 2-4 times more than bare-rooted runners (Appendix III).

Results also showed that leaf-on runners of the newly-available cultivar, Benicia, produced 24% more fruit and 23% higher revenue ($1.17 more per plant) than the traditional cultivar Fortuna.

Impacts and Consequences:

At the beginning of this project, the anticipated outcomes from the research program were:

(1) Earlier yields (commencing in April / May) in the strawberry fruit industry, which increases gross returns for fruit growers by at least 10%.

Achieved. Research in this project showed that cold-stored runners of specific day-neutral cultivars produce earlier fruit yields (April-May) than traditional leaf-on cultivars at Wanneroo, WA.

Table 9. *Runner tip yields of five cultivars of strawberry grown in a hydroponics system under protected and outdoor conditions in a trial at Toolangi, Vic in 2014/15. Values followed by different letters in each column are significantly different where p < 0.05. (SD = short-day cultivar, DN = day-neutral cultivar).*

Production System	Runner Tip Yield (nodes/mother plant)				
	San Andreas (DN)	Albion (DN)	Monterey (DN)	Camarosa (SD)	Festival (SD)
Protected	60.1 b	74.3 b	82,4 b	108.2 b	109.8 b
Outdoor	37.2 a	42.6 a	49.0 a	36.9 a	62.5 a

Table 10. *Cumulative marketable fruit yields (g/plant) in a field trial at Wanneroo, WA (2015) of bare-rooted runners and plug plants of four strawberry cultivars. All material was planted in late March (30/3/15). Values followed by different letters in each column are significantly different where p < 0.05. (SD = short-day cultivar, DN = day-neutral cultivar).*

Planting Material	Cumulative Fruit Yield (g/plant)						
	May	June	July	August	September	October	November
Fortuna SD Bare-Root (leaf-on)	0.0 a	31.8 d	127.6 d	261.9 c	539.3 d	787.1 d	818.9 d
Fortuna SD Plug Plant	0.0 a	13.8 bc	60.8 a	148.2 a	300.2 b	491.6 b	515.3 ab
Benicia SD Bare-Root (leaf-on)	0.0 a	4.9 ab	161.8 e	391.6 b	733.6 e	994.3 e	1018.7 e
Benicia SD Plug Plant	0.0 a	0.0 a	67.1 a	213.3 d	441.6 c	596.9 c	603.9 c
San Andreas DN Bare-Root (leaf-off)	0.8 a	31.5 d	106.6 c	197.0 b	309.1 b	529.4 b	562.3 bc
San Andreas DN Plug Plant	0.0 a	5.9 a	60.1 a	126.3 a	226.3 a	425.9 a	452.1 a
Albion DN Bare-root (leaf-off)	0.0 a	22.9 cd	86.3 b	188.5 b	342.1 b	543.9 bc	559.3 bc
Albion DN Plug Plant	0.1 a	16.6 c	75.8 ab	182.1 b	312.7 b	493.2 b	528.8 b

Table 11. *Cumulative revenue ($/plant) in a field trial at Wanneroo, WA (2015) of bare-rooted runners and plug plants of four strawberry cultivars. All material was planted in late March (30/3/15). Revenue was calculated from marketable fruit yields and wholesale fruit prices from the Perth market (FreshLogic, 2015). Values followed by different letters in each column are significantly different where p < 0.05. (SD = short-day cultivar, DN = day-neutral cultivar).*

Planting Material	Cumulative Revenue ($/plant)						
	May	June	July	August	September	October	November
Fortuna SD Bare-Root (leaf-on)	0.00 a	0.35 d	1.12 c	2.00 d	3.45 f	4.88 d	5.16 e
Fortuna SD Plug Plant	0.00 a	0.15 bc	0.53 a	1.10 a	1.90 b	3.00 b	3.21 b
Benicia SD Bare-Root (leaf-on)	0.00 a	0.05 ab	1.31 d	2.82 e	4.61 g	6.11 e	6.33 f
Benicia SD Plug Plant	0.00 a	0.00 a	0.53 a	1.49 bc	2.69 e	3.58 c	3.65 d
San Andreas DN Bare-Root (leaf-off)	0.01 a	0.35 d	0.95 c	1.55 c	2.13 cd	3.40 c	3.69 d
San Andreas DN Plug Plant	0.00 a	0.06 ab	0.50 a	0.95 a	1.46 a	2.60 a	2.84 a
Albion DN Bare-root (leaf-off)	0.00 a	0.25 cd	0.76 b	1.43 bc	2.24 d	3.40 c	3.53 cd
Albion DN Plug Plant	0.00 a	0.18 c	0.66 b	1.35 b	2.04 bc	3.07 b	3.39 bc

An unexpected benefit was that cold-stored runners also produced high yields late in the season (October-November) when the wholesale price for strawberry fruit was also relatively high. Over the whole season, cold-store runners of the cultivar Portola produced 50% more fruit and generated 45% more revenue for growers (up to $2.40 per plant) than leaf-on runners of the cultivar Fortuna. Cold-store runners are commercially available for use in the strawberry industry. Co-ordinated plantings of cold-store runners and leaf-on runners (see 'Evaluation & Discussion') provide a strong opportunity for growers north of Perth to achieve more even production and income through an extended season (from April to November, compared with the current season based on leaf-on runners from May/June to September/October).

(2) The incidence of plant losses to runner establishment stress syndrome (RESS) in the fruit industry will decrease from 18% in 2013 to 5% or less by 2016.

Achieved. In 2013 estimates of the incidence of RESS in leaf-on runners ranged from 10-30%, depending on the region, the cultivar, and conditions on individual fruit farms (G. Weda, personal communication). Research in this project has identified a number of factors associated with poor survival of leaf-on runners following planting, including runner architecture (e.g. small crown diameters),

low starch concentrations in runners, high P concentrations in runners, runner immaturity, mowing runners in the nursery industry too low and too close to harvest, soil-borne pathogens on fruit farms, and inadequate fumigation and irrigation practices on fruit farms (see 'Evaluation and Discussion'). Research also identified methods for runner and fruit growers to reduce the risk of RESS, including modified planting densities, applying optimal levels of P inputs for mother plant growth, mowing regimes for runners, digging runners when they are fully mature, correct application and plant-back times for fumigants in the fruit industry, and others (see 'Evaluation and Discussion'). In 2013, the incidence of RESS in the fruit industry north of Perth WA was estimated at 18%. In trials conducted in 2014 & 2015, the average level of RESS in commercial leaf-on runners of the cultivar Fortuna was 16% and 3%, respectively. It is not possible to separate the influence of environment and season and the impact of this project on the estimated reduction in the incidence of RESS in the strawberry industry north of Perth WA. However, a reduction in the incidence of RESS from 18% in 2013 to 3% in 2015 from lost plantings in this region alone is worth an estimated $360,000 p.a. (this estimate is based on a planting of 6 million runners in the industry north of Perth (Strawberries Australia, 2012) and the current price of leaf-on runners).

(3) If economic, plug plants become commercially available to the fruit industry by 2016.

Partially achieved. Analysis in this project shows that the use of plug plants is not yet economically viable in most fruit growing regions of Australia (Appendix III). Despite this, commercial trialing by the nursery industry of specific cultivars of plug plants commenced in the fruit industry in 2015 in regions where they show greatest promise (southern Victoria).

Evaluation and Discussion

Discussion:

(1) Cold-Stored Runner Trials

Cold-stored runners of specific day-neutral cultivars (particularly Portola and San Andreas) consistently provided earlier and later fruit yields than traditional leaf-on runners of short-day cultivars, such as Fortuna, in trials north of Perth WA. High fruit yields with cold-store runners occurred during periods when fruit prices were high (i.e. April - May and October - November), and when leaf-on runners were not producing. Consequently, revenue from the fruit of cold-store runners was up to 45% higher ($2.40 more per plant) than from traditional leaf-on runners. Cold-store runners of the cultivars Monterey and Albion did not survive or fruit as well as those of Portola and San Andreas. The ability of cold-stored runners of the cultivars Portola and San Andreas to fruit early in the season is consistent with their strong day-neutral characteristics (Shaw & Larson, 2009).

Planting cold-store runners early (January and February) resulted in very early fruit yields (April-May), but this practice required the use of white plastic and heavy irrigation for successful runner establishment. Nonetheless, cold-store runners planted in late-March under black plastic with standard irrigation practices still yielded earlier than leaf-on runners planted at the same time.

Cold-store runners did not fruit during the middle of the season (June-August), when leaf-on runners were producing high fruit yields. Therefore, co-ordinated plantings of cold-store runners and leaf-on runners offer growers north of Perth WA with the prospect of more even fruit production and income through an extended growing season (from April/May-November, compared with the traditional season based on leaf-on runners from May/June-September/October).

In contrast to results in WA, cold-store runners did not produce significant early fruit yields (April-May) in commercial trials at Caboolture, Qld. In this region, fruit yields from cold-store runners peaked in September-October when fruit prices were low, and therefore they were not considered commercially viable.

Seasonal issues and climate variability in the strawberry nursery industry are increasingly affecting planting times in August, the maturity and chill exposure (temperatures below 7°C) of freshly dug runners of leaf-on cultivars in late March, and their subsequent survival in the fruit industry. An advantage of cold-store runners is that they can be dug in late autumn / early winter when they have been exposed to adequate chill and are fully mature, and then stored dormant (-2°C) until planting in the fruit industry the following year. However, cold-stored runners draw on starch and other carbohydrates during dormancy, and may sometimes have insufficient reserves to establish well when planted (Lieten et al., 1995; Hicklenton & Reekie, 1998). They may also contain significant amounts of soil on their roots because they are dug under moist conditions in late autumn. Consignments of runners with high levels of soil may be rejected from entry into Western Australia under state biosecurity regulations. The challenges with cold-stored runners may be overcome by: (1) monitoring starch and non-structural carbohydrate levels during storage, (2) post-harvest washing treatments to remove

excess soil, and/or (3) specific post-harvest treatment of runners with chemical dips, which are approved by state biosecurity agencies for market access into Western Australia.

(2) Leaf-on Runner Trials

Research in this project identified several factors in leaf-on runners that were associated with their poor establishment in the fruit industry, including runner architecture (e.g. small crown diameters), low starch concentrations, high P concentration, runner immaturity, and mowing runners in the nursery industry too low and too soon before harvest. However, further controlled research would need to be conducted to prove that these factors, or combinations of these factors, cause poor runner establishment. For example, P concentrations in leaf-on runners showed a negative correlation (r = -0.7) with their survival when planted in the fruit industry (Appendix I). This correlation, however, was not considered to be due to a direct effect of P, because P concentrations in harvested runners were within accepted ranges (Ullio, 2010). Rather, it was hypothesised that the effect of higher inputs of P on the architecture of harvested runners (e.g. increased petiole lengths) affected their subsequent survival in the fruit industry. Further research is needed to confirm this hypothesis.

Irrespective of the exact cause, research in this project identified methods that nursery growers can use to reduce the risk of poor establishment of leaf-on runners in the fruit industry. For example, increasing the spacing of mother plants of the cultivar Fortuna from 1.0 m to 1.3 m at Toolangi Vic increased crown diameters and reduced the petiole length of harvested leaf-on runners. Mowing runners to ground level 4 weeks before harvest or to 20 cm 2 weeks before harvest at Toolangi Vic reduced petiole lengths of harvested leaf-on runners, and these plants had high survival rates in the fruit industry at Wanneroo WA. Moreover, mowed runners produced up to 7% more fruit and revenue ($0.46 more per plant more) in the fruit industry compared with un-cut runners. Finally, a threshold level of 500 mg P / kg soil at planting provided the maximum early growth of strawberry mother plants of the cultivar Fortuna. Commercial companies are available to provide nursery growers with soil analysis and fertiliser recommendations to meet this threshold.

Several factors were also identified at strawberry fruit farms that contributed to poor runner establishment, including cultivar selection, incidences of soil-borne pathogens, and variable fumigation and irrigation practices. For example, the strawberry cultivar Fortuna was most prone to poor runner establishment on fruit farms, with runner deaths following planting as high as 21.3% in research trials (Appendix I). In contrast, the newly-released cultivar Benicia survived well after planting, and produced 24% more fruit and 23% higher revenues ($1.17 more per plant) over the season, compared with Fortuna.

A small pathogen survey conducted in the fruit industry surrounding Wanneroo WA (8 farms) consistently isolated the pathogens *Phytophthora cactorum* or *Fusarium oxysporum* from wilting and dying leaf-on runners, and soil surrounding them. Minor-use fungicides are currently available for fruit growers to manage *P. cactorum* infestations following planting, but none are effective for post-plant management of *F. oxysporum*. Consequently, strawberry fruit growers use fumigants to control soil-borne pathogens before planting. Collaborative research with Project BS12025 showed that fumigation practices in the strawberry fruit industry north of Perth WA were highly variable. They included poor fumigant distribution following application, resulting in areas within the strawberry bed that were over- or under-dosed, and insufficient plant-back times (period between fumigation and planting) following treatment. These factors alone can directly kill newly planted runners (e.g. Mattner et al., 2014), or

reduce soil-borne pathogen control. Project BS12025 also identified that poor planting practices (e.g. leaving runners in bags on black plastic before planting), and uneven soil wetting and sub-optimal overhead irrigation (both in terms of coverage and scheduling) contributed to reduced runner establishment on strawberry fruit farms north of Perth WA.

(3) Plug Plant Trials

Production of runner tips and plug plants from a range of strawberry cultivars was consistently higher (up to 200% higher) under protected cropping systems than outdoor systems. However, the cost of plug plants was estimated to be 4-times more expensive ($1.50 per plant) than that of bare-rooted runners. This was mostly due to the higher labour inputs and infrastructure needed for the production of plug plants compared with bare-rooted runners (Appendix III). The higher cost of plug plants combined with their inconsistent yields and returns in trials in the fruit industry means they are not yet suitable for widespread adoption. For example, plug plants yielded an average 30% less fruit than bare-rooted runners in trials at Wanneroo WA (Table 10), but 30% more fruit in trials at Millgrove Vic (Appendix II). Similarly, plug plants have yielded between 40% less to equivalent fruit yields as bare-rooted runners in trials in southern Queensland (Menzel & Waite, 2006; Menzel et al., 2010). Menzel et al. (2010) also concluded that the fruit yields of plug plants do not yet warrant their additional cost and adoption by the fruit industry. Further research is needed on methods to reduce the cost of production of plug plants (such as incorporation of micro-propagation steps into the system), and their physiology (conditioning requirements, chilling hours, non-structural carbohydrate levels, container sizes, and substrate types) to achieve more consistent yields in the fruit industry.

Evaluation:

At the beginning of this project, the anticipated product from the research program was 'commercially-available strawberry runners and/or plug plants that yield much earlier (April / May) in specific regions of Australia, and establish much better than current leaf-on cultivars'. The overall outcome anticipated from the research program was 'increased profits for strawberry fruit growers and greater consistency of runner quality for strawberry nursery growers'.

Research in this project has effectively met its anticipated outcomes (see 'Outcomes: Impacts & Consequences') and products because it identified:

1. Cold-stored runners of specific day-neutral cultivars can produce earlier (April/May), later (October/November), and greater total fruit yields (up to 50% more) in the strawberry fruit industry north of Perth than traditional leaf-on runners of short-day cultivars, such as Fortuna. Cold-store runners are commercially available to fruit growers through the nursery industry.
2. Cold-stored runners of specific day-neutral cultivars can generate more revenue for growers (up to 45% or $2.40 more per plant) in the strawberry fruit industry north of Perth than traditional leaf-on runners of short day cultivars, such as Fortuna. Cold-store runners are commercially available to fruit growers through the nursery industry.
3. Multiple factors were associated with poor establishment of leaf-on runners in the fruit industry, and on-farm practices were identified that runner and fruit growers can implement to reduce the risk of poor runner establishment (see 'Recommendations').
4. Plug plants show promise as planting material in specific regions in the fruit industry, but require

more research to improve their consistency in fruit yields and reduce their cost. The runner industry has initiated commercial trials of plug plants in specific regions of the fruit industry (southern Victoria).

The effectiveness and quality of the research program can also be measured by:

1. The production of three refereed publications (see 'Scientific Refereed Publications'), and the prospect of developing further journal papers after the completion of the project.
2. An invitation from the conveners of the International Convention and Exhibition on Soil-less Culture to present research from the program as an opening address.
3. A request from the Victorian Branch of the Australasian Plant Pathology Society to tour the nursery industry and research sites within this project.

In addition to research, this project also conducted a communication program that delivered an average of one activity or output per month to strawberry growers in three states (see 'Outputs'). Key components of the communication program that proved particularly successful included:

1. Conducting research trials at sites where industry held field days and grower meetings. This allowed growers to review the results and outcomes from trials at oral presentations, then assess the performance of treatments in the field, and provide direct feedback on research directions and treatments. An example of grower input into the research was the concept of calculating the revenue from fruit through the season from the different treatments.
2. Employing the use of Vietnamese translators at oral presentations, and translation of printed materials into Vietnamese. A high proportion of growers in the strawberry fruit industry north of Perth have English as a second language, and industry meetings that had Vietnamese translators available were well attended. Best-practice flyers were made available to growers at meetings in English and Vietnamese, with a higher proportion of Vietnamese versions (approximately two thirds of those distributed) being selected by attendees.
3. Working in close collaboration with the previous industry development officer for Western Australia. This provided another avenue for feedback from industry into the project, and for communication of project outcomes to industry at a local level. For example, collaboration with the industry development officer initiated an investigation of fumigation practices within the fruit industry in northern WA, which proved an important contributing factor to poor runner establishment. The loss of regional industry development officers in the strawberry industry may present a challenge for disseminating information to growers in the future.

As a result of the communication program, a local horticultural consulting business in northern Western Australia offered to conduct commercial trialing of cold-stored runners with its strawberry fruit grower clients after the completion of this project. This provides a future pathway for adoption of the outcomes from this project by industry.

This project was conducted under Horticulture Australia Limited's R&D Strategic Investment Call for 2013/14 on methods for horticultural industries to manage and adapt to climate variability. Seasonal issues in the strawberry nursery industry are increasingly affecting planting times in August, the maturity of freshly dug runners in March, and their subsequent susceptibility to losses from poor establishment in the fruit industry. Cold-stored runners provide a simple solution because they can be dug in late autumn / early winter when they have been exposed to adequate chill and are fully mature, and then stored dormant (-2°C) until planting in the fruit industry the following year. Research in this project showed that cold-stored runners can supplement the use of freshly dug, leaf-on runners and make industry more resilient to climate variability.

This project has demonstrated that great gains in industry productivity and resilience can occur at a regional level (i.e. Toolangi Vic, and north of Perth WA). This project was funded through industry voluntary contributions matched by government money. The new funding structure of HIA Limited may present a challenge in the future because there is no longer a clear pathway to support industry-specific research through matched voluntary contributions, especially at a regional level. The future funding of research projects that are regionally significant, but have wider impacts, requires further consideration by the strawberry industry and HIA Limited.

Recommendations

Strawberry Fruit Industry Recommendations:

1. To achieve earlier yields strawberry fruit growers north of Perth should consider the use of cold-stored runners of specific day-neutral cultivars (Portola and San Andreas) as part of a planting strategy with leaf-on runners (e.g. Fortuna). The use of this strategy has the potential to extend the growing season because cold-stored runners fruit early in April/March and late in October/November. Research showed that cold-stored runners produced higher total fruit yields (up to 50% more) and revenue (up to $2.40 more per plant) than some traditional leaf-on runners. When planted in January and February cold-stored runners produced fruit particularly early (from April), but required heavy overhead irrigation inputs and the use of white plastic on soil for successful establishment. When planted in March, cold-stored runners produced fruit from May, but only required standard irrigation schedules and black plastic for establishment. Cold-stored runners did not yield earlier in southern Queensland (Caboolture), and are not considered commercially viable in this region.

2. To reduce establishment losses of leaf-on runners, strawberry fruit growers should: (1) consider leaf-on cultivars (e.g. Benicia) that are less susceptible to establishment losses and yield higher than current leaf-on cultivars, (2) monitor and manage soil-borne pathogens using approved fungicides and fumigants, (3) fumigate soils strictly following label recommendations especially with regards to application rates and plant-back times, (4) design and schedule overhead irrigation at planting to ensure good coverage to reduce stress on establishing plants (see BS12025), and (5) not expose runners to harsh environments (e.g. exposed on hot, black plastic) at planting and plant runners to recommended depths (as supplied by nursery growers).

Strawberry Runner Industry Recommendations:

3. To reduce establishment losses of leaf-on runners in the strawberry fruit industry, strawberry runner growers at Toolangi, Vic should consider: (1) application of P fertilisers at planting in the nursery industry to meet a threshold of 500 mg P / kg soil for optimal mother plant growth of the cultivar Fortuna, (2) cutting leaf-on runners to 20 cm, 2 weeks before harvest, or to low levels 4 weeks before harvest to reduce petiole lengths (plant height), (3) widening mother plant spacings for Fortuna from 1.0 m to 1.3 m to produce shorter runners with thicker crowns, (4) grading leaf-on runners of susceptible cultivars like Fortuna to well above 7.5 mm to ensure they are mature, and (5) only digging runners when they are fully mature.

HIA Limited Recommendations:

4. *Fusarium oxysporum* and *Phytophthora cactorum* are important pathogens causing wilt diseases in strawberry in WA. These pathogens should be included in SARP (Strategic Agrichemical Review Process) analyses being conducted for the strawberry fruit industry by HIA Limited.

5. To capture economic, social, and environmental benefits from research in the strawberry industry, HIA Limited will need to consider how to fund projects at a regional level without the matching voluntary contribution system. This is important because the strawberry industry is widely dispersed across Australia, and occurs in areas that are environmentally and sociologically diverse. The current project has demonstrated that great gains in overall industry productivity and resilience can occur from technologies applied at a regional level, but they are not necessarily directly transferable to other regions of the industry.

Scientific Refereed Publications

Mattner, S.W., Horstra, C.B., Milinkovic, M., Merriman, P.R., Greenhalgh, F.C. 2016. Evaluation of soil-less systems for strawberry transplant production. *Acta Horticulturae* (in press).

Mattner, S.W., Milinkovic, M., Merriman, P.R., Porter, I.J. 2014. Critical challenges for the phase-out of methyl bromide in the Australian strawberry industry. *Acta Horticulturae* **1044**: 367-373.
(Includes a partial budget analysis of soil-less systems for strawberry transplant production).

Milinkovic M., Mattner S.W., Greenhalgh, F.C. 2016. Performance of soil-less systems for strawberry transplant production in Australia. *Acta Horticulturae* (in submission).

Intellectual Property/Commercialisation

No commercial IP generated.

References

BS04009. Breaking the critical-use barriers preventing Australian horticulture from phasing out methyl bromide. HAL Final Report (2008), Sydney, NSW.

BS06029. Development and design of a soil-less system for production of strawberry runners. HAL Final Report (2009), Sydney, NSW.

BS09019. Development of a soil-less system for production of strawberry runners. HAL Final Report (2010), Sydney, NSW.

BS12025. A focus on irrigation and fertiliser practices to improve production efficiency for LOTE strawberry growers. HIA Final Report (2015), Sydney, NSW.

Durner EF, Poling EB, & Maas JL (2002) Recent advances in strawberry plug transplant technology. HortTechnology 20:788-793.

Greer N, Hutton D et al. (2005) Strawberry problem solver and bug identifier. QDPI.

Hicklenton PR, Reekie J (1998) Plant-age, time of digging and carbohydrate content in relation to storage vigor of strawberry plants. Acta Horticulturae 513: 237-246.

Lieten P (2013) Advances in strawberry substrate culture during the last twenty years in the Netherlands and Belgium. International Journal of Fruit Science 13: 84-90.

Lieten P, Kinet JM et al. (1995) Effect of prolonged cold storage on the production capacity of strawberry plants. Scientia Horticulturae 60: 213-219.

Mattner SW, Milinkovic M. et al. (2014) Critical challenges for the phase out of methyl bromide in the Australian strawberry industry. Acta Horticulturae 1044: 367-373.

McCleary BV, Gibson, TS et al. (1997) Collaborative evaluation of a simplified assay for total starch in cereal products (AACC Method 76-13). Cereal Foods World 42: 476-480.

Menzel CM, Smith L (2011) Effect of time of planting, plant size and nursery-growing environment on the performance of 'Festival' strawberry in a subtropical environment. HortTechnology 21: 56-66.

Menzel CM, Smith L (2012a) Effect of time of planting on the productivity of Festival and Florida Fortuna strawberry plants in a sub-tropical environment. HortTechnology 22: 330-337.

Menzel CM, Smith L (2012b) Relationship between levels of non-structural carbohydrates, digging date, nursery-growing environment, and chilling in strawberry transplants in a subtropical environment. HortScience 47: 459-464.

Menzel CM, Toldi A (2010) An evaluation of containerised plants for strawberries growing in a subtropical environment. HortTechnology 12: 545-550.

Menzel CM, Waite GK (2006) The performance of strawberry plugs in Queensland. Acta Horticulturae 708: 217-224.

Shaw DV, Larson KD (2009) Strawberry plant named 'Portola'. US Patent US PP20552 P3.

Strawberries Australia (2012) Strawberries Australia Inc. strategic investment plan 2012-2017. HAL, Sydney, NSW.

Ullio L (2010) Strawberry fertiliser guide. Primefacts, NSW Government.

Acknowledgements

The project team acknowledges the in-kind support and assistance from growers who hosted trials. The team also acknowledges technical input and expert advice from Rohan Davies and Graeme McIntrye on phosphorus nutrition and from Jason Koenders on cooling systems for runners. We thank for Lam Ti Muir for providing Vietnamese translation and industry insight at field days, Susan Bolsenbroek for assistance with picking trials and running field days, and Diane Davies for helping with data collection.

Appendices

Appendix I: Mattner S.W., Verheyen, G. et al. (2014) BS13002 Earlier yields and better establishment of strawberry runners. Summary report of research. VSICA Report.

Appendix II: Mattner, S.W., Milinkovic M. et al. (2015) Performance of strawberry plug plants. *VicStrawberries*, Victorian Strawberry Industry Newsletter, May Edition.

Appendix III: Mattner S.W., Horstra, C.B. et al. (2016) Evaluation of soil-less systems for strawberry transplant production. Review paper. (abstract).

Appendix IV: Mattner S.W., Verheyen G. et al. (2014) Earlier yields and better establishment of strawberry runners (BS13002). VSICA Flyer.

Appendix V: Mattner S.W., Verheyen G. et al. (2015) Cold-store runners and plug plants. VSICA Flyer.

Appendix VI: Mattner S.W., Verheyen G. et al. (2015) Runner maturity and earlier yields. VSICA Flyer.

VSICA

BS13002 EARLIER YIELDS AND BETTER ESTABLISHMENT OF STRAWBERRY RUNNERS – SUMMARY REPORT OF RESEARCH

HAL Project: BS13002 (November 2014)

Scott Mattner, Gerry Verheyen, Mirko Milinkovic, Peter Merriman

Victorian Strawberry Industry Certification Authority

Executive Summary

BS13002 – Earlier Yields and Better Establishment of Strawberry Runners

Field trials were conducted in the strawberry fruit industry at Wanneroo, Western Australia and the strawberry nursery industry at Toolangi, Victoria on strategies to achieve earlier fruit yields and better establishment of runners. Experiments considered: (1) the use of cold-stored runners of day-neutral cultivars planted in summer, (2) improved agronomic regimes in the nursery industry for short-day cultivars of leaf-on runners, and (3) plug transplants and soil-less production systems for runners.

Results showed:

- The cultivar Portola has the potential to deliver WA growers around Perth with earlier fruit yields when planted as cold-stored runners in January under white plastic.
- The cultivar San Andreas has the potential to deliver WA growers around Perth with late fruit yields in October when other cultivars have stopped fruiting.
- Phosphorus concentrations in soil of 500 mg/kg in the Victorian nursery industry provide optimum early growth of mother plants of the strawberry cultivar Fortuna.
- Strawberry leaf-on runners (cv. Fortuna) from high-yielding stands in the Victorian nursery industry, with long petioles, thick crowns and large leaf areas were associated with the highest rates of plant losses (c. 15% runner losses) in the fruit industry in WA.
- Widening mother plant spacings from 1 m to 1.3 m in the Victorian nursery industry, for the leaf-on cultivar Fortuna, increased early (March) runner yields by 7%.
- Prototype hydroponics systems for runner tip production produced 58% less yields compared with bare-rooted runners produced in fumigated soil.

Further research is needed to:

- Confirm the potential for cold-store Portola and San Andreas runners to deliver early and late yields, respectively, in the WA fruit industry around Perth.
- Develop mowing regimes, confirm plant spacing recommendations, and refine nutrient regimes for leaf-on runners in the Victorian nursery industry to produce transplants with the correct plant architecture for improved establishment.
- Improve the production efficiency of hydroponics systems for plug plant production, e.g. by incorporating micropropagation steps into the design.

Contents

1. Introduction

Early fruit production attracts a premium price and higher profits for strawberry growers. In Western Australia and Queensland, for example, planting leaf-on runners in March / early April is one of the key factors that can influence early fruit yields (e.g. Menzel & Smith, 2012). However, strawberry runners dug in the nursery industry in March / early April can be immature and prone to 'runner establishment stress syndrome' (RESS). In 2013, establishment of some leaf-on runners in the Western Australian and Queensland fruit industries was poor, with 10-30% losses of plants due to RESS, depending on the region and cultivar. Seasonal issues and climate variability in the strawberry nursery industry are increasingly affecting planting times in August / September, the maturity of freshly dug runners in March / early April, and their susceptibility to RESS in the fruit industry.

The best way to prevent RESS is to dig strawberry runners when they are fully mature (Greer et al., 2005), but this strategy does not allow fruit growers to achieve earlier yields. There are no published papers in the scientific literature specifically on the management of RESS in strawberries. However, personal communication with researchers and industry representatives in the US, Spain, and EU suggests that RESS in runners can be minimised through combinations of cold-storage, modified agronomic practices, or the use of plug transplants.

In California, fruit growers achieve earlier yields by planting cold-stored runners (-2 degrees C) of day-neutral cultivars in summer (Prof Doug Shaw, UC, personal communication). This strategy allows the nursery industry to dig plants in late autumn / winter when they are fully mature, and then cool-store them until summer. It avoids the influence of climate variability on the maturity of runner transplants and reduces their susceptibility to RESS. The challenge for fruit growers using this strategy is to successfully establish runners over summer and maintain their vegetative growth until autumn. Californian fruit growers achieve this through the use of lighter coloured plastic mulches, carefully monitored irrigation regimes, and deflowering plants until autumn. This strategy has strong potential to provide the strawberry fruit industry (particularly Western Australia and Queensland) with earlier yields in April / May, but has not been tested in Australia.

In Spain, nursery growers manipulate plant nutrition (optimum phosphorus, reduced nitrogen and late application of potassium, sulphur and copper) in short-day cultivars grown as leaf-on runners to harden their roots and improve their establishment in the fruit industry (Annelle Reid, Emco Cal & Jose Lopez-Aranda CIFA Spain, personal communication). Also, leaf-on runners are cooled using combinations of vacuum and hydro-cooling. These treatments can lower the temperature of harvested runners more rapidly than conventional cooling.

The use of appropriate densities and mowing regimes is also important to achieve desired petiole lengths and crown diameters of leaf-on runners. In Australia, recommendations for crown sizes of leaf-on runners are well defined for improved establishment and fruit yields (Menzel & Smith, 2012). However, it is difficult to achieve these crown sizes in strawberry nurseries by early March / April. Current recommendations for planting densities for short-day cultivars of leaf-on runners in Australia are based on those used in the US (e.g. 40 inches for the cultivar Fortuna). It is possible that the use of wider plant spacings may increase the crown

diameters and reduce petiole lengths of harvested runners, but this research has not been conducted in Australia.

In Europe (reviewed by Lieten, 2013) and south-eastern US (reviewed by Durner et al., 2002), specific cultivars of plug plants (containerised transplants) produced in protected cropping systems have shown better establishment and yields than bare-rooted runners. In contrast, previous research conducted in Australia (Menzel & Toldi, 2010) has shown that plug plants do not produce significantly greater fruit yields than bare-rooted runners. This combined with their higher cost means that plug plants are not currently economically viable in Australia. However, research concluded that better conditioning of plug plants may improve their capacity to produce earlier and higher fruit yields. The impending withdrawal of soil fumigants (e.g. methyl bromide), which the nursery growers rely on to produce bare-rooted runners, is also forcing industry to reconsider the adoption of plug plants. For example, the UN have recently recommended that the Australian strawberry nursery industry adopt soil-less systems, including production of plug plants under protected cropping, as an alternative to methyl bromide for runner production (MBTOC, 2013).

2. Aim & Scope of Report

This project was approved by Horticulture Australia to conduct research trials in the Victorian nursery and Western Australian fruit industries, and grower trials in the Queensland fruit industry, on strategies to achieve earlier yields and better establishment of runners in the fruit industry. These strategies include:

(1) the use of cold-stored runners of day-neutral cultivars planted in summer,

(2) improved agronomic regimes in the nursery industry for short-day cultivars of leaf-on runners, and

(3) plug transplants and soil-less production systems.

This report summarises key results from trials conducted in the first year of this project.

3. First Year Trials of Cold-Stored Runners Planted in Summer

3.1 Wanneroo Scientific Trial

Aim: A field trial was conducted in the strawberry fruit industry at Wanneroo WA to test the hypothesis that cold-stored runners of day-neutral cultivars planted in summer produce early yields, and have higher survival rates than a standard leaf-on cultivar planted in autumn.

Trial Design: Randomised factorial design that consisted of three main treatments in four blocks. There were 68 plots in total and each plot contained 32 strawberry plants.

Treatments: 1. Cultivars: Portola, Albion, Monterey, and San Andreas

2. Plastic Mulch: black plastic mulch, and white plastic mulch

3. Planting Date: January (02/01/2014), and February (19/02/2014)

Industry standard control: Fortuna leaf-on planted under black plastic (20/03/2014)

Key Assessments: soil temperature (datalogged)

plant establishment (leaf area, crown diameter, April)

plant survival (April)

early fruit yield (yield April - May)

late fruit yield (from October - November)

total fruit yield (April – November)

Key Results:

Plant survival of the day-neutral cultivars Portola and San Andreas were equivalent to that of the leaf-on cultivar Fortuna, irrespective of planting time or colour of plastic film (Fig. 1). Plant survival of the cultivar Albion was also equivalent to Fortuna, but only when grown under white plastic mulch. The cultivar Monterey had very low survival rates in the trial.

By April, crown diameters (Fig. 2) and leaf area (data not shown) of all day-neutral cultivars, except Monterey, were significantly higher than those of Fortuna. Crown diameters and leaf area of the cultivars Portola and San Andreas were significantly higher when planted in January than when planted in February. Plastic colour did not affect crown diameters or leaf area of plants.

Early fruit yields (April – May) of the cultivar Portola planted in January under white plastic were significantly greater than those of Fortuna and other day-neutral cultivars (Fig. 3). Overall, early yields were greater in day-neutral cultivars planted in January than in February, and when grown under white plastic than black plastic.

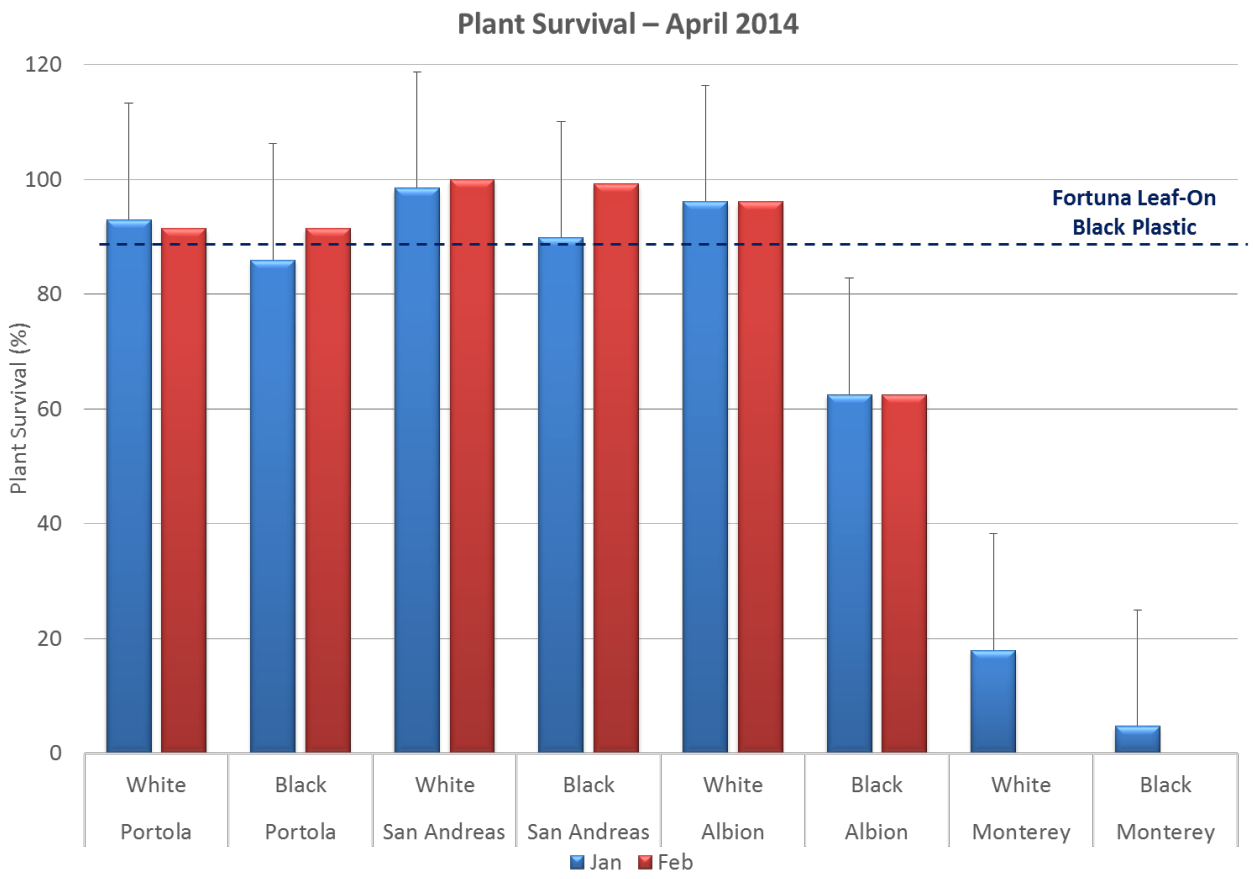

Figure 1. Survival (%) of different day-neutral cultivars of cold-stored runners planted in January or February under black or white plastic in a field trial in the strawberry fruit industry at Wanneroo, WA. The dashed line is the industry standard control of the short-day cultivar Fortuna planted in March as a leaf-on runner. The bars represent the least significant difference, where p = 0.05.

Late yields (October - November) of the cultivar San Andreas planted in February were significantly higher than other day-neutral cultivars, irrespective of the colour of plastic used (Fig. 4). By comparison, day-neutral cultivars planted in January, and the leaf-on cultivar Fortuna had stopped fruiting by October.

Overall, total yields of the day-neutral cultivars Portola (planted in January under white plastic) and San Andreas (planted in February) averaged 3 punnets/ plant, which is equivalent to commercial standards.

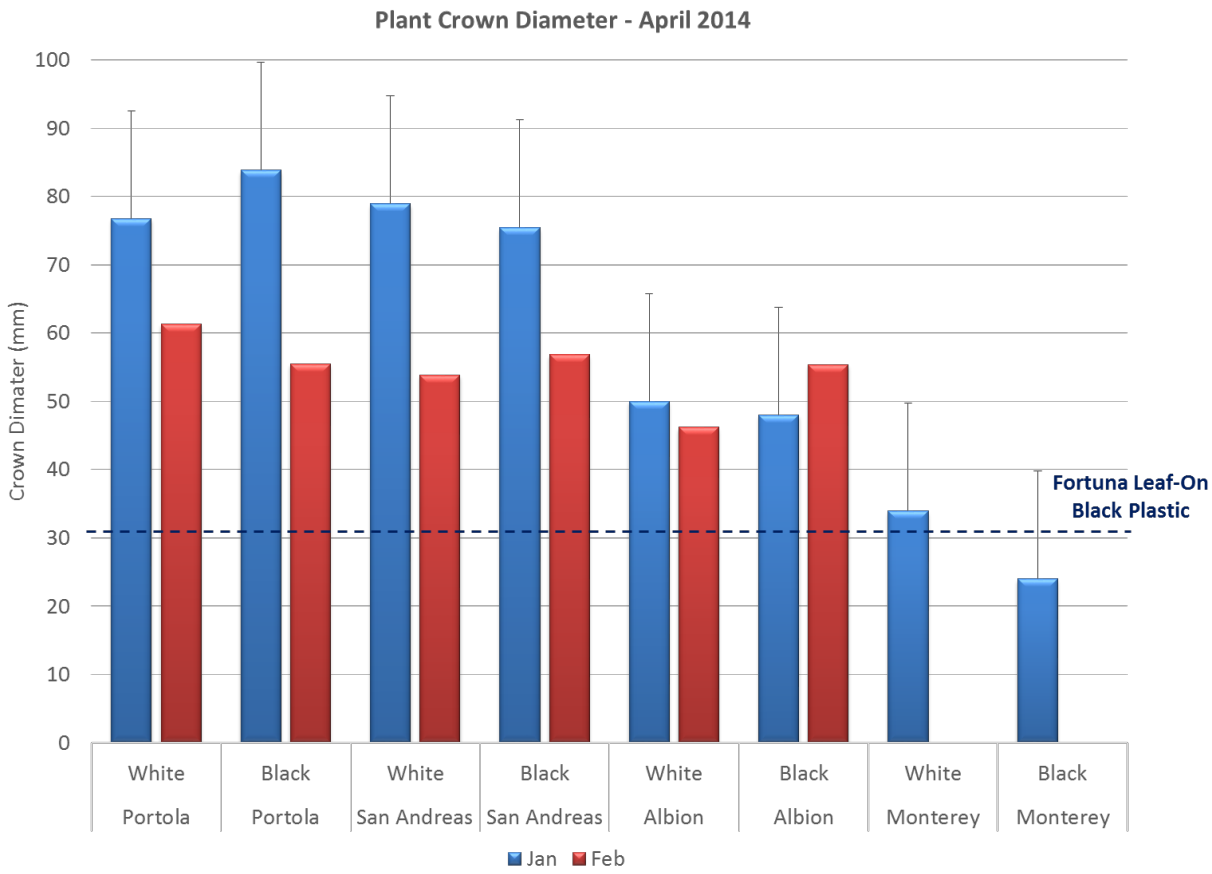

Figure 2. Crown diameter (mm) of different day-neutral cultivars of cold-stored runners planted in January or February under black or white plastic in a field trial in the strawberry fruit industry at Wanneroo, WA. The dashed line is the industry standard control of the short-day cultivar Fortuna planted in March as a leaf-on runner. The bars represent the least significant difference, where p = 0.05.

Discussion / Conclusions:

This trial showed the potential for plantings of cold-store runners of day-neutral cultivars to increase the growing season in the strawberry industry around Perth WA, and allow growers to access higher-priced fruit markets early and late in the season.

Cold-stored runners of the day-neutral cultivar Portola showed the greatest potential for increasing early fruit yields. Early yields occurred when this cultivar was planted in January and grown under white plastic to lower heat stress. Successful plant establishment also required high levels of water inputs. Fruit prices during the April - May period fetch between $12-16/kg (FreshLogic, 2013). Under this pricing scenario, revenue for Portola planted in January under white plastic in this trial averaged $1.05 per plant in April - May. By comparison, revenue for the industry standard of Fortuna leaf-on plants in this trial averaged

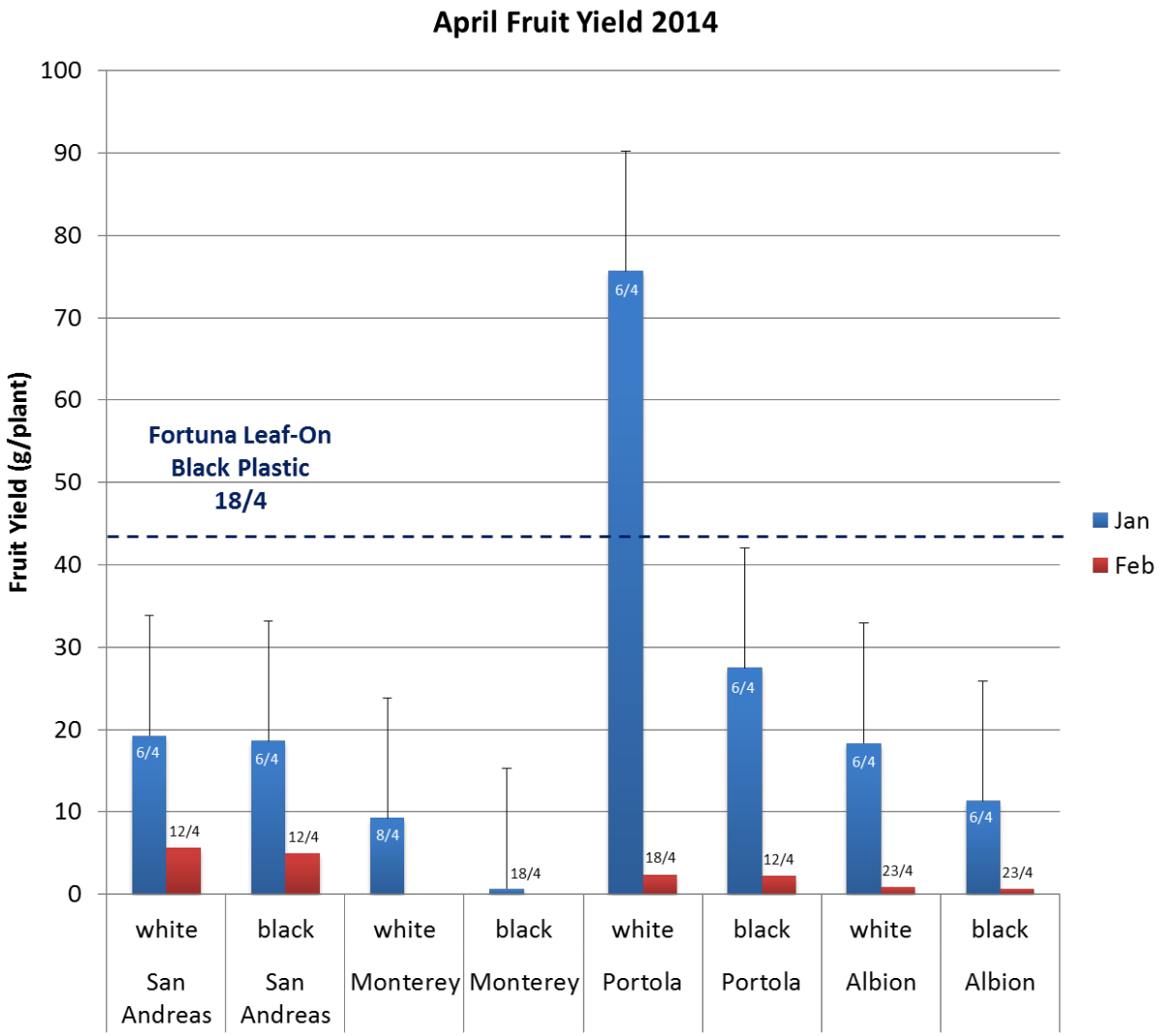

Figure 3. Strawberry fruit yields (g/plant) in April-May of different day-neutral cultivars of cold-stored runners planted in January or February under black or white plastic in a field trial in the strawberry fruit industry at Wanneroo, WA. The dashed line is the industry standard control of the short-day cultivar Fortuna planted in March as a leaf-on runner. Dates on columns are the first fruit pick for each treatment. The bars represent the least significant difference, where p = 0.05.

$0.59 per plant over the same period. The performance of Portola in this trial is consistent with its particularly strong characteristic as a day-neutral cultivar (flowers in response to temperature and not day length) (Shaw & Larson, 2009).

Late yields in October - November can also fetch relatively high prices for WA fruit growers of up to $7/kg, compared with prices during peak production in August - September of $4/kg (FreshLogic, 2013). Under this pricing scenario, revenue for San Andreas planted in February averaged $1.92 per plant in this trial during October - November, at a time when the industry standard of Fortuna leaf-on was not producing.

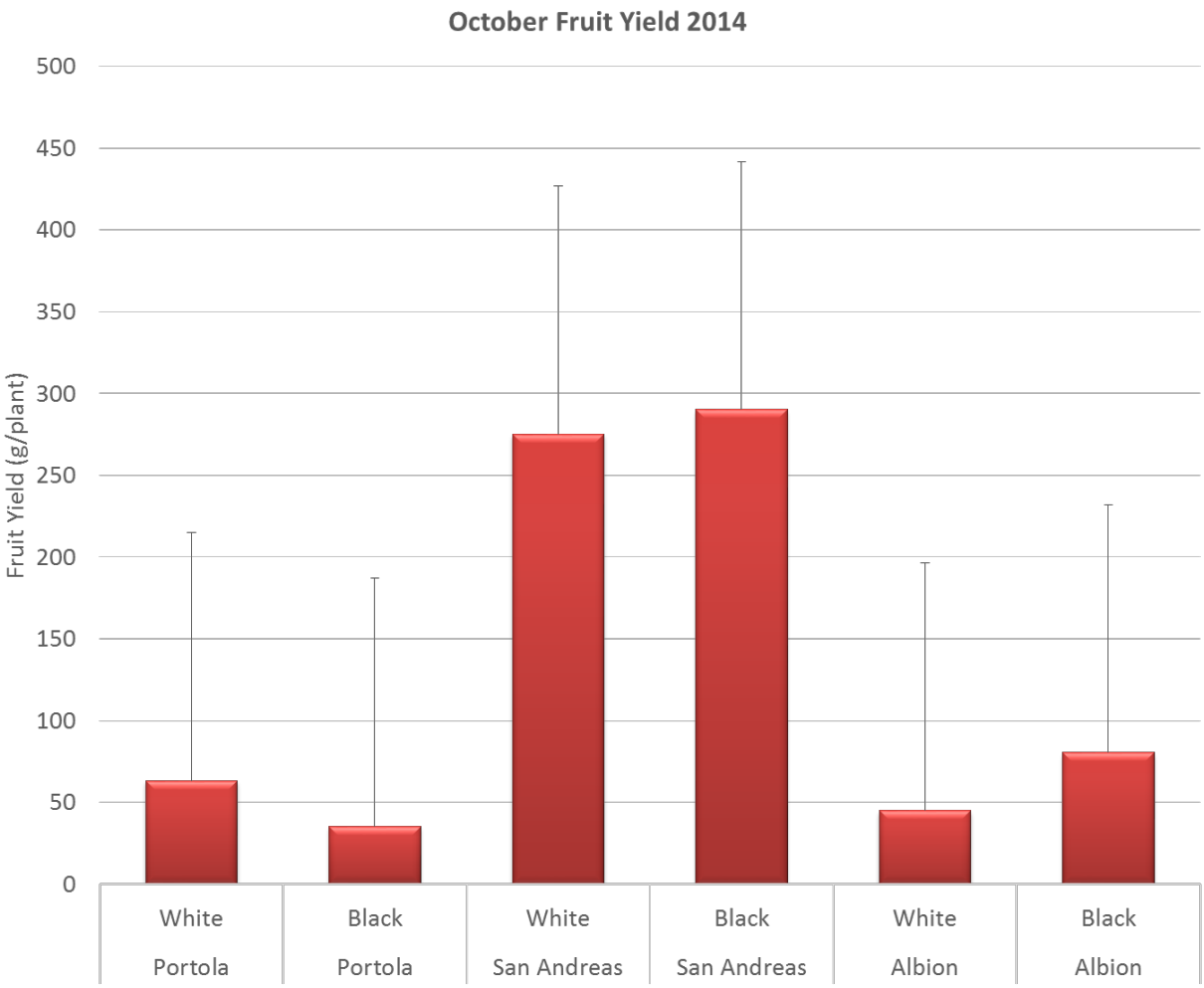

Figure 4. Strawberry fruit yields (g/plant) in October-November of different day-neutral cultivars of cold-stored runners planted in February under black or white plastic in a field trial in the strawberry fruit industry at Wanneroo, WA. Day-neutral runners planted in January, the cultivar Monterey, and the short-day cultivar Fortuna did not yield in October-November. The bars represent the least significant difference, where p = 0.05.

Trials in the second year of the project will concentrate on summer plantings of Portola and aim to quantify the water inputs required for their establishment. Trials will also focus on late summer plantings of San Andreas, and their late season yields.

3.2 Queensland Grower Demonstration Trials

Aim: Grower trials were conducted in Caboolture, Qld to commercially assess the performance of cold-stored runners of a day-neutral cultivar planted in summer.

Trial Design: Randomised design with no blocking.

Treatments: 1. Cultivar: cold-stored San Andreas planted on 19/02/2014

2. De-flowering: de-flowered in throughout summer / early autumn or not deflowered

3. Grown under protected (poly tunnels) or outdoor production systems

Key Assessments: plant establishment (leaf area, crown diameter, April)

plant survival (April and July 2014)

fruit yields reported by growers

Key Results:

In April (6 weeks after planting), deflowered plants had 20% larger leaf area (Fig. 5) and 140% greater crown diameters (data not shown) than non-deflowered plants in the outdoor production system. Under protected production, however, there was no difference in plant establishment between deflowered and non-deflowered plants. Survival rates of plants were high in the trial (all above 95%), irrespective of the production system used or the de-flowering regime.

Despite successful plant establishment, the grower reported that cold-store plants only produced vegetative growth and produced little fruit early in the season. This response was consistent under protected and outdoor production systems, and in deflowered and non-deflowered plants. Fruit yields came in late in the season (August) when strawberry prices had fallen. Overall, the grower reported that yields with cold-store plants were less than half those from leaf-on cultivars of runners.

Discussion / Conclusion:

The late production of strawberry fruit by cold-stored San Andreas is consistent with results in a scientific trial with this cultivar in WA (see Section 3.1). Late fruit production is of little value for Queensland growers because prices fetch less than $4/kg during the August-September period (FreshLogic, 2013). Results from WA suggest that cold-store runners of the day-neutral cultivar Portola may provide a better opportunity to deliver earlier fruit yields for growers in Southern Queensland, particularly if grown on white plastic. This hypothesis needs to be tested in further commercial trials.

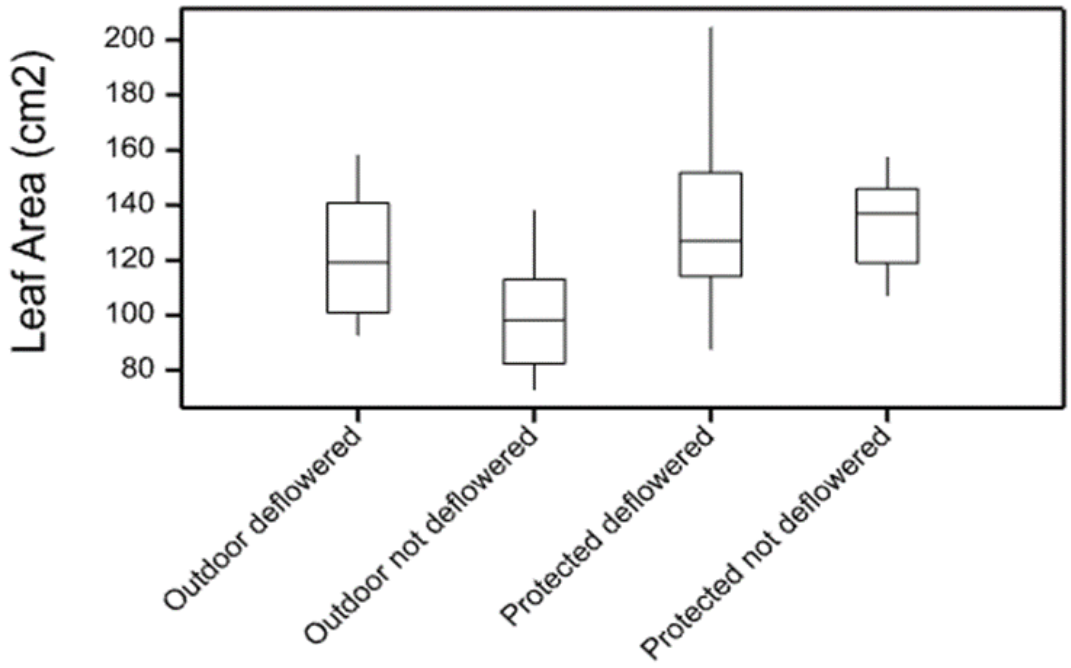

Figure 5. Boxplot (n = 15) of the area of the most expanded leaf (cm^2) of the cold-stored runner San Andreas at 6-weeks after planting in a demonstration trial in the strawberry fruit industry at Caboolture, Qld. Plants were grown under protected or outdoor production systems and deflowered or not deflowered.

4. First Year Trials of Agronomic Regimes in the Nursery Industry for Short-day Cultivars of Leaf-on Runners

4.1 Plant Density Trial

Aim: A field trial was conducted in the strawberry nursery industry at Toolangi Vic to test the hypothesis that wider planting spacing increases the marketable yield and crown diameter of leaf-on runners.

Trial Design: Randomised complete block design with five treatments arranged in four blocks. There were 20 plots in total; each plot was 8 m long by 2.71 m wide.

Treatments: A single row of mother plants (cv. Fortuna) was planted on 10/10/2013 at densities of: 0.09 mother plants/m^2 (4 m apart), 0.18 mother plants/m^2 (2 m apart), 0.28 mother plants/m^2 (1.3 m apart), 0.40 mother plants/m^2 (1 m apart), and 0.46 mother plants/m^2 (0.8 m apart).

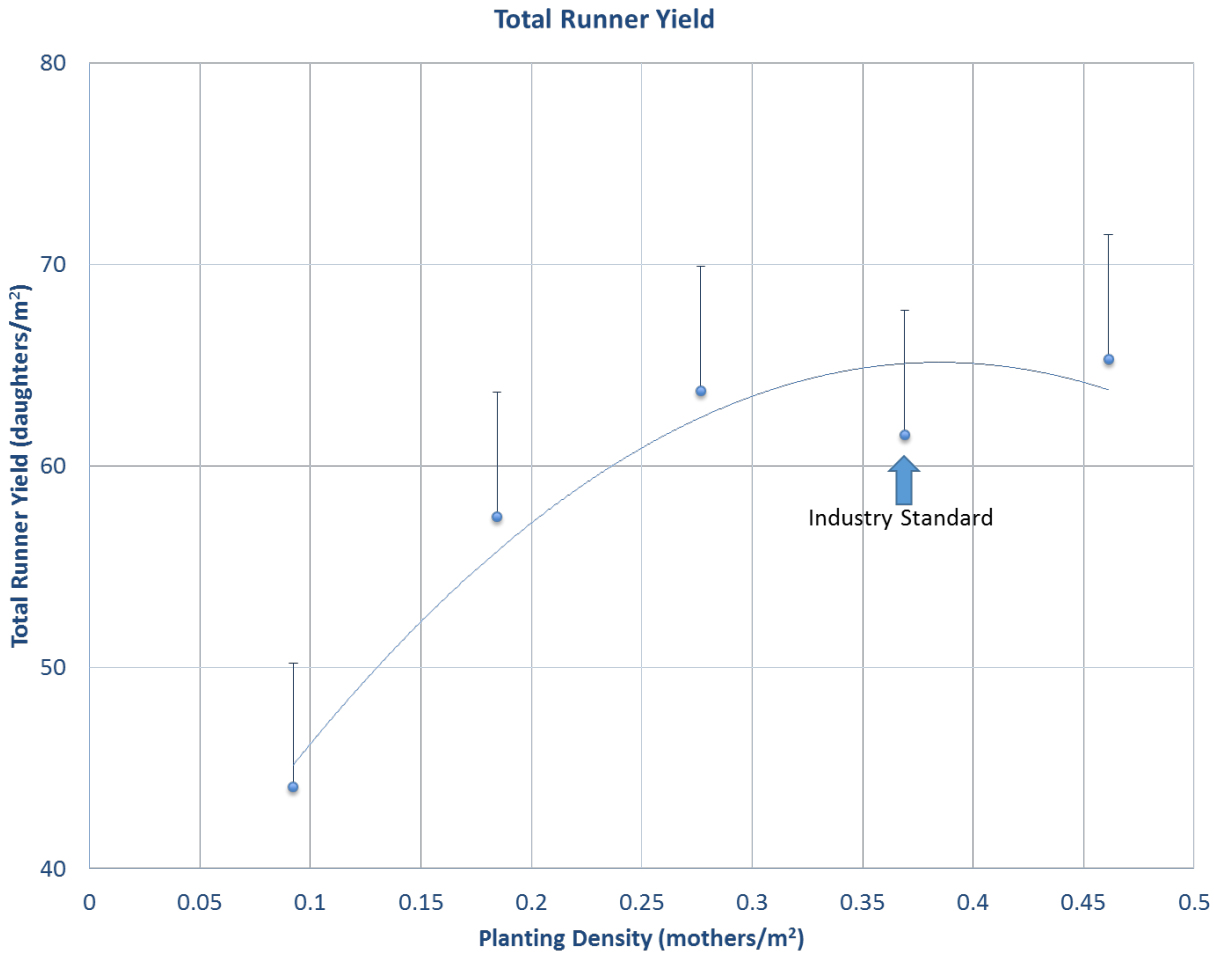

Figure 6. Total runner yield of the cultivar Fortuna planted at different densities in a field trial in the strawberry nursery industry at Toolangi, Vic. Bars represent the least significant difference where p = 0.05.

Key Assessments: total runner yield

marketable runner yield

crown diameter of harvested runners

petiole length of harvested runners

Key Results:

Increasing planting density up to 0.28 mother plants/m^2 increased total runner yields. Thereafter, further increases in planting density had no effect on runner yields (Fig. 6). This

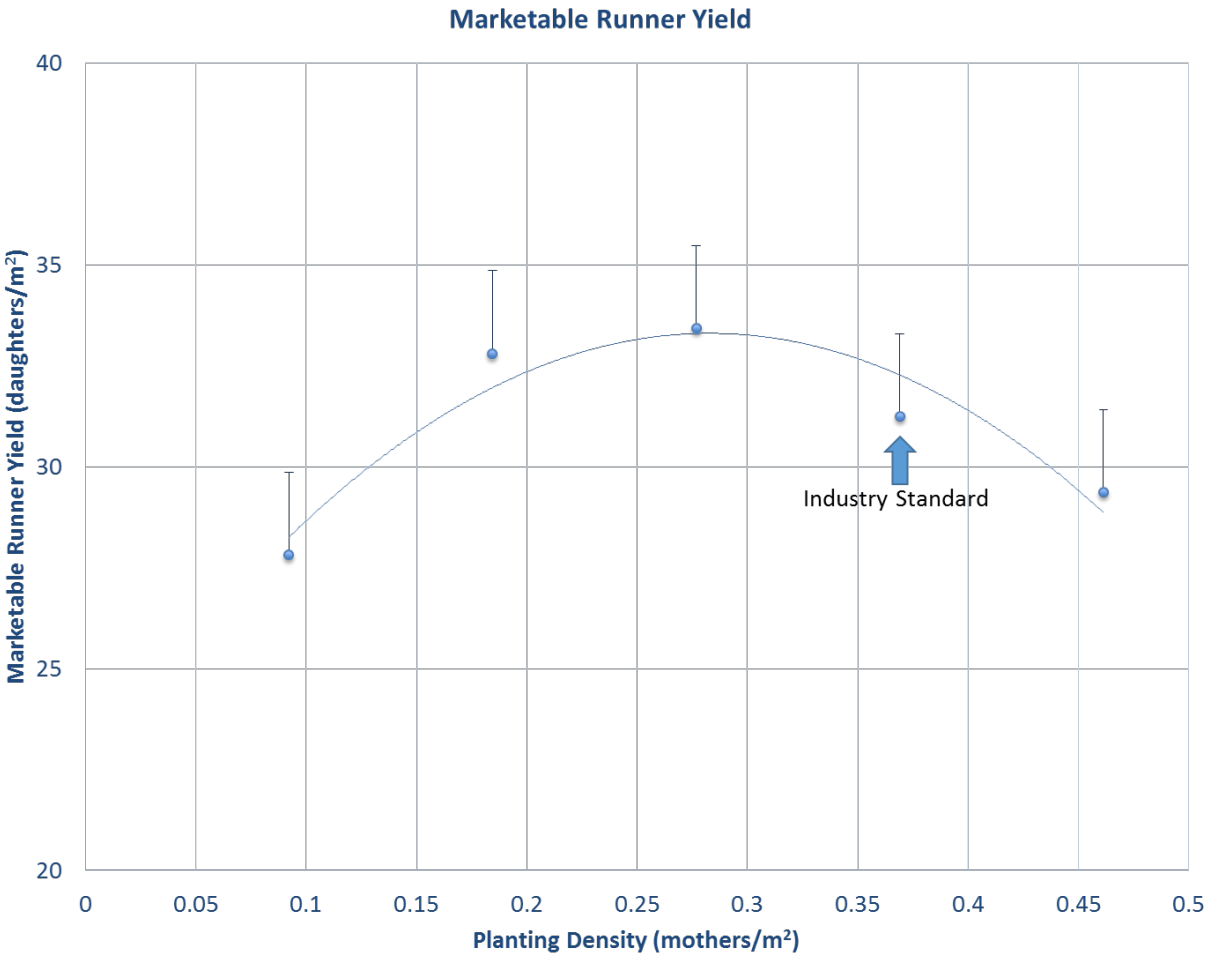

Figure 7. Marketable runner yield of the cultivar Fortuna planted at different densities in a field trial in the strawberry nursery industry at Toolangi, Vic. Bars represent the least significant difference where p = 0.05.

result is consistent with the 'Law of Constant Final Yield' (Kira et al., 1953). Marketable yields of runners (runners with crown diameters above 7.5 mm) peaked at a planting density of 0.28 mother plants/m^2 (mother plants spaced 1.3 m apart) (Fig. 7).

The crown diameter and petiole lengths of harvested runners followed a linear response to planting density (Fig. 8). Crown diameters decreased as planting density increased, as expected under the 'Reciprocal Yield Law' (Shinozaki & Kira, 1956). In contrast, runner petiole lengths increased as plant density increased, probably due to increased intra-specific competition for light.

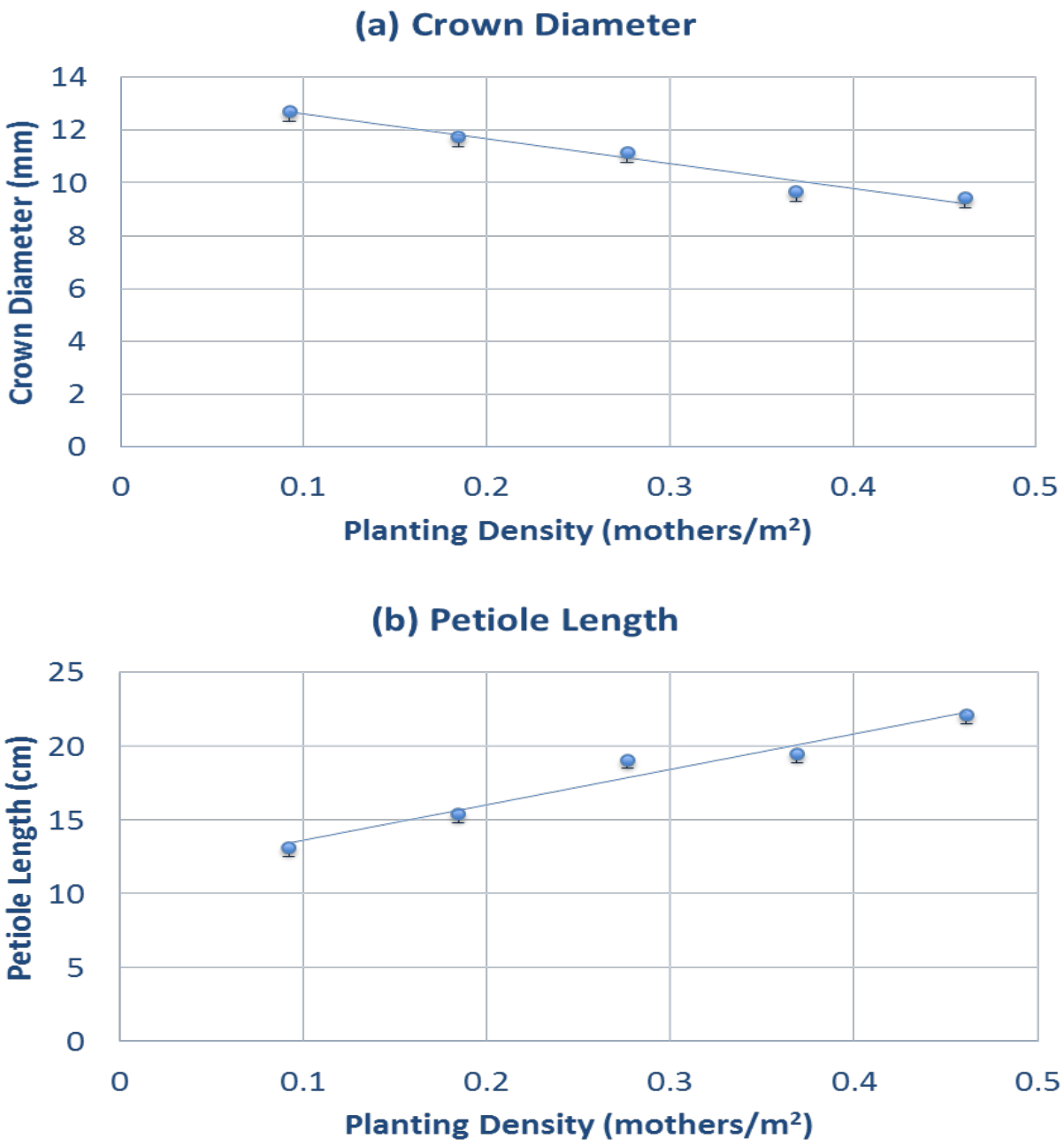

Figure 8. (a) Crown diameters (mm) and (b) petiole lengths (cm) of harvested runners of the cultivar Fortuna planted at different densities in a field trial in the strawberry nursery industry at Toolangi, Vic. Bars represent the least significant difference where p = 0.05.

Discussion / Conclusions:

This trial showed that the plant architecture of runners is highly responsive to planting density. Growers aim to produce runners with crown diameters above 7.5 mm and short petioles. Currently the standard plant spacing for the cultivar Florida Fortuna is 40 inches (1.02 m). This trial suggests that increasing plant spacing to 1.3 m could increase marketable yields of runners by 7%, crown diameters of harvested runners by 15% and reduce petiole heights by 10%. Further research is needed in 2014/15

to confirm these preliminary findings, and assess the effect of plant architecture (crown diameter, petiole length and other parameters) on plant survival in the fruit industry.

4.2 Phosphorus Trials

Aim: Two field trials were conducted in the strawberry nursery industry at Toolangi Vic to determine optimum Phosphorus (P) inputs for high commercial runner yields in March of the leaf-on cultivar Fortuna.

Trial Design: Randomised complete block design with twelve treatments arranged in four blocks. There were 48 plots in total; each plot was 5 m long by 2.71 m wide. Two separate field trials were established; one on a Red Ferrosol (clay texture) and the other on a Brown Ferrosol (clay loam texture).

Treatments: A single row of mother plants (cv. Fortuna) was planted on 25/09/13 (Red Ferrosol) and 10/10/13 (Brown Ferrosol) at plant spacings of 40 inches. Treatments were applied using combinations of monoammonium phosphate, single superphosphate, ammonium sulphate, potassium sulphate, and elemental sulphur. Treatments were applied equally across three application times (planting, 8 weeks after planting, and 14 weeks after planting) to give total nutrient inputs of:

(a) Untreated control

(b) 250 kg/ha S (S control)

(c) 150 kg/ha N + 250 kg/ha S (NS control)

(d) 200 kg/ha P + 250 kg/ha S (PS control)

(e) 150 kg/ha K + 250 kg/ha S (KS control)

(f) 150 kg/ha N + 150 kg/ha K + 250 kg/ha S (P_0 treatment)

(g) 150 kg/ha N + 50 kg/ha P + 150 kg/ha K + 250 kg/ha S (P_1 treatment)

(h) 150 kg/ha N + 100 kg/ha P + 150 kg/ha K + 250 kg/ha S (P_2 treatment)

(i) 150 kg/ha N + 150 kg/ha P + 150 kg/ha K + 250 kg/ha S (P_3 treatment)

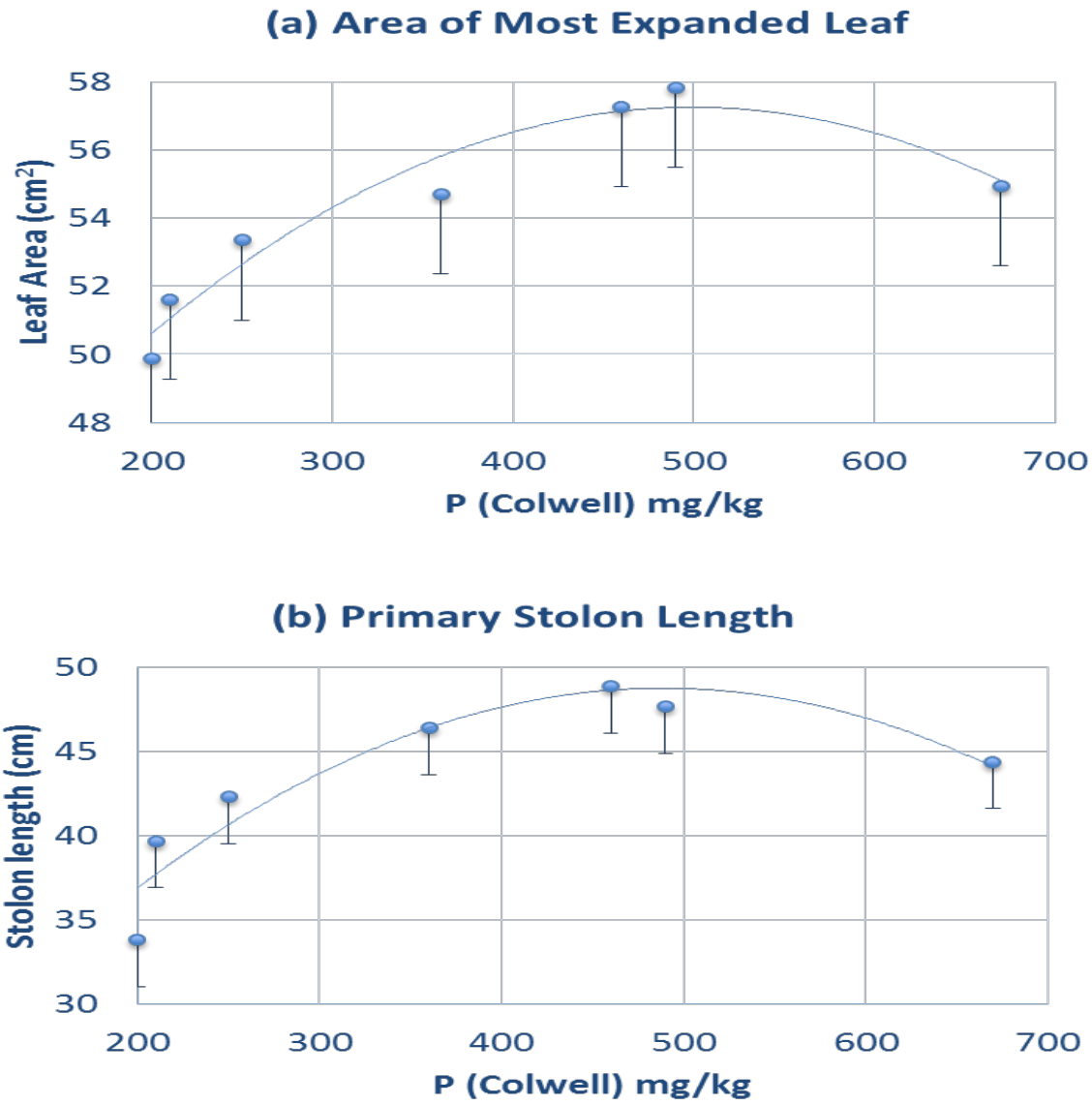

Figure 9. Relationship between P concentration in soil (mg/kg) and (a) the area of the most expanded leaf (cm^2) and (b) stolon length (cm) of strawberry mother plants (cv. Fortuna) in a field trial on a Red Ferrosol in the strawberry nursery industry at Toolangi, Vic. Bars represent the least significant difference where p = 0.05.

(j) 150 kg/ha N + 200 kg/ha P + 150 kg/ha K + 250 kg/ha S (P_4 treatment)

(k) 150 kg/ha N + 300 kg/ha P + 150 kg/ha K + 250 kg/ha S (P_5 treatment)

(l) 200 kg/ha N + 280 kg/ha P + 260 kg/ha K + 270 kg/ha S (industry standard control).

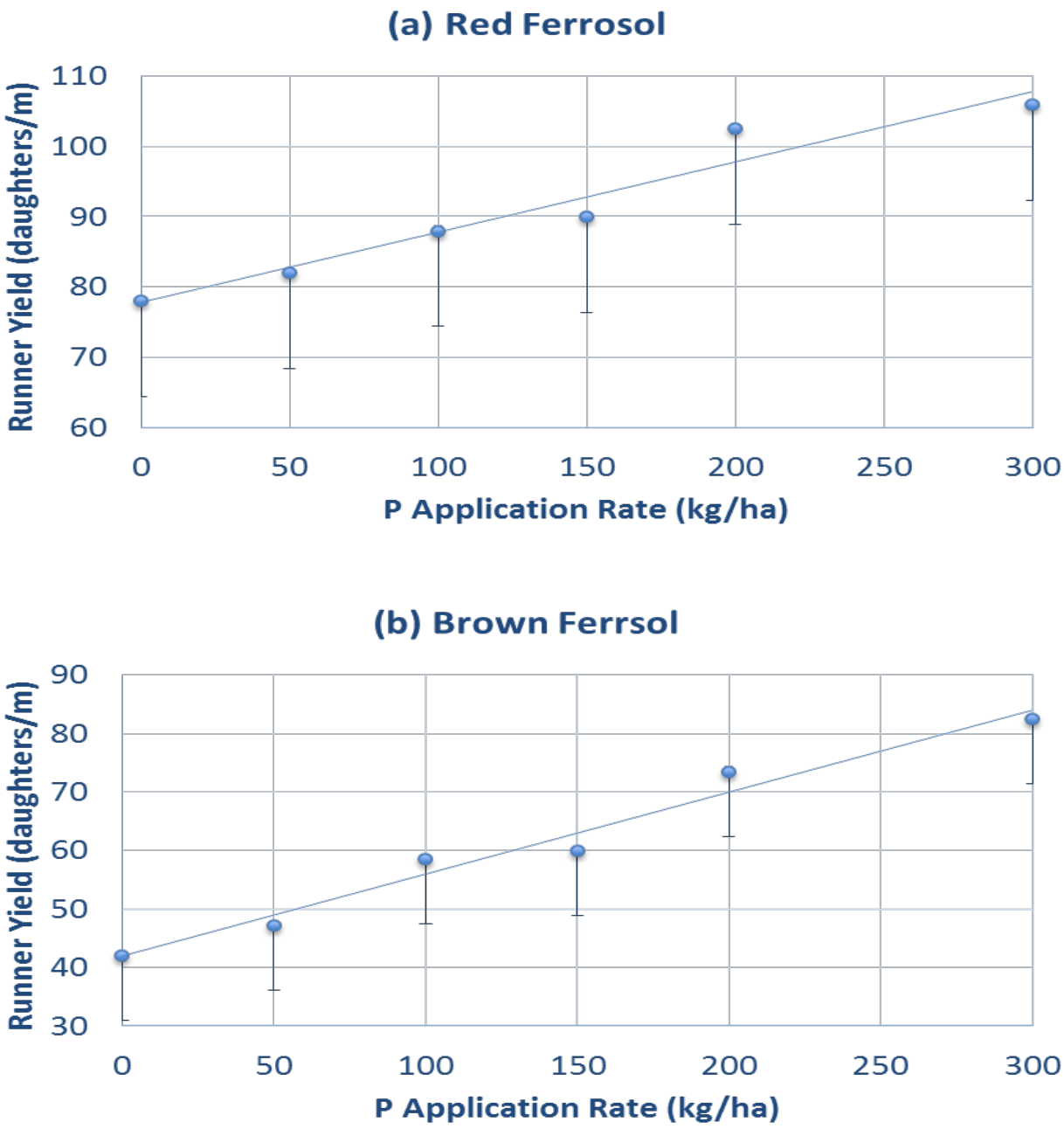

Figure 10. Runner yields of the cultivar Fortuna in (a) Red Ferrosol and (b) Brown Ferrosol soils treated with different rates of P fertilisers in a field trial in the strawberry nursery industry at Toolangi, Vic. Bars represent the least significant difference where p = 0.05.

Key Assessments: mother plant establishment (leaf area, stolon number, leaf number, and stolon length) (8 weeks after planting).

soil and tissue nutrient levels (planting, top dressings, and harvest).

marketable runner yields (25/03/14 Red Ferrosol site, 02/04/14 Brown Ferrosol site)

leaf area, crown diameter, leaf number, petiole length and root length of harvested runners

Key Results:

At 8 weeks after planting, results from both trials showed that the optimum level of P in soil for the early growth of mother plants (e.g. leaf area and stolon length, Fig. 9) was 500 mg/kg soil. This level of soil P was achieved with the application 50 kg/ha P at planting.

At final harvest, regression analysis in both trials showed a linear response between P application rate and increased commercial runner yields (Fig. 10).

The concentration of P in plant tissues of harvested runners increased as P-fertiliser input increased (e.g. Fig 11). High rates of P inputs also influenced the architecture of harvested runners. In particular, runners from high-P treatments had significantly larger crown diameters, larger leaf areas, and longer petioles than those from low-P treatments (see Table 1, Section 4.3).

Discussion / Conclusions:

Previous trials in the runner industry at Toolangi have shown that the availability of P can limit yields (R. Davies, Incitec Pivot, unpublished data). It was hypothesised that optimising P application rates would increase plant maturity and commercial yields of leaf-on cultivars of strawberry runners early in the season in March. Strawberry yields showed a positive, linear response to P inputs. As such, the trials did not show a clear optimum level of P for maximising yields in March. However, the early growth of strawberry mother plants reached a maximum level at soil concentrations of 500 mg/kg of P, and this is considered an important threshold for runner production in Ferrosol soils.

In addition to increasing early yields, P application modified the architecture of harvested Fortuna runners, particularly by increasing their crown diameter and leaf areas, and lengthening their petioles. Menzel & Smith (2012) showed that Fortuna runners with large crown diameters (8-17 mm) had better survival and yielded more fruit than those with small plant diameters (5-8 mm). Therefore it was hypothesised that high P inputs for runner production in the nursery industry and its effects on transplant architecture would reduce the severity of runner establishment stress syndrome in the fruit industry. This hypothesis was tested in a subsequent fruit trial (Section 4.3).

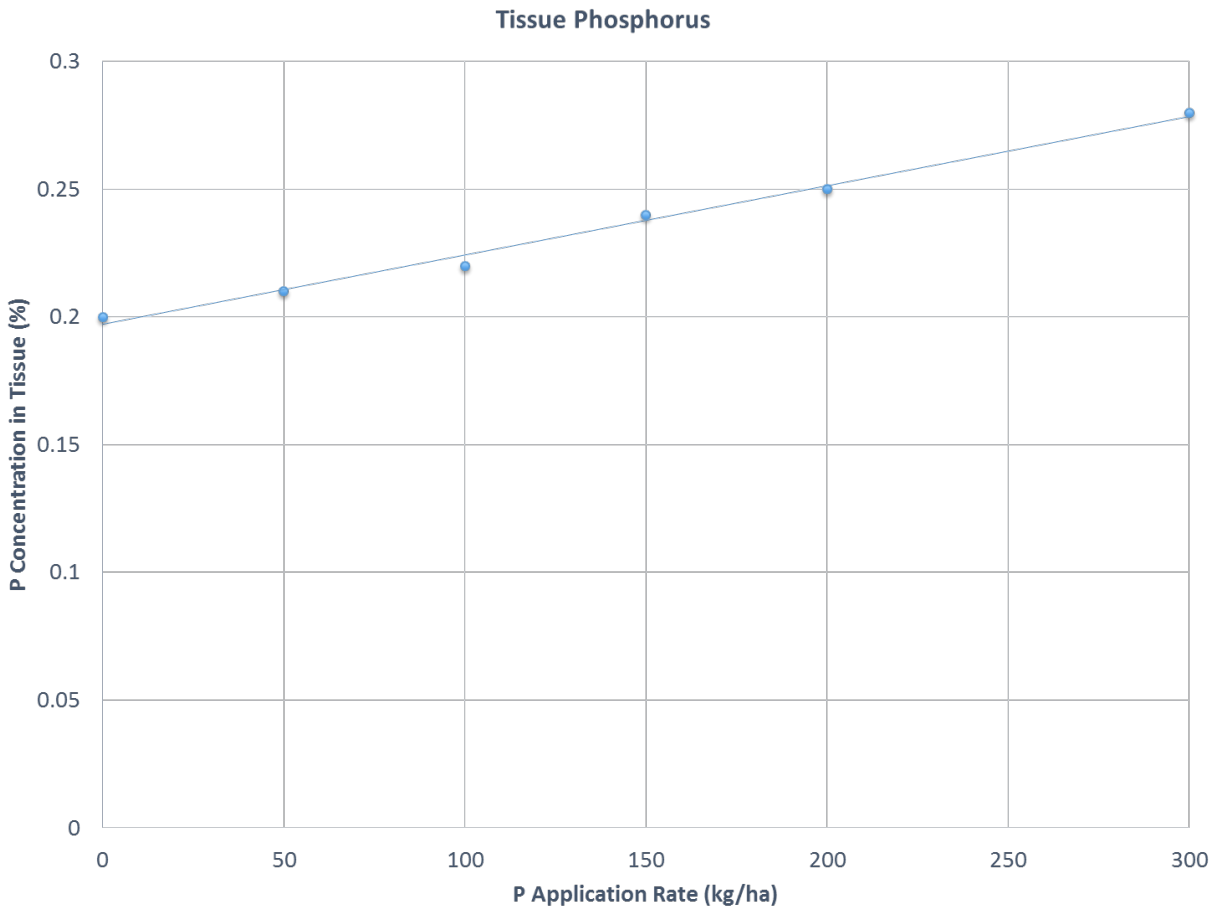

Figure 11. Relationship between P application rate to soil and P concentration in the tissue of harvested runners of the cultivar Fortuna grown in a Red Ferrosol in a field trial in the strawberry nursery industry at Toolangi, Vic.

4.3 Phosphorus Plant-out Trial

Aim: A field trial was conducted in the strawberry fruit industry at Wanneroo WA to test the hypothesis that high P inputs for runner production in the nursery industry and its effects on transplant architecture reduce the severity of runner establishment stress syndrome in the fruit industry for the leaf-on cultivar Fortuna.

Trial Design: Randomised complete block design with eight treatments arranged in four blocks. There were 32 plots in total and each plot contained 32 strawberry plants.

Treatments: Runners were sourced from the Phosphorus trial at the Red Ferrosol site as described in Section 4.2, and planted in the fruit industry on 29/03/14. Plants were grown in the following treatments in the nursery industry:

(a) Untreated control

(b) 150 kg/ha N + 250 kg/ha S (N control)

(c) 200 kg/ha P + 250 kg/ha S (P control)

(d) 150 kg/ha K + 250 kg/ha S (K control)

(e) 150 kg/ha N + 150 kg/ha K + 250 kg/ha S (P_0 Treatment)

(f) 150 kg/ha N + 150 kg/ha P + 150 kg/ha K + 250 kg/ha S (P_{150} Treatment)

(g) 150 kg/ha N + 300 kg/ha P + 150 kg/ha K + 250 kg/ha S (P_{300} Treatment)

(h) 200 kg/ha N + 280 kg/ha P + 260 kg/ha K + 270 kg/ha S (industry standard)

Key Assessments: leaf area, stolon number, leaf number, and stolon length of mother plants (8 weeks after planting).

plant survival (July & October 2014)

Key Results:

Runners from high-P treatments (i.e. P_{150}, P_{300} treatments, and the industry standard) in the nursery industry, except the P control, established poorly and had significantly lower survival rates than runners from low-P treatments (i.e. Untreated, N Control, K Control, and P_0 treatments). The poor establishment and survival of runners from high-P treatments in the fruit industry was associated with planting material with larger crown diameters and leaf areas, and longer petioles (Table1).

Discussion / Conclusions:

In contrast to our original hypothesis, results from this trial showed that leaf-on runners grown in high P-treatments that produced high yields in the runner industry, survived poorly in the fruit industry. It is unlikely that this effect is due to the direct effect of P. This is because P concentrations in harvested runners were within accepted ranges (Ullio, 2010), and because runners from the P control treatment survived well in the fruit industry.

Low survival rates of plants in the fruit industry were associated with high runner yields (see Section 4.2), large crown diameters and leaf areas, and long petioles. Therefore, it is possible that the architecture or physiology of harvested runners affected their subsequent survival in the fruit industry, rather than a direct effect of P treatment. For example, shoots of Fortuna runners with long petioles and large leaves are known to collapse and die at planting

	Crown Diameter (mm)	Petiole Length (cm)	Leaf Area (cm^2)	Concentration of P in tissue (%)	
Untreated	10.25 a	17.4 ab	32.6 a	0.22 ab	97.3 d
N Control	10.12 a	16.5 a	36.7 abc	0.20 a	94.7 cd
P Control	10.05 a	16.9 ab	35.5 abc	0.27 cd	93.3 cd
K Control	10.18 a	17.3 ab	32.9 ab	0.22 ab	97.3 d
P_0 Treatment	10.24 a	18.3 a	34.8 abc	0.21 ab	94.7 cd
P_{150} Treatment	10.81 ab	18.7 bc	40.4 cd	0.24 bc	88.0 bc
P_{300} Treatment	11.99 b	20.3 c	44.4 d	0.28 d	84.0 ab
Industry Standard	11.52 b	20.2 c	40.0 bcd	0.26 cd	78.7 a
LSD (p = 0.05)	1.25	1.8	7.3	0.03	8.9

Table 1. Plant architecture and P concentrations in harvested runners (cv. Fortuna) grown in different P-treatments in the nursery industry at Toolangi Vic, and their survival when planted in the fruit industry at Wannerro WA. Data followed by different letters in each column are significantly different where p = 0.05.

compared with those with shorter petioles and smaller leaves (G. Weda, personal communication). Alternatively, runners from high-yielding stands with thick crown diameters in the nursery industry may receive less chilling (vernalisation) than those in sparser stands with thinner crown diameters.

Further trials are planned to examine mowing regimes in the nursery industry to shorten plant petioles, withholding late applications of fertilisers, and manipulating plants densities to provide more open stands of runners late in the season.

4.4 Vacuum Cooling Trial

Aim: A field trial was conducted to test the hypothesis that vacuum cooling harvested leaf-on runners (cv. Fortuna) in the nursery industry at Toolangi Vic reduces plant losses in the fruit industry at Wanneroo WA compared with refrigerated cooling.

Trial Design: Randomised complete block design with two treatments arranged in three blocks. There were 6 plots in total and each plot contained 32 strawberry plants.

Treatments: Runners were dug and cooled with a vacuum cooling system (Fig. 12) or traditional refrigerated cooling. Runners were shipped to WA using refrigerated transport and planted in the fruit industry at Wanneroo on 19/04/14.

Figure 12. Vacuum cooling strawberry runners in an experimental unit at Toolangi, Vic.

Key Assessments: plant establishment (leaf number, crown diameters, crown number) (8 weeks after planting).

plant survival (July 2014)

Key Results:

There were no significant differences in the establishment and survival of plants cooled using different methods (Fig. 13).

Discussion / Conclusions:

Vacuum cooling is a method used extensively in the vegetable industry to lower the temperature of produce rapidly. In the current trials, vacuum cooling lowered the field temperature of small batches of runners to 4^0C within 1-2 minutes. The current trial did not

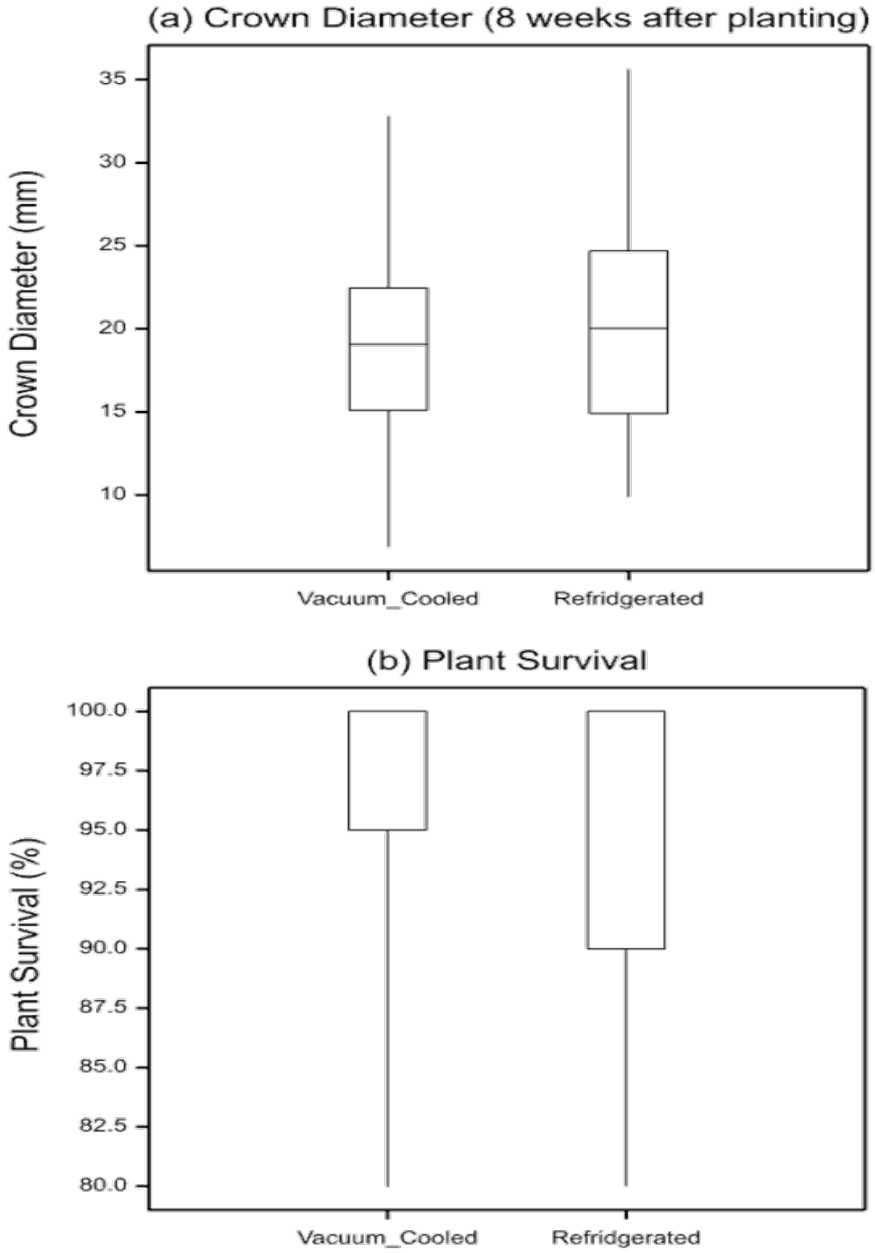

Figure 13. Boxplots of (a) the crown diameter (mm) and (b) survival (%) of leaf-on runners (cv. Fortuna) cooled using vacuum or refrigerated methods and planted in the strawberry fruit industry at Wanneroo WA. There was no significant differences between cooling treatments.

show any benefit or detriment from this form of cooling in terms of plant establishment or survival in the fruit industry. Converting to vacuum cooling systems is expensive and runner growers need clear demonstration of the benefits of this method before widespread adoption would occur. Analysis also needs to consider other forms of cooling, such as hydro-coolers.

5. First Year Trial of Plug Plant / Soil-less Production Systems

5.1 Plug Plant Trials

Aim: Different production systems were developed to evaluate the yields of plug plants and soil-less runners compared with bare-rooted runners grown in fumigated soil in the nursery industry at Toolangi, Vic. The subsequent survival of transplants was assessed in the strawberry fruit industry at Wanneroo WA.

Trial Design: Randomised design with four treatments (indoor hydroponics production, outdoor hydroponics production, indoor production in soil-less media, and outdoor production in fumigated soil, methyl bromide / chloropicrin 50/50, 500 kg/ha). There were ten replicates per treatment, and treatment means were compared by Student's t-test.

Transplants from the different production systems were planted in the strawberry fruit industry at Wanneroo WA on 29/03/2014 in a randomised complete block design, with four blocks. There were 32 plants per plot.

Treatments: A prototype hydroponics design was developed, based on overseas models (Lieten, 2013), to produce hanging stolons bearing daughter plant tips. Tips were later planted into seedling trays containing soil-less media to produce plug transplants. Prototype hydroponics systems were developed for outdoor and indoor (screenhouse) production of runner tips (see Fig. 14). Yields of daughter plants were compared with bare-rooted runners produced in soil-less media in a screenhouse or in fumigated soil outdoors. The strawberry cultivar was San Andreas.

Key Results:

Daughter plant yields of strawberry were equivalent in outdoor fumigated systems and indoor production in soil-less media (Fig. 15). Daughter plant yields in the indoor hydroponics system was significantly higher (by 47%) than in the outdoor hydroponics system. Daughter plant yields in the hydroponics systems were significantly lower (by an average of 58%) than those in fumigated soil or in soil-less media.

All transplants produced by the hydroponics systems and in soil-less media survived when planted in the fruit industry. Bare-rooted runners grown in fumigated soil also had high survival rates of 99.2% when planted in the fruit industry.

Figure 14. Prototype hydroponics systems for outdoor (L) and indoor (R) production of hanging stolons and daughter tips of strawberry (cv. San Andreas) at Toolangi, Vic.

Discussion / Conclusions:

Plug plants and bare-rooted runners grown in soil-less media appear to provide a technical solution for reducing plant losses in the fruit industry due to runner establishment stress syndrome. In fact, improved plant survival rates was one of the early drivers for the adoption of plug plants in the strawberry fruit industry in Europe (Hennion et al., 1997). Despite this, transplant yields using hydroponics systems for plug plant production were low in this trial, relative to conventional production in fumigated soils. Improving production efficiency of hydroponics systems is important because plug plants are more costly than bare-rooted runners. For example, Menzel & Toldi (2010) reported that plug plants were double the cost of conventional bare-rooted runners. Moreover, partial budget analysis conducted by Mattner et al. (2014) showed that the break-even price for bare-rooted runners produced in soil-less media was $2.00 per plant, compared with $0.30 per plant for those produced in fumigated soil.

Further research needs to consider methods to increase the production efficiency of plug plants, such as incorporating and micro-propagation step, in addition to evaluation of their performance in the fruit industry.

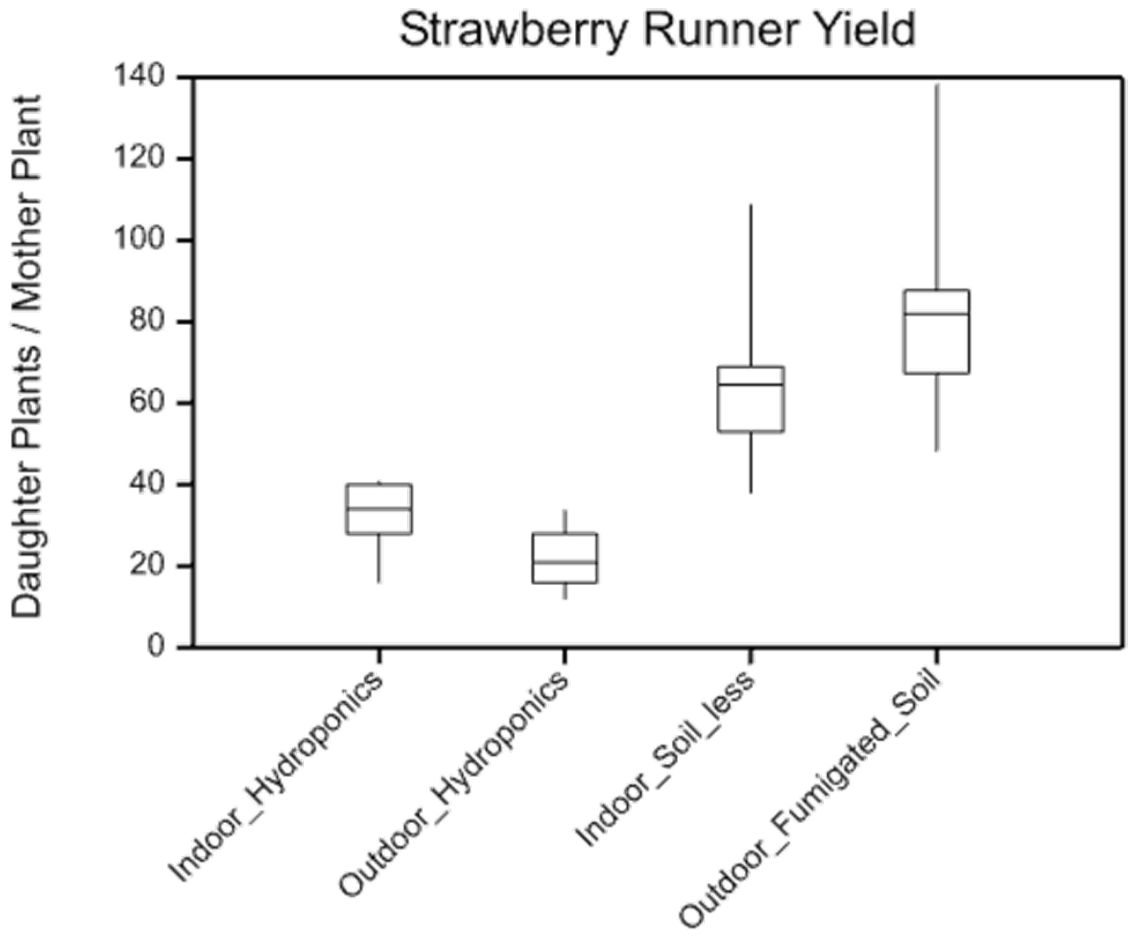

Figure 15. Boxplot of runner yields (daughter plants/mother plant) of strawberry (cv. San Andreas) grown under four production systems at Toolangi, Vic.

6. Conclusions and Recommendations

Research from the first year of this project showed that cold-store runners of the cultivars Portola and San Andreas have great potential for delivering strawberry growers around Perth with earlier and later fruit yields, respectively. This is important because early and late fruit markets attract higher prices and can contribute to increased farm profitability. The suitability of cold-store Portola and San Andreas runners for the WA fruit industry needs to be confirmed in research in the second year of this project, with particular emphasis on understanding the irrigation inputs required for plant establishment.

Other research in this project unexpectedly showed that leaf-on runners from high-yielding stands in the nursery industry had low plant survival rates in the fruit industry in WA. These runners were characterised by long petioles, and large crown diameters and leaf areas. Research in the second year of this project needs to identify the reason for the poor performance of these runners, and identify methods nursery growers can use to mitigate this.

Prototype hydroponics systems developed in the first year of this project provided proof-of- concept that plug plants can have high survival rates when transplanted in the fruit industry. Further research needs to concentrate on improving the production efficiency of hydroponics systems for plug plant production, with the aim of reducing their cost, in addition to evaluation of their performance in the fruit industry.

7. Literature Cited

Durner EF, Poling EB, & Maas JL (2002) Recent advances in strawberry plug transplant technology. *HortTechnology* 20:788-793.

FreshLogic (2013) Strawberry market profile. University of Tasmania.

Greer N, Hutton D et al. (2005) Strawberry problem solver and bug identifier. QDPI.

Hennion B, Schupp J, Longuesserre J. (1997) Fraisimotte: A strawberry plug plant developed by CIREF. Acta Horticulutrae 439: 469-474.

Kira T, Ogawa H, & Shinozaki K (1953) Intraspecific competition among higher plants. I Competition-density-yield interrelationships in regularly dispersed populations. *Journal of the Institute of Polytechnics, Osaka City* 4:1-16.

Lieten P (2013) Advances in strawberry substrate culture during the last twenty years in the Netherlands and Belgium. *International Journal of Fruit Science* 13: 84-90.

Mattner SW, Milinkovic M. et al. (2014) Critical challenges for the phase out of methyl bromide in the Australian strawberry industry. Acta Horticulturae 1044: 367-373.

MBTOC (2013) Evaluation of 2013 critical use nominations for methyl bromide and related matters. Final Report. UNEP, Nairobi.

Menzel CM, Toldi A (2010) An evaluation of containerised plants for strawberries growing in a subtropical environment. *HortTechnology* 12: 545-550.

Menzel CM, Smith L (2012) Effect of time of planting on the productivity of Festival and Florida Fortuna strawberry plants in a sub-tropical environment. *HortTechnology* 22: 330-337.

Shaw DV, Larson KD (2009) Strawberry plant named ‘Portola’. US Patent US PP20552 P3.

Shinozaki K, Kira T (1956) Intraspecific competition among higher plants. VII Logistic theory of the C-D effect. *Journal of the Institute of Polytechnics, Osaka City* 7: 35-72.

Ullio L (2010) Strawberry fertiliser guide. Primefacts, NSW Government.

Performance of Strawberry Plug Plants in Victoria

Scott Mattner, Mirko Milinkovic, Corina Horstra, Tom Ridley and Larissa Coridas

Victorian Strawberry Industry Certification Authority
swmattner@hotmail.com

Summary

A commercial trial undertaken by the Victorian Strawberry Industry Certification Authority (VSICA) in Victoria in 2014/15 showed that plug plants (containerised transplants) of cv. 'Albion' produced 35% more fruit than bare-rooted runners. Plug plants do not require soil fumigation for production, and are one of a number of options that VSICA and the Victorian runner industry are investigating to phase out the use of methyl bromide. The economics of using plug plants are still being determined, but plugs are expected to cost significantly more than bare-rooted runners. The performance of plug plants in other parts of Australia has been variable, so further trials are needed in Victoria in the upcoming season to verify current results.

What are plug plants?

Plug plants are containerised transplants produced in soil-less media (Fig. 1). They are rapidly gaining popularity as planting material for strawberry fruit production in many countries. For example, plug plants have been popular in central Europe for the last 20 years (Lieten, 1999: 2004). Production of plug plants does not rely on soil fumigation, and the increased adoption of plug plants worldwide is partly due to the reduced availability of methyl bromide for the production of bare-rooted runners (Mattner et al., 2003).

Figure 1. Strawberry tip (left) and strawberry plug plant (right).

Production of Plug Plants

Plug plants are produced from strawberry tips, which are un-rooted daughter plants (Fig. 1). Overseas, tips are produced from mother plants grown in hydroponic systems, or in fumigated soil. Tips are planted into plug trays containing a soil-less media and misted to produce roots.

Figure 2. Production of runner tips in Europe using (a) hydroponics in protected systems (left) and (b) outdoor production in soil (right), where straw mulch in the inter-rows prevents tips from rooting.

Potential Benefits of Plug Plants

In addition to reducing reliance on soil fumigation in the runner industry, plug plants may offer growers several other benefits, including:

1. Mechanical transplanting. Technologies already exist for transplanting plugs into plasticulture systems (e.g. water-wheel planters for vegetable seedlings).
2. Reduced irrigation. Overhead irrigation after planting is much less critical for plug plants than for bare-rooted runners, because the root system of plug plants is undisturbed and actively growing. In the USA there have been water savings of 16-33% for the establishment of plug plants compared with bare-rooted runners (Santos et al., 2012).

Effects of Plug Plants on Yields

Plug plants are more expensive than bare-rooted runners, and need to yield more or earlier to justify their cost. Total strawberry fruit yields with plug plants have been variable compared with bare-rooted runners in different regions of the world. In Europe (Netherlands, Belgium, France) plugs have been rapidly adopted because they consistently yield 20% more fruit than bare-rooted runners, and help extend the growing season (Hennion et al. 1997, Lieten, 2013). In other regions of the world, plug plants may not offer this same advantage. For example, trials in Queensland showed that plug plants of short-day cultivars (Festival, Sugar Baby, and Rubygem) yielded between 0 - 40% less fruit than bare-rooted runners (Menzel & Waite, 2006; Menzel & Toldi, 2010). Similarly, plug plants of the day neutral cultivar Diamante yielded 25% less fruit than bare-rooted runners in Western Australia (Mattner et al., 2008). Much more research is required on the physiology of plug plants in Australia to achieve consistently higher yields. Furthermore, plug plants of day-neutral cultivars have not been trialed extensively in Victoria.

Victorian Plug Plant Trial

VSICA established a trial with plug plants and bare-rooted runners (cv. Albion) in the Yarra Valley in 2014/15. Runner tips were produced in a prototype hydroponic system at the Research Centre, Toolangi, Victoria, and plugged into seedling trays containing a soil-less mix. Plugs and bare-rooted runners were planted into soil treated with PicPlus® under black plastic on two-row beds in a replicated design (Fig. 3).

Figure 3. Establishment (October 2014) of strawberry (cv. Albion) plug plants (left) and bare-rooted runners (right) in a field trial in the Yarra Ranges, Victoria.

During plant establishment, crown and root growth of plug plants were greater (by 28% and 24%, respectively) than bare-rooted runners (Fig. 3). Initially, fruit yields of plug plants were significantly lower than bare-rooted runners (Fig. 4). As the season progressed, however, fruit production of plug plants gradually increased and eventually out-yielded bare-rooted runners (Fig. 4). By the end of March, plug plants had produced 35% more fruit than bare-rooted runners. The trial is continuing to the end of the season, and currently the root health of plants is being determined.

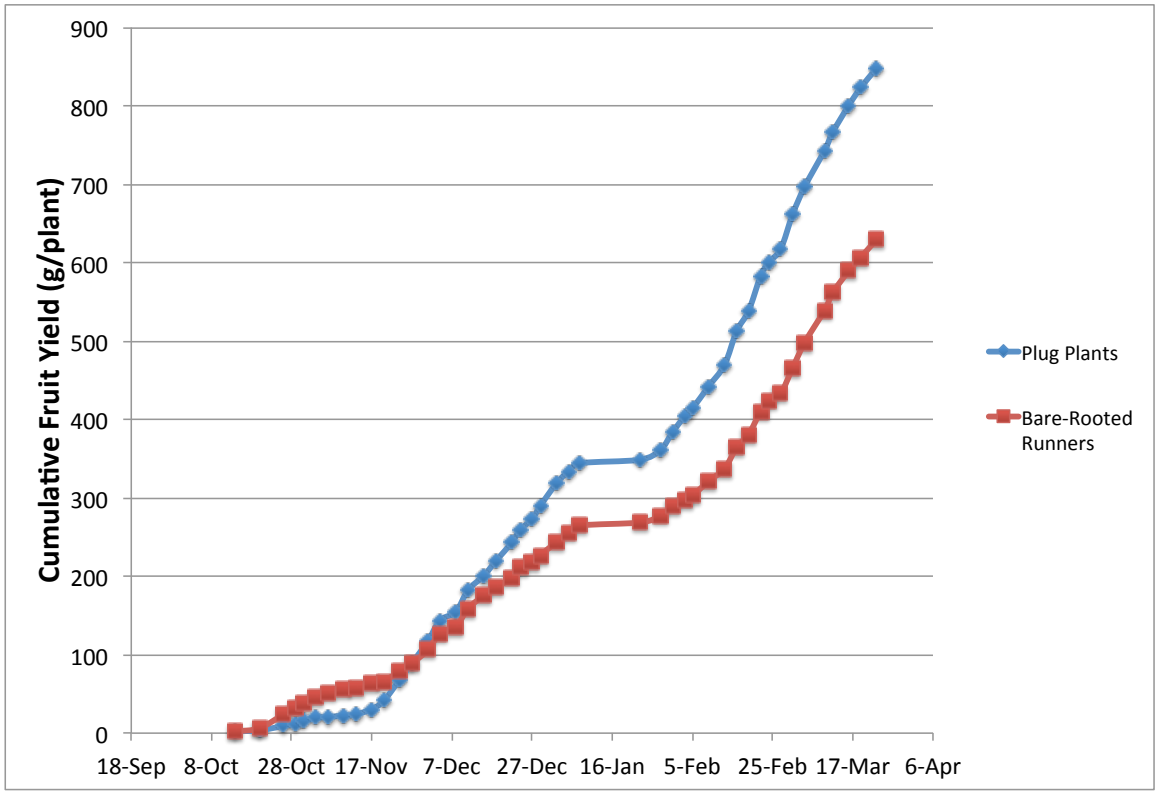

Figure 4. Cumulative commercial fruit yields of strawberry (cv. Albion) produced from plug plants and bare-rooted runners in a field trial in the Yarra Ranges in 2014/15.

Costs of Plug Plants

For a short period around 2010, strawberry nurseries in Queensland produced plug plants commercially. At that time the cost of plugs was $0.60 compared with bare-rooted plants at $0.32. Menzel & Toldi (2010) found that the fruit yields of these plug plants did not warrant their increased cost, and this prevented their adoption. In other parts of the world, plug plants are about 2-4 times more expensive than bare-rooted runners. Analysis is underway on the economics of plug plants in Victoria.

Conclusion

The current trial shows that the use of plug plants in the Victorian strawberry industry increased fruit yield. Results must be interpreted with caution, however, due to variable yields of plug plants in other regions of Australia. Further work is needed to verify the

performance of plug plants across different regions in Victoria in the upcoming season, and to analyse the economics of this production method.

Funding
This research is a component of a project (BS13002) funded by Horticulture Innovation Australia Limited with co-investment from Toolangi Certified Strawberry Runner Growers Co-operative, the Victorian Strawberry Industry Certification Authority, the Strawberry Growers Association of Western Australia, and funds from the Australian government.

References

Hennion, B. Schupp, J. Longuesserre, J. 1997. "Fraisimotte": A Strawberry Plug plant developed by CIREF in France. Acta Horticulturae 439: 469-474.

Lieten, F. 1999. Modules steal the strawberry scene. The Grower (February, 1999): 45-47.

Lieten P. 2013. Advances in strawberry substrate culture during the last twenty years in the Netherlands and Belgium. International Journal of Fruit Science 13: 84-90.

Lieten, P., Longuesserre, J., Baruzzi, G., Lopez-Medina, J., Claude Navatel, J., Krueger, E., Matala, V. and Paroussi, G. 2004. Recent situation of strawberry substrate culture in Europe. Acta Horticulturae. 649: 193-196.

Menzel, C.M., Toldi, A. 2010. An evaluation of containerized plants for strawberries growing in a subtropical environment. HortTechnology 20: 786-793.

Menzel, C.M. and Waite, G.K. 2006. The performance of strawberry plugs in Queensland. Acta Horticulturae 708: 217-224.

Mattner, S.W., Porter, I.J., Gounder, R.K., Mann, R.C., Williams, E., Milinkovic, M., Horner, I.J., Bigwood, E., Fraser, P., and Coram S. 2008. Breaking the critical-use barriers preventing Australian horticulture from phasing out methyl bromide. Horticulture Australia Limited, Final Report, Project No. BS04009. Sydney, NSW.

Mattner S.W., Porter, I.J., and Gounder R.K. 2003. Strawberry plug plants in perspective. CD-Rom. *In* Proceedings of the 1st Trans-Tasman Berryfruit Conference. July 2003. Auckland, NZ.

Santos, B.M., Stanley, C.D., Whidden, A.J., Salame-Donoso, T.P., Whitaker, V.M., Hernandez-Ochoa, I.M., Huang, P. Torres-Quezada, E.A. 2012. Improved sustainability through novel water management strategies for strawberry transplant establishment in Florida United States. Agronomy 2: 312-320.

Evaluation of Soil-less Systems for Strawberry Transplant Production in Australia

S.W. Mattner, C.B. Horstra, M. Milinkovic, P.R. Merriman, and F.C. Greenhalgh
Victorian Strawberry Industry Certification Authority, Toolangi, Victoria, Australia

Abstract

Currently the strawberry runner industry in Victoria, Australia relies on mixtures of methyl bromide (MB) and chloropicrin (Pic) to disinfest field soils for production of high-health, bare-rooted transplants (runners). However, MB is being phased-out under the Montreal Protocol. Soil-less production techniques avoid the need for soil disinfestation, and may offer an alternative. This paper reviews the technical and economic benefits, and challenges of soil-less technologies for strawberry runner production in Australia, including the use of: plug plants, soil-less substrates, micro-propagation, hydroponics, aquaponics, aeroponics and production from seed. Overall, these methods are currently more costly than bare-rooted runner production in MB/Pic-treated soils, and are estimated to increase the price of runners by 4.4 – 15 fold. It is concluded that these technologies have the greatest potential for application in the early generations of runner multiplication, and may assist in reducing the number of generations needed to produce Certified runners. The development of plug plant technologies, integrated with micro-propagation is considered the highest priority for evaluation in future research in the Australian runner industry, with particular emphasis on developing more cost-effective production systems and consistent yields in the subsequent fruit industry. In the short-term, this research also needs to be integrated with the development of alternative soil fumigants to replace MB.

Full article submitted and accepted by Acta Horticulturae

PROJECT UPDATE: EARLIER YIELDS AND BETTER ESTABLISHMENT OF STRAWBERRY RUNNERS (BS13002)

Background

Strawberry fruit can attract increased prices for northern WA growers early (April – May) and late (October – November) in the season. Some of the key constraints to early fruit yields are the maturity and availability of strawberry runners for planting in March / early April.

Fruit growers in some regions of California achieve early yields by planting cold-stored runners of day-neutral cultivars in summer. These runners are mature because they have been harvested in late autumn / early winter, and then cold-stored until summer. Day-neutral cultivars initiate flowering in response to temperature, and can commence fruiting early in the season.

2014 Cold-Store Runner Trial

A field trial was conducted at Wanneroo, WA with cold-store runners of the day-neutral cultivars Portola, San Andreas, Albion, and Monterey. Runners were planted in January and February 2014, under black or white plastic.

Results showed that the cultivar Portola had the strongest potential to deliver early fruit yields in April, but only when it had been planted in January and grown under white plastic (Fig. 1). These plants required high water inputs to establish well. Although the cultivars San Andreas and Albion also established adequately when planted in summer, they did not produce as much early fruit as Portola (Fig. 1). Monterey runners did not survive well when planted in summer, and produced low or no fruit yields through the trial (Fig. 1).

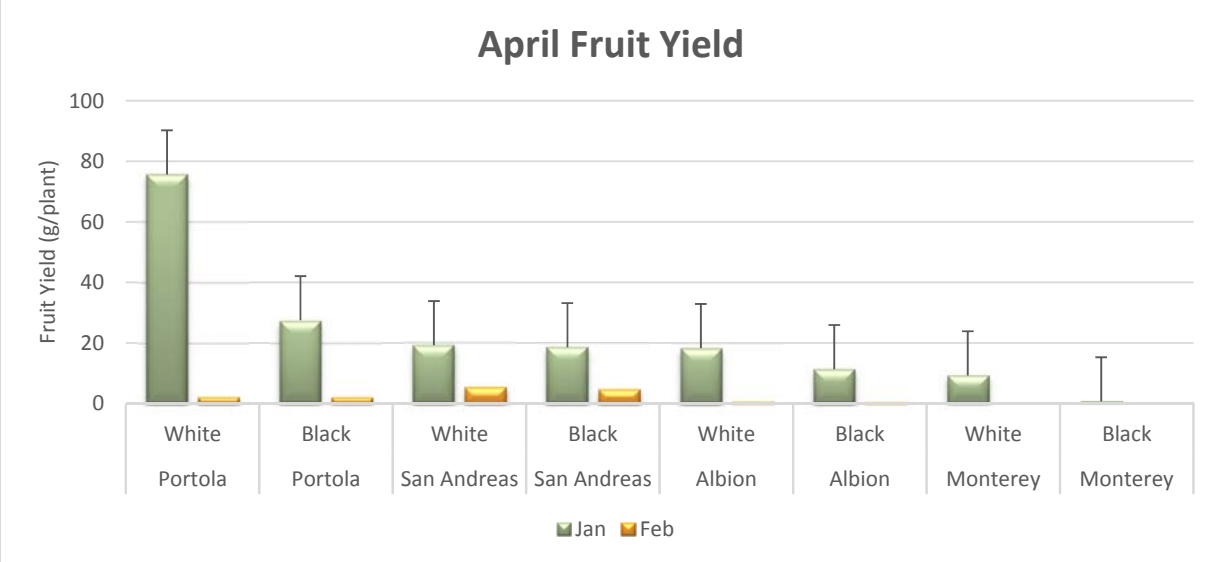

Figure 1: Fruit yields in April of cold-store runners (day-neutral cultivars) planted in January and February under black or white plastic in a field trial at Wanneroo, WA.

Later in the season, the cultivar San Andreas produced high yields in October, but only when it had been planted in February (Fig. 2). Runners planted in January did not produce significant fruit yields in October.

Overall, the cultivars Portola and San Andreas yielded just under 3 punnets / plant in the trial. Their real value, however, may be to deliver earlier and later yields when prices for fruit are relatively high. Currently, analysis is continuing on the economics of cold-stored runners from the trial.

Other project outcomes

This project has conducted other field trials in the Victorian nursery industry and WA fruit industry in 2014. Key outcomes from this research include:

- Better recommendations developed for phosphorus inputs in the nursery industry for production of leaf-on cultivars of runners.
- Different cooling methods evaluated for harvested leaf-on runners to improve plant survival in the fruit industry.
- A prototype system designed for production of strawberry plug plants (containerised transplants), and their performance assessed in the fruit industry.

Ultimately, the anticipated product from this project will be commercially-available runners that yield earlier and establish better than current leaf-on cultivars of runners.

This work has been funded by Horticulture Innovation Australia Limited with co-investment from the Strawberry Growers Association of Western Australia, Toolangi Certified Strawberry Runner Growers Co-operative, and the Victorian Strawberry Industry Certification Authority and funds from the Australian Government.

For further information contact Dr Scott Mattner from VSICA (swmattner@hotmail.com) or Gerry Verheyen (gaverheyen@iinet.net.au).

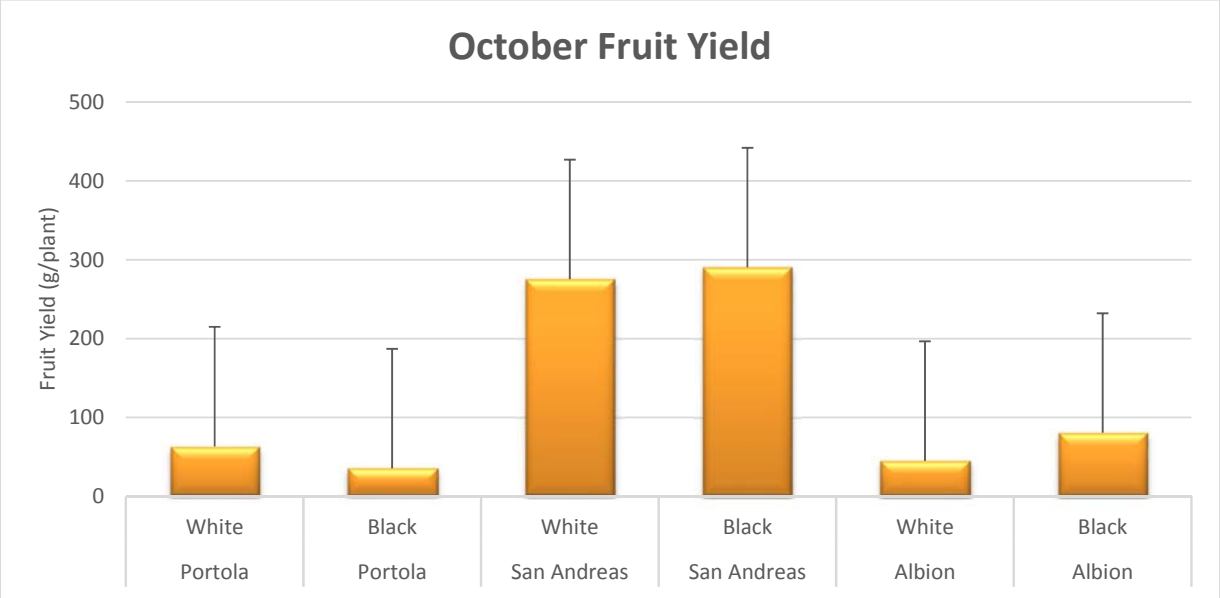

Figure 2: Fruit yields in October of cold-store runners (day-neutral cultivars) planted in February under black or white plastic in a field trial at Wanneroo, WA.

PROJECT BS13002: UPDATE ON RUNNER MATURITY TRIAL 2015

Background

Many strawberry fruit growers north of Perth want to receive and plant runners early, to get earlier yields when the price of fruit is high.

Nursery growers do not want to dig runners too early when plants are immature and have not had enough chill. This is because immature runners may die when planted.

A field trial was set up at Wanneroo to test whether the maturity of runners affects their establishment and fruit yields.

Treatments

Leaf-on runners (variety Fortuna) with different levels of maturity were dug in the nursery industry at Toolangi, Vic in late March 2015.

Treatments included: first daughter runners (D1), second daughter runners (D2), third daughter runners (D3), and fourth daughter runners or rejects (Rj). First daughters were the most mature runners, and fourth daughters were the least mature. Runners were planted at Wanneroo, WA in early April 2015.

Measurements in the trial include: (1) starch levels in the crowns of harvested runners, (2) the size and shape of the crown, leaves and roots of harvested runners, (3) runner survival in the fruit industry, and (4) fruit yields and revenue through the season.

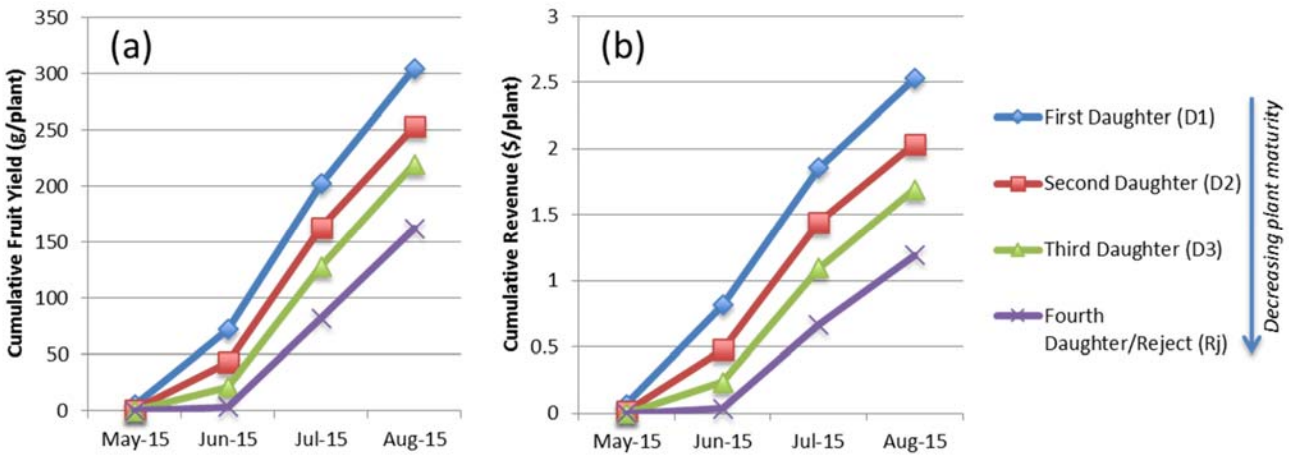

Figure 1: (a) Cumulative fruit yield and (b) cumulative revenue of leaf-on runners with different levels of maturity (variety Fortuna) in a field trial at Wanneroo in 2015. First daughters are the most mature and fourth daughters are the least mature. Revenues were calculated from wholesale strawberry prices for Perth (FreshLogic, 2015).

Results and Discussion

So far, results show that the greater the maturity of the runner, the greater their survival, and the more fruit and revenue they produce (Fig 1). The trial is continuing through the season.

This means that receiving immature runners early does not necessarily mean they will perform and yield early, or make more money.

Other ways to achieve earlier yields and increase early revenue include the use of different varieties (e.g. Benecia), or cold-store runners as a component of farm plantings (see Update on Cold Store Runner / Plug Plant Trial 2015).

This work has been funded by Horticulture Innovation Australia Limited with co-investment from the Strawberry Growers Association of Western Australia, Toolangi Certified Strawberry Runner Growers Co-operative, and the Victorian Strawberry Industry Certification Authority and funds from the Australian Government.

For further information contact Dr Scott Mattner from VSICA (swmattner@hotmail.com) or Gerry Verheyen (gaverheyen@iinet.net.au).

Figure 2: Growth of strawberry plants from mature runners (D1, Left image) and immature runners (Rj, Right image) in a field trial in strawberry industry at Wanneroo.

PROJECT BS13002: UPDATE ON COLD-STORE RUNNER / PLUG PLANT TRIAL 2015

Background

Many fruit growers north of Perth want to plant early to get earlier yields when the price of strawberry fruit is high. However, planting freshly dug runners too early can reduce their establishment and fruit yields (see Update on Runner Maturity Trial 2015). This is because runners have not received enough chill in the nursery, and are immature.

In California, fruit growers can achieve earlier yields by using cold-stored runners of day-neutral varieties, plug plants (containerised transplants, Fig 1), or newer varieties. In 2014, a trial at Wanneroo showed that cold-store runners of the varieties San Andreas and Portola yielded early (April and May) and late (October and November), when wholesale prices for strawberry fruit were relatively high. Cold-store runners are less prone to losses from early planting because they are dug late in the previous season when they are fully mature.

A field trial was set up at Wanneroo to compare the fruit yields and revenues from different types and varieties of strawberry transplants, with the aim of achieving early yields.

Treatments

Leaf-on and leaf-off runners (bare-rooted) were produced in the 2014/15 season at Toolangi, Vic, and dug in late March 2015. Cold-store runners (bare-rooted) were produced in the 2013/14 season at Toolangi, Vic, dug in early June 2014, and then placed into cold storage. Plug plants were produced from strawberry tips grown at Toolangi, Vic, and then plugged into seedling trays at Wanneroo, WA in February 2015.

Varieties tested in the trial included: Benecia (short-day, Fig 1), Fortuna (short-day), San Andreas (day-neutral), Albion (day-neutral) and Portola (day-neutral). All transplants were planted at Wanneroo in early April 2015.

Figure 1: Strawberry plug plant (left) and the variety Benecia (right) in a trial at Wanneroo in 2015.

Results and Discussion

So far, leaf-on Benecia has produced the most fruit in the trial, and has delivered high revenues (Table 1). Benecia (Fig 1) is a relatively new variety, and shows good promise as an alternative to other leaf-on varieties for northern-Perth. The trial is continuing to determine if the high yields of Benecia continue through the whole season.

Plug plants of all varieties have not yielded well up until August (Table 1). They require more research to develop conditioning treatments (e.g. artificial chilling) in the nursery industry to improve their performance in WA.

Table 1: Total fruit yields and revenues (until August) of different strawberry transplants and varieties in a field trial at Wanneroo in 2015. Revenues were calculated from wholesale strawberry prices for Perth (FreshLogic, 2015).

Treatment	Total Fruit Yield (g/plant)	Total Revenue ($/plant)
Benecia (leaf-on)	291.1	2.17
Benecia (leaf-off)	243.8	1.79
Benecia (plug plant)	168.1	1.21
Fortuna (leaf-on)	208.0	1.66
Fortuna (plug)	111.5	0.86
San Andreas (leaf-off)	275.9	2.25
San Andreas (cold-store)	74.0	0.90
San Andreas (plug)	69.5	0.53
Albion (leaf-off)	148.0	1.18
Albion (plug plant)	137.4	1.07
Portola (leaf-off)	190.9	1.63
Portola (cold-store)	51.8	0.60

Cold-store runners (particularly San Andreas) yielded the earliest in the trial, and had returned $0.90 per plant by June (Fig. 2). This was more than double the revenue of traditional leaf-on varieties like Fortuna. However, cold-store runners did not produce fruit in July and August, and are only now coming back into production (late August). This is similar to the pattern of production at Wanneroo in 2014, when cold store runners produced their highest yields early and late in the season. Therefore, cold-store runners have the potential to supplement other strawberry plantings to increase yields when fruit prices are high.

This work has been funded by Horticulture Innovation Australia Limited with co-investment from the Strawberry Growers Association of Western Australia, Toolangi Certified Strawberry Runner Growers Co-operative, and the Victorian Strawberry Industry Certification Authority and funds from the Australian Government.

For further information contact Dr Scott Mattner from VSICA (swmattner@hotmail.com) or Gerry Verheyen (gaverheyen@iinet.net.au).

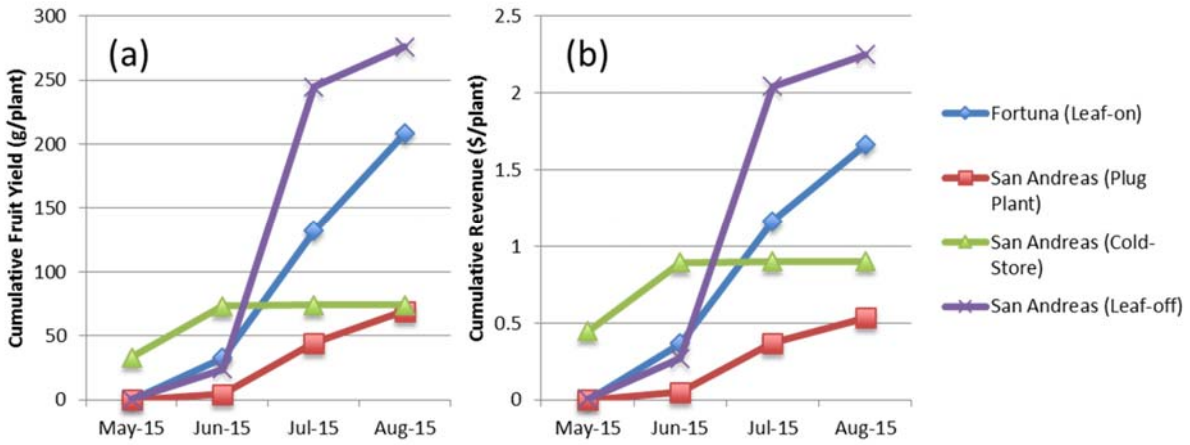

Figure 2: (a) Cumulative fruit yield and (b) cumulative revenue of different strawberry transplants and varieties in a field trial at Wanneroo in 2015.