Horticulture Innovation Australia

Final Report

Determine optimum nitrogen and potassium requirement to maximise yield and quality of day-neutral Victorian strawberries

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Applied Horticultural Research

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BS12010

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Summary

For several years since its introduction, the day-neutral variety "Albion" has dominated strawberry plantings in southern Australia, primarily due to its superior flavor. However, it is widely acknowledged to be a much less vigorous, hardy and lower yielding plant than its predecessors, in particular "Selva". Since its introduction, southern Australian growers have struggled to produce yields anywhere near to those of Californian crops (typically no more than 50–60%). The most widely accepted reason for this relates to the extreme climate variability of southern Victoria, where coastal California has a much more uniform climate, in particular, the lack of extreme heat and many more days inside the desirable flowering temperature range, especially days below about 29°C. As there is very little that growers can do to control this, the Victorian industry wished to see if any other agronomic factors might be playing a more significant role than expected, such as nutrition and watering.

Foliar nutrient reference levels for strawberry growers in Australia do exist, but are not universally adopted by all testing laboratories, are based on old overseas data and are a composite of both blade only and blade plus petiole data.

The project has produced new reference nutrient tissue levels for whole leaves and for leaf blades using a combination of extensive nutrient analysis of 8–12 separate commercial strawberry blocks in Victoria each season for three seasons, fruit yield and quality data, and comparison with published information.

New, validated ***leaf blade*** (B) and ***leaf plus petiole*** (B + P) nutrient-reference values have been produced for all the essential strawberry nutrients and presented in a simple-to-use factsheet.

The research found a good correlation between phosphorus levels and yield, and to a lesser degree nitrogen and yield in the first season, but these observations were not repeated in the second season. The two main factors limiting the yield of Albion strawberries in Victoria were irrigation management and the disease charcoal rot. In general, plant nutrition was well managed by growers and not limiting yields. There is a large amount of data accompanying this report in the appendix. This may be used to more closely examine any other correlations, for example, with micronutrients.

Keywords

Victoria; strawberries; Albion; day neutral; nutrition; tissue; nutrient levels; dry ash; soil; benchmarking

Introduction

The most well accepted reason for Albion not achieving yields in Victoria comparable to those in California relates to the extreme climate variability of southern Victoria, where coastal California has a much more uniform climate, in particular, the lack of extreme heat and many more days inside the desirable flowering temperature range, especially days below about 29°C. Given there is very little that growers can do to control this, the Victorian industry wished to see if any other agronomic factors might be playing a more significant role than expected, such as nutrition and watering.

Foliar nutrient reference levels for strawberry growers in Australia do exist, but are not universally adopted by all testing laboratories, are based on old overseas data and are a composite of both blade only and blade plus petiole data. Project BS12010 was initiated in autumn 2013 at the request of Victorian Strawberries.

While there are many testing facilities for Victorian growers, a lack of any consistent reference values for strawberries makes interpreting tissue test results very difficult. There were for example no strawberry specific reference levels provided at the laboratory where project tissue samples were all analysed (Nutrient Advantage Laboratories, Werribee, Victoria). The only values referenced in local literature are those of Reuter & Robinson, CSIRO, 1997. These values are based on overseas data (USA) from 1980 and 1991, and combine B and B+P data using values not obviously referenced in any of the more recent literature. Fortunately, there have been several more recent studies producing reference values for strawberries, starting with Hochmuth & Albregts in Florida in 1992, with most recent and relevant references established by Hartz *et al.* in California in 2012. All reference levels readily available for strawberries come from the USA.

There is a range of soil types across the growing area: from ferrosols (red soils) through brown to yellow and grey clays. Nearly all are heavy soils with a high clay content, pH 5.1-6.8 ($CaCl_2$), showing a range of differing base-level nutrition levels. However, all areas have been used for strawberry production for many years with significant additions of gypsum, lime and both slow-release and immediately available fertiliser being used. While growers take differing approaches to nutrition, management, there is an increasing use of slow-release fertilisers applied at planting. These are either incorporated through beds or placed near the roots at planting. Most growers are in a position to provide additional nutrition by fertigation through their drip-lines but the use of this may vary from weekly to only once or twice during the growing season. While individual approaches to nutrition vary, production systems are similar –all production is outdoors, using beds about 35cm high at around 1.5m spacings, mostly with two rows of plants/bed, black plastic mulch and a single dripper line on each bed for irrigation.

The vast majority of Victorian production is currently focused on the day-neutral variety "Albion". This means deriving a set of tissue nutrient levels for this variety has broad application to the Victorian industry. While the industry is being encouraged to only grow crops through a single season as is standard practice in California, for example, the high establishment costs and the lower yields of local crops, means, in fact, most growers retain first year plantings until around December in the following season. While plants are generally much less productive in the second year, they often have reasonable productivity early in the second season. After December, these crops are then generally removed and the ground is prepared either for a summer planting or given a short fallow up until April–June for winter planting. Having both summer and winter plantings on the same farm allows growers to even out crop production over the farm as the summer plantings may produce good autumn crops and are usually more productive than winter plantings in the following early spring. To ensure standardised results, samples were only taken from outdoor-grown (no shade netting, for example) first-year Albion plantings.

The approach taken by the project to determine optimum tissue nutrient levels for Albion strawberries in Victoria was to sample leaf blades and leaf blades plus petioles from 8–12 commercial production blocks over two years at five timings covering the growing cycle for first-year Albion crops. Leaf nutrient levels would then be related to yields and from this, nutrient levels for the higher yielding blocks used to construct reference values for all the major and minor elements. The objective of the project was to produce validated leaf blade and leaf + petiole tissue reference values for Albion strawberry on commercial farms in Victoria.

Methodology

Methods overview

Twelve blocks of first-year Albion strawberries, covering the range of soil types and climates where most Victorian production occurs were monitored on five occasions for the 2013–14 growing season, from early establishment through to late autumn before Victorian production ceased. Given the nature of strawberry production, where fruit is harvested every 2–7 days over an eight-month growing cycle, with in-field losses of perhaps 30% or more, and different picking and grading standards, it was difficult to obtain reliable and comparable yield records from all growers. Nonetheless, records considered as accurate as possible were obtained for about half the sites monitored. Results showed good correlations with phosphorus, nitrate levels and late season nitrogen levels. This approach was repeated with 12 growers in the following season (2014–15) in new blocks of first-year Albion plantings. Again, reliable yield data was only obtained for about half of these sites.

Prior to the final season (2015–16) one additional complication in comparing various reference standards was identified. Most of the recent references established in the US are based on blade only values (B), while the way leaves have mostly been collected in the past in Victoria has been blade + petiole (B+P). Sometimes the method used is clearly identified in reference standards but many of the older methods are either ambiguous or in some cases based on a composite of both methods. A study from Pennsylvania State College of Agricultural Sciences (Demchak, K, 2015), has suggested that blade only samples should be collected, while acknowledging the vast majority of samples received for analysis are often B+P. In an attempt to better understand variations in nutrient levels between blades and petioles, all samples in the final season were collected and analysed as separate blade and petiole samples, then B+P levels calculated from dry weights.

The final years work then consisted of continuing to monitor eight grower blocks as done previously but in addition to this, three trials were established to investigate whether yield could be improved through three high dose early-mid season additions of N and P in line with the correlations observed from the first year. With total additions of 3.55g P and 1.68g N per plant above grower's standard programs, no significant differences in yield or even clear differences in foliar nutrient levels were observed. The results suggest either nutrition was already adequate or that applications were ineffective in delivering the additional nutrition applied to plant roots.

Surveys of soil and leaf tissue levels of commercial strawberry growers

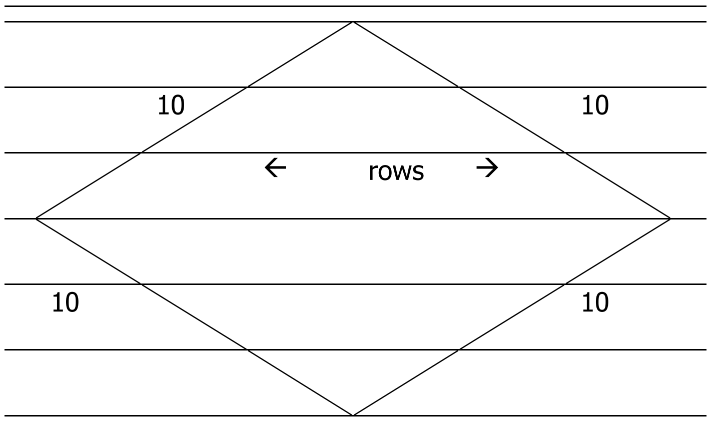
Twelve grower blocks covering a representative range of soil and environmental conditions in the industry were monitored in the first and second seasons of the project. In the third and final season, eight growers were monitored and three trials were established, one at each of three from the group of eight. Soil samples (0–30cm) were taken from beds after planting at the same time as the first leaf sampling. Whole leaves – blades (B) plus petioles (P) were collected in the first two seasons and analysed in a commercial testing laboratory. In the third and final season, B+P samples were collected into plastic bags, sealed and kept cool, then weighed, P and B parts separated and reweighed, and sent to the testing laboratory in paper bags, to allow fresh weights, dry weights and nutrients to be calculated for separated B and P parts for each sample. In all seasons, samples were collected on five occasions corresponding with key seasonal growth stages – once early on after plant establishment but before significant flowering – pre-harvest (20 Aug – 30 Sep), then on four subsequent occasions – early harvest (18 Oct – 17 Nov); peak harvest (10–21 Dec); summer low harvest/plant renovation (1–20 Feb) and finally during the autumn harvest (14 Apr – 7 May).

Leaf selection was based on taking the youngest mature leaf or fully expanded leaf (YML), although in a well developed canopy, there were usually several suitable leaves on each plant. Leaves were not taken from unhealthy looking plants or those of less than average vigour in that part of the field. Physically damaged leaves were also avoided. When sampling early in the season, this generally corresponded to the largest plant leaves but later in the season with full canopy closure, this could be any mature, healthy leaf at the top of the canopy of at least average size or larger. Leaves with clearly visible spray residues were avoided and where small deposits were visible, the upper side of leaves were gently but firmly rubbed once on cotton clothing to remove visible residues. The target point to cut leaves was close to the crown where the stipule meets the petiole. This was achieved in a practical way by laying the flat side of the blade of a retractable craft-type knife against the crown, which generally cut the petiole near this point. Leaves were collected into paper bags (other than as detailed above) and refrigerated the same night, and where they generally remained for 1–3 days before being deposited directly at the local analytical laboratory or sent there overnight by express post.

Figure 1. Petiole detachment point – immediately above stipule.

Leaves were sampled in a trapezoidal pattern to cover a representative area of the field, avoiding plants in the outermost row or last couple of metres around the edge, sampling about 10 plants at roughly even intervals along each of the sides of the trapezium, as detailed in Figure 2 below.

Figure 2. Generalised leaf sampling pattern for project strawberry fields.



Commercial trial yield data was collected from the growers using their commercial recorded yields for the block that was sampled over the season. The accuracy of records varied considerably. Results were only included in nutrient analyses where accurate records of weights harvested or punnets packed and plant numbers were obtained. This meant analyses were based on about half the sites monitored in each of the first and second seasons. Yields were compared on a total harvested kg fruit/ha basis, taking account of plant spacings, numbers of rows/bed and bed spacings.

At each of the fruit samplings, approximately 20 pieces of fruit ripe for harvest were collected at random and taken to measure average fruit weight and Brix. After counting and weighing, the calyx was removed by hand though not any of the stalk entering the fruit, which is normally removed for eating. Fruit was then pulped with a kitchen stick-type blender for about 20–30 seconds until the fruit was reduced to a relatively smooth and even consistency. Brix was then determined from samples of this pulp using an Atago Pocket PAL-1 digital refractometer (Brix output readings to +/- 0.1°). The first five readings within a 0.2° Brix range were then averaged to provide a reliable sample figure. In the first two seasons, fruit pH was also measured using a Hanna HI 8314 pH meter incorporating a separate temperature compensating thermometer probe (readings output to +/-0.01 pH).

On sampling days, flowers/m bed, numbers of leaves and crowns/plant and other relevant observations were made in the first two seasons but not in the last one.

Nutrient addition trials

There were three trials in the final season of the project, established on different farms. The objective of these trials was to assess the impact of additional nitrogen (N) & phosphorus (P) on yield and quality. These were the two major nutrients that had shown some correlation with yield in the first season.

Trials were replicated (two replicates at site 2 and four replicates at sites 1 and 3). These compared the grower's standard program with a second treatment involving additional N & P in line with correlations from first-year yield data. Applications of additional fertiliser for the second treatment were made by weighing out soluble fertiliser (MAP and KNO_3) into 35 litres of clean water and then using a 500mL measuring cup to apply the solution at the base of each plant – one 500 mL measure/plant or at one site where the rate of penetration was slower, 2 x 250mL measures/plant. Three applications were made at each site as detailed in Table 1 below:

Table 1. Fertiliser Application Schedule for 3rd Season Nutrition Trials.

Dates	Application No.	Fertiliser & Rate	N (g/plant)	P (g/plant)	K (g/plant)
7-14 Nov 2015	1	MAP 2.29g+KNO3 0.54g/ 500mL/plant	0.30	0.51	0.21
23-24 Nov 2015	2	MAP 6.86g/500mL/plant	0.69	1.52	
18-26 Feb 2016	3	MAP 6.86g/500mL/plant	0.69	1.52	
Season Total		MAP 16.01g+KNO3 0.54g/ 500mL/plant	**1.68**	**3.55**	**0.21**

Each trial plot consisted of 20 or 30 plants. Where plots were in the same row, a four-plant buffer was used between plots. All eight plots were in the same row at site 3. Single plots were in eight adjacent rows at site 1. Two plots were in each of two different rows at site 2. Additional plots alongside the harvest plots were also treated to ensure young plants early in the season were not defoliated by leaf sampling, which may otherwise have affected early yields. This meant that up to several hundred plants were treated at each fertiliser application.

Yield data for the three small plot trials in the final year was taken by weighing total ripe fruit from each plot at each picking, giving a cumulative total for each plot. Trials were only yielded up to mid-April due to the project finishing in May. However, by this time data and trends were sufficiently well established to draw conclusions. In addition to total yield, average fruit weights and subjective assessments of firmness and flavour were done by the cooperating grower at site 2.

Outputs

- Reference values for plant tissue testing of Victorian strawberries, cv. Albion
- A factsheet with the new reference leaf blade and leaf plus petiole tissue nutrient levels for cv. Albion
- The complete data set for all tissue and soil samples taken over the project as well as Brix, pH, average fruit weights and other observations from individual assessment.
- Two industry magazine articles for Victorian strawberry growers on key project findings (spring 2014 and in the next edition or as requested)
- A project summary and findings update to the Victorian Industry Association in 2016
- A complete set of their own testing results has been provided to all participating growers along with benchmark values (2016). Individually identifiable grower results have not been labelled in any publications prepared by AHR; however, detailed data was provided by AHR to HIA and Vic Strawberries have identifiable data and should be used with discretion; individual growers should be consulted before any uniquely identifiable data is publicly disclosed.

Outcomes

- A set of local nutrient reference values to guide the Victorian strawberry industry nutrient practice
- Confirming charcoal rot and irrigation are the key issues that are currently limiting yields and more likely to be limiting productivity and require addressing by further research, development or communication.

Evaluation and Discussion

Commercial yield, quality and nutrient correlations

Based on two seasons of commercial grower data and a single (final) season of small-plot trial data, no consistent trends or significant correlations between nitrogen, phosphorus or potassium levels in leaf tissue and total yield, Brix or fruit size were observed. However, data from the first season (2013–14) did show a number of significant correlations between yield and tissue phosphorus levels. The strongest of these (Figure 3) was the correlation between late season P and yield (R^2=0.91). Seasonal average P levels and yield (Figure 4) were well correlated (R^2=0.70). Some of the earlier tissue P levels were also more weakly correlated (R^2=0.58-0.60).

Figure 3. Correlation between yield and <u>late</u> season leaf (B+P) levels of P (2013–14).

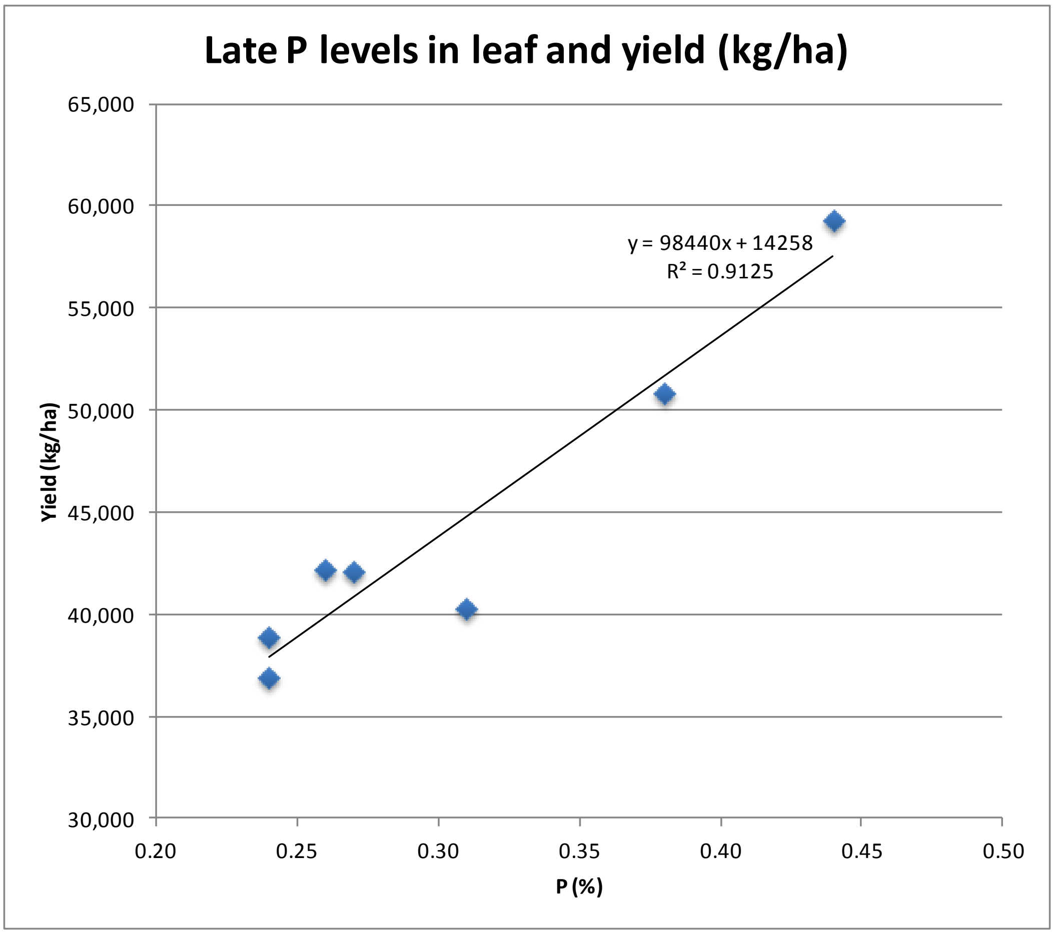
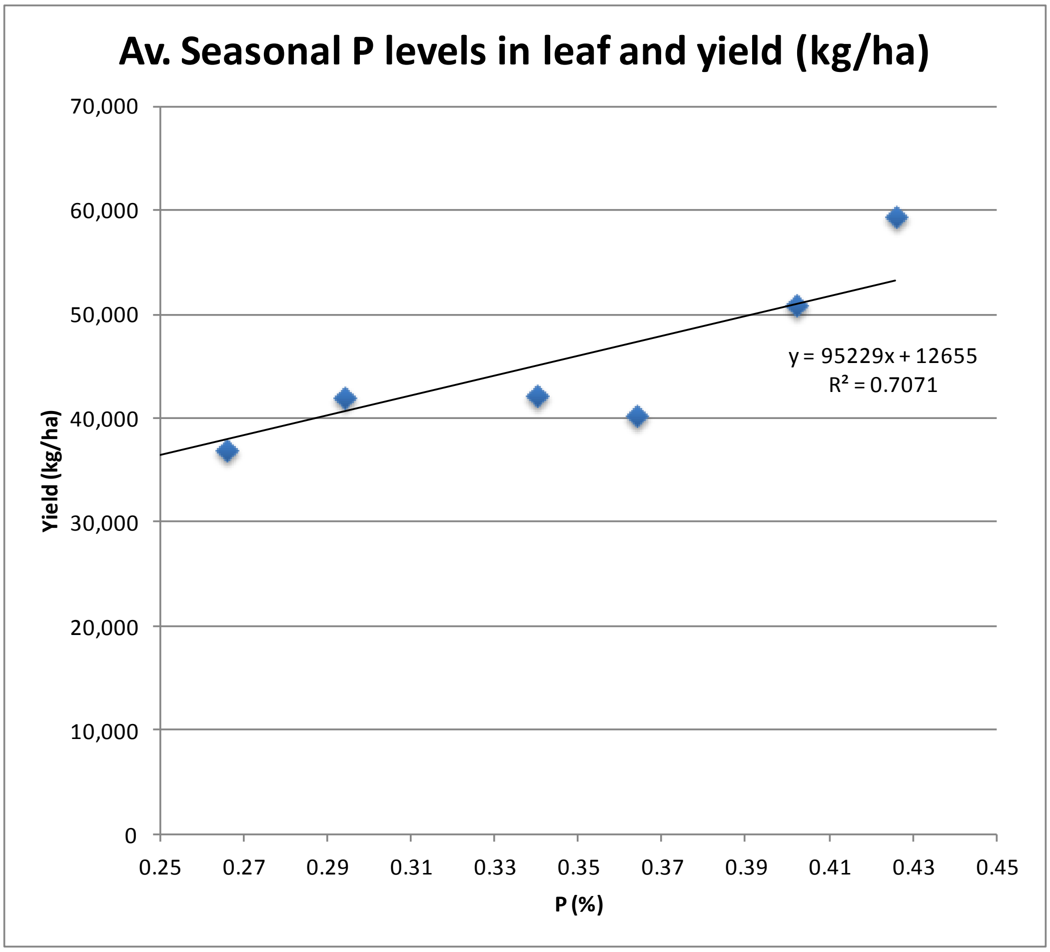


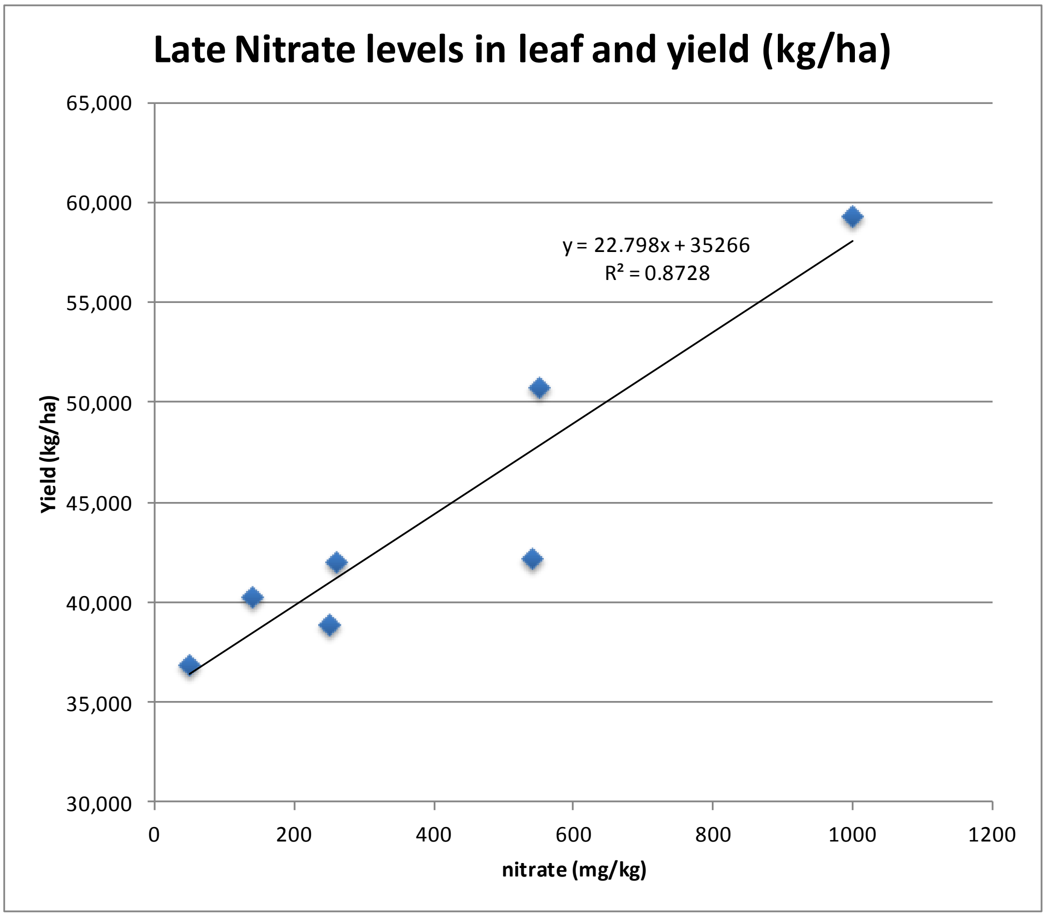
Figure 4. Correlation between yield and <u>average</u> season leaf (B+P) levels of P (2013-14).



Levels of nitrogen were not generally correlated with yield, apart from late season N in 2013–14, where there was a weak correlation (R^2=0.54). However, Leaf nitrate levels were more strongly linked to yield (2013–14), with late season nitrate levels (Figure 5) showing a good correlation (R^2=0.87) and average seasonal levels showing a weak correlation with yield (R^2=0.52).

There was a much higher degree of variation in nitrate levels both within and between sites, so care needs to be exercised so as not to overstate the significance of any nitrate results. Nitrate results were most valuable when averaged across all sites at each sample timing. Higher average timing levels were observed to be strongly linked to periods of rapid plant growth. Lower ammonium levels were sometimes well correlated with yield but trends were quite variable and sometimes indicated the reverse of this. The trends for ammonium were similar but much more subtle and even less reliable than for nitrate. The broad message from all nitrogen group results (N, nitrate and ammonium) was that while individual sample % N results were useful, nitrate and ammonium results were not.

Figure 5. Correlation between yield and <u>late</u> season leaf (B+P) levels of nitrate (2013–14).



Whole Leaf (B+P) compared with Blade only (B) nutrient levels

There were two key components to the final season (2015–16) measurements of nutrient levels using either of these methods:

1. Changes in petiole size as a proportion of whole leaf (B+P) weight.
2. The relative levels of nutrients in blades and petioles and any changes in these values over the season.

The results in Table 2 show leaf weight (size) peaks in the early harvest period, then steadily diminishes over the season. Blade dry matter is relatively stable over the season, averaging around 30.1% over the season. Petiole dry matter increases slightly over the season from around 17.4% to 20.3%. The leaf blade as a proportion of total leaf (B+P) dry weight decreases from about 85.2% to 77.1% over the season.

Table 2. Changes in petiole and blade fresh and dry weights during the season (2015–16).

	Crop stage				
	Pre-harvest (20 Aug – 30 Sep)	Early Harvest (18 Oct – 17 Nov)	Peak Harvest (10–21 Dec)	Summer low Harvest (1–20 Feb)	Autumn Harvest (14 Apr – 7 May)
Fresh weight of B+P (g)	1.90	8.9	7.1	5.3	4.2
Blade (% dry matter)	28.6	30.6	31.0	30.4	30.1
Petiole (% dry matter)	17.4	17.8	18.8	18.8	20.3
Blade – dry weight as % of total (B+P) dry weight	85.2	82.2	80.9	78.8	77.1

The results in Table 3 show seasonal changes in the relative amounts of nutrients in blades and petioles:

- Blade compared with petiole levels of nitrogen, nitrate, potassium, sulphur, copper, and to a lesser extent iron, increased from pre-harvest to early harvest, then declined at peak harvest, then steadily increased again until the final autumn harvest
- Blade compared with petiole levels of ammonium and manganese increased steadily from pre-harvest through the whole season
- Blade compared with petiole levels of phosphorus declined from pre-harvest to peak harvest, then increased again until autumn
- Blade compared with petiole levels of calcium and boron increased from pre-harvest to peak harvest, then increased again until autumn; magnesium and zinc were similar but peaked in the early harvest period.

Table 3. Dry weight nutrient ratios (Blade/Petiole) during the season (2015-16). Note: These values are ratios not nutrient levels but ratios that can be used to convert nutrient levels between blade and petiole nutrient values.

	Crop stage				
	Pre-harvest (20 Aug – 30 Sep)	Early Harvest (18 Oct – 17 Nov)	Peak Harvest (10-21 Dec)	Summer low Harvest (1-20 Feb)	Autumn Harvest (14 Apr – 7 May)
Nitrogen	2.52	3.11	2.54	3.27	4.31
Nitrate N	0.20	0.32	0.30	0.35	0.39
Ammonium N	1.70	2.22	2.48	2.75	2.86
Phosphorus	2.12	1.85	1.50	1.53	1.81
Potassium	0.59	0.63	0.57	0.67	0.76
Sulphur	3.08	4.25	3.46	4.04	5.29
Calcium	1.01	1.27	1.46	1.19	1.22
Magnesium	0.67	1.25	1.24	1.20	1.00
Manganese	1.84	2.36	2.98	2.90	3.97
Iron	1.50	4.81	2.66	2.61	3.26
Copper	1.50	1.31	1.22	1.31	1.70
Zinc	1.07	1.65	1.26	1.24	1.02
Molybdenum	2.74	3.13	2.34	3.15	2.64
Boron	1.14	1.89	2.23	1.89	1.59

The main conclusions from Tables 2 and 3 are:

- Blades have up to 50% more dry matter than petioles (30% compared with 20%) and account for a significantly higher proportion of a whole leaf (B+P) sample (77–85%) on a dry weight basis
- For most nutrients, the increase in petiole size during the season is too small to markedly change the Blade compared with Blade + Petiole nutrient ratios, as the blade remains the largest part of the sample at all times.

Leaf tissue results and reference levels

The data in Table 4 shows actual leaf blade plus petiole nutrient values whereas, the data in Table 5 includes the use of blade/petiole nutrient ratios (Table 3) to calculate extrapolated values for leaf blades only based on the three seasons of blade and petiole data. The extrapolated (B) levels taken from the local blade plus petiole levels were generally similar to the reference values established by Hartz *et al.* (2012) in California for Albion. None of the commercial crops monitored showed any clear signs of nutrient deficiency and all produced high quality fruit, although quality itself (mainly Brix and average fruit size) was very dependent on recent local conditions prior to sampling.

Table 4. New nutrient reference values for southern Victorian strawberries cv. "Albion" – youngest mature <u>leaf blade plus petiole.</u>

Nutrient	Crop stage				
	Pre-harvest	Early harvest	Peak harvest	Summer low harvest	Autumn harvest
Nitrogen (%)	3.1-3.6	2.4-3.1	1.9-2.7	1.9-2.5	1.7-2.4
Nitrate N (mg/kg)	170-1000	670-1440	320-990	110-820	40-520
Ammonium N (mg/kg)	112-237	137-252	110-195	106-205	95-164
Phosphorus (%)	0.28-0.50	0.21-0.32			
Potassium (%)	2.0-2.4	1.6-2.2			
Sulphur (%)	0.19-0.27	0.13-0.18			
Calcium (%)	0.7-0.9	0.9-1.3	1.1-1.6	1.2-1.8	1.3-1.8
Magnesium (%)	0.34-0.42	0.32-0.43			
Manganese (mg/kg)	Av. 140-159				
Iron (mg/kg)	67-293	75-161			
Copper (mg/kg)	2.8-6.2	2.5-5.8			
Zinc (mg/kg)	12-30	10-28			
Molybdenum (mg/kg)	0.6-1.1	0.5-1.0			
Boron (mg/kg)	27-35	28-54			

- Local phosphorus values are slightly low by current USA standards; growers should aim to achieve a minimum value of 0.30%
- Mo figures are 0.5xSTDEV
- Mn has a low average but is highly skewed by a few very high values; Australian figures are generally similar to USA; growers should use existing reference ranges for Mn
- Minor adjustments to upper limits of N & Ca in summer low and autumn period without altering seasonal averages.

Table 5. New nutrient reference values for southern Victorian strawberries cv. "Albion" – youngest mature <u>leaf blade.</u>

Nutrient	Crop stage				
	Pre-harvest	Early harvest	Peak harvest	Summer low harvest	Autumn harvest
Nitrogen (%)	3.4-3.9	2.7-3.5	2.2-3.0	2.2-2.9	2.1-2.9
Nitrate N (mg/kg)	100-600	460-990	220-670	80-570	30-340
Ammonium N (mg/kg)	119-251	152-278	125-219	122-237	111-191
Phosphorus (%)	0.30-0.54	0.23-0.35			
Potassium (%)	1.8-2.1	1.5-2.0			
Sulphur (%)	0.21-0.30	0.16-0.21			
Calcium (%)	0.7-0.9	0.9-1.3	1.2-1.7	1.3-1.8	1.4-1.9
Magnesium (%)	0.32-0.39	0.33-0.44			
Manganese (mg/kg)	Av. 150-183				
Iron (mg/kg)	70-307	84-182			
Copper (mg/kg)	3.0-6.5	2.6-6.0			
Zinc (mg/kg)	12-30	10-29			
Molybdenum (mg/kg)	0.7-1.2	0.5-1.2			
Boron (mg/kg)	28-36	30-60			

- Local Phosphorus values are slightly low by current USA standards. Growers should aim to achieve a minimum value of 0.30%
- Mo figures are 0.5xSTDEV
- Mn has a low average but is highly skewed by a few very high values; Australian figures are generally similar to USA; growers should use existing reference ranges for Mn
- Minor adjustments to upper limits of N & Ca in summer low and autumn period without altering seasonal averages.

Comparisons of local and USA reference values are covered in the recommendations section. Table 6 below compares local leaf blade (extrapolated) reference values with the two most relevant sources. Hartz *et al.* (2012) is most relevant because it is also for Albion; is most climatically comparable with Victoria; is the global benchmark for this variety; and was only published in 2012. Hochmuth & Albregts (2003) in Florida is climatically the next most relevant reference and is one of the few based on blade plus petiole values, although no varieties are defined – short day or day neutral. Victorian average values +/- their standard deviation generally shows very similar ranges to Hartz *et al.* (2012). The most notable exception is phosphorus, although the local range is similar to the older reference values of Hochmuth & Albregts (2003), and UC Publication 4098. The standard deviation range spread of some of the minor elements was considered too great in comparison with key reference ranges, but changing this to 0.5x the standard deviation as noted gave a tighter range very much in line with these.

Table 7 shows other references that have been established in Eastern USA for short day varieties and are therefore less relevant (e.g. Cornell University, 2005 and Campbell & Miner – North Carolina Department of Agriculture, 2000). The only locally established reference, still based on USA data and not used at all local analytical laboratories for interpretation, is also shown.

Table 6. Victorian vs. primary USA reference values for strawberry leaf samples.

Source	New reference values AHR (2016)		Hartz *et al.* (2012) DRIS Optimum Range		Hochmuth & Albregts (2003)		Ulrich *et al.* (1980) Uni. Cal. Pub. 4098
Location	southern Victoria		California		Florida		
Plant Type	Day neutral		Day neutral		-		
Variety	Albion		Albion		-		
Part Sampled	Blade		Blade		Blade+Petiole		
Sample Timing	Pre-Harvest	Harvest	Pre-Harvest	Main Harvest	Initial Harvest	Mid Harvest	Main Harvest
Nitrogen (%)	3.4-3.9	2.2-3.2	3.1-3.8	2.4-3.0	3.0-3.5	2.8-3.0	>3.0
Phosphorus (%)	0.30-0.54	0.23-0.35	0.50-0.90	0.30-0.40	0.20-0.40	0.20-0.40	0.15-1.30
Potassium (%)	1.8-2.1	1.5-2.0	1.8-2.2	1.3-1.8	1.5-2.5	1.1-2.5	1.0-6.0
Sulphur (%)	0.21-0.30	0.16-0.21	0.19-0.23	0.15-0.21	0.25-0.80	0.25-0.80	>0.10
Calcium (%)	0.7-0.9	1.1-1.7	0.6-1.3	1.0-2.2	0.4-1.5	0.4-1.5	3-30
Magnesium (%)	0.32-0.39	0.33-0.44	0.33-0.45	0.28-0.42	0.25-0.50	0.20-0.40	0.20-0.40
Manganese (mg/kg)	Av. 150-183		75-600	65-320	30-100	25	30-700
Iron (mg/kg)	70-307	84-182	70-140	85-200	50-100	50	50-3000
Copper (mg/kg)	3.0-6.5	2.6-6.0	3.3-5.8	2.6-4.9	5-10	5	
Zinc (mg/kg)	12-30	10-29	13-28	11-20	20-40	20	20-50
Molybdenum (mg/kg)	0.7-1.2	0.5-1.2				0.5	
Boron (mg/kg)	28-36	30-60	31-46	40-70	20-40	20	35-200

- Local phosphorus values are slightly low by current USA standards; growers should aim to achieve a minimum value of 0.30%
- Manganese has a low average but is highly skewed by a few very high values; Australian figures are generally similar to USA; indicated range is based on USA data.

Table 7. Secondary reference values for strawberry leaf samples.

Source	Cornell University, courtesy of Penn. State Uni (2013)					Campbell & Miner (2000)	Reuter & Robinson[**], CSIRO (1996)	
Plant Type	Short Day*					SD[*]	-	
Part Sampled	Blade					Blade	Blade+/-Petiole	
	Excessive	Above Normal	Normal	Below Normal	Deficient	Sufficient	Optimum	Deficient
Nitrogen (%)	>3.25	2.80	2.00	1.80	1.50	3.0-4.0	2.0-2.5	
Phosphorus (%)	>0.50	0.40	0.35	0.25	0.20	0.20	0.30-0.50	<0.1
Potassium (%)	>3.00	2.50	2.00	1.50	1.20	1.1	2.0-3.0	<1.0
Sulphur (%)						0.15	0.10-0.20	<0.1
Calcium (%)	>2.00	1.70	1.50	0.70	0.60	0.5	1.5-2.0	<0.3
Magnesium (%)	>0.65	0.50	0.45	0.30	0.25	0.25	0.40-0.60	<0.2
Manganese (mg/kg)	>250	250	150	50	40	30-300	50-350	<30
Iron (mg/kg)	>325	250	150	60	50	50-300	50-150	<50
Copper (mg/kg)	>25	20	10	7	5	3-15	5-10	<3
Zinc (mg/kg)	>65	50	35	20	15	15-60	30-50	<20
Molybdenum (mg/kg)							>0.5	<0.5
Boron (mg/kg)	>85	70	60	30	20	25-50	25-50	<25

[**]Some of the CSIRO values come from Ulrich *et al*. (1980), used in the Uni. Cal. Pub. 4098 figures (Table 6).
[*]Values derived for short day varieties – Demchak, K. (pers. comm., 2016).

Soil nutrient levels

Table 8 shows average soil nutrient results for the sample group (n=32) from all three seasons as a whole. Individual and soil group types (ferrosols, brown clays, brown clay loams, grey clays, yellow clays etc.) can be viewed in the original data appending this report.

Table 8: Average, lowest, highest and reference values for soil analytes taken from all 32 blocks monitored over three seasons (2013–14, 2014–15 and 2015–16).

	Mean	Lowest	Highest	Nutrient Advantage Laboratories Reference Range
pH (1:5 Water)	6.4	5.5	7.3	6.0-7.5
pH (1:5 CaCl2)	6.0	5.1	6.8	4.9-6.5
Electrical Conductivity (1:5 Water) - dS/m	0.48	0.22	0.96	
Electrical Conductivity (Saturated Extract) - dS/m	3.1	1.5	6.0	<1.0
Chloride - mg/kg	91	17	330	<180
Organic Carbon (OC) - %	2.1	1.3	3.7	2.0-10.0
Nitrate Nitrogen (NO3) - mg/kg	92	4	190	20-30
Ammonium Nitrogen - mg/kg	38	2	270	
Phosphorus (Colwell) - mg/kg	190	50	360	40-70
Phosphorus Buffer Index (PBI-Col)	268	63	700	
Sulphate Sulphur (KCl40) - mg/kg	156	36	610	
Cation Exchange Capacity - cmol(+)/kg	14.0	7.4	21.1	
Calcium (Amm-acet.) - %	70	53	83	65-80
Calcium (Amm-acet.) - cmol(+)/kg	9.9	4.4	14.0	5.0-50
Magnesium (Amm-acet.) - %	20	12	34	10-20
Magnesium (Amm-acet.) - cmol(+)/kg	2.8	1.8	5.2	1.6-50
Sodium (Amm-acet.) - %	1.94	0.47	8.50	<5.0
Sodium (Amm-acet.) - cmol(+)/kg	0.24	0.06	0.70	
Potassium (Amm-acet.) - %	7.1	2.9	12.0	5-15
Potassium (Amm-acet.) - cmol(+)/kg	1.00	0.24	1.80	0.77-50
Available Potassium - mg/kg	391	94	700	
Calcium/Magnesium Ratio	3.7	1.6	6.8	2.5-5.0
Potassium to Magnesium Ratio	0.4	0.1	0.7	
Zinc (DTPA) - mg/kg	2.17	0.40	6.20	2.0-20
Copper (DTPA) - mg/kg	2.45	0.30	12.00	0.3-10
Iron (DTPA) - mg/kg	92	16	400	2.0-100
Manganese (DTPA) - mg/kg	8.2	2.0	44.0	4.0-45
Boron (Hot CaCl2) - mg/kg	1.06	0.30	2.30	1.0-2.0

It is not possible to give a comprehensive analysis of soil results based simply on average values. Nonetheless, the primary purpose of the soil tests was to see if there were any major underlying problems in the soils in case particular deficiencies or high results then occurred in tissue tests. Strawberries have been grown on the same land for a very long time in southern Victoria, with very little new land coming into production. Soil nutrients or other factors were not generally seen to be key factors in limiting plant nutrient uptake unless noted. The following were the key conclusions from the 32 samples collected and tested.

Salinity: Based on the EC_{se} values alone, the higher than desirable results (EC_{se} Av 3.1, range 1.5-6.0 dS/m) suggests salinity to be a potential problem. EC (1:5 Water) values were on average at the upper recommended upper limit. However, a number of other measures tend to mitigate this actually being a problem:

- High EC values are not just a measure of NaCl but often indicate the presence of fertiliser, gypsum and other desirable salts
- Sodium levels (Av 0.24, range 0.06-0.70 cmol(+)/kg) were well within most reference ranges (0.3-3.0 cmol(+)/kg)
- Sodium as a % of Base saturation was also mostly well within the desirable range (Table 8); chloride (mg/kg) levels were also mostly inside the reference range (Table 8)
- Chloride levels measured in the leaves were inside the reference range during the growing season, perhaps reaching marginal values towards the end of the season
- Some of the highest quality and best yielding crops were grown where these higher EC_{se} values were recorded
- Many growers are using Melbourne domestic water for at least part of their irrigation requirements; this water has extremely low EC, typically 0.06-0.19 dS/m, while strawberries are regarded as being tolerant to irrigation water provided it is <1.5 dS/m (Bolda M, 2014).
- Growers continuing to record high soil EC values and higher sodium or chloride levels (especially early in the season) need to test dam water used for irrigation.

Phosphorus: While most soils showed high Colwell P values, most of the project soils also have a high to very high phosphorus buffering index (PBI). Of particular note were the ferrosols which all had a PBI-Col of 280-700. This means these soils must be given much higher initial rates of P to overcome the soils natural tendency to retain P and allow more to become plant-available.

Replicated trials – supplemental nitrogen and phosphorus

The three final season trials (Table 9) did not show any significant differences ($P>0.05$) in yield. There were no increases in tissue N in the supplemented treatments at two sites but marked increase at the third. There was a slight increase in tissue P at all three sites in the supplemented treatments. A small amount of additional K was also supplied at the first application only because of the form the fertiliser was in, not through a desire to boost K which was present at levels surplus to requirement.

At trial site 2, other subjective parameters measured (firmness and flavour), showed no differences. Four fruit samples were collected at each site corresponding to leaf sampling dates. However, the extreme dry and early heat experienced in the region made it one of the worst production seasons in memory. This meant samples collected were sometimes compromised by a lack of completely suitable fruit for measuring Brix and average fruit weights, especially when fruit size was highly variable. Average fruit weights from these samples at trial site 2 showed a higher average weight in the standard but the opposite was true at the same site using the much more accurate accumulated average figure for the whole trial period. Brix was slightly higher at all three sites based on the four samples taken at each. No significant ($P<0.05$) correlations between nutrition and quality aspects were found.

Table 9. Key yield results from the three trials comparing standard grower nutrition with extra nitrogen, phosphorus and potassium (1.68g, 3.55g & 0.21g/plant).

	Trial 1		Trial 2		Trial 3	
Location	Coldstream		Wandin		Wandin	
Soil	Brown Clay		Red Clay/Ferrosol		Red Clay/Ferrosol	
Soil pH ($CaCl_2$)	5.6		6.8		5.9	
Start – Soil Phosphorus (Colwell) mg/kg	92		170		310	
Phosphorus Buffering Index (PBI-Col)	93		340		500	
Start - Soil Nitrate (mg/kg)	100		92		150	
Start – Soil Ammonium (mg/kg)	270		44		80	
Yield period of Trial	24 Oct 2015 – 12 Apr 2016		20 Oct 2015 – 25 Apr 2016		18 Oct – 22 Apr 2016	
Plants/ha	49,438		56,738		44,959	
Treatment	Standard	Extra	Standard	Extra	Standard	Extra
*Yield/plant (g)	687	684	585	581	901	932
*Yield/ha (kg)	33941	33837	33198	32948	40504	41912
****Yield (% of Standard)***	**100.0**	**99.7**	**100.0**	**99.2**	**100.0**	**103.5**
*Av. Fruit Weight (g) 4 sample times	12.2	12.5	14.5	12.8	18.2	17.7
*Av. Fruit Weight (g) Whole Trial Period			16.2	17.2		
*Av. Brix (4 sample times)	9.7	9.0	10.4	9.9	10.7	10.0
Av. Flavour (1-5) 5=Best			4.6	4.6		
Av. Firmness (1-5) 5=Best			4.5	4.5		
Harvest Season Av. Nitrogen % (B+P)	2.0	2.5	2.1	2.1	2.2	2.2
Harvest Season Av. Nitrogen % (B)	2.3	2.9	2.4	2.4	2.6	2.6
Harvest Season Av. Phosphorus % (B+P)	0.26	0.31	0.23	0.25	0.23	0.25
Harvest Season Av. Phosphorus % (B)	0.27	0.33	0.25	0.27	0.25	0.28

*Not significantly different results for these parameters at each trial site (LSD, P=0.05).

Overview & Other Issues

A key observation made over the course of the project was the difficulty most growers had in irrigating plants efficiently, which may well relate to effectively delivering nutrition to plant roots. While growers applied a lot of water, and soils are almost invariably heavy textured clays, the lateral movement of water in beds is generally very poor. Standard practice tends to produce open structured beds with fine clods that should allow free root movement, but this also produces soils which allow rapid vertical movement of water, even at high flow rates using closely spaced emitters. This means that while plants may well be receiving more moisture than required in the bed centres, little wetting occurs further out towards the shoulders of beds, especially when there is only a single drip-line down the centre of beds (standard practice). In conjunction with this, Albion seems to have much less root vigour than older varieties such as Selva (various growers, pers. comm.). Growers who cooperated in the project all reported how much better rainfall or overhead irrigation works to wet up beds, even with plastic mulch preventing most of this water from directly penetrating beds.

The other key issue which continued to worsen over the life of the project was charcoal rot. This complex problem appears to be getting worse each season, while it tends to follow somewhat predictable patterns where its presence has been identified. There seem to be better and worse locations, often in very short distances from each other, although there are no clear explanations for the patterns. The problem seems to become most apparent from the peak of summer onwards. In 2015–16 some growers were observing up to 40% plant losses in specific affected blocks.

Despite there being no consistent correlations being established between nutrient levels and yield, a large set of data collected has allowed a set of reference values to be established for both the major and minor elements, based on the standard deviation range for average values at five key times during the growing season. While they are only average values from commercial Victorian crops, most of these reference levels are remarkably similar to those established for the highest yielding crops by Hartz *et al.*, 2012. These should serve as reasonable references as to how southern Victorian growers compare with each other, given all samples were taken from crops that appeared healthy and all produced high quality fruit. The B+P levels are the most reliable but the B levels extrapolated from the final years work are also likely to be a reasonable guide, if slightly less reliable than the B+P results.

Conclusions

New leaf blade and leaf plus petiole nutrient reference levels have been established for the Albion strawberry in Victoria.

Strawberry nutrition is not currently one of the main factors limiting Victorian strawberry yields. This is based on the generally poor correlations between yield and nutrition and the poor responses seen to additional N & P in the third season trials.

Soil testing data and late season tissue testing suggest growers need to be careful about salinity. Detailed additional sodium and chloride data for both tissue and soil tests can be found in the appended Excel data. While it does not appear to be obviously interfering with production or producing obvious symptoms, growers with high EC_{se} soil values should ensure a good source of low EC irrigation water for at least strategic applications throughout the season.

An additional 2–3 years' of data would assist in verifying the accuracy of the blade-only (B) tissue reference data. However, the extrapolated values already generally correspond well with recent Californian reference values for high yielding Albion crops.

Average nutrient values from the tissue testing undertaken in this project agree well with Californian values for Albion and either are likely to function well as reference values for the local industry.

Nitrogen levels compare well with Californian values. Most growers are achieving adequate values and there is no good evidence that higher rates, especially early in the season will be of any significant benefit.

Potassium levels are similar to slightly elevated compared with Californian and other USA reference values. There is no evidence growers need to increase potassium nutrition.

Phosphorus is the most important nutrient, local growers may be under-applying. While the average level sits inside most USA optimal ranges, lower values inside the local standard deviation can sit below the USA desirable range. Growers should focus more attention on phosphorus management. Nearly all Victorian strawberry soils tested had a high phosphorus buffering index (PBI) and this indicates soils need to be "loaded" up with phosphorus for more P to become plant available. Unlike nitrogen, where growers can easily over or under-dose individual applications soil phosphorus applications are long-term investments due to the poor soil mobility and slow rate it is removed from the profile. The growers most likely to benefit from additional phosphorus are those on the ferrosol soils (e.g. Wandin) where PBI-Col values can be 700 or greater.

Copper levels in local Albion crops are similar to those in California (Hartz *et al.*, 2012). Interestingly, both of these Albion reference ranges are lower than other established strawberry reference ranges which generally assign a critical minimum of 3-5mg/kg.

Calcium, sulphur, magnesium, zinc, iron and boron levels in local crops are comparable with reference levels in California.

Manganese is also comparable with USA references but a few very high values skew the results and make it impossible to express a range inside a normal standard deviation. While no obvious deficiency symptoms were seen, about 20% of growers show periodically marginal (low) values (around 30mg/kg or less) and should address this if it is showing up consistently.

Molybdenum reference values are generally lacking around the world but local levels are consistent with recommended sufficiency ranges where they exist (Hochmuch & Albregts (2003) & Reuter & Robinson (1996).

Nitrate and ammonium values – there is little value in growers measuring nitrate and ammonium to support decisions about nitrogen sufficiency levels due to the high degree of variability. This is particularly true in the case of ammonium which has not been included in any other references before and is considered even less reliable than nitrate. Despite this, average values from the same seasonal timing for both do show consistent trends across the season.

Fertiliser placed close to the roots at planting, rather than incorporated through the whole bed is likely to be much more efficiently used - first, because of the poor lateral movement of water in beds, leaving dry shoulders where any fertiliser present will not be available and, second, because of the relatively low root vigour of Albion.

Root and crown disease (especially charcoal rot) and more efficient irrigation are considered to be higher priorities for improving Victorian strawberry yields than nutrition.

Recommendations

1. Further research is required in relation to better managing soil moisture. Current drip irrigation systems are not always resulting in optimum soil moisture levels throughout crops.
2. Further research should focus on developing effective control measures for the disease charcoal rot which is causing major losses in the Victorian strawberry industry.
3. The Victorian strawberry industry publicises and adopts the standards developed in the project as their target leaf nutrient levels for strawberry growing.
4. Growers adopt regular leaf testing through the crop to best manage their nutrient program.

Scientific refereed publications

A paper outlining the nutrient reference values derived from the project is currently being drafted.

Intellectual property/commercialisation

No commercial IP generated.

References

Bolda, M. & Cahn, D. 2014 (7 Jan). Further Understanding Salinity in Berries. http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=12509

Campbell, C. and Miner, G. 2000. Reference Sufficiency Ranges For Plant Analysis in the Southern Region of The United States – Fruit & Nut Crops – Strawberry – Annual Hill Culture: 111-112, Southern Cooperative Series Bulletin #394. http://www.ncagr.gov/agronomi/saaesd/scsb394.pdf

Cornell University. Courtesy of Penn. State Uni (2013). The Mid-Atlantic Berry Guide, 2013-14. Critical Nutrient Values for Strawberries at Renovation. Appendix B, Diagnostic Services: 251

Demchak, K. 2015. Sampling Strawberry Leaves for Nutrient Analysis – Penn State Extension Blog. http://extension.psu.edu/plants/tree-fruit/news/2015/sampling-strawberry-leaves-for-nutrient-analysis

Hartz, T. 2012. Establishing Nutrient Management Practices For High-yield Strawberry Production California Strawberry Commission Annual Report 2011-12: 41-55. http://www.calstrawberry.com

Hartz, T. 2012 (b). Strawberry Plant Sufficiency Levels Revised. 5 Mar 2012. http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=6958

Hochmuth, G. and E. Albregts. 2003. Fertilization of strawberries in Florida. IFAS Publ. CIR1141, http://edis.ifas.ufl.edu/cv003

Reuter, D. & Robinson, J. 1996. Plant Analysis – An Interpretation Manual: 376-377.

Ulrich, A., M.A.E. Mostafa and W.W. Allen. 1980. Strawberry Deficiency Symptoms. A visual and plant analysis guide to fertilization. Univ. Calif. Bulletin 4098.

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Appendices

1. Draft Factsheet
2. Full data set attached in spreadsheet format (not published due to grower privacy)

New tissue nutrient reference levels for Victorian day-neutral strawberries cv. "Albion"

New leaf tissue reference levels for Albion strawberries have been established from a three-year study of commercial strawberry farms in Victoria. Currently available foliar nutrient reference levels for strawberry growers in Australia exist but are based on old overseas data and are a composite of both blade only and blade plus petiole data.

Local data was generated from 8–12 representative commercial strawberry crops, sampled 4–5 times over three growing seasons (2013–14, 2014–15 and 2015–16) – all field-grown, first year Albion plantings.

Californian data is based on a larger data set: two seasons of data from 53 different first-year Albion blocks, each sampled five times during the season.

The main difference between local and Californian reference values is that local values are based on sample averages, while Californian values are based on adjusted (DRIS method) nutrient levels from the higher yielding crops only. Despite this differing methodology, local average values correspond well with these recent Californian reference values.

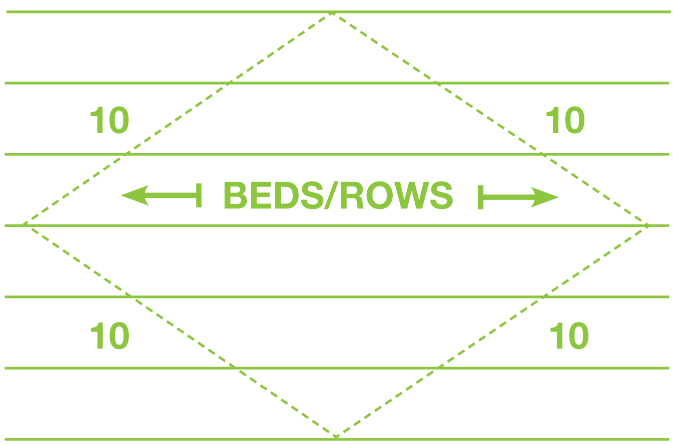

Figure 1. Generalised leaf sampling pattern for project strawberry fields.

More detailed information on these reference levels and how they compare with other global references can be found in HIA Report BS12010.

The tables in this fact sheet allow growers to review their test results based on either leaf sampling method, show both local and USA reference values.

The micronutrient levels reflect local leaf tissue levels in Victoria, and the tolerance range may be wider. You are referred to the Reuter and Robinson data for micronutrient tolerance ranges.

How to collect samples

Samples can be collected at any time but those taken earlier in the season, ideally after first harvest but before peak harvest, are likely to be most useful by allowing growers to make any necessary adjustments early.

Use disposable gloves or clean, washed hands to collect 30–40 leaves into paper sample bags and refrigerate overnight if samples cannot be dispatched same day.

Leaf selection is based on taking the youngest mature leaf or fully expanded leaf (YML), although in a well developed canopy there are usually several suitable leaves on each plant.

Leaves should NOT be taken from unhealthy looking plants or those of less than average vigour in that part of the field. Physically damaged leaves should also be avoided.

Early in the season, the youngest mature leaves are usually the larger leaves but later, and after full canopy closure the youngest mature leaves are the healthy leaves at the top of the canopy of at least average size or larger.

Aim for larger, healthy, fully expanded leaves. Avoid sampling within several days of spraying nutrients or other chemicals. Leaves with clearly visible spay residues should not be sampled.

This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government.

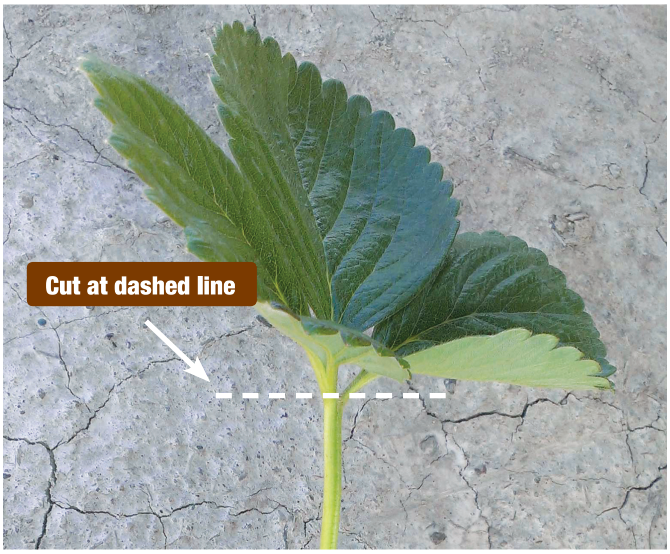

Photo 1: Preferred method for leaf sampling – blade only

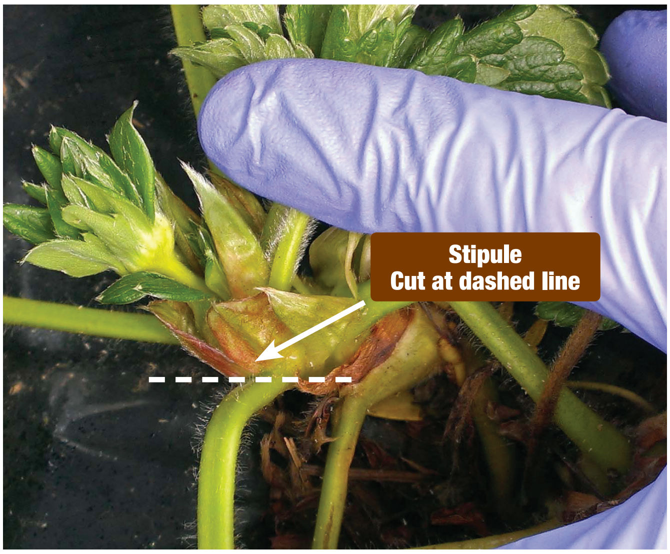

Photo 2: Older method for leaf sampling – blade+petiole

Recent studies in the USA recommend taking blades-only leaf samples. This is the preferred method for collection in future for local samples as well. Petioles increase in size over the season and this can alter the proportions of nutrients in blades and petioles. For blade-only samples, cut immediately below the junction of the trifoliate leaf blade (photo 1).

For blade+petiole samples, the target point to cut leaves is close to the crown where the stipule meets the petiole. Lay the flat side of a clean, sharp knife blade against the crown. This will generally cut the petiole near this point (photo 2).

Leaves should be sampled in a roughly trapezoidal pattern, to cover a representative area of the field, avoiding plants in the outermost row or last couple of metres around the edge, sampling about 8–10 plants at roughly even intervals along each of the sides of the trapezium, as detailed in Figure 1.

Key messages for Victorian Albion growers

- **Blade rather than blade+petiole testing is currently the preferred method for strawberry tissue testing**
- **Sampling earlier is generally more useful than sampling later in the season**
- **Tissue nitrogen levels are comparable with Californian reference values**
- **Tissue potassium levels are comparable to higher than average Californian reference values**
- **Tissue phosphorus levels are similar to some older reference values but slightly below Californian values; this may simply be related to the very high phosphorus buffering index of many Victorian soils (particularly the red soils or ferrosols); however, there is some evidence growers may benefit from increasing soil phosphorus levels to achieve tissue levels above 0.30% (blade only)**
- **Micronutrient requirements are difficult to accurately predict from these types of surveys; while many Victorian average values are similar to those in California, the Californian values may be a better reference for minimum values; recommended minimum values for copper in most established standards is 3–5 mg/kg.**

Leaf blade nutrient reference values for southern Victorian strawberries cv. "Albion" (youngest mature leaf blade).

NUTRIENT	CROP STAGE				
	Pre-harvest	Early harvest	Peak harvest	Summer low harvest	Autumn harvest
Nitrogen (%)	3.4-3.9	2.7-3.5	2.2-3.0	2.2-2.9	2.1-2.9
Phosphorus (%)	0.30-0.54	0.23-0.35			
Potassium (%)	1.8-2.1	1.5-2.0			
Sulphur (%)	0.21-0.30	0.16-0.21			
Calcium (%)	0.7-0.9	0.9-1.3	1.2-1.7	1.3-1.8	1.4-1.9
Magnesium (%)	0.32-0.39	0.33-0.44			
Manganese (mg/kg)	Use existing references*				
Iron (mg/kg)	70-307	84-182			
Copper (mg/kg)	3.0-6.5	2.6-6.0			
Zinc (mg/kg)	12-30	10-29			
Molybdenum (mg/kg)	0.7-1.2	0.5-1.2			
Boron (mg/kg)	28-36	30-60			

Leaf blade + petiole reference values for southern Victorian strawberries cv. "Albion" (youngest mature leaf blade plus petiole).

NUTRIENT	CROP STAGE				
	Pre-harvest	Early harvest	Peak harvest	Summer low harvest	Autumn harvest
Nitrogen (%)	3.1-3.6	2.4-3.1	1.9-2.7	1.9-2.5	1.7-2.4
Phosphorus (%)	0.28-0.50	0.21-0.32			
Potassium (%)	2.0-2.4	1.6-2.2			
Sulphur (%)	0.19-0.27	0.13-0.18			
Calcium (%)	0.7-0.9	0.9-1.3	1.2-1.7	1.3-1.8	1.4-1.9
Magnesium (%)	0.34-0.42	0.33-0.44			
Manganese (mg/kg)	Use existing references*				
Iron (mg/kg)	67-293	75-161			
Copper (mg/kg)	2.8-6.2	2.5-5.8			
Zinc (mg/kg)	12-30	10-28			
Molybdenum (mg/kg)	0.6-1.1	0.5-1.0			
Boron (mg/kg)	27-35	28-54			

New tissue nutrient reference levels for Victorian day-neutral strawberries cv. "Albion"

How the new Victorian reference values for strawberry leaf samples compare to other references sources

SOURCE	HIA PROJECT BS12010 – AHR (2016)		HARTZ ET AL. (2012) DRIS OPTIMUM RANGE		HOCHMUTH & ALBREGTS (2003)		REUTER & ROBINSON, CSIRO (1996)	
LOCATION	Southern Victoria		California		Florida			
PLANT TYPE	Day neutral		Day neutral					
VARIETY	Albion		Albion					
PART SAMPLED	Blade		Blade		Blade+Petiole		Blade+/-Petiole	
SAMPLE TIMING	Pre-harvest	Harvest	Pre-harvest	Harvest	Main Harvest	Initial Harvest	Optimum	Deficient
Nitrogen (%)	3.4-3.9	2.2-3.2	3.1-3.8	2.4-3.0	3.0-3.5	2.8-3.0	2.0-2.5	
Phosphorus (%)	0.30-0.54*	0.23-0.35*	0.50-0.90	0.30-0.40	0.20-0.40	0.20-0.40	0.30-0.50	<0.1
Potassium (%)	1.8-2.1	1.5-2.0	1.8-2.2	1.3-1.8	1.5-2.5	1.1-2.5	2.0-3.0	<1.0
Sulphur (%)	0.21-0.30	0.16-0.21	0.19-0.23	0.15-0.21	0.25-0.80	0.25-0.80	0.10-0.20	<0.1
Calcium (%)	0.7-0.9	1.1-1.7	0.6-1.3	1.0-2.2	0.4-1.5	0.4-1.5	1.5-2.0	<0.3
Magnesium (%)	0.32-0.39	0.33-0.44	0.33-0.45	0.28-0.42	0.25-0.50	0.20-0.40	0.40-0.60	<0.2
Manganese (mg/kg)	Use existing references*		75-600	65-320	30-100	25	50-350	<30
Iron (mg/kg)	70-307	84-182	70-140	85-200	50-100	50	50-150	<50
Copper (mg/kg)	3.0-6.5	2.6-6.0	3.3-5.8	2.6-4.9	5-10	5	5-10	<3
Zinc (mg/kg)	12-30	10-29	13-28	11-20	20-40	20	30-50	<20
Molybdenum (mg/kg)	0.7-1.2*	0.5-1.2*				0.5	>0.5	<0.5
Boron (mg/kg)	28-36	30-60	31-46	40-70	20-40	20	25-50	<25

***Notes**

- Victorian range values are based on +/- 1.0xSTDEV
- Molybdenum figures are 0.5xSTDEV. There is little recent data on molybdenum
- Victorian Manganese average is highly skewed by a some very high values; at the same time, a small number of samples were borderline-deficient by existing standards, although local figures are generally similar to USA; growers should use existing (Non-Victorian) reference ranges for manganese
- Local phosphorus values are slightly low by current USA standards; growers should aim to achieve a minimum value of 0.30%.

References Hartz, T. 2012. Strawberry Plant Sufficiency Levels Revised. 5 Mar 2012. http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=6958 Hochmuth, G. and E. Albregts. 2003. Fertilization of strawberries in Florida. IFAS Publ. CIR1141, http://edis.ifas.ufl.edu/cv003 Reuter, D. & Robinson, J. 1996. Plant Analysis – An Interpretation Manual: 376-377.