Growing Sub-Tropical Bananas for Quality and Yield

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GROWING SUB-TROPICAL BANANAS FOR QUALITY AND YIELD

Project No. BA08003

FINAL REPORT

November 2013

Horticulture Australia Limited,
Department of Agriculture and Food, Western Australia,
and
Sweeter Banana Co-operative

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PURPOSE OF THIS REPORT:

This document reports on the results of a project that investigated approaches to improve yield and quality of sub-tropical banana production in Carnarvon, Western Australia. The project has demonstrated that protective netting structures improve productivity of bananas but did not significantly improve quality or profitability. Evaluation of planting densities highlighted that current industry practice was the most profitable of all options evaluated in this project. The project has also identified a number approaches that could still offer productivity improvements for sub-tropical banana producers.

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Horticulture Australia Ltd.
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Media summary

The Australian banana industry has recognised the importance of satellite production with two cyclones significantly affecting output from the main production areas of north Queensland in the past decade. This project undertook several activities to identify opportunities that may improve profitability of banana production in sub-tropical Carnarvon.

This study has shown that in Carnarvon, Western Australia, protective cultivation of bananas under full enclosure of fabric netting improves productivity but is less profitable than producing bananas in the open field.

Investigation into optimal planting densities demonstrated that current industry standards of planting at 3 x 3 metre row and plant spacing with three psuedostems from the one corm is the most profitable option for growers.

A full revision of production practices including a visit and expert review by Dr John Robinson (South Africa) has led to the publication of a growers production guide 'Growing Bananas in Carnarvon, Western Australia'.

Technical summary

Industry significance of the project

- Australian banana production is heavily dependent on north Queensland production.
- Two significant cyclones have had major effects on north Queensland production and national supply of bananas in the past decade.
- Efficient satellite production in other regions around the country (including sub-tropical Carnarvon) provides some mitigation against seasonal influences in north Queensland.
- Productivity of banana production in Carnarvon has declined in recent years.

Science undertaken

- Two demonstration trials were undertaken to;
  - Evaluate the use of protective netting in the form of a fully enclosed structure to improve productivity and profitability.
  - Evaluate several planting densities to identify optimal productivity and profitability.

Major findings and industry outcomes

- Use of protective netting structures improves productivity of bananas when compared to open field production.
- Cultivation of bananas under protective netting in Carnarvon is less profitable than open field production.
- A planting arrangement of 3 x 3 meters and developing three psuedostems from a central corm was the most profitable planting density in Carnarvon.

Recommendations and future work

- It would be worthwhile to investigate production of bananas at higher planting densities (up to 3333 plants per hectare) under protective netting to ascertain if this density would be more profitable than open field production.
- Investigation into the productivity and profitability gains of four metre high vertical windbreaks positioned around the perimeter of open field bananas in one or one-half hectare blocks to determine if this is a better option than fully enclosed structures.
- 3333 plants per hectare (3 x 3 metres with three psuedostems) is the optimal planting density in the open field but plants could be spatially better arranged. Investigation of planting arrangements of 2 x 1.5 meters with one follower warrant investigation.
- Investigate the relationship between bunch mass and waste component. The bunch masses recorded in all patches of the protective netting trial were high. A higher bunch weight appears to be associated with a higher waste proportion. Further investigation in conjunction with Sweeter Banana Co-operative would be required to quantify this relationship.

Introduction

In Australia bananas are a staple food item which are available year round and are well known to consumers. The Australian banana industry produces around 310,000 tonnes of bananas from about 14,000 hectares. This has an estimated value of AU$450 million (ABGC, 2013). The industry is dominated by bananas from the wet-tropics in Queensland where 90% of Australia's commercial bananas are grown. Bananas are also grown in subtropical areas of south-eastern Queensland and north-eastern New South Wales, and subtropical Western Australia.

In March 2006 Tropical Cyclone Larry and then again in February 2011 Cyclone Yasi devastated the banana industry in the wet tropics. During the 12 months after the cyclone there were shortages in supply of bananas Australia-wide. The industry has recognised that is must place greater emphasis on spreading the production risk to areas outside the wet tropics and increase the capacity of subtropical banana growers so that this could be achieved.

The industry in Western Australia

In Western Australia bananas are grown commercially in arid subtropical Carnarvon (24°51'S and 113°43'E) and semi-arid tropical Kununurra (15°46'S and 128°44'E). The Western Australian banana industry reached peak production in 1991 when 40,481 tonnes of fruit worth AU$27 million was produced (DAFWA, 1992). The major market for the crop was Perth where bananas from Carnarvon accounted for 56% of total volume, Kununurra supplied 23% and the rest came from tropical Queensland. In 2012 Carnarvon produced 6700 tonnes valued at $9.8M (DAFWA, 2013). Today, the industry in Kununurra is very small due to competition from north Queensland and annual storms which continually damage plantations making them struggle for viability.

The banana industry in Carnarvon has a long history and began with small plantings in the 1940's. Since that time the industry has grown and become one of the main stay of the regions horticulture industry. The industry is situated on the alluvial soils that adjoin the Gascoyne River, close to the coast. The soils are fertile and with good drainage but have slow infiltration rates. Owing to the dry climate, crops require year round irrigation. Horticulture in Carnarvon is limited by the infrastructure which supplies water for irrigation. Water is pumped from aquifers in the Gascoyne River. Regular river flows recharge these aquifers. Water is rationed and each grower receives an annual allocation. An efficient irrigation system is an essential component of horticultural management. The average yield of banana crops in Carnarvon during the last decade was high at around 43 tonnes per hectare. This had dropped to 33 tonnes per hectare in 2012 (DAFWA, 2013), partially in response to effects from flooding in late 2010 – early 2011, locust plague in March – April 2011 and near freezing low temperatures in July 2012.

Production is periodically affected by cyclone, flood and drought. The climate in Carnarvon is arid subtropical with hot dry summers and cool winters. It is considered harsh and marginal for bananas despite the high yields achieved: the mean maximum temperature in the hottest month, February, is 36°C and the mean minimum in the coolest month, July, is 10.8°C. The extremes are 45°C in summer and 1 to 5°C in winter. Rainfall, which occurs predominately in the winter months, is only 229 mm per year. Annual evaporation is 2580 mm. The area receives regular strong winds with the average speed ranging from 11.2 to

13.5 kilometres per hour from October to March each year. Cyclones occur most commonly from mid-January to mid-April. Cyclones that affect Carnarvon occur on average every 5 years. Banana production in Carnarvon peaked during 1991 at around 360 hectares producing 12,895 tonnes of marketable fruit (DAFWA, 1992).

Production was virtually destroyed in 2000 when a rain bearing ex-tropical cyclone caused extensive flooding and erosion to the plantation area. Drought followed the flood, delaying the industries efforts to rebuild to previous levels. By 2006 the banana industry had replanted 135 hectares and was producing 5000 tonnes of marketable fruit. A severe flooding event occurred again in late 2010 – early 2011 during the course of this project.

The Sweeter Banana Cooperative was formed in Carnarvon after the 2000 cyclonic flooding. The Sweeter Banana Cooperative provides growers with marketing and promotional power, a central packing shed and quality control system as well as industry representation. Ninety per cent of banana growers in Carnarvon are members of Sweeter but not all actively supply the packing shed.

A large number of new growers have entered the banana industry since the 2000 floods. The Sweeter Banana Cooperative was concerned that many growers have a limited understanding of banana production to achieve high yields and high quality fruit.
This is resulting in small, blemished fruit, low yields, poor pack-outs and poor returns for growers. Sweeter Banana Cooperative commissioned a pack-out study in 2007 to determine the level of poor quality fruit passing through the packing facility. It found that 50,000 boxes or 650,000 Kg of fruit worth $600,000 at current prices was second grade and badly blemished or waste product.

The banana industry in Carnarvon is a vital component of the Australian banana industry and it is important that it remains economically viable for the long term future of the industry. Innovative farming techniques will overcome the climatic problems of the Gascoyne, increasing quality and value of production.

Growers from Carnarvon visited Israel in 2006 to examine innovative farming technology. The Israelis have grown bananas under full protective net structures in order to manipulate the growing environment. They have found that bananas grown under full protection have reduced water usage, increased bunch weights and over 10% improved pack-out of first grade fruit.

Research and development

Department of Agriculture and Food WA (DAFWA), has been examining the growth of perennial tree crops under full protective structures. Results show that permanent protective structures reduce wind run, radiation and evaporation and may increase ambient and soil temperature compared to outside the protective structure. This significantly improves tree growth, shortens time to production and improves skin quality of fruit.

DAFWA has a long history of subtropical banana research including variety selection, selection of planting material, planting density, time of planting and crop cycling. Extensive trials on irrigation management have shown that a combination of under tree sprinklers used in summer and drip tape used in winter gives the best yields. Work has also been done on nutrition management and bunch management for subtropical bananas.

Observations have shown that a plantation density of 3333 plants per hectare is most common in Carnarvon. Previous research has shown that a planting configuration of 3 metres between rows and 1 metre between plants, leaving 1 sucker per site to replace the mother plant makes the most efficient use of light and land resources for the yield which can be achieved (Kesavan, 1999). While this planting system requires more planting material, it results in significantly higher yields in the parent crop.

Dr John Robinson (South African sub-tropical banana expert) visited Carnarvon at the invitation of Sweeter Banana during May 2008 to carry out a critical appraisal of the industry in Western Australia. He found that most growers were planting at densities lower than 3333 plants per hectare and then retaining multiple suckers per plant to save costs at planting. This can severely impact on the cycle time, yield potential and quality of crops.

Aims of this project

This project aimed to collate and build on results from past research carried out by DAFWA and package this with evaluation trials of bananas grown under a permanent protective structure versus field grown bananas to demonstrate the increased production and quality which may be achieved by manipulating the growing environment. The information will then be made available for subtropical banana growers to assess the options available for achieving high quality and yields.

Working in collaboration with Sweeter Banana, the project aimed to examine current production practices of growers and from this information, information developed during the trial phase and from past research, and formulate a production manual for growing subtropical bananas.

Materials and Methods

The main field work component of this project constituted two trials on the Gascoyne Research Station. The first trial evaluated the effectiveness of a protective netting structure in improving yield and quality of banana. The second trial evaluated the perceived benefits of several different planting densities for sub-tropical Carnarvon. Tissue cultured plantlets were sourced from a Queensland laboratory for planting material for these trials. Plantlets were transferred to pots in December 2009 and then field planted on February 5th 2009.

Trial design

Protective netting trial

The trial was carried out to assess bananas grown in a permanent protective structure with 75% windbreak cloth on the south and west walls, 50% windbreak cloth on the north and east walls and 16 quad-cross netting with 15% light interception on the roof. The netted area was six meters in height. A comparison open-field block will use windbreaks at the southern end of the field grown crop as per industry practice.

Two planting densities were used.

The first treatment was a density of 2500 plants per hectare planted at 2.5 metres between rows x 1.25 metres with one follower per plant every second row has a 4 meter wide spacing to create a tramline arrangement.

The second treatment had a density of 2000 plants per hectare planted in at 2.5 metres x 2 metres with one follower per plant. All other management factors inside and outside the protective structure are to be the same.

Two plant densities were evaluated under protective netting and then replicated in the open field. The row by plant spacing arrangements were;
Patch A; 2500 plants per hectare (under netting)
Patch B; 2000 plants per hectare (under netting)
Patch C; 2500 plants per hectare (open field)
Patch D; 2000 plants per hectare (open field)

Plant density trial

Four plant densities were trialled. The row by plant spacing arrangements were;
Patch E; 3 metres x 1 metre with 1 follower (DAFWA recommendation) 3333 plants per hectare,
Patch F; 3 metres x 3 metres with 3 followers (standard grower practice) 3333 stems per hectare from a common corm,
Patch G; 2.5 metres x 1.5 metres with 1 follower (density used by a new grower) 2666 plants per hectare and,
Patch H; 2.5 metres x 1.6 metres with 1 follower (JC Robinson recommendation) 2500 plants per hectare.

Figure 1. Established banana patches inside protective netting, August 2009, with patch B and weather station in the foreground.

Crop management

All patches in both the netting trial and density trial were approximately 0.12 hectares in area planted in their respective orientations. Both trials were established on T-tape^{TM} drip that emitted 5 litres per meter per hour at twenty centimetre spacing. After six months the irrigation system was changed to Wingfield^{TM} micro-spinner sprinklers delivering 101 litres per hour at nominal operating pressure.

Irrigation was scheduled to a crop factor of 0.8 of EPAN year round (recorded at the Gascoyne Research Station weather station - outside of net). Irrigation and nutrient delivery was managed via a Netafim-Pro^{TM} irrigation controller. Irrigation was delivered daily, with periodic breaks in June or July in the event of significant rainfall. Irrigation was also paused for most of January 2011 following the flooding event. The irrigation controller was set to deliver by volume with proportional nutrient dosing to allow for a uniform volume of water and nutrient to be applied to each patch. Table 1 lists the annual nutrient application rate used in these trials.

Table 1. Nutrient application rate for banana trials.

Product	kg/ha/year
Potassium sulphate	2000
UAN (Flexi-N)	1400
Calcium nitrate	1000
Magnesium sulphate	160
MAP	160
Zinc sulphate	48
Manganese sulphate	40
Copper sulphate	4
Iron sulphate	4

Field observations

Both field trials were monitored from planting in February 2009 through to September 2012. Data on crop cycle time was captured using software PatchSpy^{TM} with the assistance from local grower Darrell Munro. Yield data was captured by using a walk-over weigh station as bunch pickers collected ripe bunches from the patch and took them to the picking trailer. Pack out and quality data was captured at the Sweeter Banana packing shed where bunches from individual patches in the trial were graded and packed separately. These measurements allowed for an accurate assessment of the experimental treatments.

Figure 2. Walk-over weigh system used for collecting bunch weights. Net weight of the bunch was calculated from gross weight less the pickers' body weight.

Weather and climate data

Climatic parameters inside and outside the protective structure were monitored using weather stations from the DAFWA weather station network. This included a station positioned inside the netting structure on bare soil adjacent to trial banana patches.

Microclimate observation experiment

An experiment was conducted to capture more discrete information on the micro-climate under protective netting. Tiny-Tag data loggers with thermocouples were used to monitor ambient temperature at 1m above ground height whilst a second set of loggers were attached to a 150mm thermocouple probe fully inserted to the pseudostem of the plant to monitor stem temperature. Care was taken to avoid direct sunlight on the monitoring equipment. This experiment was conducted in the Patch B and Patch D, inside and outside of the netting structure respectively. Temperature was logged every thirty minutes for the month of June 2012.

Gross margin analysis

Gross margin budgets were developed from each patch in the protective netting trial. Gross margin budgets were also compared for each patch in the plant density trial. A benefit – cost comparison was made for the production of bananas under protective netting.

Benefit – cost analysis for production under protective netting

An analysis of the costs and benefits of using permanent protective structures to increase quality and yield of bananas was conducted by DAFWA economist Paul Mattingley. Data generated from the field trials, along with industry information was used to generate the analysis.

Expert review of project activities

Dr John Robinson, a subtropical banana production expert from South Africa was invited to review the field trial and meet with growers. In September 2012, Dr Robinson independently assessed the two field trials in-situ and reviewed associated harvest and pack out data to date. Two extension events were held with growers for Dr Robinson to share some of the latest information on production techniques in subtropical banana as well his assessment on the trial activities in Carnarvon. Dr Robinson also conducted a number of on farm visits with growers. Upon his return to South Africa Dr Robinson prepared a report on his findings that was delivered to the project manager and shared with industry.

Production manual

In addition to field trials, the second major component of the project was to collate and review production information and develop a production guide for subtropical banana growers in Carnarvon. This process involved, reviewing previous experimental work by

DAFWA and other agencies, integrating information from the field activities, as well as including feedback from the report that was provided by Dr Robinson.

Results

Inclement weather during the trial

From the 17th-19th December 2010 the trial site was affected by a tropical low system that shed 327 mm of rainfall. A number of plants in all patches were bearing 1st ratoon bunches and fell over in the sodden soil when subject to strong winds. Following this rainfall, on the 20th-21st December 2010, the Gascoyne River flooded and inundated the trial site to a depth of up to 1.5 metres. This lead to further crop loss. Figures 3 to 5 picture the extent of this damage. Whilst every attempt has been made to minimise error variation within the experimental data, it must be noted that in some instances analysis for the 1st and 2nd ratoon crop includes extrapolated data from the remaining plants with their respective treatment patches.

Figure 3. View of patch B (patch A behind, and patch D beyond the net wall to the right of picture, after flood waters had subsided. The maximum flood level was approximately 1.2 metres above the level in this image. Some collapsed plants can be seen in facing side of patch B in the distance.

Figure 4 (above) and 5 (left). Crop damage following heavy rain and strong winds from a tropical low in late December 2010. The number of plants that fell in patch C was close to five fold that that fell in patch A. There was significantly less fallen plants in patch B and D.

Protective netting trial

Crop cycle time

A diagrammatic representation of crop cycle time and harvest duration is shown in Figure 6. Table 2, lists the days from planting to first harvest, then lists duration of harvest periods and gaps between harvests of subsequent ratoon crops.

Table 2. Time in days from planting for key events in the parent, first and second ratoon harvests.

	Parent harvest		1st ratoon harvest		2nd ratoon harvest	
Patch	**Start**	**Finish**	**Start**	**Finish**	**Start**	**Finish**
A	419	559	708	939	986	1231
B	410	497	672	937	986	1174
C	442	567	1037	843	986	1174
D	442	567	672	843	986	1148
E	567	665	790	1043	1082	1301
F	524	672	755	944	1000	1229
G	489	567	748	938	1000	1229
H	461	578	748	938	1000	1229

Bunch emergence was observed slightly earlier in patches A and B than C and D outside the protective netting. Of the four patches, patch B was the first to be harvested, nine days before patch A. Patches C and D were harvested a further 23 days later. Harvest of patch B was the most contracted at 87 days. Patches C and D took 125 days to complete the harvest and patch A took 140 days.

After the flood event patch D developed quickly and the 1st ratoon harvest commenced 105 days later. This coincided with the 1st ratoon harvest of patch B, although patch B experienced a longer duration since the previous harvest. Patches A and C were slower in commencing the 1st ratoon harvest than their lower density counterparts taking 149 and 167 days respectively to commence their 1st ratoon harvest.

Duration of the 1st ratoon harvest ranged considerably between the four patches. Patches C and D were finished after 109 and 171 days respectively. Patches A and B took 231 and 265 days to complete the harvest.

Lines started to get a little blurred by the start of the 2nd ratoon, with harvest in all patches commencing 986 days after planting.

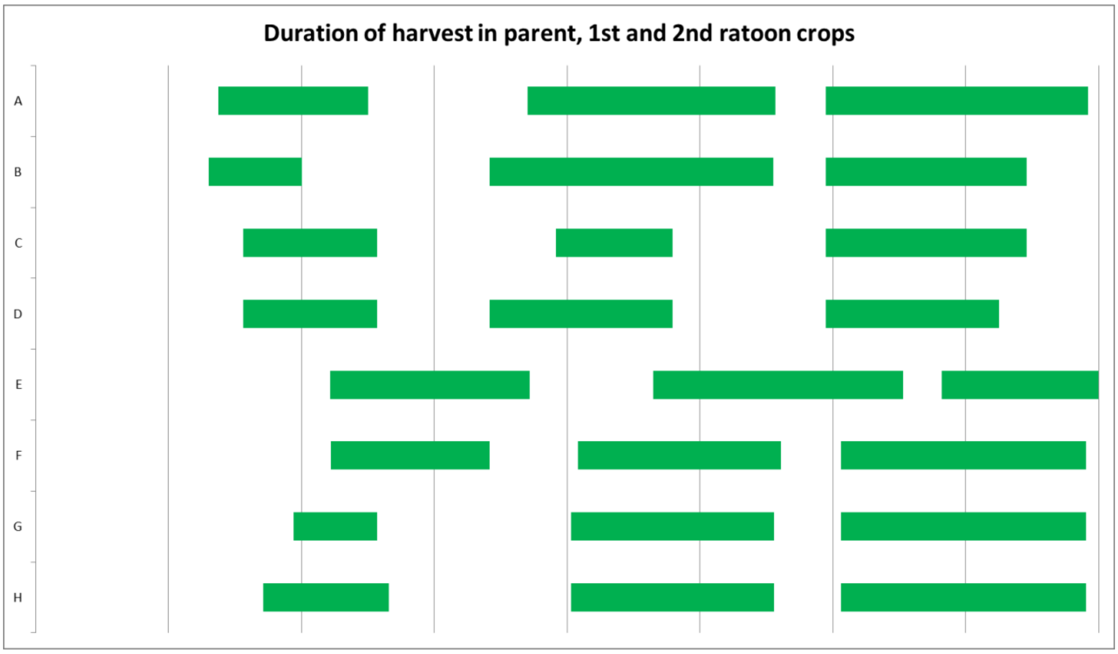

Figure 6. Diagrammatic representation of harvest duration and cycle time in Patches A – H.

Yield

Crop yield has been presented here in two formats; bunch mass and total yield per hectare. Figure 7 shows bunch mass as recorded in the field, prior to transportation to the packing shed where it is weighed again prior to grading and packing. Figure 8. Shows the second indicator, total crop yield per hectare; calculated from paddock bunch mass and multiplied by the plant density for that patch.

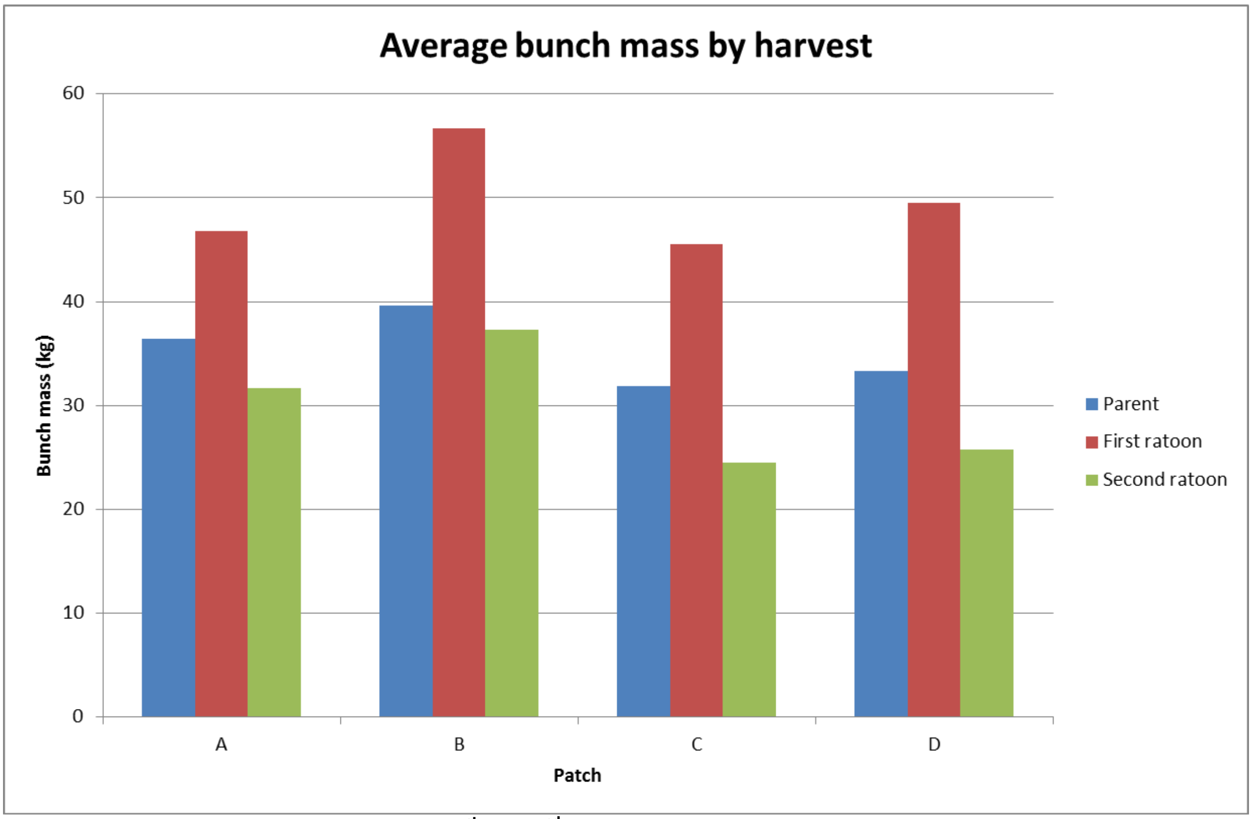

Figure 7. Average bunch mass for parent, 1st and 2nd ratoon harvests for patches A – D.

Figure 7 illustrates a trend in bunch mass from the parent crop through to the second ratoon crop. A clear increase in bunch mass can be seen in the first ratoon crop for all four patches in this trial with patch B exceeding and average of 56 kilograms. Average bunch mass is 43 – 48 per cent higher in the first ratoon crop in patches B,C and D. The first ratoon bunch mass is 28 per cent higher in patch A. Bunch mass averages 87 and 91 per cent of the parent crop in the second ratoon harvest of patches A and B. It is only 77 per cent of the average parent crop bunch mass in the second ratoon of patches C and D.

Some extreme bunch masses were recorded following the flooding event. This coincided with the commencement of the 1st ratoon harvest of several patches during mid-January 2011. Some bunches were past their ideal harvest date (but had not field ripened). Patch B recorded many bunch weights in excess of 80 kilograms, with the heaviest mass of 100 kilograms.

It is also clear that average bunch mass is consistently higher for those patches grown under protective netting (Patches A and B) when compared to the open field patches C and D.

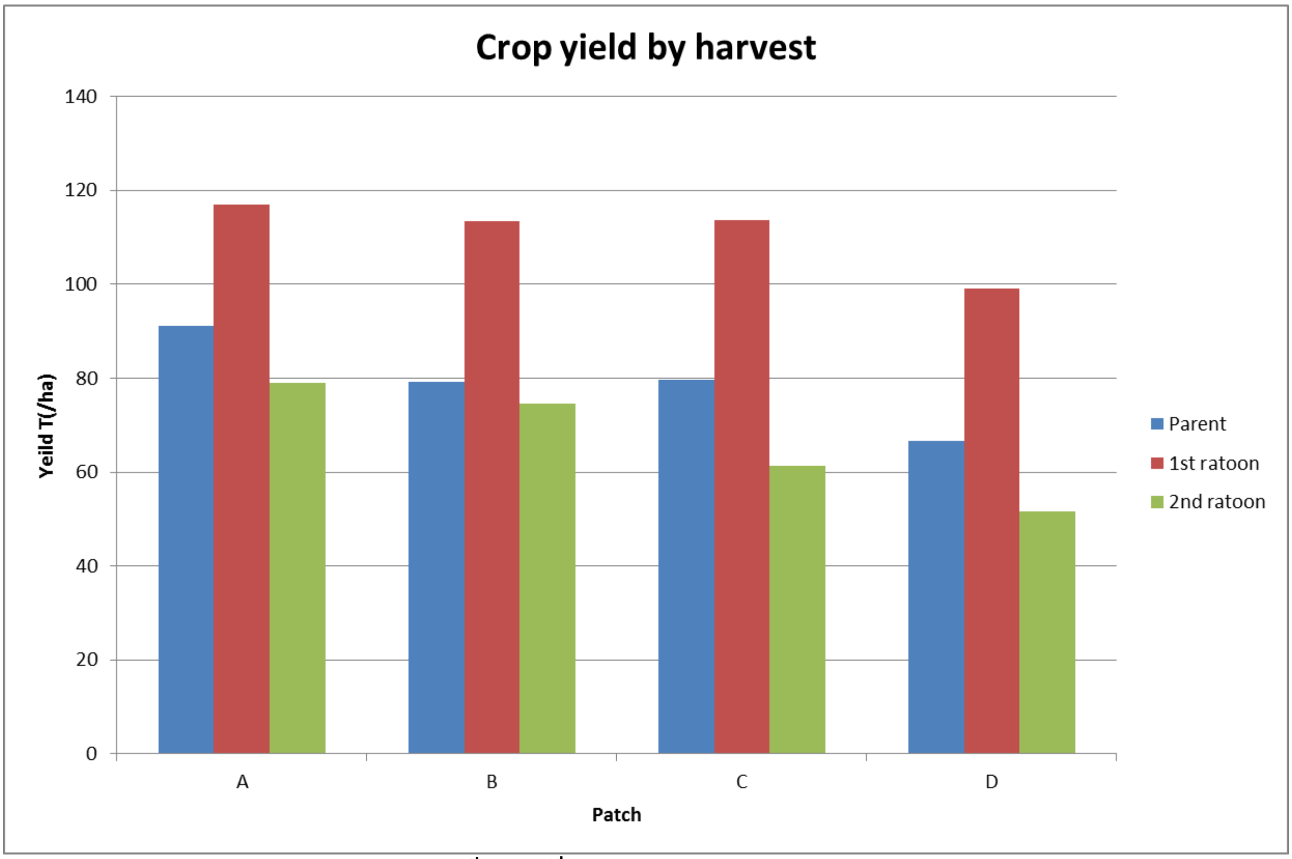

Figure 8. Calculated crop yield for parent, 1st and 2nd ratoon harvests for patches A – D.

When the planting density is factored with average bunch mass one can see (Figure 8) that patches under netting (A and B) yielded higher than their open field equivalents. At a density of 2000 plants per hectare the total yield of patch B was marginally less than the higher density (2500 ppha) open field patch C. As a function of bunch mass, total yield increases with the first ratoon and then declines below parent crop yield in the second ratoon for all patches.

Quality

Cartons per bunch

Figures 9a through to 9d show the number of cartons packed per bunch on a given date in the crop cycle for patches A – H respectively. In all patches these results follow the general trend of bunch mass, with the highest individual pack out rates (number of cartons packed per bunch) occurring in the first ratoon harvest and pack out rates dropping to parent harvest levels or below in the second ratoon harvest. Patch D is the only patch that differs with a slightly lower pack out rate in the first ratoon when compared to the parent crop harvest.

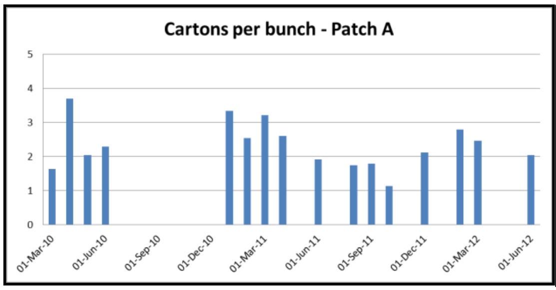

Figure 9a. Cartons per bunch Patch A.

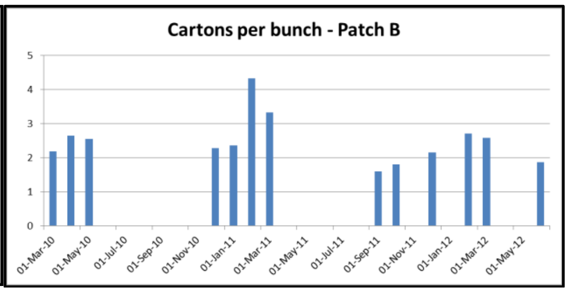

Figure 9b. Cartons per bunch Patch B.

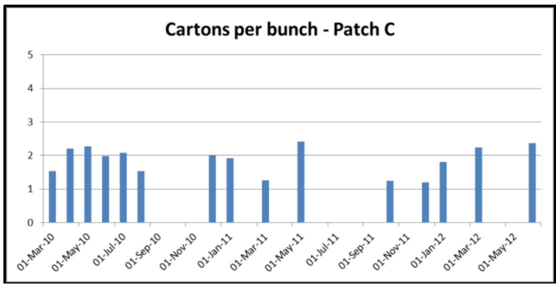

Figure 9c. Cartons per bunch Patch C.

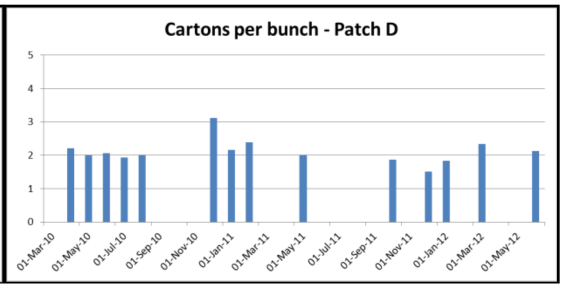

Figure 9d. Cartons per bunch Patch D.

Figure 10, views the pack out information from a profitability perspective. The data presented shows the proportion of the average bunch weight that was packed out in cartons as marketable product. Also shown on the chart is the 83 per cent mark that Sweeter Banana estimate is the marketable proportion of any given bunch. This figure is used for cost accounting to allow for the proportion of the total bunch weight that can be packed for marketing. It allows for the waste component of the bunch stalk and a small amount of unmarketable fruit usually of a small size at the base of the bunch.

Figure 10 shows that the proportion of marketable fruit does not exceed the packing shed standard. This has shown to have an inverse relationship with bunch mass as the high average mass first ratoon bunches tend to have the lowest proportion of marketable fruit. The second ratoon harvest data is not presented as its distribution was too wide to be considered to have statistical significance.

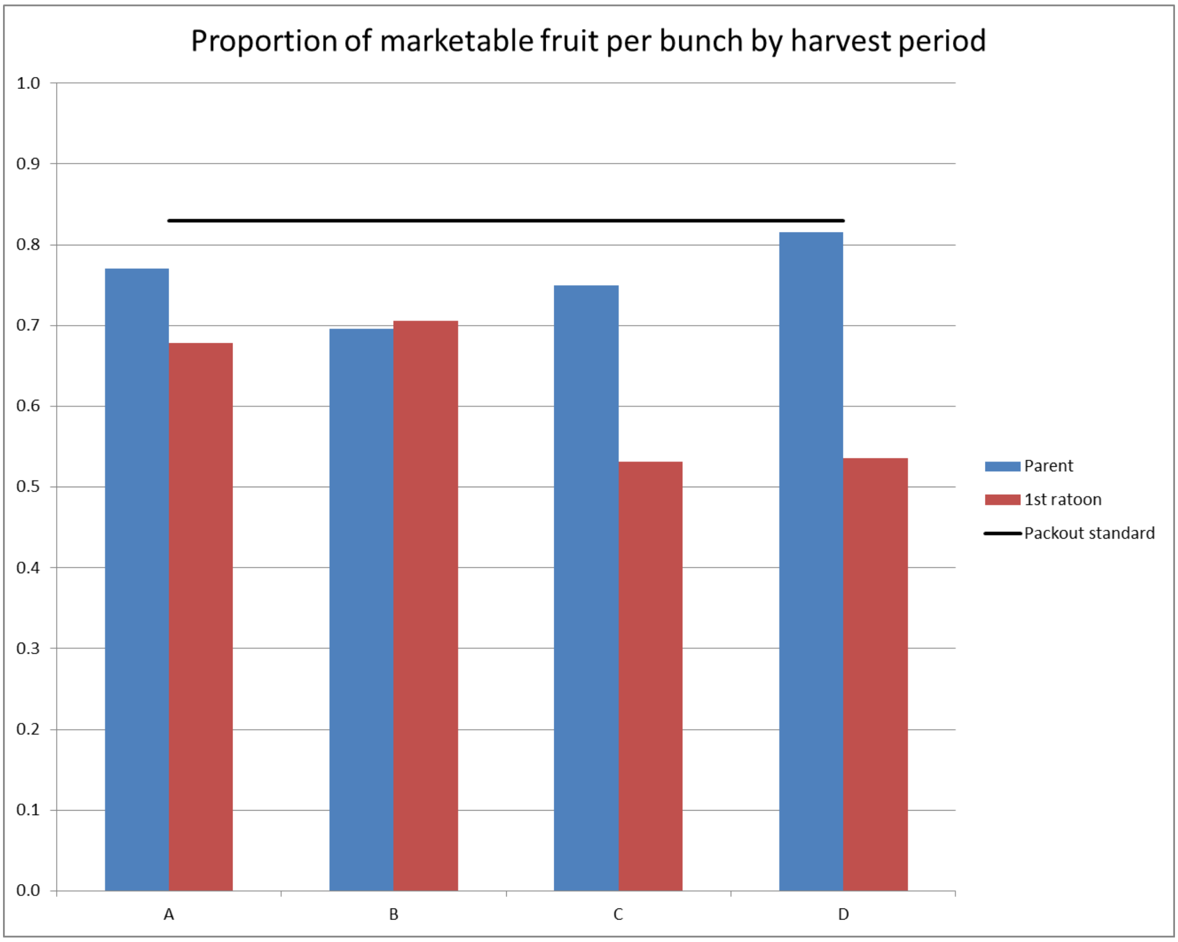

Figure 10. Proportion of marketable fruit as a component of average bunch mass in patches A – D over two harvest periods (Parent and 1st ratoon). Sweeter Banana estimated proportion of pack out also shown.

Weather station data

Figures 11a through to 11d show a comparison between two weather station sites on the Gascoyne Research Station. One site is located inside the crop net structure adjacent to banana patch B, but not within the actual patch. The second weather station is located outside the structure approximately 150 meters away in an open field. Red lines represent the 'outside net' weather station, the green lines represent the 'inside net' weather station.

These charts illustrate that there are the netting structure creates a slightly warmer environment all year round, by up to approximately one degree Celsius. The relative humidity is consistently higher outside the net, this is more pronounced when high humidity weather is experienced. There is a significant difference in wind speed with the net structure keeping wind speed below 9 kilometres per hour, that is 4 – 7 kilometres per hour less than outside the net.

Importantly the monthly evaporation data shown in figure 11a show consistently lower evaporation from the weather station located inside the net structure. This calculates to approximately 525 millimetres less evaporation from inside the net when compared to the site in the open field.

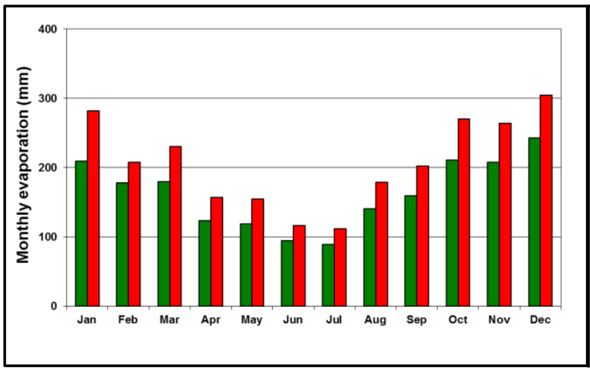

Figure 11a. Evaporation.

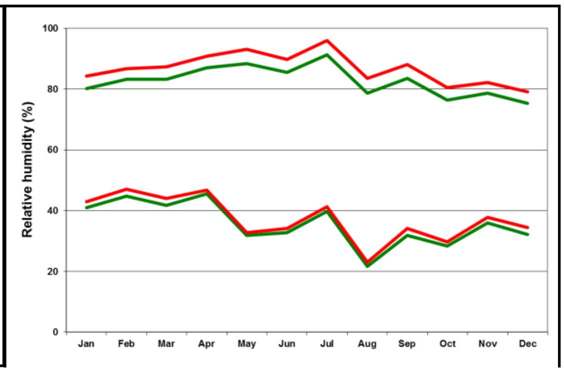

Figure 11b. Relative humidity.

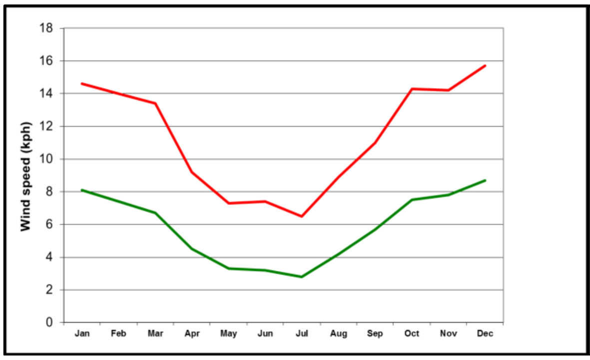

Figure 11c. Wind speed.

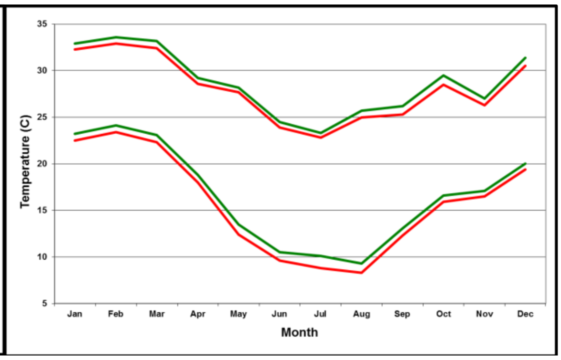

Figure 11d. Temperature.

Microclimate observation experiment

This short study found that there is a greater diurnal variation in ambient temperature in open field bananas when compared to those grown under netting (Figure 12). The variation was minimal, being no more than a couple of degrees Celcius. It can be seen that hotter days (those with a higher maximum temperature) tend to have a larger diurnal variation than cooler days.

Figure 12 also shows that pseudostem temperatures were subject to much less variation in temperature than the ambient temperature within the patch. A relatively consistent seven hour delay from peak ambient temperature to peak pseudostem temperature was observed in bananas monitored inside and outside the net.

Maximum ambient temperatures were often eight degrees Celsius higher than the pseudostem temperature on any given day, but this was more pronounced on high temperature days. Variation of the ambient temperature below the pseudostem temperature during night (daily minimum) was not as great (up to 5.4^{o}C).

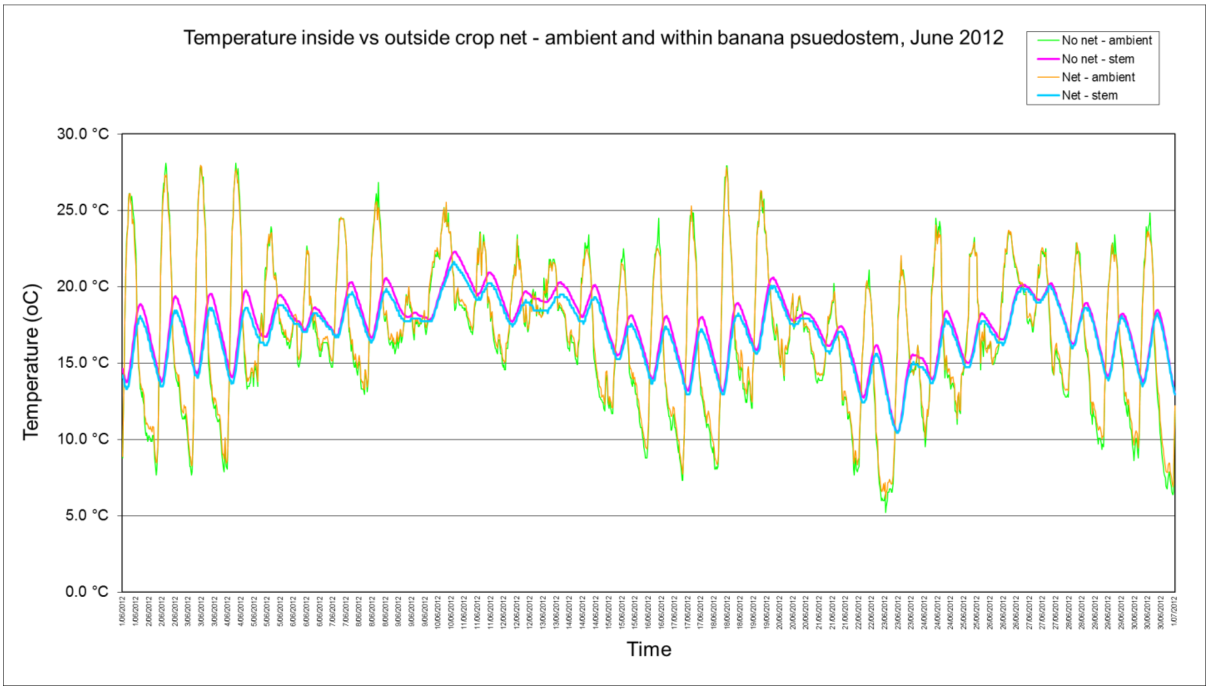

Figure 12. Plot of ambient and pseudostem temperature in patches B (inside net) and D (outside net).

Gross margin comparison of the impact of netting

The economic analysis compared the gross margin returns for differing management systems. A gross margin is calculated by subtracting variable costs from total income. Variable costs are those costs which vary with the area of production such as fertiliser and labour. Overheads such as rates, accountancy fees and capital depreciation were not included in the analysis.

The economic analysis focuses on the parent crop harvest of 2010 as the weather problems detailed previously limit the validity of the following harvests when it comes to drawing reliable conclusions.

The income for each trial is calculated by multiplying yield x grade x an average price by grade for the trial period provided by the Sweeter Banana Cooperative. The packing, marketing and levy costs were provided by the Sweeter Banana Cooperative.

Income

Table 3. Production and income ($/ha) for protective netting trial patches A to D.

Patch	**A**	**B**	**C**	**D**
Number of plants	2500	2000	2500	2000
Experimental treatment	Netted	Netted	Open	Open
Gross yield (t/ha)	90.67	78.88	79.34	66.27
Marketable yield (t/ha)	75.56	65.74	66.12	55.23
% first grade	85%	85%	86%	85%
% second grade	15%	15%	14%	15%
Total income	**144,132**	**124,082**	**132,095**	**109,645**

The highest yield was achieved by the trial with 2,500 plants per ha which had been netted. Income was highest in patches that were netted when compared to the same density in the open field. The percentage of first grade and second grade fruit did not differ with or without netting.

Approximately 16.7% of the material that is sent to the packing shed is wastage.

Costs and gross margin

Table 4. Variable costs, gross margin and benefit ($/ha) for protective netting trial patches A to D.

Patch	**A**	**B**	**C**	**D**
Number of plants per hectare	2500	2000	2500	2000
Experimental treatment	Netted	Netted	Open	Open
Machinery	925	925	925	925
Fertiliser	2,878	2,878	2,878	2,878
Chemicals	980	980	980	980
Other materials	250	200	250	200
Other labour	3,634	3,234	4,043	3,234
Irrigation costs	6,088	6,088	6,088	6,088
Packing, marketing & levies	90,545	77,947	82,358	68,587
Total costs	**105,300**	**91,925**	**97,521**	**82,892**
Gross margin	**38,832**	**32,158**	**34,574**	**26,753**
Annualised cost of netting	7,376	7,376		
Benefit (over open field production)	-3,118	-1,972		

Packing, marketing and levies are the highest variable cost representing between 83% and 86% of variable costs.

Harvest labour costs are lower for netted crops compared to the non netted crops as the number of harvests for netted crops was 6 compared to 9. The netting has an impact on the rate of maturity of the crop. Figure 13 details the percentage of crop harvested throughout the season. The netted crop had over 60% of production harvested in one harvest.

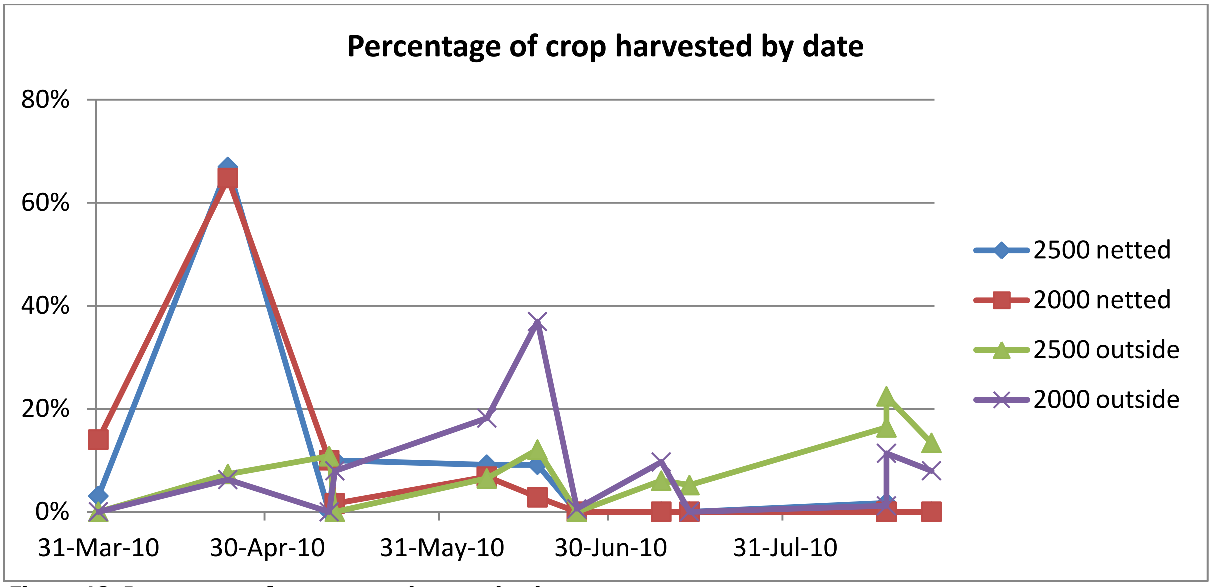

Figure 13. Percentage of parent crop harvest by date.

It costs approximately $100,000 to establish netting on a hectare of bananas and $1000 per annum in repairs and maintenance. The netting is estimated to need replacement after 15 years. The netting costs $7,376 per hectare/per annum, this being the annualised discounted cost. When this figure is subtracted from the gross margins for patches A and B it can be seen that the netting does not provide a financial benefit. The netting cost leads to a gross margin return $3118/ha lower for trial patch A compared to trial patch C and $1972/ha lower for trial patch B compared to trial patch D. Patches A and C both 2,500 plants/ha and patches B and D both have 2000 plants/ha.

Plant density trial

Harvest cycle time

Referring back to Table 2 and Figure 6, it is noted that patch H was the first to commence harvest of the parent crop at 461 days after planting, followed by patch G 28 days later. This was followed by Patches F and E commencing harvest at 524 and 567 days after planting.

Patches G and H had relatively short duration parent crop harvests of 87 and 117 days. Patch F took 148 days and patch E 202 days to harvest.

Patches F, G and H and all commenced their 1st ratoon harvest around late February 2011, with patch E some time later in early April. The duration of the 1st ratoon harvest was very similar between patches F, G and H. Patch E took considerably longer at 253 days.

Yield

Similar to results from the netting trial an increase in bunch mass was observed in the first ratoon crop, followed by a decline in the second ratoon below the average bunch mass of the parent crop. This is consistent across all planting densities. Bunch mass was highest in the first ratoon in patch G (2666 ppha) at 45.5 kilograms. Patch H had the heaviest bunches in the parent crop and second ratoon.

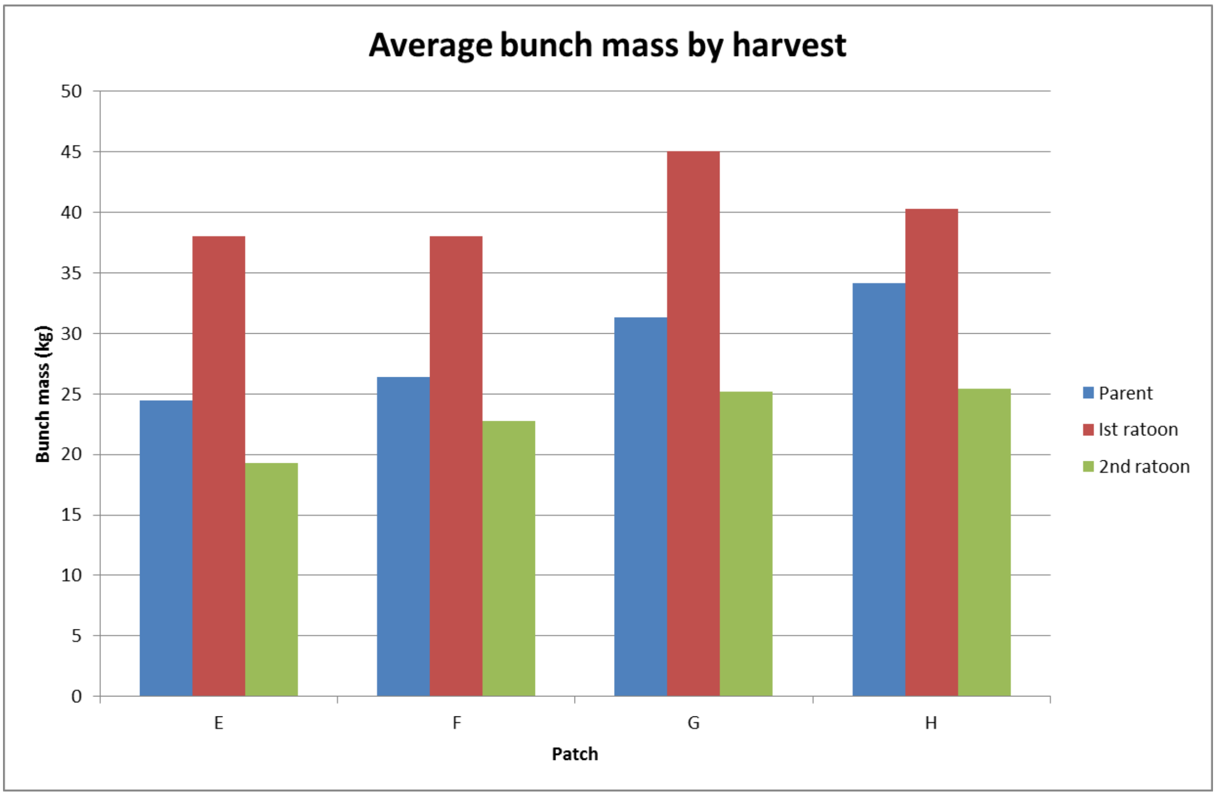

Figure 14. Average bunch mass for parent, 1st and 2nd ratoon harvests for patches E - H.

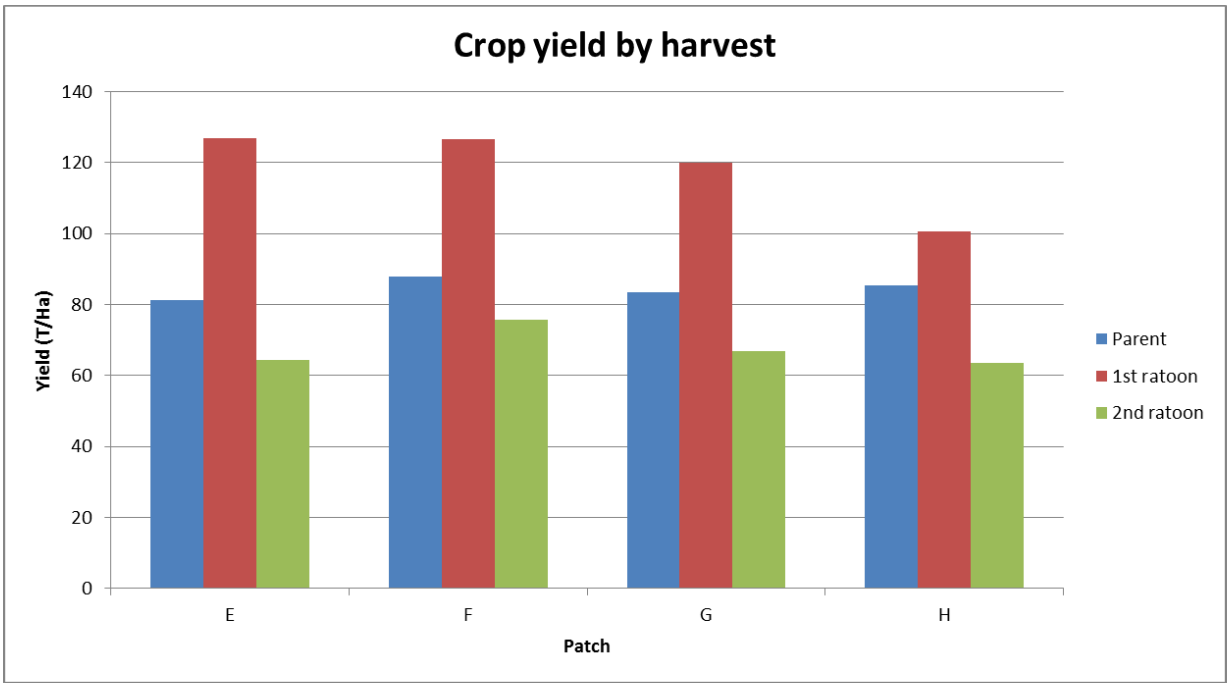

Figure 15. Calculated crop yield for parent, 1st and 2nd ratoon harvests for patches E – H.

Figure 15 presents per hectare yield once the bunch mass from Figure 14 is multiplied by plant in plant density. There is little variation in parent crop yield amongst all patches, however in the first ratoon harvest, higher density patches E and F out yield G and H. In the second ratoon yields fall back between 60 and 80 tonnes per hectare. Patch F has the highest yield of 75.9 tonnes per hectare.

Quality

Figures 16a through to 16d show the pack out rates (cartons per bunch) on given harvest dates for patches E – H. The highest values are recorded during the first ratoon harvest, consistent with the highest average bunch mass values.

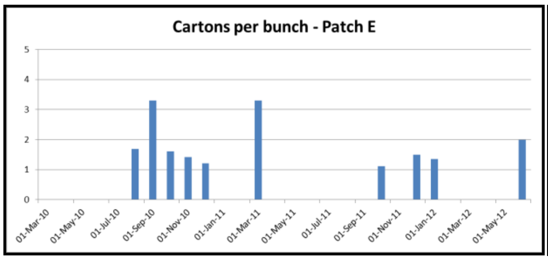

Figure 16a. Cartons per bunch patch E.

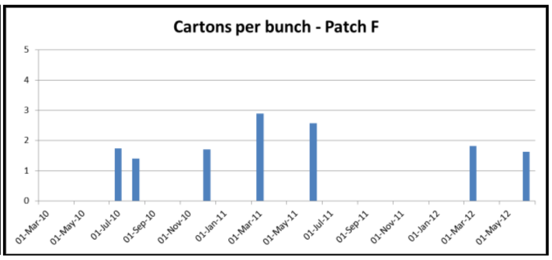

Figure 16b. Cartons per bunch patch F.

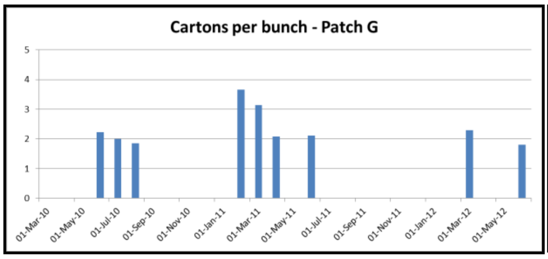

Figure 16c. Cartons per bunch patch G.

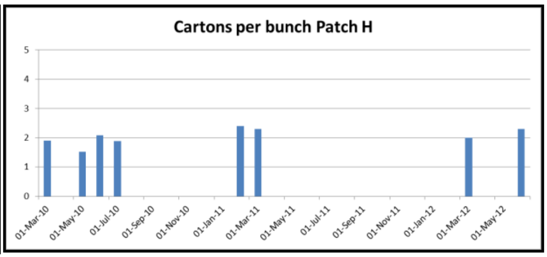

Figure 16d. Cartons per bunch patch H.

Figure 17 shows the proportion of the average bunch mass that was marketable in the parent and first ratoon harvest. Patches E and G had higher proportions of marketable fruit in the parent crop compared to their first ratoon harvest. The inverse occurred in patches F and G. In most instances the proportion of marketable fruit in terms of cartons per bunch did not exceed the packing shed standard estimate.

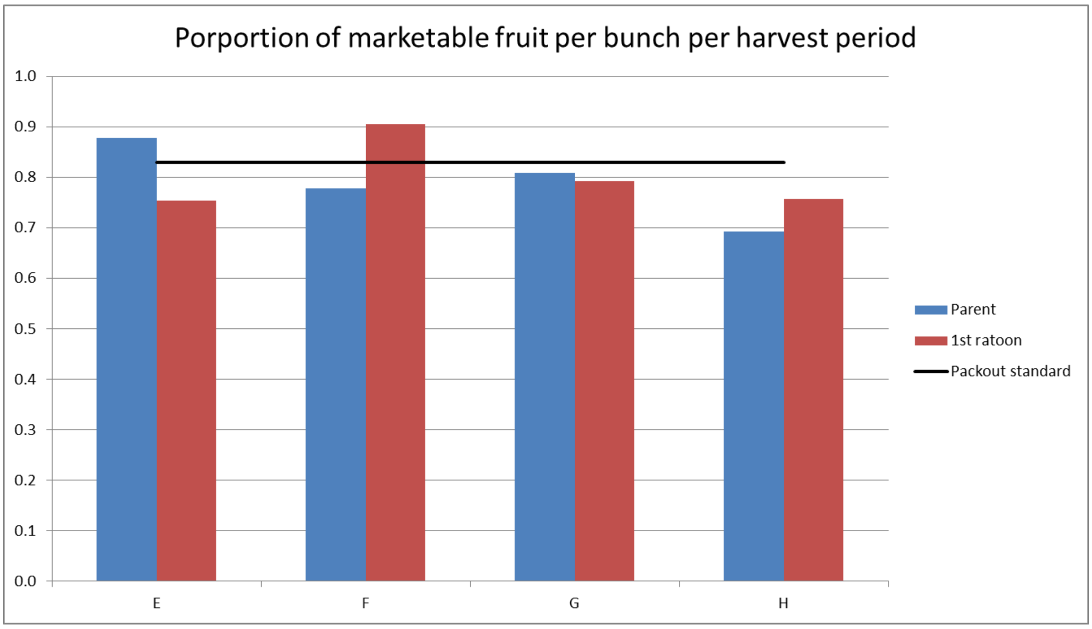

Figure 17. Proportion of marketable fruit as a component of average bunch mass in patches A – D over two harvest periods (Parent and 1st ratoon). Sweeter Banana estimated proportion of pack out also shown.

Gross margin comparison of density trial

Income

Table 5. Production and income ($/ha) for density trial patches E – H.

Patch	**E**	**F**	**G**	**H**
Number of plants/ha	3333	3333	2666	2500
Gross Yield (t/ha)	81.39	87.86	83.45	85.43
Marketable yield (t/ha)	67.83	73.21	69.54	71.19
% first grade	83%	91%	87%	83%
% second grade	17%	9%	13%	17%
Total income	**135,588**	**146,235**	**137,754**	**136,552**

The highest marketable yield and highest percentage of first grade was achieved by Patch F which is the traditional system used by banana growers. The use of 1111 plants to generate 3333 stems provided a significantly higher return in this trial than the use of 3333 plants.

Table 6. Variable costs and gross margins ($/ha) for density trial patches E – H.

Patch	**E**	**F**	**G**	**H**
Machinery	925	925	925	925
Fertiliser	2,878	2,878	2,878	2,878
Chemicals	980	980	980	980
Other Materials	333	333	267	250
Other labour	5,389	5,389	4,311	4,043
Irrigation costs	6,088	6,088	6,088	6,088
Packing, marketing & levies	85,087	90,007	85,591	86,032
Total costs	**101,680**	**106,600**	**101,039**	**101,195**
Gross Margin	**33,908**	**39,635**	**36,715**	**35,357**

Packing, marketing and levies are the highest variable cost representing between 83% and 85% of variable costs.

As with all enterprises, profit and in this case the gross margin is highly sensitive to price and yield. Figure 18 charts the relationship between yield and gross margin returns across the trials conducted on patches A - H.

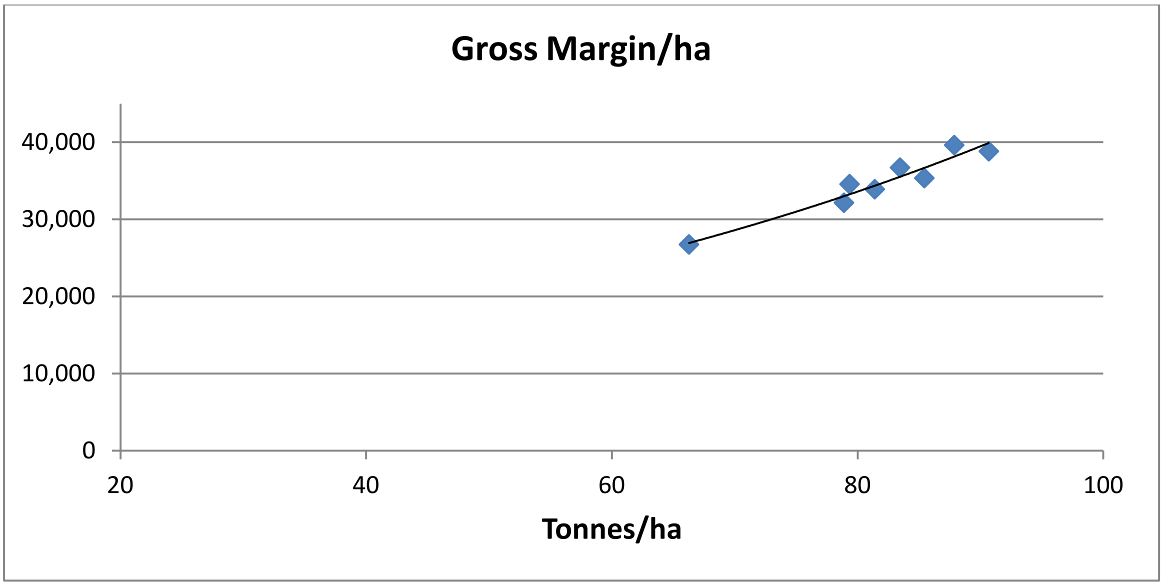

Figure 18. Relationship between yield and gross margin.

Expert review of project activities

Dr John Robinson conducted a rigorous review of the field activities and local industry. A copy of this report is attached in Appendix 1.

Production manual

A production manual entitled 'Production of Bananas in Carnarvon, Western Australia' has been printed and was distributed to growers at a meeting in December 2013. Banana producers not in attendance will receive a copy via mail. The production manual is being uploaded to the DAFWA web page in 2014.

A copy is attached in Appendix 2.

Discussion

Protective netting trial

Weather data and observations from the pseudostem temperature monitoring experiment have highlighted the differences in climatic conditions that the respective experimental treatments were subject to, both inside and outside of the netting structure. Warmer and drier conditions were experienced inside the net structure but these parameters did not vary at levels thought to have a significant effect on crop production. Probably the most outstanding variation between patches inside (A and B) and those outside (C and D) was the difference in wind speed and evaporation. Evaporation (and when applied to crop physiology evapotranspiration) rate is strongly correlated with wind speed and for most of the year wind speed recorded inside the protective netting was seen to be reduced by one half of that in the open field. Importantly the reduction in evaporation correlates with improved crop production.

When making comparisons in crop yield one must remember that all patches in this trial were treated equally in terms of the amount of irrigation water and nutrients applied. Noting that evaporative demand was 525 millimetres less under the protective netting (compared to the open field) and applying the crop factor of 0.8 (as used in this environment) the resultant gain is an extra 420 millimetres of irrigation per annum. Reduced wind shear on leaves and less radiant heat may have provided some of the gains, but reduced incidence of moisture stress is the main contributing factor as it became clear that patches A and B are growing in a more favourable environment.

Crop cycle time

The first observation of the benefit of the crop net was apparent in parent crop cycle times. As commonly found when making plant density comparisons in banana, the lower density of patch B (2000 ppha) is likely to have accounted for the slightly accelerated development time of the two patches inside the net structure. Despite some outlying individual plants, the difference in cycle time of patches outside the net was not significant enough to warrant an earlier harvest of patch D compared to patch C.

The higher density of patch C is likely to have caused the protracted the harvest of this patch. The evidence indicates that planting at 2000 ppha is preferable to higher densities when aiming for a more rapid cycle time.

Similarly to previous planting density studies in Carnarvon (Kesavan *et al* 1999), the higher density patches (A and C) took longer to complete their second crop cycle. The influence of crop netting appears to lose some influence with Patches B and D undergoing their second harvest from the same date.

One could argue that despite the error created by weather experienced during this trial, the data collected indicates that protective netting structure is not having a long term benefit on crop cycle time.

Yield

The trends observed in bunch mass over the crop cycles were consistent across all patches, peaking in the first ratoon crop (second harvest). The beneficial effect of reduced evaporation was evident where the patches grown under netting yielded consistently larger bunches compared to their equivalent densities grown in the open field. A more favourable environment under the netting has facilitated improved water use efficiency.

Linked to bunch mass, gross yield is an important productivity indicator. Plant density proved to have a greater influence on gross yield rather than bunch weight. A plant density greater than 2500 ppha may achieve a greater yield than what was observed in the two densities used in this experiment.

Working against this theory is the observation that cycle time increases with plant density. A higher yield may be achievable by pushing densities to the industry benchmark of 3333 ppha but only at the detriment of cycle time. Dr John Robinson postulated that bunch mass may decrease, however in crop cycle time would certainly be adversely affected. Testing this hypothesis would be of merit. Support for this argument can be gleaned from the results of the density experiment.

Quality

Cartons per bunch

Carton pack out rates were also used as an indicator of productivity. Not surprisingly, the results showed a close correlation between cartons per bunch and bunch mass for all patches in this trial. What is most interesting is the proportion of marketable fruit per bunch. This is a good indicator of fruit quality as any fruit that is severely scarred, sun burnt or too small for packing is discarded in the packing shed. The remaining saleable fruit is then graded into first and second grade marketing categories.

There could be no discrimination in the pack out of the parent crop when comparing patches inside and outside the net. It is likely that sound maintenance of the patches via regular leaf trashing and good canopy cover minimised fruit damage and any variation is due primarily to fruit size.

A clear distinction is observed in the pack out of the first ratoon harvest, with under the netting patches (A and B) outperforming patches in the open field (C and D) by the order of around 25 per cent. It must be noted that the majority of this harvest was immediately after the tropical storm and flooding. It could be argued that the netting structure has provided benefit not only in preventing plants from toppling under strong winds but may have also limited the amount of leaf shear and fruit rub that has led to down-grading of such a high proportion of the bunch in the subsequent harvest period after this extreme weather event.

An observation to note is that none of the patches in either parent or first ratoon harvest yielded a marketable fruit proportion that exceeded the packing shed benchmark of 83 per cent. The bunch masses recorded in all patches of this trial were high compared to the industry benchmark of around 20 to 30 kilograms. A higher bunch weight appears to be associated with a higher waste component. Further investigation would be required to quantify this relationship.

Pack out of first and second grade fruit

Profitability also is driven by the amount of first grade fruit taken from the marketable component of any bunch. Consistent with most banana crops, the parent harvest in all patches of this trial had a high proportion off first grade fruit. The reduction to as low as 40 -50 per cent of first grade fruit in all patches during the first ratoon harvest is a consequence of the inclement weather experienced during this stage of the trial as the first grade component improves in the second ratoon harvest.

The first grade market categories used in this analysis included the pre-packaged 'Lunchbox' banana and extra-large fruit. Second grade categories included 'Value-pack' and 'Smoothies'; smaller sized and marked fruit.

Larger bunches and more marketable fruit produced under netting have not necessarily correlated with better quality pack outs. Bunches from patches C and D outside the net achieved a slightly higher proportion of first grade fruit on many individual harvest consignments in the parent and first ratoon harvest, albeit from small bunches. It is possible that this may be a result of the discarding of more severely damaged bunches post-flood.

Gross margin comparison of the impact of netting

Gross yield is a major driver for profitability in bananas and this was evident in the total income received for the patches grown under netting out-grossing their open field equivalents. Little variation in the overall proportion of first and second grade fruit between patches did not make a significant difference to the bottom line with the bananas under protective netting providing a higher gross margin than producing in the open field for the given plant densities. In summary yield was the bigger driver of income in this experiment.

Other benefits from growing under netting include concise harvest events, where large proportion of the crop is removed in an individual harvest event. It must be noted however that this information is from the parent crop harvest only. Despite this analysis being conducted on the parent harvest only, crop production data indicated that longer term crop cycle time was not improved by the use of protective netting and is not likely to have an effect on profitability.

Once the annualised cost of netting was considered, it was clear that it is no more profitable to produce bananas under protective netting than the open field, despite the productivity gains.

Growing more bunches per hectare was more profitable option than producing bananas under protective netting. This was observed where higher density patch C (2500 ppha) in the open field outperformed patch B (2000 ppha) grown under netting.

Conclusion

A compromise between improved plant productivity and cost effectiveness may best be achieved through the use of vertical windbreaks, strategically positioned around patches. These shade cloth fabric windbreaks are already commonly used along the boundary of patches in Carnarvon for wind mitigation. Currently, at around $80 per linear meter it would cost around $32,000 per hectare to install these structures. Depending on the orientation of the property and patches and using common structures for adjoining patches, an additional one hectare patch would cost $24,000. Reducing the spacing between windbreaks by half would increase the cost to $40,000 for the initial patch and $32,000 for additional one hectare patches.

Density trial

Crop cycle time

This trial clearly demonstrated that crop cycle time is significantly influenced by planting density. Lower density patches reached harvest earlier than the higher density patches and this trend continued onto the first ratoon crop, albeit to a lesser extent. Harvest duration became lengthy in all patches of the trial as they moved through the ratoon crops.

It is noted that patch F took slightly longer to complete its parent crop harvest than patch E (same density but different spatial arrangement), however its first and second ratoon harvests were much more concise. Patch F is the most common planting density currently used in Carnarvon, with plants positioned in a 3 x 3 meter arrangement allowing three suckers to develop. It is a better spatial arrangement that the 3 x 1 meter positioning of Patch E, however all three suckers are competing for light as well and nutrient and water from the same corm and roots. It is common to see stems in this planting density leaning away from the centre of the plant, posing a risk of bunch loss from pseudostem breakage.

Yield

Similarly to the protective netting trial, lower density plantings exhibited a positive relationship with bunch mass in all harvest cycles. Only in the first ratoon harvest, the slightly higher density patch G (2666 ppha) out-weighed lowest density patch H.

Once again overall crop yield was influenced more by the number of bunches in the patch rather than the mass of individual bunches. This was most evident in the high yielding first ratoon crop where higher density patches performed best. Once again the benchmark planting density in patch F performed best in cumulative yield over the three crop cycles. This supports the argument that a wider spacing with multiple suckers is a better option than close spaced plants in three metre rows when planting at this overall density.

Quality

Cartons per bunch

Consistent with observations in the netting trial and other experiments, the high bunch mass patches yielded more cartons per bunch. Using the parent harvest observations only the pack out rate in terms of cartons per bunch was around 25 per cent greater in the lower density patches G and H.

There can be no clear discrimination between patches when assessing the proportion of marketable fruit between patches, only that patch H yielded around 10 per cent less marketable fruit. A possible explanation here is that the more open canopy of the lowest density patch H allowed wind tunnelling and solar exposure to the ground, leading to fruit rub and heat damage in the summer months.

It is also noted that only on two occasions did the proportion of marketable yield reach the Sweeter Banana shed benchmark, lending support to the previous argument that this calculation may need to be revised to account for larger bunches.

Proportion of first and second grade fruit

Patch F performed very well in the pack out of first grade fruit from the parent harvest, highlighting that smaller bunch size does not necessarily translate into poorer fruit quality. Whilst outperforming patch E of the same overall density, the results indicated that improved spatial arrangement has contributed to improved fruit quality, with less fruit rub than the tightly packed one meter spaced plants in the rows of patch E.

The lower density patches were not significantly worse off in pack out grades, all averaging greater than 83 per cent first grade fruit. As all the patches were managed uniformly, adding to the theory that good plant spatial arrangement will assist in improving fruit quality.

Gross margin comparison of planting density

The additional costs of higher density plantings in this trial did not adversely affect the gross margin of these patches. Considering packing and marketing are the largest variable cost components of the production system, these are only a concern once fruit has been processed through the packing shed.

The main drivers for profitability were bunch mass and plant density. Given the inverse relationship between these two factors, the optimal balance is struck at around 3333 plants per hectare. This density achieved both the highest (patch F) and lowest (patch E) gross margin with a difference between the two of $5727 per hectare per harvest. With all other variable inputs relatively equal, the importance relies on maintaining quality fruit within the patch to achieve high marketability and high grade fruit. This again highlights the importance of plant spatial arrangement in the Carnarvon environment and allowing good cover and clear space around bunches.

Conclusion

With gross margin being so tightly linked to yield it important to note that there are still some changes that could be made at this planting density to achieve more profit. This may include the move away from a single corm with three psuedostems to a more even spacing between rows and within rows to limit competition for resources and prevent fruit rub from neighbouring plants.

Some options for improved production may include;

1. 2 metre rows and 1.5 plant spacing to give 3333 plants per hectare with one follower.
2. 1.8 metre rows and 1.8 metre plant spacing to give 3086 plants per hectare with one follower.

Plants would be positioned, offset from those in neighbouring rows to minimise interference.

Technology transfer

2013 December 12th
Meeting with Carnarvon banana growers at Gascoyne Research Station

- Discussion on output and outcomes of this project
- Dissemination of production guide
- Discussion on future direction of banana R&D in Carnarvon

2013 May 15th
Video presentation on trial results for HAL banana levy payers meeting (provided to Jane Wightman)

2012 September 3rd-9th
Visit by sub-tropical banana expert Dr John Robinson

- Two grower group meetings at the Gascoyne Research Station, presenting latest information in sub-tropical banana research and observations from Dr Robinson's visit
- Visit 11 grower properties comprising approximately 60% of the industry
- Visit and inspect Sweeter Banana packing facility and discuss and advise on operational practices
- Media article in Northern Guardian newspaper outline Dr Robinson's visit and findings

2012 May 30th
Meeting with banana growers to discuss actions on bunch cover work

- Presented literature review on bunch cover work
- Growers opted not to focus on bunch cover studies in this trial
- Decision to conduct micro-climate monitoring adopted

2012 February 7th
Host teleconference with Shane Comminsky and several local growers

- Discussion on finding from recent industry benchmarking activity with several Carnarvon growers

2011 June 3rd
9th Australian Banana Growers Congress

- Oral presentation by Dr Chris Schelfhout on preliminary findings of the project

2010 Oct 4th
Visit and inspection of trial by WA Minister for Agriculture and Food, Hon. Terry Redman

2010 May 26th
Media release by DAFWA on the progress and preliminary results of trial activities

2010 April 27th
Sweeter Banana members meeting

- Presentation if initial harvest results to members

2009 October 27th
Sweeter Banana members meeting and field walk

- Inspect trials and discuss progress and initial interpretations with grower advisory committee and members.

Recommendations – scientific and industry

1. Production of bananas under protective netting in Carnarvon is less profitable than open field cultivation at the densities trialled in this project. Despite improved productivity of bananas grown under protective netting, the costs of net construction and maintenance outweighed the benefits of increased production.

2. Improved profitability may be better achieved though strategically positioned vertical windbreaks. At a lower per hectare cost (Around $32,000 versus $100,000 per hectare for full enclosure) further investigation is required to identify improved profitability with this revised wind mitigation strategy.

3. Profitability under netting may outperform the open field through higher planting densities. Despite Dr Robinson's claim that increased planting density will increase crop cycle time, increased plant density has also been seen to lead to higher yields. A density of 3333 plants per hectare was not trialled under netting and being the most profitable option in the open field is worthy of evaluation under netting.

4. 3333 plants per hectare is the optimal density in the open field but it needs to be spatially well arranged. An arrangement of 3 x 3 meters (with three followers) was more profitable than 3 x 1 (with 1 follower). Even better performance could be achieved at 2 x 1.5 meters with one follower.

5. Planting density is a better productivity driver than bunch mass. Growing more bunches per hectare was more profitable option than producing bananas under protective netting. This was observed where higher density patch C (2500 ppha) in the open field outperformed patch B (2000 ppha) grown under netting.

6. Investigate waste component of larger bunches. No patches in either parent or first ratoon harvest yielded a marketable fruit proportion that exceeded the packing shed benchmark of 83 per cent. The bunch masses recorded in all patches of the netting trial were high compared to the industry benchmark of around 20 to 30 kilograms. A higher bunch weight appears to be associated with a higher waste component. Further investigation in conjunction with Sweeter Banana Co-operative would be required to quantify this relationship.

Acknowledgements

This project has been funded by HAL using the banana levy, voluntary contributions from Sweeter Banana Cooperative and matching funds from the Australian Government. The Western Australian Department of Agriculture and Food provided additional funding support for the project.

Technical assistance was provided by staff at the Gascoyne Research Station in Mike Littlely, Chris Cunningham, Ken Drummond, Joe Henry, Kim Miller, Michael Allingame and Alan Higgins.

Operational and technical support provided by Sweeter Banana Cooperative, in particular Michael Nixon, Chris Collins, Bryce Guthrie, Darrell Munro, Doriana Mangili and Tim Hyde is acknowledged.

Valerie Shrubb and Georgina Wilson were instrumental in producing the publication 'Growing Bananas in Carnarvon'.

We acknowledge and thank Dr John Robinson for his willingness to review trial activities and meet with Carnarvon banana producers.

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Appendices

Appendix 1. Report by Dr John Robinson.

Appendix 2. Production guide.

JOHN ROBINSON
BANANA CONSULTATION SERVICES

REPORT ON A CONSULTATION VISIT TO: CARNARVON, WESTERN AUSTRALIA, TO EVALUATE BANANA TRIALS AND BANANA GROWING PRACTICES

DATE: 3 to 8 SEPTEMBER, 2012

CONSULTANT: Dr. J.C. ROBINSON

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REPORT ON A TECHNICAL VISIT TO CARNARVON, WESTERN AUSTRALIA, TO EVALUATE BANANA TRIALS AND BANANA GROWING PRACTICES – 3 TO 8 SEPTEMBER, 2012

Dr. J. C. Robinson, Banana Consultant, White River, South Africa

Background and General

The consultant was invited to make a technical visit to the Banana growing area of Carnarvon, Western Australia, by the WA Department of Agriculture (Dr. Chris Shelfhout) and the Sweeter Banana Company, as a combined initiative. The motivation for the visit was to (a) evaluate progress and results from banana trials at the Gascoyne Research Station, (b) visit individual farmer members of the Sweeter Banana Company to evaluate and recommend on banana production practices, and (c) make technical presentations to local banana farmers at the Gascoyne Research Station. The visit lasted for one week, and is basically a follow-up visit to a similar technical visit made by the consultant to Carnarvon in May, 2008.

Climatic conditions at Carnarvon in relation to Banana Production

Mean ambient temperatures

The mean monthly maximum, mean absolute maximum, mean monthly minimum, mean absolute minimum, and monthly heat units, are presented in the table below (means of 65 years data from Carnarvon Airport – 1945 to 2010).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MM max(ºC)	31.3	32.5	31.6	29.1	26.2	23.4	22.3	23.0	24.4	25.9	27.6	29.3
MM max(ºC)	33.0	33.4	34.4	30.8								
M **abs** max	35.5	36.3	34.8	32.0	28.9	25.4	24.8	25.4	27.3	29.1	30.4	32.0
MM min(ºC)	22.5	23.4	22.1	19.1	14.9	12.3	10.9	11.5	13.8	16.4	18.6	20.6
MM min(ºC)						11.7	10.3	11.0				
M **abs** min	20.3	21.3	20.1	17.1	11.7	9.8	8.0	9.1	12.5	14.3	16.9	18.8
Mean (ºC)	26.9	28.0	26.8	24.1	19.0	17.8	16.6	17.3	19.1	21.1	23.1	25.0
M heat units	400	391	398	303	203	115	80	100	153	222	273	339

Figs in blue are equivalent 12 year mean monthly temps from automatic weather station at GRS.

Mean monthly heat units are computed from the formula (MM Max + MM Min ÷ 2) – 14 x number of days in the month. Annual heat units are the sum of the monthly heat units, which in the case of Carnarvon amount to **2977.** The threshold temperature of 14ºC is regarded as the minimum mean temperature for banana growth.

Analysis of temperatures **(means)** – The optimum mean monthly (MM) temp for plant development **(leaf emergence rate and crop cycling)** is 32ºC and the optimum MM temp for growth **(photosynthesis and bunch weight)** is 22ºC, while the optimum mean temperature overall is **27ºC**. The data for Carnarvon show that about four months of the year (December to March) are suitable overall for the correct balance between "growth" and "development". The MM temps are not hot enough for a very fast **development** rate of banana due to (a) cool night temps throughout the year which decrease the daily mean, and (b) the lower daily means in autumn, winter and spring. However, the 8 months from April to November are very good for optimal **photosynthesis** and bunch weight.

NOTE: **a good balance between growth and development** is required because very high mean maximums (32ºC and more) create a fast cycle time but small, poorly-filled bunches, whereas low MM temps (22ºC or less) induce very slow cycle times but good quality, well-filled bunches. The Carnarvon temperatures are fairly typical of a "warm subtropical/mediterranean" climate which has cold, wet winters and hot, dry summers.

Analysis of temperatures **(extremes)** - The consultant was able to access 12-year mean monthly temperatures from the automatic weather station located at Gascoyne Research Station. The equivalent temperatures from this AWS were about 2ºC warmer in summer than those at the airport, whereas the AWS temperatures were about 0.6ºC colder in winter than those at the airport. Thus the **seasonal extremes of temperature appeared to be wider in the banana growing areas than they are at the airport.** It is the **extreme** temperatures which normally cause physiological problems in subtropical banana growing regions of the world. The Carnarvon extreme maximums of 35 to 40ºC in the banana areas from January to March, are likely to cause leaf folding and temporary wilting **in the afternoons** when the plant cannot absorb water at the rate it needs to be transpired from the leaves. With optimal irrigation, the banana plant can replenish water overnight and be **physiologically normal from sunrise to about midday**. The temporary wilt phenomenon is also the reason why it is unnecessary to increase daily irrigation if daily evaporation increases to 7 mm or more. The plant cannot cope with daily transpiration in excess of 7 mm/day. If the temperature increases above 40ºC, there may also be serious bleaching and/or burning on the already wilted leaves.

As can be seen from the table of extreme minimum temperatures, the absolute minimum can drop to 7 or 8ºC at the airport and maybe lower at the GRS site (**ground frost occurred in winter, 2012**). This will certainly result in the cessation of growth and development but visible cold symptoms on the leaf will **not be severe at 8ºC** (maybe some slight yellowing from chill and some bleaching from winter photo-oxidation due to high light intensity and reduced root function). However, on bunches which either initiate or emerge in a cold winter, there will be evidence of **"November dump" or "choke throat"**, respectively, and the latter was clearly seen on bunches during my visit. There will also be clear signs of underpeel discolouration (UPD) which develops when bunches are exposed to temperatures under 12ºC and the fruits ripen to a dull grey/yellow colour. UPD is the main reason why areas with cold winters cannot export banana fruit. We saw **obvious signs of UPD in the Sweeter Banana Packshed**, but for the Perth market it is not a limiting factor since local consumers appreciate the sweet taste of ripe fruit from this area, despite its dull colour.

Analysis of heat units (HU) – Analysis of HU is a very important productivity index for bananas. The formula for computing daily HU is **(daily max + daily min ÷ 2) – 14**. Monthly HU are then the cumulated daily HU for that month. The base temp of 14ºC is used because this is considered to be the lower mean temp threshold for banana growth. There is a correlation between HU and leaf emergence rate and therefore also between HU and crop cycle time. Assuming that 27ºC is the optimal mean daily temp for banana productivity, optimum daily HU would be 27 – 14 = 13. Optimal monthly HU are then 13 x 30 = 390 and optimum annual HU are 13 x 365 = 4745. This is the **theoretical optimum**, assuming uniform day/night conditions which are not often achieved due to rain, clouds etc. In addition, one can get an overkill of HU such as in very hot, dry banana areas, where many months are dangerously hot coupled with low humidity, which completely detracts from optimum growth and productivity. Thus a country like Sudan which has 5092 HU/year, is unproductive since too many days cause heat-stress problems and plant wilting. Conversely, a cool subtropical area like Kiepersol, South Africa, with 2250 HU, is too mild for optimum banana growth.

In the case of Carnarvon, the annual HU are 2977, and the **ratoon cycle time potential** of this climate can be extrapolated from the following comparisons:

Kiepersol (RSA)–cool subtrop with cold winters, warm summers - HU 2250/yr. Cycle 15 mths
Carnarvon (WA) – arid subtrop, cold winters, hot dry summers – HU 2977/yr. Cycle 12 mths
Komatipoort (RSA)–warm subtrop, cold winters, hot summers – HU 3022/yr. Cycle 12 mths
Chokwe (S Moz)-warm subtrop with cool winters, hot summers – HU 3509/yr. Cycle 10.5 mths
Matanuska (N Moz)-warm semitropical, warm winters, hot summers–HU 3641/yr. Cycle 9 mths
Guapiles (Costa Rica) – humid tropics, warm temps all year round – HU 3800/yr. Cycle 8 mths

The relation of Carnarvon HU and cycle time potential compared with other banana areas can be seen in the above comparison. Carnarvon has very similar HU to Komatipoort, South Africa, and it has warmer, sunnier summers, but it has a higher plant density (3333 plants/ha compared with only 2222 in South Africa) which tends to delay the crop cycle, thus cancelling the advantage of warmer, sunnier summers. Assuming the optimum monthly HU in summer is 390, Carnarvon has 3 months at this ideal level (Jan, Feb and March), with another 2 shoulder months above 300 HU (Dec and April). However, growth and development processes are severely reduced by low HU from May to September due to the cool, wet winters. The very short 8 month ratoon cycle in Costa Rica is because every month is a hot “summer month” regarding mean temperatures and heat units and there is absolutely no winter to restrict growth.

Rainfall and evaporation rates

The mean monthly rainfall (Carnarvon Airport) and mean monthly evaporation rates (Gascoyne Res Stn AWS) are shown in the table below:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain (mm)	12.1	20.9	16.5	14.1	35.7	47.8	45.9	18.2	5.7	5.4	4.1	5.6
Evap (mm)	287	242	247	188	163	118	128	164	203	239	265	288
Evap mm/day	9.3	8.6	8.0	6.3	5.3	3.9	4.1	5.3	6.8	7.7	8.8	9.3

The mean annual rainfall is only **232 mm/year of which only 84 mm or 36% of this rain falls in the 8 months September to April,** which comprises the hot spring, summer and autumn months. In effect therefore, there is minimal relief coming from rainfall during the entire hot period of the year. Conversely, 148 mm rain (64%) falls during the 4 winter months May to August when there is minimal growth potential anyway due to low minimum temperatures. Consequently, banana growth and productivity can be said to be totally dependant on irrigation.

Because very little rain falls during the spring to autumn hot period, it follows that average evaporation rates are very high, as shown in the table above. From September to December there are only two days or less per month which can be considered “cloudy”, the remainder being totally open to the sun. Around 3 to 4 days/month are cloudy from January to March. Annually, there is an average of **2532 mm/year evaporation at Carnarvon** which is very high. December and January have the highest evaporation rates at 288 mm/month or an average of 9.3 mm/day. On some hot, windy days in December or January, evaporation rates have been **regularly as high as 12 or 13 mm/day, and occasionally as high as 15 mm/day which places great stress on the banana plants**

In terms of **evapotranspiration**, the annual water use of the banana crop will be much less than the total evaporation measured, for two main reasons, namely (a) the reduced crop factor used during winter, and (b) the upper limits of the banana plant potential to transpire water from the leaves in summer. Thus, if we consider the winter period from May to August, and we apply a crop factor of only 0.5 to the pan evaporation rates occurring (which is net after rain), we are left with an **evapotranspiration of 285 mm for this period**. If we then consider that the banana plantation **cannot transpire in excess of 7 mm water per day** even if the evaporation rate is more than 10 mm/day, then the total evapotranspiration for the period **September to April is 1665 mm** (based on 7 mm/day, or the actual evaporation rate if less than 7 mm/day, using a crop factor of 1.0). Thus the annual **estimate of evapotranspiration** is 285 + 1665 = **1950 mm/year** (77% of the evaporation rate). NOTE: this is a ball park estimate in terms of historical data, which may vary from year to year. If we accept that irrigation water is being used at 1950 mm/year, this amounts to 19 500 m³/ha/year which, when multiplied by the total number of hectares, should represent the annual irrigation water use of the banana industry in Carnarvon. Farmers are allowed only **72 000 m³/year from their boreholes**, making efficient irrigation scheduling critical.

Wind

Winds blow mainly from the south or south east and shadecloth windbreaks should be orientated in this sector to afford maximum protection to the banana plantations. Winds are strong in Carnarvon and severe wind stripping of leaves was seen in all plantations. Winds blow strongly every month of the year but data from the AWS at Gascoyne Res. Stn. indicate that the **strongest winds blow from October to February, in other words during the hot, dry period of the year**, thus enhancing the already high evaporative demand. Wind speeds during winter (especially June and July) are definitely lower than during summer (December and January).

The average maximum windspeed at the Research Station for December and January (12 year means) were 31.4 and 31.0 km/hour, respectively. If this is the mean of the daily maximum windspeeds for the 12 year period, it is safe to assume that certain days would have had maximum windspeeds between 40 and 50 km/hour, to create such a mean. With wind, average windspeeds do not mean a great deal because it is the short peaks or gusts of wind which cause the damage. It is known that windspeeds of between 10 and 20 km/hour reduce fruit quality by enhancing leaf and dust abrasion, and windspeeds of 20 to 40 km/hour cause leaf tearing which may significantly reduce productivity. **Windspeeds of 40 km/hour or more can cause severe leaf tearing** in which the lamina shreds may desiccate completely or be torn away from the midrib leaving just the midrib spikes on the plant. **Such damage was frequently seen in Carnarvon plantations during September.**

In a trial in South Africa it was determined that leaf photosynthesis was reduced by 11, 20 and 33% when banana leaves were torn into strips of 50 mm, 25 mm and 12 mm width, respectively. This damage is due to (a) leaf strips drying out quicker than whole leaves, and (b) leaf strips hanging down where they do not intercept sunlight. Wind is therefore a large problem facing the banana growers of Carnarvon, and is the **main reason why the possibility of using shade net protection is being investigated by the Department of Agriculture**.

Carnarvon banana productivity potential in relation to climatic parameters
Productivity potential is defined as the **marketable yield potential in t/ha/annum**. This comprises 3 components, namely (a) ratoon crop cycle time, (b) bunch mass potential, and (c) percentage marketable fruit. As indicated earlier, the ratoon cycle time is regarded as about 12 months from the local growers visited, and this is backed up with knowledge of the relationship between heat units and cycle time potential as shown earlier. Also, at the Research Station experimental block, the trials were planted in February, 2009 and the 4th cycle is carrying bunches which will all be harvested in about 2 months' time (average cycle time of 11.5 months).

I was advised by the staff at GRS that the **average cartons/bunch on the trials was 2.25** and that of **the growers was 1.50 cartons/bunch**. This works out as 29 and 20 kg/bunch marketable fruit respectively, at 3333 plants/ha which is the standard ratoon density. The Sweeter Banana packshed advised me that there could be up to 20% waste due to wind damage etc, which would not be packed for the market.

Thus if one calculates on the theoretical basis of 20 kg marketable fruit/bunch, a density of 3333 plants/ha, and a ratoon cycle time of 12 months, the average annual yield **potential** in Carnarvon would be in the region of **66 t/ha/annum** which is very high. Some growers do actually achieve this level, but in reality the average farm yield is around **40 t/ha/annum** which is still quite high but the potential marketable yield is not reached due to many factors such as (a) severe wind damage to leaves, (b) premature harvesting of fruit, (c) blemish damage to fruit, (d) heat stress in open, damaged plantations, (e) three bearing stems growing in one position, (f) use of sucker planting materials, (g) high % of choke throat and (h) tendency to overirrigate.

The factors contributing to a **high potential yield** in Carnarvon, are as follows:
1. The ability to achieve a 12 month ratoon crop cycle at a density of 3333 plants/ha
2. High summer heat units to encourage plant development
3. Long summer days with a high photosynthesis potential - Only 2 to 4 cloudy days per month from September to March
4. The acceptance of short fingers on the Perth market which increases the amount of marketable fruit (does not apply to other markets).

<u>Soil and Irrigation water analyses</u>
Soil Analysis – Gascoyne Research Station (2008)
<u>Soil texture</u> – Light brown heavy clay soils which are difficult to work, but which have high water holding capacity and high cation exchange capacity.
pH (water) – very high at 8.6 – should be in range of 5.8 to 6.8. **Need to gradually reduce with sulphate fertilisers. No lime required.**
Organic carbon – Very low at about 0.3%. **Need to uplift the OC %** with cow manure, chicken manure, compost or heavy mulch. Difficult to achieve at Carnarvon.
Potassium – high at 600 to 700 mg/kg – will be helpful in K nutrition
CEC – quite high at 17 meq/100g. **Soil has good cation exchange capacity**.

Exchangeable Ca – 70% of CEC (normal range)
Exchangeable Mg – 16% of CEC (below normal range). **Need to boost Magnesium**.
Exchangeable K – 11% of CEC (slightly high)
Exchangeable Na – 2% of CEC (borderline high). **Some fields much higher than 2%.**

With regard to the irrigation water, there is only a 2006 analysis available and a combined analysis of the Scheme and Basin A showed that pH was normal, conductivity was borderline high, dissolved sodium borderline high, chlorides borderline high. I am not sure how these values have changed from 2006 to the present.

Gascoyne Research Station banana trials

Shade net trial

Shade net specifications – The net, which was erected in 2008, was designed to reduce the strong prevailing winds that blow through the Carnarvon area, and to allow an evaluation of the cost-effectiveness of shade net protection on banana production. The objective was to compare the initial capital cost, against the increase in yield achieved, and to explain any yield/quality improvements in terms of physiological and climatic parameters inside and outside the net. This net is made of woven white nylon mesh and comprises a 70% weave on the south and west sides where most of the prevailing wind comes from; a 50% weave on the north and east sides, and only a 15% weave on the roof. **The roof was considered to be a weak point of the net specifications because it allowed 85% open pores through which wind gusts could easily enter** and cause visible damage to banana leaves growing inside the net. A much better option, and a recommendation for future work, would be to use a fine translucent interlaced weaved mesh which **allows only 10% light transmission but reduces wind speed significantly so that banana leaves remain intact**. Such material is from Israel and widely used in the Jordan Valley, but is available from an Australian supplier (Chris Shelfhout has details).

Treatments inside and outside the net

The shade net trial was planted in Mid-February, 2009, with two density treatments inside the net and repeated outside the net. **Planting material was tissue culture plants sourced from Queensland**. With a trial of this nature it was not possible to have replications and randomized treatments thus single plots of each treatment were used (approx. 0.2 ha plot size ?). Statistical analysis was not possible.
Treatment A – Density 2460 pl/ha (4 x 2.5m) x 1.25m = double row (**under shade net**)
Treatment B – Density 2000 pl/ha (2.5 x 2.0 m) = single row **(under shade net)**
Treatment C – Density 2460 pl/ha (4 x 2.5 m) x 1.25 = double row **(open field)**
Treatment D – Density 2000 pl/ha (2.5 x 2.0 m) = single row **(open field)**

Results of shade net x density trial

I attempted to calculate the yield in t/ha from the graphs provided, which showed the different harvest dates (x-axis) and the number of cartons (blue bars) and average cartons per bunch (red dots) at each plot harvest date. I did this for each treatment/crop cycle combination in turn and I had to calculate the TOTAL number of bunches actually harvested and the TOTAL number of cartons packed from these bunches in order to get an accurate average of cartons/bunch for each treatment/crop cycle combination (not a weighted average). The yield in t/ha was calculated from the average cartons/bunch and the density used. I did not use the actual number of bunches harvested in the field because so many bunches had fallen and could not be included, thus the results would be incomplete and biased. By using the actual cartons/bunch and the density used, a more-accurate estimate of the yield potential could be achieved. NOTE: I was not provided with the actual data that were used to compile the graphs and therefore I had to **extrapolate from the graphs to obtain yields, which may not be completely accurate.**

Plant crop cycle - Treatment A – (2460 plants/ha under shade net)
Total cartons = 568; total bunches = 225
Average cartons/bunch = **2.52**
2.52 x 2460 plants/ha = 6199 cartons/ha x 13 kg = **80.6 t/ha**
Time to 50% harvest = **14 months**

Plant crop cycle - Treatment B – (2000 plants/ha under shade net)
Total cartons = 369; total bunches = 187
Average cartons/bunch = **1.97**
1.97 x 2000 plants/ha = 3940 cartons x 13 kg = **51.3 t/ha**
Time to 50% harvest = **14 months**

Plant crop cycle - Treatment C – (2460 plants/ha in open field)
Total cartons = 518; total bunches = 278
Average cartons/bunch = **1.86**
1.86 x 2460 plants/ha = 4576 cartons x 13 kg = **59.5 t/ha**
Time to 50% harvest = **16 months**

Plant crop cycle - Treatment D – (2000 plants/ha in open field)
Total cartons = 327; total bunches = 167
Average cartons/bunch = **1.96**
1.96 x 2000 plants/ha = 3916 cartons x 13 kg = **51.0 t/ha**
Time to 50% harvest = **16 months**

The results of the **first cycle (plant crop**) show the following trends:

1. The crop was cycling up to 2 months quicker under the shade net than in the open field, for both densities, due probably to extra climatic stress in the open
2. The yield in t/ha under the net was highest at the high density – this is because there was no difference in light competition between the two densities in the first cycle.
3. The yield in t/ha in open field was also highest at the higher density, as expected, but much lower than the high density inside the net.
4. Initial indications from the first cycle suggest that the **use of shade net is better than the open field, and the use of a higher density of 2500/ha is better than a lower density of 2000 plants/ha inside or outside the net**

First Ratoon cycle – Treatment A – (2460 plants/ha under shade net)
Total cartons = 170; total bunches = 60
Average cartons/bunch = **2.83**
2.83 x 2460 plants/ha = 6962 cartons x 13 kg = **90.5 t/ha**
Planting to 50% harvest of R1 = **23 months**

First Ratoon cycle – Treatment B – (2000 plants/ha under shade net)
Total cartons = 197; total bunches = 72
Average cartons/bunch = **2.74**
2.74 x 2000 plants/ha = 5472 cartons x 13 kg = **71.1 t/ha**
Planting to 50% harvest of R1 = **22 months**

First Ratoon cycle – Treatment C – 2460 plants/ha in open field)
Total cartons = 83; total bunches = 41
Average cartons/bunch = **2.02**
2.02 x 2460 plants/ha = 4980 cartons x 13 kg = **64.7 t/ha**
Planting to 50% harvest of R1 = **24 months**

First Ratoon cycle – Treatment D – 2000 plants/ha in open field)
Total cartons = 157; total bunches = 66
Average cartons/bunch = **2.38**
2.38 x 2000 plants/ha = 4758 cartons x 13 kg = **61.8 t/ha**
Planting to 50% harvest of R1 = **22 months**

The results after **two cycles (P + R1)** show the following trends

1. Many bunches in the second cycle did not seem to be recorded and their numbers were much fewer than in the first cycle. This is most likely due to the **floods which occurred during December, 2010** and which played havoc with the banana growth and plants falling over in the trials.
2. Average cartons/bunch for each treatment in the second cycle was much higher than that achieved in the first cycle – Plants were much larger and R1 bunches also much larger, which is usual and to be expected.
3. Once again the highest yield/ha was achieved by the higher density under the shade net (treatment A). **Both treatments under the net yielded much higher than the equivalent treatments in the open field, showing conclusively that the shade net improved banana productivity in the Carnarvon conditions.**
4. Under the net, the higher density performed better than the lower density, despite taking an extra month to complete two cycles. In the open field the yield difference between the densities was less obvious because the cycle time at lower density was two months shorter.

The third cycle (R2) could not be accurately analysed because the harvest dates were very spread out, flood damage was carried over, and cartons per bunch data were variable. An estimate of the average cartons/bunch for the harvest data available from the third cycle was **1.99, 2.15, 1.75, and 1.93 for treatments A, B, C and D, respectively**. These data indicate that (a) treatments inside the net continued to be better than those outside the net, (b) the lower density inside or outside the net **was starting to have larger bunches than the respective higher densities,** and (c) overall average for cartons/bunch was reduced in the third cycle compared with the second cycle and even compared with the first cycle. Thus overall vigour in this trial was being reduced.

During my visit, I viewed this trial which was carrying bunches in the fourth cycle (third ratoon), and some interesting observations could be made by this stage in the comparison, as follows:

<u>Visible benefits of growing under under shade net</u>

1. Leaf canopy was more vigorous with an increased number of green leaves and less tearing of the leaves than outside the net (wind effects?). Leaf tearing did occur under the net but visibly much less damage than in the open field.
2. Fewer plants carrying bunches fell down inside the net. This is due to reduced wind speed inside the net (props were not used at all).
3. Increased shade on the ground due to the increased leaf number and the lower extent of leaf tearing or leaf hanging, than in open field.
4. Reduced wilting of the leaf canopy due to the extra protection, increased leaf overlap and less hanging down of leaf lamina parts than in open field
5. Fewer weeds seen on the ground under the net compared with open field due to increased shading.

<u>Visible comparison between high density in double row arrangement and lower density in single row arrangement (inside or outside net)</u>

The double row arrangement performed better than the single row arrangement in the first cycle, due simply to the extra 500 plants/ ha when no difference in competition was felt. This difference was also carried over to the second cycle although not so pronounced in the open field. By the third cycle the plants at lower density were performing better than those at the higher density double row system, and by the fourth cycle (visual impact only) **the plantation clearly looked much worse at the higher density of 2460 plants/ha in double rows than at 2000 plants/ha with single row spacing.** The reasons for this were:

1. Plants were too crowded in the narrow rows at 1.25 m spacing, creating extra competition between plants, compared with 2.0 m between plants at the lower density.
2. Plants in the narrow row were clashing with each other so that suckers and bunches were frequently growing into each other.
3. Too much sunlight was entering the wide row of 4 m causing excessive sunlight on the ground, heat stress from reflected sunlight, wasted sunlight on the ground instead of intercepted by the canopy, and extra weeds on the ground.
4. Wind could funnel down the wide rows causing turbulence inside the plantation
5. Bunches were more exposed to the sun thus increasing the burning potential
   Plants established at 2.5 x 2.0 m (2000 plants/ha) received equal distribution of light, more canopy protection, no clashing of bunches with suckers, and improved microclimate in the plantation.

The **<u>conclusions</u>** I can draw from this trial so far are as follows:

1. The shade net definitely improved gross yield potential compared with open field plantations, irrespective of density used.
2. The shade net reduced physical blemish damage on fruits thus improving marketing possibilities with better quality fruit
3. The shade net allowed too much wind to enter inside through the roof, thus allowing for considerable wind damage to occur to the canopy although at a lower

level than outside. I feel that a huge improvement to the benefit potential of a shade net could be made by using a hi-tech, fine-weave, translucent net which is available in Australia and which will allow for total canopy protection (no leaf stripping) as well as certain other microclimatic benefits.

4. The cost-effectiveness of using a shade net has been clearly proven in other Mediterranean countries with very hot, dry and windy conditions, such as the Jordan Valley of Israel, and Lebanon. This must still be done in Carnarvon.
5. The climatic conditions of Carnarvon which are very hot, dry and windy in spring and summer (see earlier section of report), would justify a high density to be used for the main purpose of canopy protection, microclimatic improvement, and maximizing yield potential under conditions of high heat units. However, I believe the **current commercial density of 3333 plants/ha is too high except for two or maybe three crop cycles.** For a plantation life of 7 to 10 years, a density of 2500 plants/ha would be more appropriate. A density of 2000 plants/ha would be too low in the open field at Carnarvon, as shown in the trial, but this **could certainly be considered inside an efficient shade net**, due to the massive increase in canopy cover and efficient leaf area that could be expected.
6. Regarding spatial arrangements, I conclude from the trial that a **double row arrangement in the Carnarvon climate is unsuitable** due to increased competition between plants in the narrow row but the waste of light and high burning potential in the wide row. A square or rectangular arrangement would be more appropriate, while also ensuring that the in-row spacing does not become less than 1.5 m between plants.
7. Thus from this trial, and anticipating the use of a more-efficient net structure, I would propose 2200-2500 plants/ha on a rectangular single row arrangement in which the in-row banana spacing is 1.5 m or more. In the open field, where extra canopy protection is needed from wind and heat stress, I would propose between 2500 and 3000 plants/ha but also on a rectangular, single row and single sucker arrangement.

<u>Climatic parameters under the Carnarvon shade net</u>

In order to explain the differences between shade net and open field productivity, I looked at various climatic parameters that were measured by the AWS at GRS. These are presented in the table below, and are means for the year 2008 which is actually the year before the banana trial was planted:

	Mean wind Speed (kph)	mean max temp (ºC)	mean min temp (ºC)	Mean min RH (%)	Epan evap (mm/year)	Total solar $mJ/m^2/yr$
Inside net	5.83	28.7	16.6	35.6	1955	6693
Open field	11.38	28.0	15.8	37.4	2479	8299

The table above clearly shows that the climate is modified under the shade net to the benefit of banana growth and productivity:

1. <u>Mean wind speed</u> – In the open field the **average windspeed is double that inside the shade net.** This implies that the peak wind speeds will also be less inside the tunnel than outside the tunnel, as also indicated by the AWS data, and consequently there should be less leaf tearing inside the net. This is exactly what happened because visually the leaves are much more damaged and torn outside

the net than inside (see attached photos of this effect). Less leaf tearing means that leaves are more functional and more photosynthetically-active than those which are badly torn. Since wind reduction is probably the most important parameter we are looking for, the shade net definitely provides this benefit. However, as previously indicated, if the leaf damage can be reduced still further by using a closer net weave, then the productivity benefit would increase significantly.

2. Mean max temperature – very little difference was recorded in this parameter and it appeared that heat stress per se would not be reduced under the net.
3. Mean min temperature – The mean minimum temperature was increased by about 1ºC inside the net which is a reasonable benefit to the plants in terms of growth rate in summer and reduction of choke throat and November dump in winter. An average increase of 1ºC in winter has a bigger benefit than expected.
4. Man minimum humidity – Inside the net the mean min RH was 2% lower than outside which is not an advantage and may be related to the fact that maximum temperature was higher inside the net. A higher max temp and lower RH would be expected to increase the evaporative demand inside the net but this was not borne out by the evaporation data.
5. Annual evaporation rate – there was a large benefit from growing the crop inside the shade net. Total annual evaporation was about 25% higher outside the net which means the evaporative stress on the banana plants was much less inside the net. Other users of shade nets claim that water saving is about 30% under a net which could be justified by the much lower evaporation rate. Once again, a closer weave net is likely to reduce the evaporation rate still further.
6. Solar radiation – Total annual solar radiation was recorded at about 25% higher outside the net than inside. In other words there was considerable shading inside the net which may or may not affect photosynthesis adversely. If the peak diurnal radiation outside was in excess of the threshold for photosynthesis, then a 25% reduction inside the net may not have had an adverse effect on photosynthesis and productivity. This is why comparative photosynthesis data need to be taken in such a trial.

It is clear that for most climatic parameters, the conditions inside the net were more favourable for banana growth and development than outside (reduced windspeed, increased minimum temperature, reduced evaporation and water use, and possibly reduced light stress (photo-oxidation damage). It is my perception that by using a better quality net which has a closer weave, UV protection and more translucency, there will be even greater benefits to be derived due to (a) reduced windspeed, (b) less leaf tearing, (c) higher photosynthesis rate, (d) more bunch protection and better fruit quality, (e) reduced weed growth (f) fewer winter chill phenomena, (g) reduced transpiration rate and lower water use, and (h) less photo-oxidation and less burning of leaves and exposed fruit. Thus my recommendation for the Dept of Agric (GRS) is to repeat this trial using a different type and quality of shade net (available in Australia and details already sent to Dr Chris Shelfhout). Then, in addition to all the climatic parameters currently being measured by the AWS, the study should include (a) an in-depth study of diurnal and seasonal transpiration rates with a porometer, (b) diurnal and seasonal photosynthesis rates using an infra-red gas analyser, and (c) an accurate comparison of water use inside and outside the net structure. I also recommend investigating additional environmental modification using a cooling overhead irrigation system inside and outside a shade net, such as the

South African-designed floppy sprinkler. This system is much more resistant to wind dispersion and evaporation effects than an impact sprinkler and would be an additional input to complement the advantages of an efficient shade net in the hot, dry and windy Carnarvon conditions. The details of Floppy sprinkler have been supplied to Dr Chris Shelfhout with details of application successes using this system. Finally, a detailed economic analysis needs to be conducted to determine the breakeven period.

Open field density trial
Outside the shade net at GRS, an open field banana planting density trial was conducted over the past three years, and the treatments were as follows:

Treatment 1 – 2500 (P) > 2500 (R1) – 2.5 m rows x 1.6 m in row
Treatment 2 – 2666 (P) > 2666 (R1) – 2.5 m rows x 1.5 m in row
Treatment 3 – 3333 (P) > 3333 (R1) – 3.0 m rows x 1.0 m in row
Treatment 4 – 1111 (P) > 3333 (R1) – 3.0 m rows x 3.0 m in row

The treatments were single plots with no replication. Planting material was tissue culture sourced from Queensland. Planting date was mid–Feb 2009. Treatments 1, 2 and 3 had single sucker selection from P to R1, whereas Treatment 4 had **3 suckers** selected from P to R1. A severe flood in December, 2010 caused considerable damage and disruption to this trial.

<u>Results of the **first cycle (plant crop)**</u>
<u>Treatment 1 – 2500 plants/ha</u>
Total cartons = 401; total bunches = 216
Average cartons/bunch = **1.86**
1.86 x 2500 plants/ha = 4641 cartons/ha x 13 kg = <u>**60.3 t/ha**</u>
Planting to 50% harvest = **16 months**

<u>Treatment 2 – 2666 plants/ha</u>
Total cartons = 302; total bunches = 151
Average cartons/bunch = **2.00**
2.00 x 2666 plants/ha = 5332 cartons/ha x 13 kg = <u>**69.3 t/ha**</u>
Planting to 50% harvest = **16 months**

<u>Treatment 3 – 3333 plants/ha</u>
Total cartons = 345; total bunches = 209
Average cartons/bunch = **1.65**
1.65 x 3333 plants/ha = 5502 cartons/ha x 13 kg = <u>**71.5 tha**</u>
Planting to 50% harvest = **20 months**

<u>Treatment 4 – 1111 plants/ha</u> (with 3 suckers selected)
Total cartons = 114; total bunches = 71
Average cartons/bunch = **1.61**
1.61 x 1111 plants/ha = 1784 cartons/ha x 13 kg = <u>**23.2 t/ha**</u>
Planting to 50% harvest = **17 months**

The results of the first cycle (plant crop) show the following trends:

1. At 2500 to 2666 plants/ha, the cycle time to 50% harvest was 16 months, similar to the outside plots of the shade net trial. By having 3333 plants/ha the cycle time was extended to 20 months with bunches hanging over the second winter. The density of only 1000 plants/ha still had a 17 month cycle due to the increased competition of three suckers growing around each parent.
2. Cartons/bunch was higher at 2666 plants/ha than 2500/ha although these should really have been similar in the first cycle. **At 3333 plants/ha the cartons/bunch was low at 1.65, but the yield/ha of 71.5 t/ha was higher only because of the higher density**. However, with a cycle time of 20 months, the yield/ha/annum is actually much lower than that achieved at 2666 plants/ha.
3. An initial density of 1111 plants/ha with three suckers per plant is exactly what most growers at Carnarvon are doing. However, this is really not a good option because (a) the yield potential is very low in the first cycle, (b) the cycle time of the first cycle is quite long due to the competition of three suckers growing around it, and (c) the second cycle is suppressed due to having three plants each producing a bunch from the same spot, and (d) sucker selection after the second cycle becomes very difficult.
4. The optimum density for open field remains the same as discussed earlier, namely 2500 to 3000 plants/ha but on a rectangular system with single suckers per plant, and not the option of starting low then selecting 3 suckers to get to 3000 or more/ha. This is justified by the performance of treatments 1 and 2 in this trial.

Unfortunately, the data of the second cycle could not be analysed because it was obvious from the graphs that many bunches were missing, either from (a) flood damage to the second cycle plants in December 2010, which damaged the roots (b) a severe locust plague which destroyed the leaf area in March 2011, (c) bearing plants falling over due to large bunches and strong winds, or (d) the absence of props in the plantation to support the bunches. Currently the trial is carrying bunches of the 4th cycle but the trial looks very patchy, with many missing plants, many bunches toppled over and many bunches being choked in the neck of the plant due to a very severe winter in which ground frost was seen next to the trial in July.

Conclusions on Dept of Agric. banana trials

Although the data from these trials became more and more incomplete as the cycles progressed, there was a large amount of valuable information that came out of the plant crop results, and in the case of the shade net comparison, out of the second cycle as well (notwithstanding flood and locust damage). I have tried to highlight above some of the conclusions of the trial and management recommendations that could be made, especially regarding densities, spatial arrangements and the use of a shadenet. I would just like to emphasise at this stage that the staff of GRS have done a great job of trying to manage these trials and collect data, in the face of labour shortages and a series of unavoidable environmental disasters (floods, locust plague, strong winds and a very cold winter in 2012). However, **at this stage I would recommend to terminate the two trials rather than spend time and money collecting minimal extra data and in managing the patches**. I would instead concentrate on putting up a new shade net with superior net specifications, and repeating the study inside and outside the net using (a) three densities of 2000, 2500 and 3000 plants/ha, (b) square or rectangular plant arrangements (not double row), (c) single sucker followers from the beginning, (d) overhead floppy sprinklers vs undercanopy microspinners, (e) detailed measurement of climatic parameters (as done now), (f) measuring detailed physiological parameters (transpiration, photosynthesis and water use), and (g) an economic analysis to compare the cost-effectiveness of all these treatments, both inside and outside the new shade net.

General management practices of Carnarvon banana growers

Industry statistics –There are approximately 200 ha of bananas in Carnarvon and 53 growers. About 20 growers are relatively large (5 ha or more), and 33 are small growers with about 1 ha each. Farm sizes are limited by the availability and cost of farm labour, which forces many growers to manage the entire operation themselves, with help from either the wife, the sons who are interested in farming, or some backpacker labour. The latter are untrained in banana management but still attract a wage of $20 /hour since the grower has to complete certain tasks on time and the backpacker may be his only option. Of the 53 growers, about 30 of them are members of the Sweeter Banana Cooperative, and the other 23 are independent packers and marketers. A shortage of water allocation is another reason for farm sizes being small.

Bananas are all pre-packed in Carnarvon and sold exclusively on the Perth market. The demand in Perth is always larger than the supply from Carnarvon, but the shortfall is made up from Queensland fruit. In times of short supply from Queensland (cyclones) the National banana price increases and this also reflects in the Perth price for Carnarvon bananas. In times of oversupply from Queensland, excess fruit is sent to Perth which reduces the price to Carnarvon growers, but there tends to be a better price for Carnarvon bananas because (a) they are sweeter than the Queensland product, and (b) there seems to be a premium market for shorter bananas, called “lunch box bananas”. This seems to contradict the international trend which is to pay premiums for longer bananas. This new development in promoting shorter bananas in Perth has saved the Carnarvon industry from danger, since before this the shorter bananas were rejected and banana production was marginal. The minimum finger length for lunch box bananas is 140 mm and the maximum is 210 mm, whereas 4 years ago the minimum finger length was 170 mm. **The degree of blemish on the fruit is still unacceptably high**, but the Perth market tolerates more blemish than 4 year ago due to the demand for the lunch box brand overriding the existence of blemish.

The economics of banana production in Carnarvon is still relatively marginal despite the “lunch box” bonanza. In winter the market price per 13 kg carton is $40-42 for lunch box, $34 for singles (smoothies packed in 750 g bag) and $ 20-22 for value packs. In summer the prices are lower, namely $30 for lunch box, $25 for smoothie and $18 for value pack. The grower pays to Sweeter Bananas $11-12/carton for marketing costs, and the growers own production costs are about $10-12/carton. Therefore the grower needs to achieve a minimum of $24/carton in order to break even on production and marketing, and nearer to $30/carton to make a living out of bananas, which evidently he can only do in the cooler period of the year. It is most unusual worldwide, but in Perth, the lunch box bananas can realize $42 /carton and the “extra-large” only $36.

The packshed has made significant strides since my previous visit in 2008. In particular, the two main improvements have been in (a) product brand development (lunch box) and (b) Cold chain management which has allowed fruit to be marketed with a longer green life leading to a longer shelf life for the customer. The main goals now for the packshed are (a) to develop a crop forecasting technique which will enable a more streamlined inflow of fruit and better preparation by the shed to cope with gluts and shortages, and (b) persuading the grower members of the shed to take up better plantation practices and hygiene inputs in order to reduce the high amount of blemish seen and thereby to exploit and add value to the already successful Brand name. The farmers I visited during my stay in Carnarvon were Bruce and Darryl Munro, Gerry Gugliamana, Darryl Hardman, Brad Warren, Chris Collins (Tim Hyde), Michael Nixon, Tom Day and Romeo de Boni.

Planting material – The GRS banana trials were planted with tissue culture material sourced from North Queensland. The value of TC planting material could be seen in the first cycle of the shade net trial in which average cartons/bunch of 2 to 2.5 were achieved giving yields of 60 to 80 t/ha. Growers maintain that they cannot buy TC plants locally and that they are too expensive to import from Queensland. They maintain that they can plant a sucker in the field for $1.50 compared with $4.00 for a TC plant grown out to field-ready condition. This may indeed be the case but everywhere in the world where bananas are grown commercially, TC plants are used and not suckers. A method must be found to either establish a TC laboratory in Carnarvon, or to import in-vitro plants in tubs from Queensland which can then be weaned and nursery-hardened locally, to reduce the initial cost. Trials worldwide have conclusively shown that the yield and uniformity of TC is greater than suckers in the first cycle and that a carry-over yield benefit of TC occurs into the second and third cycles, which pays for the initial cost of the plant.

Planting dates – There are various interacting factors here, namely that it takes about 13 months from planting to first harvest if planting date is in September to December, but 16 or more months if planting occurs from January to March (Research Station trials). The reason is that with early planting the crop only goes through one winter period of reduced growth. With planting in February or March, the young plants go through one winter period and bunches go through part of a second winter period before harvest. Planting in September to December is also less stressful on the young plants, whereas planting in January/February causes heat stress on the young plants in the field. However, a crop in spring/summer does not achieve the same price as a crop in autumn/winter, therefore planting in Jan/Feb is more likely to achieve good market prices from a 16 month harvest in May to July. Growers need to weigh up these factors before deciding on planting dates.

Planting densities – This topic has been discussed at length earlier in this report. One of the things I have noticed in years of travel is that **a widely accepted growers practice cannot easily be changed and growers are rather resistant to make changes**. Thus, the standard density of 1111 plants/ha at planting, increasing to 3333 plants/ha in the second and subsequent cycles by selecting three suckers per plant is an accepted practice in Carnarvon which they do not want to change. In my opinion, such a density and spatial arrangement is not ideal, because (a) 1111 plants/ha in the first cycle gives a very low yield and excessive light and heat stress in the plantation, (b) selecting three suckers at one spot is not as productive as selecting single suckers at a wider spacing, and (c) it is difficult to continue the sucker selection process into the later ratoon cycles. As discussed earlier, I would recommend to plant and maintain a lower density of 2500 plants/ha and have a rectangular spatial arrangement like 2.5 m x 1.6 m and continue by just selecting one sucker per plant in the same direction. Some growers are in fact starting to adopt this recommended strategy. Some growers are persisting with a high density of 3333 plants/ha but moving to single plants at spacings of 2 m x 1.5 m. Others are trying a lower density of 2500 plants/ha with good results (10 month cycles and 13 to 14 hand bunches). In my opinion, spacings which involve 3 plants/mat, or a double row system with wide interrows, are not to be recommended in the harsh climate of Carnarvon.

Irrigation – Irrigation is probably the most important management factor for bananas in this area where the growing season is hot, dry and windy, and the rainfall does not contribute much to the water demand of the plant. Thus the plants are virtually totally dependant on irrigation water but the supply of water is being reduced. Farmer allocations on the water scheme are being reduced by about one-third due to previous over-allocations and the need to cut back on the scheme network. Water has become more scarce, more saline and they need to prevent salt water intrusions into the farming area. Regarding boreholes, farmers all have the same allocation of 72 megalitres/annum which is probably enough to irrigate 3.5 ha over a year. Thus, **efficient and controlled irrigation scheduling is of paramount importance on these farms.**

Most growers adopt a system of irrigating for the first 6 months using **cheap disposable drip lines that can be discarded after 6 months.** This is a good idea because it enables scarce water resources to be targeted to the small growing plants and not to the whole land where roots are not initially found. The only disadvantage is that if planting date is in December or later, the small plants will be heat-stressed and cannot be cooled down by a water spray which would occur if microspinners were used from the beginning.

Following the initial 6 months period of targeted drip irrigation, most growers convert to a microspinner or undercanopy sprinkler system of one sort or another. On the Research Station they were using spinner nozzles that delivered 100 L/hour and the irrigation lines were positioned in every row at 3 m apart with nozzles spaced every 3 m along the line. Gross application is therefore 100 ÷ (3 x 3) = 11 mm/hour x 85% application efficiency = **9.5 mm/hour net**. There are three main problems here:

1. For a soil that has only 5 mm/hour infiltration rate, it is clearly an overkill to have a system applying 11 mm/hour gross. There will be puddles everywhere and runoff on sloping soil even when the application is only for 1 hour.
2. The irrigation lines should be positioned every second banana row (6 m apart, not in every row at 3 m apart).
3. The schedule is to irrigate for one hour every day in summer and 20 minutes/day in winter. This means applying 11 mm/day gross in summer and 3.5 mm/day in winter. The banana plant is only capable of taking up and transpiring about 7 mm/day maximum even when the daily evaporation is 10 mm or more. Under an evaporative demand of more than 7 mm/day, the plant wilts at about midday or even earlier, and the leaves fold flat under peak transpiration. Then no further transpiration loss takes place until the evaporative demand eases, which allows the plant to regain turgor and continue transpiring again. In practice this means that the plant loses very little water from early afternoon until the following morning when the plant has regained full turgor overnight. This happens despite

there being enough water in the rootzone to be taken up – it is simply that the daily loss from the leaves exceeds the replenishment rate from the soil and the plant wilts and remains physiologically non-functional. The higher the evaporation rate the more severe the wilting phenomenon becomes. Thus I would recommend that a maximum of 8 mm/day gross should be applied in summer (about 7 mm/day net) to avoid a situation of waterlogging in the soil.

On one of the larger commercial farms, they were also irrigating with large nozzles of 120 L/hour, with a nozzle spacing of 4 x 3 m, thus the gross application is 10 mm/hour or 8.5 mm/hour net. This is once again very high for the infiltration capacity of the soil, leading to a lot of puddling. But in addition, the schedule was applying water for 4 hrs x twice a week. This means applying 68 mm/week net (10 mm/day net) which is too high for the evapotranspiration capacity of the plantation, leading to the possibility of waterlogging even at very high evaporation rates.

I would recommend the following for irrigation:

1. Use the disposable drip system for the first 6 months as used now
2. After 6 months change to microspinner system which has a nozzle size of 70 L/hour maximum (not 100 to 120 L/hour)
3. The irrigation lines to be spaced every second row according to the banana rows (lines 6 m apart for 3.0 m banana rows or 5 m apart for 2.5 m banana rows). Nozzles to be spaced 3 m apart along the line. Nozzle spread to extend 0.5 m beyond the banana row
4. This system would apply 70 ÷ (6 x 3) = 3.9 mm/hr gross or **3.3 mm/hr net.** The application rate is then much less than the infiltration rate which means less puddling and/or runoff
5. In summer apply a maximum of 7 mm/day net (8.2 mm/day gross). This means irrigating for 2 hrs 15 min if done daily or 4 hrs 30 min if done every second day.
6. I would recommend irrigating every second day rather than every day so that the water can penetrate to the full rootzone rather than just to the top 200 mm.
7. Use tensiometers to indicate the water status at 200 and 400 mm below the surface – this will be a check on the evaporation-based system as well as indicating any underirrigation or waterlogging potential. The tensiometer reading should be at 20 kPa before irrigating.

Fertilization – Growers use a variety of chemicals in a fertigation mix which is applied through the irrigation system at regular intervals. Hand application would be difficult due to the high labour costs for application. However, one grower was applying by hand because he said the cost of granular fertilizers was very much cheaper than fertigation chemicals. The labour cost of application may nullify this advantage?. The following general recommendations apply for Carnarvon:

1. Take a soil sample every year for pH and cation levels and balances
2. For a 50 t/ha crop, apply 800 kg K/ha/annum and 300 kg N/ha/annum. For a 25 t/ha crop apply half of these levels. The K can be reduced slightly if there are high levels in the soil, but "mining" of soil K should be avoided.
3. Monitor the availability of soil nutrients to the plant by doing regular leaf analyses and measuring against standard concentrations.
4. With fertigation, split the chemicals for weekly or 2-weekly application. Do not apply chemicals daily (excessive dilution) or monthly (dissolving problems)

5. Due to the high pH levels use as much sulphate fertilizer as possible (Potassium sulphate, ammonium sulphate, magnesium sulphate, zinc sulphate). One can also use liquid urea, potassium nitrate if necessary.
6. Organic nutrition is very important but there seems to be a shortage of manures and composts in Carnarvon. Where possible collect all the bunch stalks and reject fruit, and put this material through a shredding or chipping machine. Apply evenly over the plantation in as high a quantity as possible. This is high in K.
7. In the event that the TSS level in the soil goes much above 500 ppm or that conductivity goes above 750 µS/cm, there may be a risk of some salinity effects. This will normally indicate itself as a necrotic band on the leaf margins like I saw on many plantations in Carnarvon. This may not be too detrimental but if the signs are there then remedial action should be taken. As a % of the CEC, sodium should be less than 2%, but I was advised by some growers that in some cases the Na % was higher than 10% of all cations, which is dangerous. To rectify this, I recommend that gypsum is applied so that Ca can replace the Na on the clay colloids, and that occasionally a "leaching" over-irrigation should be given to leach the released Na from the rootzone. A visiting American agronomist has recommended applying calcitic lime as the best method of dislodging the sodium from the clay colloids, despite increasing the pH which is already too high. I am not convinced of this logic being correct, but some growers are trying it.

Bunch quality management
Bunch propping – There was no propping seen in the Dept of Agric banana trials, consequently many bunches were seen lying on the ground because the stems were unable to support these large bunches, especially when strong winds were blowing. Research blocks should ensure that no data bunches are lost to wind after the bunch has been grown to maturity. In many growers properties, I did not see many wooden props being used because these are not readily available, thus many fallen bunches were seen. In the plantations where three ratoon plants were growing outwards from the same spot, a method of tying string around the upper part of the 3 stems was used, which is partially successful and better than nothing, but these plants lean naturally and do tend to fall over if weakly held in the soil. It is essential to support mature bunches waiting to be harvested and a complete waste of money to let them fall over and be damaged. I saw many bunches arriving at the Sweeter packhouse which had some mud on them and had obviously fallen over before harvest. A stock of wooden poles or bamboo stems should be kept on each farm so that at least **selective propping of large leaning bunches can be achieved.** The packshed would be happy with any policy to protect bunches from falling.

Bunch covering – This is another practice which would be useful to protect bunches and induce better quality in the packshed. Bunch covers have proved to be cost-effective worldwide where better fruit quality is being sought. I did not see many bunch covers in the field at all, but **one grower who markets his fruit independently was using white bunch covers for bunch protection and heat reflection, and his packhouse had some good quality fruit being packed**. Better quality fruit can definitely be achieved with covers, but in the event of weak and open leaf canopies, it will be necessary to place a sheet of newspaper inside the cover to protect the top hand from direct sunlight on the bunch. A bunch cover can only be used twice before disposal, and re-using the cover many times causes rub damage on the fruit which is what many growers were complaining about.

Flower parts – In nearly all plantations worldwide, flower parts are removed from the end of the fruit, either early in bunch development when the flowers are still white and fleshy, or after harvest in the packshed when they are black and hard. In Carnarvon this practice is not done and bunches are dehanded, washed and packed still with the black flower parts attached to the fruit. This is another quality factor because the flower parts scratch the neighbouring hands during harvest, transport, dehanding and packing, and is one of the main factors that increases fruit blemish. The reason why deflowering is not done is the overriding labour issue and these growers have decided that it is not cost-effective to use expensive labour for removing flower parts. Apparently the Perth market accepts fruit with black flower parts on them, but most world markets would reject such fruit. Bunches coming into the packshed (Sweeter packshed or private packshed) should be fed through a water spray race before dehanding to (a) remove field heat quickly, wash field dirt and dust from the fruit, and (c) soften the hard flower parts to reduce scratching.

Male bells – Worldwide, the practice is to break off the male bells and attached peduncle as soon as it can be gripped and snapped off. The male bell contains the primary growing point and this will just continue extending if not removed, resulting in a lot of nutrients and reserves relocating to the bell and stalk, instead of to the fruit. The bell and long stalk also add to the weight of the bunch with a greater risk of bunch toppling, if left attached. In Carnarvon, I saw that one or two growers were leaving the male bell to just grow and extend downwards, the reason being that they wanted to suppress fruit growth and achieve shorter fingers!. I did not agree at all to this logic and it does not make sense to apply stress to the banana bunch on purpose in order to get smaller bunches with shorter fingers. As I understand it, the acceptable finger length for lunch box bananas has been reduced to 140 mm from 210 mm previously, which opens up a new market range. However, the fruit length can still be up to 210 mm max length and still be acceptable, so it seems logical to try and produce fruit in the upper limit of this acceptable range and achieve a larger weight of fruit marketed. Instead of trying to produce smaller fruit for the lunch box concept, I believe the growers should go for the longest possible fruit allowed, while increasing yield/ha, and to rather concentrate on improving blemish quality on the fruit surface. Thus, allowing male bells to grow is not advisable.

Harvest maturity – The longer one can leave the bunch on the plant without getting fruit splitting or premature ripening, the better for increasing yield **(15% higher yield for every week the bunch remains on the plant).** There is a tradeoff here in that delayed harvest increases yield, but with greater risks of premature ripening or fruit splitting, together with increased surface blemish. Season also plays a role in that currently they are getting very thin fruit due to poor canopy conditions. When the canopy is better in autumn/early winter, fruit can be left hanging for longer. Also, the green life requirement is very short since fruit only has to reach Perth to be ripened. Carnarvon growers are fortunate they don't have to ensure a long green life of 10 to 20 days, in which case they would not be able to produce commercial bananas easily, due to the continually stressed canopies (wind, evapotranspiration, sunburn, photo-oxidation, winter chill).

Harvesting and transport – There is no doubt this could be improved to get better quality in the packshed, but most damage seems to come from pre-harvest field practices. The best harvest/transport combination I saw was to **carry harvested bunches on a soft shoulder pad and then dehand in the field next to a trailer and place whole hands on layers of thick sponge foam for transport to the packshed**. Whole bunches coming to the packshed on centre board trailers had a large amount of blemish on them (see photo).

Hygiene management

Leaf removal – In my opinion, **this was the factor causing most mechanical blemish on the banana fruit.** Again due to the high labour cost, the removal of dead/diseased leaves was not considered a priority and in many cases, a large skirt of dead leaves could be seen hanging around banana stems. This is made worse by the high densities of 3333 plants/ha. **I also saw dry dead leaves threading through exposed banana bunches and causing serious scratches to the fruits when winds were strong (most of the time)**. If these leaves were removed regularly, it would benefit the plantation by (a) opening up the suckers to more sunlight, (b) relocating dry mulch matter from the stems to the soil surface where it would have multiple benefits, and (c) removing speckle disease spores to ground level where they would not spread so easily. I believe it would be worthwhile to employ backpackers to do this task say every 2 months and clean up the plantation.

Leaf speckle infection – This leaf disease should not be a large problem in an area like Carnarvon, which has hot dry summers and cold wet winters. Theoretically, it should be too dry in summer and too cold in winter for the right climatic combination to occur for speckle infection. However, I did see a large amount of leaf speckle lesions in the plantations in September, which I suspect is due to late infections the previous autumn and **caused by (a) warm day and night temperatures, (b) early morning dew which triggered spore germination, and (c) old, dry and infected leaves giving rise to a high level of inoculum.** It is essential to remove all old, dry leaves and place them on the ground to remove the spore load from the canopy. **Much less speckle was seen where there was regular deleafing.**

Weed control – Generally I did not see many weeds due to the use of drip irrigation in the first 6 to 9 months of plantation life, and the high density canopies which could crowd out weed growth. There is no labour for hand weeding, thus spot sprays with herbicides should be done if and when necessary. In the event of a weak canopy and excessive sunlight, weeds must be controlled since they compete for water and nutrients.

De-suckering – This is a critical banana management operation but unfortunately it is another very labour-intensive operation that most growers find difficult to do correctly. It is particularly difficult to desucker effectively when (a) the density is very high, (b) the spatial arrangement gets out of line or is based on three plants per clump, and (b) when the plantation gets older than 4 or 5 cycles. It is also physically difficult for growers to gouge out suckers all the time and simply cutting them back does not help. Some growers were using diesel which is quite cheap, effective and less strenuous, but in other countries diesel has been discontinued due to concerns about the environment.

Nematodes – This can be a hidden problem which can reduce vigour without the grower realizing what is going wrong. I recommend that **root samples are taken every year in**

September and an analysis made of nematode species distribution and population levels. If necessary, nematicides should be applied but the products should be rotated and applied strictly according to accepted guidelines for effective nematicide application. Unfortunately there are no organic nematicides which are effective, and to apply any chemical nematicide just as a precaution is very expensive. I suspect that growers who told me that nematicides were not working, were not applying them correctly or did not have a serious nematode infestation.

Summary of grower management recommendations for Carnarvon

1. Use tissue culture planting material for higher productivity and uniformity in first 3 cycles.
2. Reduce planting density from 3333 plants/ha or higher down to around 2500 plants/ha. Plant out at this density and maintain it rather than plant at 1111 plants/ha and selecting 3 suckers.
3. Maintain a square or rectangular spatial arrangement with one bearing plant and one sucker per mat, rather than a double row or "3 in a clump" arrangement.
4. For irrigation, use a lower-delivery microspinner system (3 to 4 mm/hour) and do not exceed 8 mm/day gross application even in hot dry conditions, because plants cannot absorb and transpire water under very high evaporation rates.
5. Apply fertigation chemicals weekly or every two weeks, not daily or monthly. Concentrate on sulphate fertilizers to reduce pH and apply up to 800 kg/ha/annum potassium for a yield of 50 t/ha (reduce pro-rata for lower yield). Use Organic amendments wherever possible.
6. Use wooden props selectively to "rescue" large bunches from falling to the ground and becoming unmarketable.
7. Use perforated white bunch covers to achieve better fruit quality, but only re-use them once before discarding.
8. Do not manage specifically for short fingers (lunch box fingers) but manage for the maximum finger length permissible and go for highest yield and reduced blemish damage.
9. Manipulate harvest maturity according to canopy cover, season and green life requirement to reach Perth (15% increase in bunch weight for every week left on the plant). However, harvest immature if canopy is depleted and wind-torn.
10. Regularly remove old dead leaves hanging from the plant, to reduce incidence of speckle disease, create better hygiene and accessibility, and to improve the important mulch layer.
11. Test for nematodes annually and treat carefully with nematicides if necessary.

<u>Disclaimer – J.C. Robinson</u>

The information and recommendations given in this report are presented in good faith, according to the professional knowledge of the consultant and the application of this knowledge to the conditions of the project being evaluated. No responsibility is accepted by the consultant if, for one or other reason, the client does not achieve the expected results, and/or the assumptions made in the report are not confirmed in practice. No warranty will be given by the consultant as to the accuracy or completeness of the information and opinions expressed within the report.

GOVERNMENT OF WESTERN AUSTRALIA
Department of Agriculture and Food

Growing bananas in Carnarvon, Western Australia

Supporting your success

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Introduction

Banana is an herbaceous plant of the genus *Musa* and is one of the oldest cultivated plants. Banana is native to tropical South and Southeast Asia, and is likely to have been first domesticated in Papua New Guinea. The first recorded appearance of bananas in Australia was near Carnarvon, Western Australia in the early to mid-1800s, planted by Chinese migrants who brought them from their home provinces.

The banana industry in Carnarvon began with a small planting in the 1940s. Since that time the industry has grown and become a mainstay of the region's horticulture industry.

In recent years the area planted to banana stabilised at around 180 hectares. From 2008 to 2012 the average gross value of banana production was $12.5 million although climatic conditions in Carnarvon and Queensland caused significant price fluctuations. The major market for Carnarvon bananas is the Perth metropolitan area.

The industry is based on land flanking the Gascoyne River, upstream from the coast, spanning 18 kilometres. The average yield of banana crops in Carnarvon is higher than the national average at 40-43 tonnes per hectare. Production is periodically affected by cyclones, floods, drought and poor water quality. The major variety grown is the giant Cavendish type, Williams.

Carnarvon banana plantation.
Photo: Sweeter Banana

Damage to banana plantation from the December 2010 flood. Photo: DAFWA

Climate

Banana plants with leaves damaged by wind. Photo: Sweeter Banana

Carnarvon has an arid subtropical climate with hot summers, mild winters and low rainfall, with bananas generally requiring year-round irrigation. Water is sourced from the Gascoyne River and its aquifer. The local environment is favourable for growing bananas with high solar radiation and low humidity. Productivity is greater than in other banana growing areas of tropical north Queensland, subtropical south-east Queensland and northern New South Wales primarily due to higher planting densities.

Disadvantages of the Carnarvon environment are the extremes: temperatures to 46^{o}C, summer humidity below 10 per cent, low rainfall and evaporation rates of up to 15 millimetres per day.

Temperature

The optimum mean monthly (MM) temperature for plant development (leaf emergence and crop cycling) is 32ºC while the optimum temperature for growth (photosynthesis and bunch weight) is 22ºC, with the optimum mean temperature overall being 27ºC.

Carnarvon weather data shows that from December to March conditions are suitable for the correct balance between growth and development. The MM temperatures are not hot enough for very fast development of banana fruit due to:

- cooler night temperatures in parts of the year which decrease the daily mean
- lower daily means in autumn, winter and spring.

The eight months from April to November are very good for optimal photosynthesis and bunch weight.

A balance between growth and development is required because very high MM maximums (32ºC and more) create a fast cycle time but small, poorly-filled bunches, whereas low MM temperatures (22ºC or less) induce very slow cycle times but good quality, well-filled bunches. Carnarvon temperatures are typical of a warm subtropical to Mediterranean climate which has cool, wet winters and hot, dry summers.

Mean monthly heat units are computed from the formula:

(MM maximum + MM minimum / 2) – 14 x number of days in the month.

Annual heat units are the sum of the monthly heat units, which in Carnarvon is 2977**.** The threshold temperature of 14ºC is regarded as the minimum mean temperature for banana growth.

Rainfall and evaporation

The average monthly rainfall and evaporation rates for the DAFWA Gascoyne Research Station are shown in Figure 1 below.

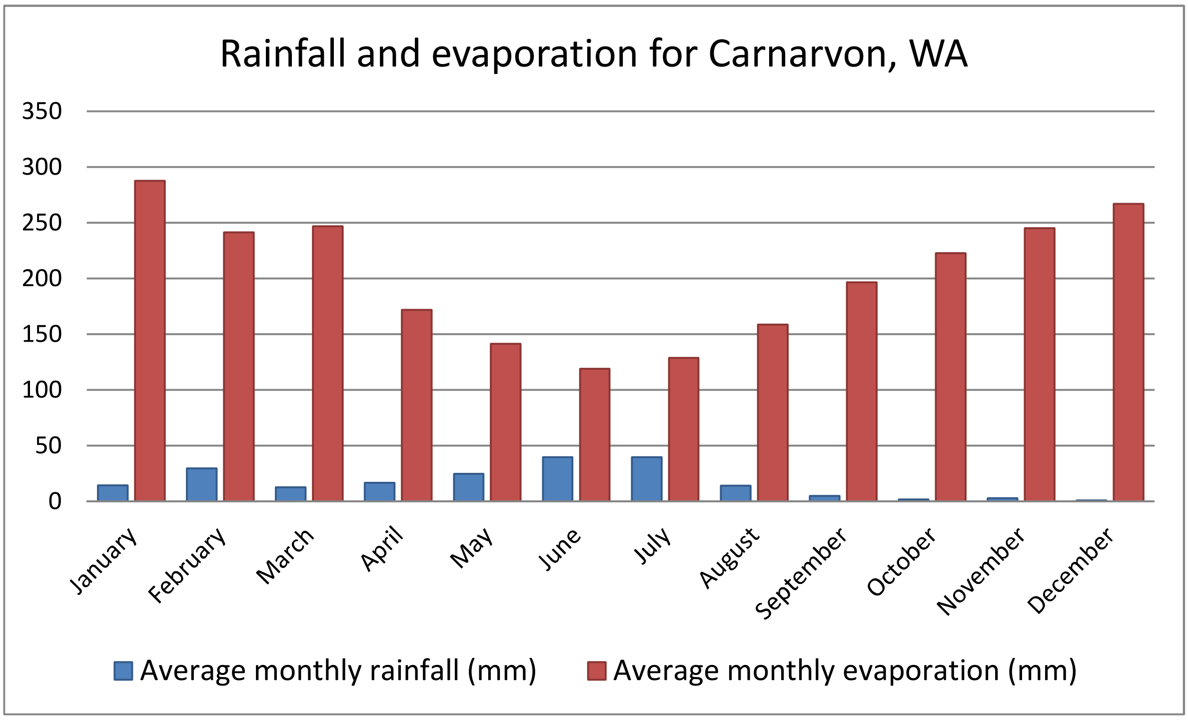


Figure 1 Comparison of average monthly rainfall and evaporation for Gascoyne Research Station Carnarvon

The mean annual rainfall is 232mm of which 36 per cent falls in the warmer months of September to April. There is minimal rainfall during the hot period of the year. Conversely, 64 per cent falls during the four winter months May to August when there is minimal growth potential due to lower temperatures. Consequently, banana growth and productivity are totally dependent on irrigation.

During the spring to autumn period, average evaporation rates are very high, as shown in Figure 1. Annual average evaporation is 2532mm. December and January have the highest daily evaporation rates averaging over 9mm. On hot windy days rates reach 13mm and occasionally have been as high as 15mm, placing great stress on the banana plants.

Wind

Winds are strong in Carnarvon and severe wind stripping of banana leaves occurs. Strong winds blow every month of the year but the strongest winds blow from October to February, during the hot, dry period of the year, increasing evaporative demand.

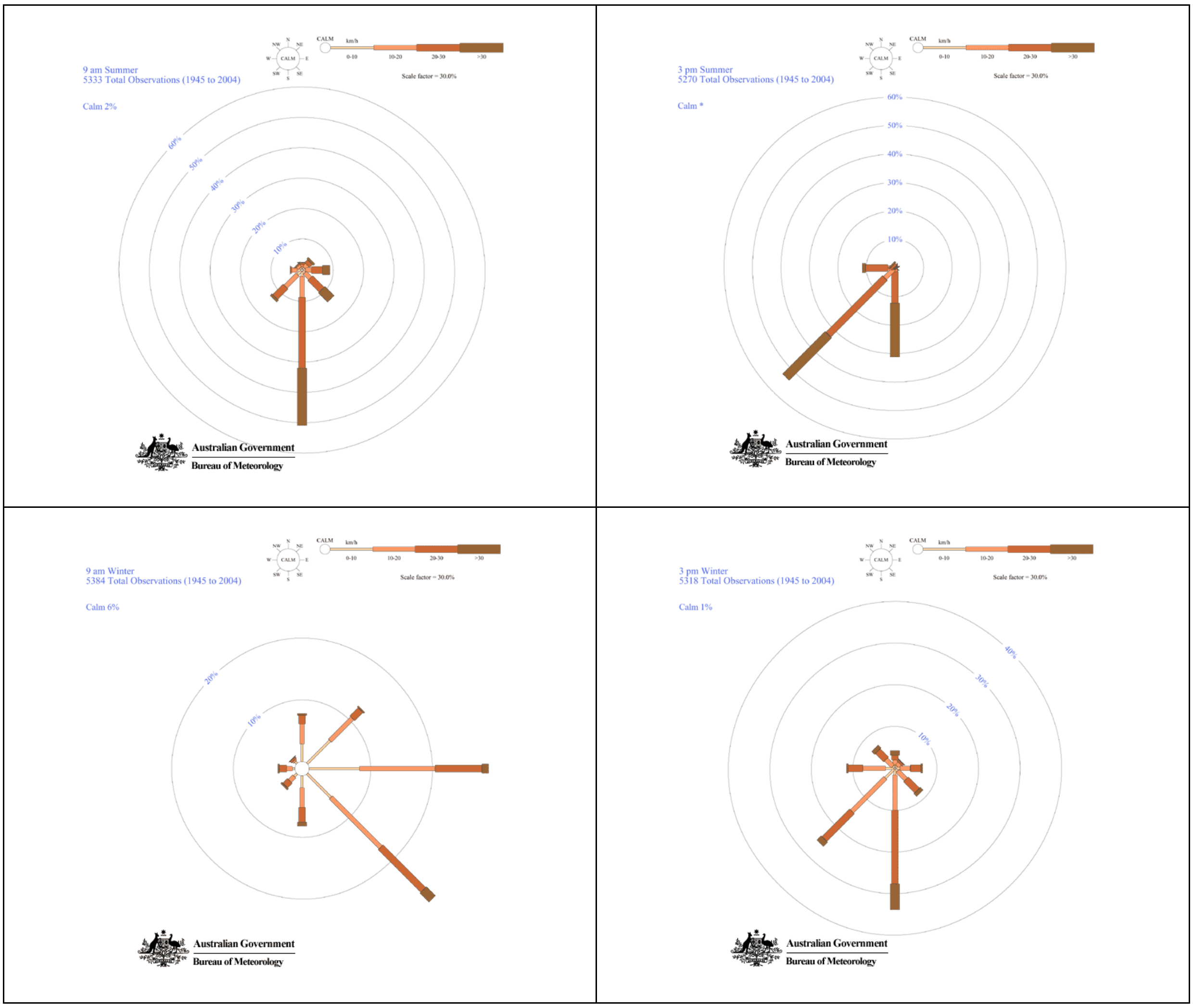


Figure 2 Wind roses for summer and winter at 9am and 3pm

The average maximum wind speed at the Gascoyne Research Station for December and January is 31.0 km/h. High sustained winds drive evapotranspiration but brief gusts cause leaf shear damage. Wind speeds of 10-20km/h reduce fruit quality by increasing leaf and dust abrasion and speeds of 20-40km/h cause leaf tearing which may significantly reduce productivity. Wind speed of 40km/h or more can cause severe leaf tearing in which the lamina shreds may desiccate completely or be torn away from the midrib leaving just the midrib spikes on the plant.

Studies in subtropical South Africa determined that leaf photosynthesis was reduced by 11%, 20% and 33% when banana leaves were torn into strips of 50, 25 and 12mm width, respectively. This damage is due to:

- leaf strips drying out quicker than whole leaves
- leaf strips hanging down where they do not intercept sunlight.

Wind is a major productivity constraint facing banana growers in Carnarvon.

Soil

The alluvial soils that adjoin the Gascoyne River are free draining with uniform texture. Textures vary from loamy fine sands, silty loams to silty clay loams. They have good moisture and nutrient retention capacities but low infiltration rates. Gypsum should be applied pre-planting at 2 tonnes per hectare to increase infiltration.

Bananas grow better where the soil is well structured and has a build-up of organic matter. Well structured soil will have better aeration at depth which gives roots more soil in which to grow.

Gascoyne soils are prone to the development of hardpans at 20 to 30cm as a result of compaction. For good establishment and early growth, this hardpan should be broken up by deep ripping before planting.

When removing old banana plantings and establishing new ones, old crop residues should be disc-ploughed into the soil to assist in accumulating organic matter. The practice of burning old patches is discouraged as residual nutrients are lost to the atmosphere.

Water

Good quality irrigation water is essential. Carnarvon irrigators must stop drawing water from the Gascoyne River aquifer when the TDS (parts per million total dissolved salts) reaches 1000ppm. Published data has identified a 25% yield decline when irrigating with water around 2000ppm TDS.

Anecdotally, productivity will suffer once irrigation water exceeds 600ppm TDS, however there is no local data to support this notion. Water quality from private bores in Gascoyne Sub-Area A will vary with duration since the last river flow, bore depth and rate of abstraction. Water delivered by the Gascoyne Water Co-operative (GWC) varies less as it is a blend from multiple bores. Table 1 shows an analysis of GWC scheme water.

Table 1 Analysis of 2013 water quality for Gascoyne Research Station (GRS) bore water and Gascoyne Water Co-Operative (GWC) scheme water

Analysis (mg/L)	GRS bore water	GWC scheme water
Ammonium Nitrogen	<0.10	<0.10
Nitrate Nitrogen	1.58	0.71
Boron	0.18	0.3
Calcium	51.07	41.39
Chloride	190.72	169.76
Copper	<0.05	<0.05
Iron	<0.05	<0.05
Magnesium	17.98	19.53
Manganese	<0.05	<0.05
Phosphorous	<0.05	<0.05
Potassium	7.33	9.1
Sodium	99.56	94.13
Sulfur	27.52	19.77
Zinc	<0.05	<0.05
Bicarbonate	83.32	111.09
Carbonate	0	0
Conductivity (ds/m)	0.89	0.815
pH	7.1	7.9

Cleaning out Gascoyne Research Station bore. Photo: DAFWA

Varieties

The giant Cavendish type, Williams, is the primary variety grown commercially in Carnarvon. A small area of Grand Nain is also grown. With good management Williams will produce higher yields per hectare than other varieties. It is a tall plant, typically 2.5m in the parent crop and 3.4-3.5m in ratoon crops.

Preparation and establishment

Site selection and site preparation

A soil test should be taken before land preparation starts so that soil amendments such as gypsum can be broadcast. Bananas will grow on most soil types available for horticulture along the Gascoyne River.

Bananas will not perform as well away from the river on the Delta land system soil. This system is characterised by saltbush and other halophytic shrubs. These are sodic soils and require application of gypsum and compost at cost prohibitive rates.

Better soils will also benefit from adding compost or mulch to improve soil physical, chemical and biological fertility. Correct soil preparation will require deep ripping to break hardpans and allow for improved root penetration. Test for nematodes before planting if there is a history of bananas in that patch.

Pre-planting cover crops

High plant density is not favourable for inter-row cover cropping, however cover crops can assist with establishing new patches. With minimal irrigation or if adequate winter rainfall persists, grass or legume cover crops such as oats, sorghum or vetch can be grown and then sprayed out at the vegetative stage with a knockdown herbicide. Banana rows can then be planted into the dry mulch. The dry matter will assist in dust and weed suppression until the banana canopy closes.

Spacing

The effects of plant spacing:

- Bunch size and grade - planting too close will reduce bunch and fruit size.
- Bunch cycling - planting too close will reduce rate of emergence of follower suckers while the parent plant will be slower bunching, with slower filling bunches.
- Disease problems – closer plantings have reduced air circulation, increasing fungal leaf diseases including *Deightoniella*, however leaf diseases are usually not a major concern.
- Cooling – closer planting shades the inter-row, cooling the patch in the summer.

The two most common planting systems result in plant densities of 3333 plants per hectare.

- Plant in rows 3 metres apart with plants 3 metres apart, leaving three suckers per site for the first ratoon crop and then maintaining that density.
- Plant in rows 3 metres apart with plants 1 metre apart, leaving one sucker per site for the first ratoon crop and then maintaining density.

The close planting system requires more planting material but results in significantly higher yields in the parent crop.

The 2009 to 2012 trials of banana under netting at the Gascoyne Research Station have led expert Dr John Robinson to the following conclusions:

"Anticipating the use of a more efficient net structure, I would propose 2200-2500 plants per hectare on a rectangular single row arrangement in which the in-row banana spacing is 1.5m or more. In the open field, where extra canopy protection is needed from wind and heat stress, I would propose between 2500 and 3000 plants per hectare but also on a rectangular, single row and single sucker arrangement."

This lower density is being trialled by some growers.

From left to right: Carlos Ramirez (CGA), Michael Allingame (DAFWA), Dr John Robinson, Dr Chris Schelfhout (DAFWA). Photo: DAFWA

Planting time

Two planting times are used - August to November, and February to March. Most plantings are made from August to November. This gives good establishment and plants become well advanced (2.5 to 3.0m high) before the slow growth period of winter. There are various interacting factors, namely that it takes about 13 months from planting to first harvest if the planting date is September to December, but can be 16 or more months if planting occurs from January to March (DAFWA trials).

Autumn plantings are used in an attempt to have the first crop harvested in winter and spring months when prices are traditionally higher. Trial results at the Gascoyne Research Station have shown that a high density crop planted in March reaches peak harvest in September to November. Growth after March is slow and weed control over winter can be costly.

Planting material

The identification of Panama disease (Race 1) in Carnarvon in 1992 resulted in the recommendation that growers use their own planting material or tissue cultured material.

The main types of planting material are:

- **Sucker:** A good sucker is free from insects and leaf mottling and has narrow tapering leaves. Suckers should only be removed from non-fruiting plants.
- **Pieces or bits:** Portions of the corm with a mature bud or eye. To ensure good establishment, do not plant pieces or bits of less than 1kg. Roots should be pruned to minimise nematode infection.
- **Tissue culture:** Trials worldwide have conclusively shown that yield and uniformity are greater than suckers in the first cycle and that a carry-over yield benefit occurs into the second and third cycles, which pays for the initial cost of the plant. As there are no tissue culture providers, this material would have to be provided by a certified supplier from eastern Australia.

Planting material with the typical internal brown/black discolouration of Panama disease should not be used and should be shown to local DAFWA officers. With a new crop it is important to use planting material of similar size and type as this will result in more even plant growth and crop harvest.

To establish planting material, use a delver to dig a trench 30 to 40cm deep. This is then irrigated and planting material can be easily dug in. The suckers, pieces or tissue culture plants should always be planted with the growing point facing upwards and the soil firmed around them after placement. Customised planting machines have been successfully developed by growers to drop suckers or bits directly behind a moving deep ripper.

Do not fertilise until the new shoot has emerged and two leaves have developed. Replants should be made as soon as it is clear that a plant has not established.

Tissue culture plants used in Gascoyne Research Station netting trial. Photo: DAFWA

Using suckers to plant a new banana patch. Photo: Sweeter Banana

Growing productive plants

Windbreaks

Bananas are very susceptible to wind damage. For crops that are not planted in sheltered areas, some kind of windbreak system is required to avoid yield loss. Trials have shown that wind effect on crops has been observed up to 20m inside the planting.

It is common practice to close-plant the southern end row and allow multiple suckers to provide a barrier against wind. Artificial windbreaks are very effective and used widely.

Windbreaks used for banana planting at the Gascoyne Research Station. Photo: DAFWA

Net structure which gives wind protection from the sides and above. Photo: DAFWA

Irrigation water management

Banana roots

Eighty per cent of banana roots are found in the upper 300 to 400mm of soil, therefore maintaining available water in this layer is essential. Irrigation is probably the most important management factor for bananas in the Carnarvon area where the growing season is hot, dry and windy, and the rainfall does not contribute much to the water demand of the plant. Efficient and controlled irrigation scheduling is of paramount importance on banana plantations.

Soil water-holding capacity

A soil survey to assess soil types on your plantation is a good starting point to plan irrigation strategies.

Soil texture and structure information can be used to estimate soil water-holding capacity. Heavier soil types such as clays require less frequent irrigation, as they are capable of storing more water for longer periods. Sandier soils require more frequent irrigation.

Readily available water (RAW) is the water in the soil that is easily extracted by the plant. This is the amount of water held in the soil between field water capacity and permanent wilting point. Carnarvon banana plantation soils are predominately sandy loams. Table 2 is a guide to the RAW values for various soil textures, using on-farm sampling and soil moisture monitoring to refine this information over time.

Table 2 Readily available water (RAW) for a range of water tension levels for different soil textures (Qassim & Ashcroft 2012)

Soil texture	RAW (mm/m)				Total water available in soil (mm/m)
	A -8 to -20kPa	B -8 to -40kPa	C -8 to -60kPa	D -8 to -100kPa	
Sand	35	35	35	40	60
Sandy loam	45	60	65	70	115
Loam	50	70	85	90	150
Sandy clay loam	40	62	71	101	143
Clay loam	30	55	65	80	150
Light clay	25	45	55	70	150
Medium to heavy clay	25	45	55	65	140

Column A for water-sensitive crops such as vegetables and some tropical fruits.

Column B for most fruit crops and table grapes (most tropical fruits are irrigated between -25 and -40kPa).

Column C for wine grapes (except during partial root drying), most pastures and field crops.

Column D for lucernes, annual pastures and hardy crops.

Example: Banana's effective root zone is 300 to 400mm. The soil has three layers - a sandy loam (0-30cm), a loam (30–80cm) and a sandy clay loam (80-100cm). The refill point is 22kPa.

Calculation for root zone RAW:

Step 1: Identify and measure the soil layers.

Layer 1:	0-0.3m	= 0.3m
Layer 2:	0.3-0.8m	= 0.5m
Layer 3:	0.8-1.0m	= 0.3m

Step 2: Select the crop water tension and identify the RAW for each soil layer.

Crop water tension is 22 to 25 kPa therefore use column B

Layer 1:	Sandy loam	= 60mm/m
Layer 2:	Loam	= 70mm/m
Layer 3:	Sandy clay loam	= 62mm/m

Step 3: Multiply the thickness of each soil layer by its RAW value.

Layer 1:	0.3m x 60mm/m	= 18mm
Layer 2:	0.5m x 70mm/m	= 35mm
Layer 3:	0.3m x 62mm/m	= 18.6mm

Step 4: Add up the RAW stored within the crops effective root zone (use 400mm).

Layer 1 RAW + Layer 2 RAW = 18 + 35
Rootzone RAW= 53mm

In this example, 53mm of water is readily available in the soil for the plant's use. That is 53mm of water is required to refill the plant's effective root zone when the suction on a tensiometer reads 22kPa.

Soil infiltration rate

Infiltration rate is the speed at which water can move through a soil profile. The infiltration rate of a soil determines the maximum rate at which irrigation should be applied. The majority of Carnarvon soils on which bananas are grown have an infiltration rate of around 5 mm/hr. Sprinkler outputs should be matched as closely as possible to the soil infiltration rate to avoid pooling and runoff. It is important to test your own soil infiltration and alter your irrigation accordingly.

Evaporation

The water use of crops is closely related to evapotranspiration, which is the combined water loss from the evaporation of water from the soil surface and transpiration of water through the leaves of plants. In terms of evapotranspiration, the annual water use of the banana crop will be much less than the total evaporation measured, for two main reasons: the reduced ratio of the water used by the plant in relation to evaporation during winter, and the upper limits of the banana plant's potential to transpire water from the leaves in summer.

Evaporation and evapotranspiration data for Carnarvon are available on the DAFWA and Bureau of Meteorology websites.

As plants grow, the proportion of evaporation or evapotranspiration that needs to be replaced by irrigation changes. The differences in water requirements and the proportion of evaporation to be replaced are called crop factors and when using evapotranspiration are called crop coefficients. Both are equally valid but they are not the same.

Crop water use (mm) = crop factor x pan evaporation

The crop factor relates the evapotranspiration from a plant to the rate of evaporation from an open pan.

Or

Crop water use (mm) = Crop coefficient x evapotranspiration

The crop coefficient relates the crop water use to the evapotranspiration of a reference crop.

An example is given below using a crop factor of 0.8 which is for an established banana crop. The average daily evaporation for each month is multiplied by the crop factor to give a daily irrigation requirement for each month.

Table 3 An irrigation schedule using average evaporation (mm/day) recorded at the DAFWA Carnarvon weather station and crop factors

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation (mm/day)	9.7	8.9	8.1	6.7	4.8	4.2	4.0	5.6	6.7	7.3	9.2	9.7
Crop factor	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Irrigation mm/day	7.7	7.1	6.5	5.3	3.9	3.3	3.2	4.5	5.3	5.8	7.3	7.7

Initial crop establishment

When establishing a banana crop, drip tape can be used for up to six months after which the drip tape cannot supply sufficient water. The advantage is that it reduces the amount of weed growth between the banana rows and enables scarce water resources to be targeted to the small growing plants. A disadvantage of this system is that when planting in summer, the young plants will be subject to heat stress and cannot be cooled down by the water spray from a sprinkler.

High evaporation plant response

The banana plant is only capable of transpiring a maximum of 7mm/day even when the daily evaporation is 10mm or more. Under an evaporative demand of more than 7mm/day, the plant wilts at about midday or even earlier, and the leaves fold flat under peak transpiration. Then no further transpiration loss takes place until the evaporative demand eases, which allows the plant to regain turgor and continue transpiring again. In practice this means that the plant loses very little water from early afternoon until the following morning when the plant has regained full turgor overnight. This happens despite there being enough water in the root zone to be taken up, it is simply that the daily loss from the leaves exceeds the replenishment rate from the soil and the plant wilts and remains physiologically non-functional. The higher the evaporative demand the more severe the wilting becomes. It is recommended that a maximum of 8mm/day gross should be applied in summer (about 7mm/day net) to avoid waterlogging in the soil.

Soil moisture monitoring equipment

Use soil moisture monitoring equipment such as tensiometers to fine tune or confirm your irrigation scheduling plan. A range of soil moisture monitoring devices is available, from simple tensiometers to high-tech electronic systems. These devices give you information to cater your irrigation specifically to the soil conditions on your property.

General recommendations for the use of tensiometers in Carnarvon are:

- Three tensiometers installed at depths of:
    - 150mm in the upper part of the root zone
    - 300mm within the root zone
    - 600mm, this is below the active root zone. If this tensiometer is indicating rising soil moisture after irrigation, water is draining below the root zone and being wasted.
- Irrigation is applied when the 300mm tensiometer reading rises to 22 cbars (22 kPa) and the deeper tensiometer is maintained at 15 to 25 cbars (15 to 25 kPa). This ensures that the water applied is maintained in the crops root zone and does not leach below it.
- The frequency of irrigation will vary between summer and winter. In winter the tensiometer readings change slowly. In summer, bananas use water rapidly, so regular monitoring (which may be twice daily in hot weather) of tensiometers or other soil moisture monitoring equipment is required.

Fertiliser

For high yields of quality fruit, bananas require relatively large amounts of nutrients as they extract considerable quantities of nutrients from the soil.

Leaf and soil test should be undertaken annually at the same time each year with assistance from the Carnarvon Growers Association. Sample soil for pH, cation levels and nutrient balances and sample leaf for macro and microelements. To make the analysis information useful, you must maintain and record a fertiliser program for several years. The program should have applications rates of fertiliser and a set system of application times. This provides the information for adjusting your fertiliser program up or down based on long term trends.

Table 4 Typical nutrient range for subtropical bananas from leaf analysis (Reuter & Robinson 1997)

Nutrient **(%)**	Deficient	Low	Optimal	High	Toxic
Nitrogen N	<2.6	2.6-2.8	2.8-4.0		
Phosphorous P	<0.13	0.13-0.19	0.2-0.25	>0.25	
Potassium K	<2.5	2.5-3.0	3.1-4.0	>4.0	
N/K ratio			1:1.0-1:1.2		
Sulphur S	<0.1	0.1-0.2	0.23-0.27	>0.27	
Calcium Ca	<0.5	0.5-0.7	0.5-1.2	>1.25	
Magnesium Mg	<0.20	0.2-0.3	0.30-0.46	>0.46	
Sodium Na			0.01-0.10		
Chlorine Cl	0.8-0.9				
Copper Cu (mg/kg)		3-7	7-20		
Zinc Zn (mg/kg)	<14	14-20	21-35	>35	
Manganese Mn (mg/kg)	<10	25	1000-2200	4000-6000	
Iron Fe (mg/kg)			70-200		
Aluminium Al (mg/kg)			50-240		
Boron B (mg/kg)	<10	10-20	20-80	80-300	>300
Molybdenum Mo (mg/kg)			1.5-3.2		

Nitrogen is the major fertiliser required for bananas in Carnarvon. Nitrogen is important for plant growth and is a key component of chlorophyll. Trials at Gascoyne Research Station have shown that an annual rate of 260kg/ha nitrogen is optimal for yield. This application is best split over 10 months. Bananas grow very slowly in June and July and fertiliser is not necessary.

This is the equivalent of 56 kilograms of urea per hectare per month. An increasing number of growers are using sulphate of ammonia where soil is alkaline in an attempt to lower the pH. The equivalent rate is 115 kilograms of sulphate of ammonia per hectare per month. Both urea and sulphate of ammonia are soluble and can be applied to the crop through the irrigation system.

When using fertigation, split the chemicals for weekly or twice weekly application. Do not apply chemicals daily which lead to excessive dilution, or monthly which causes dissolution problems.

Phosphorus is essential for energy metabolism in plant maintenance and growth as well as good root development. Superphosphate with copper and zinc can be applied at pre-planting, up to 500kg/ha.

Potassium influences water balance, fruit quality and increases the vigour and disease resistance of plants. Bananas use very large quantities, with up to 1050 kilograms per hectare removed in 25 tonnes of fruit.

Calcium is an important element in building cell structure. Plants deficient in calcium are more susceptible to pseudostem collapse. Around 100 kg of calcium is required annually.

Magnesium is used in photosynthesis and protein synthesis - both essential functions of the plant. It should be applied at 300 kilograms per hectare per year.

High pH limits zinc availability in Carnarvon soils and is needed in small quantities. Depending on leaf test results, foliar applications or chelated formulations of zinc can be used to control this deficiency.

Boron is usually higher than required due to high levels in local water and also is present in some soils of the area, so avoid using fertilisers that contain boron. Boron availability is lowest between the soil pH of 8.0 to 9.0. Zinc should be applied when soil and leaf tests show high levels of boron and low availability of zinc.

Other trace elements that are sometimes deficient include manganese, iron and copper.

Organic nutrition is very important but manures and compost are scarce in Carnarvon. Where possible bunch stalks and reject fruit should be applied evenly over the plantation in as high a quantity as possible. This material has high potassium content.

John Robinson, a subtropical banana production expert from South Africa, notes that if total dissolved salts level in soil exceeds 500 parts per million (equivalent to conductivity above 750 microSiemens per centimetre, there may be a risk of some salinity effects. This will normally present as a necrotic band on the leaf margins. This may not be too detrimental but if the signs are there, then remedial action should be taken. Sodium should be less than 2% of the cation exchange capacity, however some soils have a sodium percentage higher than 10% of all cations, which is problematic. To rectify this, apply gypsum so that calcium can displace sodium on the clay colloids, and an occasional ‘leaching’ over-irrigation should be given to remove the released sodium from the root zone.

Irrigation controller. Photo: DAFWA

Fertiliser dosing channels working through the irrigation controller. Photo: DAFWA

Table 5 Replacement nutrients (kilograms per hectare) in a plantation yielding 25 tonnes per hectare (Growing guide: Subtropical banana growers handbook)

Nutrient	Kg/ha removed in fresh fruit	Kg/ha remaining in plant parts	Total (kg)	Proportion removed in fruit (%)
Nitrogen	95	199	294	32
Phosphorus	15	23	38	39
Potassium	390	660	1050	37
Calcium	50	126	176	28
Magnesium	25	76	101	25
Sulphur	11	50	61	18
Chlorine	38	450	488	8
Sodium	0.8	9	9.8	8
Manganese	0.25	12	12.25	2
Iron	0.45	5	5.45	8
Zinc	0.25	4.2	4.45	6
Boron	0.35	0.57	0.92	38
Copper	0.1	0.17	0.27	37
Aluminium	0.1	2.0	2.3	4
Molybdenum	-	0.0013	-	-

Table 6 Example of fertiliser program for a yield of 50 tonne per hectare, which can be obtained from the Carnarvon Growers Association

Product	Kg/ha/year	Proportion active	Kg active
Potassium sulphate	2000	0.42	840
UAN (Flexi-N)	1400	0.32	448
Magnesium sulphate	160	0.96	15.36
MAP	160	0.22	35.2
Zinc sulphate	48	0.215	10.32
Manganese sulphate	40	0.31	12.4
Iron sulphate	4	0.19	0.76
Copper sulphate	4	0.25	1
Calcium nitrate	530	0.19	100

Weed control

Weeds must be controlled for 12 to 15 months after planting. That is, until the crop has developed full canopy. If plantings are made on a furrow system, the need for weed control will be reduced.

Non-translocating contact herbicides are the safest option to control weeds when they are small. Take care to avoid herbicide contacting the banana stems. If the paddock is infested with weeds such as nutgrass or couch, repeated applications of an effective herbicide will be required.

Weedy banana patch.
Photo: DAFWA

Carnarvon banana productivity potential

Productivity potential is defined as the marketable yield potential in tonnes per hectare per annum. This comprises three components:

- ratoon crop cycle time
- bunch mass potential
- percentage marketable fruit.

Thus if one calculates on the theoretical basis of the district average of 20kg marketable fruit per bunch, a plant density of 3333/ha, and ratoon cycle time of 12 months, the average annual yield potential in Carnarvon would be in the region of 66 tonnes per hectare per annum which is very high. Some growers do achieve this level, but in reality the average farm yield is around 40 tonnes per hectare per annum which is still quite high but the potential marketable yield is not reached due to many factors such as:

- severe wind damage to leaves
- premature harvesting of fruit
- blemish damage to fruit
- heat stress in open, damaged plantations
- three bearing stems growing in one position
- use of sucker planting materials
- high percentage of choke throat
- tendency to over-irrigate
- irregular trashing and desuckering.

The factors contributing to high potential yield in Carnarvon are:

- ability to achieve a 12 month ratoon crop cycle at a density of 3333 plants per hectare
- high summer heat to encourage plant development
- long summer days with high photosynthesis potential with average of only two to four cloudy days per month from September to March
- acceptance of short fingers on the Perth market which increases the amount of marketable fruit.

Crop management

Healthy, vigorous planting material that is well looked after will bunch inside 12 months with first harvest by 18 months. Good growing conditions give best returns of high quality, high value fruit. That means managing soil fertility, irrigating appropriately and controlling competition from sucker and weed growth.

De-suckering and selection of followers

De-suckering and the selection of followers is a critical management operation. De-suckering should be done several times in the early stages of crop growth. The first selective de-suckering of a banana crop is done about six months after planting. The selection of the follower/s is then made, aiming for strong growing spear point sucker/s.

The following sucker should be one that has developed directly from the parent plant. Choose vigorous sword suckers that originate from deep seated buds. Vigour is essential because it indicates the place of origin. Deep-seated suckers are less prone to blowing over. They usually develop well out (about 10 to 15cm) from the parent plant. All sucker growth that occurs after follower selection should be removed before they reach 30cm in height until the time for selection of the second follower. If unwanted suckers are left to grow larger they take nutrients from parent plants and reduce yield. If using the 1111 plants per hectare with three following suckers, ensure they are evenly spaced about the parent plant.

There are several methods of de-suckering, the most common being the use of backpack with injection gun. Kerosene is the most common agent injected low into the centre vascular tissue of the sucker. Other methods include gouges to remove the growing tip of the sucker. When de-suckering tissue culture plants, care should be taken not to remove all vigorous suckers that are initiated early in crop growth. If these are removed there may be no follow-up suckers and choice of material at selection time is limited.

Trashing

As a banana plant grows the older leaves die back and should be removed. This practice is called trashing. This process is labour intensive and should be done on a regular basis to avoid dry leaves rubbing on bunches.

Trashing increases light infiltration into the plantation and reduces fruit marking. Trashing also removes leaves that can harbour pests and disease. The banana bell should also be removed when trashing as it will result in nutrients and reserves translocating to the fruit. Removal of the bell can be done about two weeks after the last hand has set on the bunch and can increase bunch weight by 0.5 to 1.5kg. The bell should be removed close to its base to avoid necrotic tissue affecting the fruit.

Bunch covering

Bunch covering is used in most banana growing areas of Australia and has a number of advantages.

- up to 15% higher yield and quality through increasing temperatures in the bag (especially in winter)
- reduced sunburn on outside bunches
- Fewer fruit blemishes from leaf rub
- More even fruit filling

A colour coding system on bags can be used to monitor bunch maturity.

Bunch covering on Carnarvon banana plantation. Photo: Sweeter Banana

Bunch propping

Trials at Gascoyne Research Station found that in bananas with adequate nutrition the requirement for propping was minimal. Plants with poor calcium nutrition, or on three by three spacing with three stems were more susceptible as stems tended to angle away from the base of the plant. The Williams variety benefits from propping under high input/high yield systems. The best practice is to double prop at or before bunch covering.

Double and triple propping Cavendish bananas in NSW. Photo: DAFWA

Bunch pruning

Bunch pruning is done to remove smaller fruit from the bottom of the bunch. Brunch pruning speeds up the filling of fruit and in cooler subtropical areas where low temperatures restrict the capacity of the plant to fill all fruit on the bunch adequately during winter. It is usual practice to leave a couple of fruit on the lowest hand to avoid rotting back of the bunch stalk.

Re-planting an existing plantation

Planning for replanting commences before the original bananas are destroyed.

Prior to killing the old bananas, a cover crop should be planted. This can then establish as the banana plants are dying. The best method of killing banana plants is to inject them with a systemic herbicide. Do not cut down plants before injecting them with herbicide as the leaves need to remain on the stool for the herbicide to work. This will clear the old crop while causing a minimum of soil disturbance.

After six months the trash can be disc ploughed back into the soil to build up the organic matter.

Physiological/climatic disorders

Bunch choking

Bunch choking or choke throat occurs when the bunch does not emerge normally from the pseudostem. It is common in winter and will vary year to year depending on the severity of winter. Choking can also be caused by high temperatures and drought.

Bunch choking at the Gascoyne Research Station. Photo: DAFWA

Underpeel discolouration

Underpeel discolouration develops when bunches are exposed to temperatures under 12ºC and the fruits ripen to a dull grey/yellow colour.

November dump

Very cold weather (less than 6^{o}C) at the time of bunch initiation can lead to what is known as November dump fruit. As the name implies this is a problem with bunches that emerge in November after initiating in the winter months. Occasionally a bunch will 'spit' out of the side of the pseudostem, often also as a result of 'choking'. Bunches have hands on which some fruit is poorly developed, twisted and ripens earlier, making maturity hard to gauge and packing even harder. It is a more notable problem after cold winters.

Hot weather bunch loss

In Carnarvon bunch loss through peduncle (bunch stem) snap and pseudostem breakage are common. Heaviest losses occur from October to March when strong winds, high temperatures and low humidity cause moisture stress, a factor believed to be responsible for weakening banana pseudostem.

Trials at the Gascoyne Research Station showed fewer bunch losses in the parent crop compared with the first ratoon crop. This could be from the disproportionate increase in height and bunch weight relative to girth that occurred with the ratoon crop, making it more susceptible to breakage.

A trial in 1990 at the Gascoyne Research Station showed that delayed irrigation and high evaporative demand increased bunch losses.

The use of props to support the bunch may reduce the mechanical forces sufficiently to reduce bunch loss; however this has not been shown by experimental data that support this under Carnarvon conditions.

Sunburn

High air temperatures, usually above 38ºC and high solar radiation are associated with sunburn damage on exposed fruit, especially on the top hands of the bunch. If the temperature increases above 40ºC a temporary wilt occurs in which the transpiration demands exceeds the ability of the root system to extract water, leading to bleaching and/or burning on wilted leaves.

Mild sunburn (pale markings).

Mild sunburn (note the dark patch on the left hand banana is rub damage).

Pests and diseases

Carnarvon is free of many of the pests and diseases that require control in other banana-producing regions of Australia. Carnarvon banana growers use very low rates of chemicals and pesticides in comparison with other growing regions.

The following are a list of those that are present and that cause minor or sporadic yield loss.

Pests

Aphids, mealybugs and scales

Aphids on weeds in banana patch. Photo: DAFWA

Aphids, mealybugs and scales appear on plant parts in clusters and feed on the sweet sap by inserting a needle-like sucking tube into the plant and drawing out the juice. After the sap has been used by the insects, it is excreted as honey dew, which forms the base on which a black fungus grows. This fungus is known as sooty mould and its presence reduces photosynthesis and discolours the affected fruit. Ants are often seen feeding around aphids, mealybugs and scales as they are attracted to their secretions. Affected plants appear water stressed and leaves turn yellow and fall. In some cases leaves and flowers curl up and wilt. Aphids, mealybugs and scales all have potential to transmit viruses between plants, but aphids are the most likely transmitters.

Ants herding mealybugs on banana. Photo: Scot Nelson, Flickr

Natural predation by lacewings, ladybird beetles, hoverflies and earwigs is the standard control method in Carnarvon. When population levels are high there are a number of insecticides available for use in Western Australia.

Predator of aphids, transverse lady beetle larvae, *Coccinella transversalis.*
Photo: Sonya Broughton, DAFWA, Bugwood.org

Banana spider mite and two spotted mite

Two spotted mite, *Tetranychus urticae.*
Photo: Sonya Broughton, DAFWA, Bugwood.org

Banana spider mite, *Tetranychus lambi* (also known as strawberry spider mite) and the two-spotted mite, *Tetranychus urticae* are minor though frequent pests with activity in the dry, warm spring and summer months. These two mites are similar; however the two-spotted mite leaves fine webbing and has two conspicuous black spots on the body. Damage is mainly confined to the underside of the leaves and first appears as isolated bronzed rusty patches. In severe outbreaks the mites can damage the fruit also.

Fruit damage by banana spider mite is found mainly on the cushion end of the fingers close to the bunch stalk. Two-spotted mite damage appears as silver grey patches to the tips of fruit fingers.

Severe leaf damage from mite feeding
Photo: Bill Farnsworth, Flickr

Dry dusty conditions favour the build-up of mites. Reducing dust on tracks or the use of overhead sprinklers can reduce numbers. Predatory mites and ladybird beetles are important biological controls of mites in bananas. Broad-spectrum insecticide treatments for other pests frequently cause mite outbreaks, so avoid these when possible. Sprays of water, insecticidal oils, or soaps can be used for management. Always monitor mite levels before treatment.

Banana tree badly affected by mites showing severe leaf bronzing damage to underside of leaves and some leaf margins.
Photo: Bill Farnsworth, Flickr

Leaf bronzing damage from mite feeding. Photo: Bill Farnsworth, Flickr

Silverleaf whitefly

Silverleaf whitefly, *Bemisia tabaci* is a small sapsucking pest, like aphids. Whitefly are usually found on the underside of leaves, often in large numbers. When leaves are disturbed clouds of white flying insects can be seen. Whitefly damage plants directly by sucking sap from leaves and indirectly by transmitting viruses and producing honeydew. Silverleaf whitefly rapidly develop resistance to pesticides.

Spur-throated locusts

The spur-throated locust, Austracris guttulosa, causes damage to both the leaves and fruit of bananas by chewing. It is a subtropical species of northern Australia, but extends its habitat into areas experiencing wet summers. The control of spur-throated locusts in the nymph stage is generally not economical. Adult locusts in medium to high density swarms (11-50 per square metre) pose a significant economic threat, however large numbers rapidly replace those that are destroyed. The most effective control is achieved by aerial spraying of swarms that are roosting in trees during the evening. Green GuardTM a biological control agent is another control option.

Spur-throated locust
Photo: Michael Jefferies, Flickr

Spur-throated locust damage to bananas. Photo: DAFWA

Sugar cane bud moth

Sugar cane bud moth, *Opogona glycyphaga* damage the skin of the fruit. The adult is a small (10mm long and 2mm wide) brightly coloured moth with elongate bright yellow antennae. General predators such as spiders contribute to control.

Thrips

Thrips are small, slender, soft bodied insects, just visible to the naked eye. Three species are present in banana plantations in Carnarvon: banana flower thrips (*Thrips hawaiiensis*), banded greenhouse thrips (*Hercinothrips femoralis*) and banana-silvering thrips (*Hercinothrips bicinctus*). Thrips are highly secretive and can be found in flowers, between touching fruit or deep in the leaves. General predators such as ladybird beetles and lacewings assist in reducing populations.

Nematodes

Nematodes are microscopic translucent round-worms, sometimes referred to as eelworms. Many are found in soil. Nematodes make up about 80% of the animals on earth with millions in every handful of soil. They are important to ecosystem health and function. Some nematodes feed on other microbes such as fungi and bacteria, helping to recycle nutrients; others are potential pests feeding on plant roots.

A 2009 DAFWA survey of Carnarvon banana plantations determined the presence of two pest species of nematodes: root knot nematode (RKN, *Meloidogyne* spp.) and spiral nematode (*Helicotylenchus multicinctus*). The burrowing nematode (*Radopholus similis*), which is a widespread economic pest in many banana growing areas was not present in 2009 but was found in a 2002 survey.

Healthy roots
Photo: Tony Pattison

Less severe burrowing nematode (Radopholus similis)
Photo: Tony Pattison

Severe burrowing nematode (Radopholus similis)
Photo: Tony Pattison

Root-knot nematode (Meloidogyne spp.)
Photo: Tony Pattison

Plant parasitic nematodes feed on the roots of live plants and the damage impacts on the plant's ability to uptake water and nutrients. Therefore, above-ground symptoms caused by nematodes can be difficult to detect, and are often confused with symptoms of nutrient deficiency. Nematode-infested plants grow slowly, may have yellowing leaves, wilt easily and are more prone to infection by other diseases. Typically, bunches are smaller and their bunching cycle is longer. Typical symptoms of RKN are the presence of galling, swelling and lumps on the roots. Spiral nematode symptoms are superficial lesions on root surfaces and destruction of feeder roots.

Monitoring for nematodes

To manage crops effectively, nematode populations should be monitored yearly so that if issues arise appropriate measures can be incorporated into management plans. Growers can monitor banana plants by digging up roots for assessment of nematode damage. For assessment of crops, sample uniformly over the block at bract fall. Don't sample during winter when nematodes slow their activity.

From each block take 20 samples. Collect plant roots by digging a square of soil from the base of the plant approximately 25cm wide x 25cm deep. From the 20 samples randomly choose five roots (5 x 20 = 100) and place in a bucket and rinse to remove loose dirt.

First assess roots externally for symptoms of root knot nematode. Typical RKN symptoms are swellings, galling and lumps on the roots. Next, cut each root lengthwise to assess for internal damage. RKN females look like clusters of dark brown spots and necrotic (dead) areas. Symptoms of plant parasitic nematodes such as spiral or root lesion nematode may appear as brown or black lesions that do not penetrate far into the root tissues. These can be distinguished from burrowing nematode root symptoms that include purple to black lesions extending deeper within the epidermal and cortical tissues.

If nematode issues are indicated by crop monitoring, it is recommended that professional advice is sought and more accurate assessments determined. This is important as different nematodes species may be best managed by specific treatments or management plans. Samples can be sent to trained diagnosticians like DAFWA's *AGWEST* Plant Laboratories.

Developing and maintaining soil health is important for nematode control. Healthy soils create a more competitive environment for plant parasitic nematodes and can reduce their impacts. Good soil health management practices such as crop residue placed around the base of the banana plant and less nitrogen fertiliser have been shown in Queensland to reduce the numbers of plant parasitic nematodes.

Consult Carnarvon Growers Association for current recommendations and appropriate registrations.

Fallout caused by plant parasitic nematodes
Photo: Tony Pattison

Diseases

Cucumber mosaic virus

This virus is spread by aphids and is most common on young banana plants from late summer or early spring plantings. Infected plants exhibit yellow-green mottling on the leaf blade and wrinkling of young leaves. Rotting of the heart leaf can also occur. Infected plants should be removed and destroyed to avoid further transfer of the virus into the crop.

Cucumber mosaic virus on banana inflorescence.
Photo: Scot Nelson, Flickr

Cucumber mosaic virus on banana leaf.
Photo: Scot Nelson, Flickr

Fruit speckle

Fruit speckle (*Deightoniella torulosa*) or salt and pepper spot is a problem in Carnarvon in winter. It can be recognised by the small grey to black spots (approximately 2-4mm) on the fruit. The fungus that causes this survives on banana trash. During wet humid weather its spores are discharged into the air and land and develop on banana fruit.

The removal of all old, dry leaves to the ground removes the spore load from the canopy reducing the incidence of fruit speckle.

Biosecurity

Pests and disease of national biosecurity importance

Banana blood disease

Blood disease is a serious bacterial wilt pest caused by a bacterium. Initial symptoms are yellowing and wilting of leaves, which die and can form a skirt of dead leaves around the plant stem. Fruit may appear unaffected but when cut open the pulp displays reddish-brown discolouration and may be rotten or dry. This discolouration gives the disease its name.

Plant with dead leaves
Photo: RI Davis NAQS DAFF, PaDIL

Internal browning of fruit
Photo: RI Davis NAQS DAFF, PaDIL

Internal necrotic streaks of peduncle. Photo RI Davis NAQS DAFF. PaDIL

Bacterial ooze emerging from cut surface of peduncle. Photo RI Davis NAQS DAFF. PaDIL

Black sigatoka

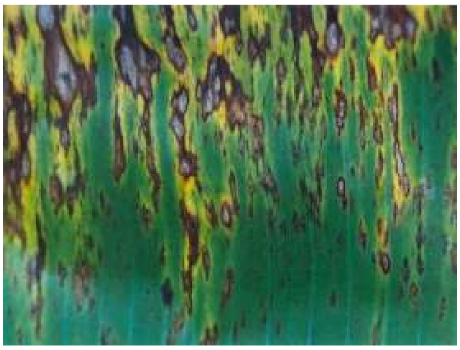
Black sigatoka (otherwise known as black leaf streak) caused by the fungus *Mycosphaerella fijiensis* is one of the most devastating banana leaf diseases around the world. The first symptoms are small (1mm) reddish-brown flecks on the lower leaf surface that gradually increase in size to form dark linear streaks (4-12mm) parallel to the leaf veins that are visible on both leaf surfaces. As the streaks mature they expand, becoming oval spots often with a distinctive yellow halo. Fruit losses occur due to the lack of functional leaf surface area.

Black sigatoka remains exotic to Australia but outbreaks have occurred and been eradicated in north Queensland in the Cape York area during the 1980s and 1990s and Tully in 2001.

Stage 2 – first streak stage Photo: RA Peterson, DPI&F, PaDIL

Internal necrotic streaks of Stage 3 – second streak stage Photo: RA Peterson, DPI&F, PaDIL

Stage 4 – first spot stage. Photo: RA Peterson, DPI&F, PaDIL



Stage 5 & 6 – second and third spot stage. Photo: RA Peterson, DPI&F, PaDIL

Moko

Moko is a devastating bacterial disease caused by *Ralstonia solancearum* race 2. Moko is closely related to banana blood disease and symptoms can be confused with those caused by Panama disease. Moko causes yellowing and wilting of leaves that eventually die and collapse. Younger leaves may develop pale green or whitish panels, before dying. The disease may cause the suckers to wilt.

Wilting of adult plants
Photo: L Gasparotto, PaDIL.

Fruit internal rot
Photo: L Gasparotto, PaDIL.

Vascular discoloration on peduncle
Photo: L Gasparotto, PaDIL.

Vascular discoloration on rhizome
Photo: L Gasparotto, PaDIL.

Banana bract mosaic disease

Banana bract mosaic disease is caused by the banana bract mosaic virus (*Potyvirus*). It reduces bunch weights with fruit rejection in severe cases.

Symptoms on the pseudostem. Photo: JE Thomas, PaDIL

Symptoms on a bract. Photo: JE Thomas, PaDIL

Spindle-shape chlorotic lesions on the leaf. Photo: JE Thomas, PaDIL

Symptoms on a bract. Photo: JE Thomas, PaDIL

Banana freckle

Banana freckle, Cavendish strain, is caused by several species of fungi *Phyllosticta Guignardia*. The pathogens infect banana leaves and fruit. Numerous, minute brown to dark brown spots up to 4mm occur on the upper surface of older leaves. The lesions are rough to

Large spots on leaf of cv. Lady Finger. Photo: S Van Brunschot, PaDIL

Small spots on leaf of cv. Lady Finger. Photo: S Van Brunschot, PaDIL

touch

.

Symptoms on leaf. Photo: K Grice, PaDIL

Symptoms on leaf. Photo: K Grice, PaDIL

Pierce's mite

Banana spider mite, *Tetranychus piercei,* is an exotic spider mite that attacks a range of tropical fruit including banana. Also known as banana leaf mite and banana red mite.

Banana skipper butterfly

Banana skipper (*Erionota thrax*) butterfly is from Southeast Asia, where the caterpillars (larvae) cause major damage to infested plants. It is also known as the banana leaf roller.

Dorsal and ventral views of wings
Photo: K Walker. PaDIL

Dorsal view
Photo: K Walker. PaDIL

Larvae
Photo: K Walker. PaDIL

Live Adult
Photo: D Sands, PaDIL

Eumusae leaf spot

Eumusae leaf spot caused by the fungus *Mycosphaerella eumusae,* is one of three closely related fungi that cause devastating leaf spot disease on banana. Symptoms are very similar to black sigatoka and yellow sigatoka.




Primary lesions are brown streaks that expand to form large brown spots. As the disease progresses, spots become grey in the centre but keep a brown border. Photos: K Grice, DAFF Qld

Banana Xanthomonas wilt

Banana *Xanthomonas* wilt (caused by *Xanthomonas vasicola* pv. *musacearum*), known as BXW, is a devastating bacterial disease in Africa. BXW is so severe that it can kill whole plants within a month of the first appearance of symptoms. The disease causes loss both through death of the plant and rotting of the fruit. The leaves gradually turn yellow and appear lifeless as if melting under intense heat. They eventually turn brown and die. The first symptoms of insect transmission are a drying rot and blackening of the male bud that start with the outer bracts and eventually extend to the rachis. The fruits ripen unevenly and prematurely, turning rapidly from green to yellow and black. The pulp of the rotting fruits shows rusty brown stains. Internal symptoms revealed by a cross-section of an infected pseudostem are yellow-orange streaking of the vascular tissues and yellow bacterial ooze, which can also be seen from any other infected plant part.

Banana sucker infected with BXW
Photo: IITA, Flickr

Banana fruits infected with BXW
Photo: IITA, Flickr

Banana fruits infected with BXW
Photo: IITA, Flickr

BXW infected banana plants
Photo: IITA, Flickr

Pests and disease of state biosecurity importance

Banana bunchy top virus

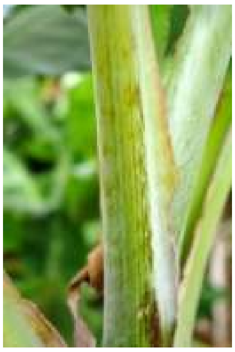
Banana bunchy top virus (BBTV) is a worldwide problem, characterised by the 'bunched' appearance of newly emerging leaves, and dot-dash flecking of leaves and stem sheaths. Affected plants do not produce fruit

Banana bunchy top virus is a regulated banana pest under official control in Australia. It is currently present in the southern areas of Queensland and northern New South Wales.

Plant stunting, reduced internode distance, mottled petioles and leaf.
Photo: Scot Nelson, Flickr

Morse code and green j-hooks in a banana leaf
Photo: Scot Nelson, Flickr

Mottled banana inflorescence
Photo: Scot Nelson, Flickr



Petiole mottling
Photo: Scot Nelson, Flickr

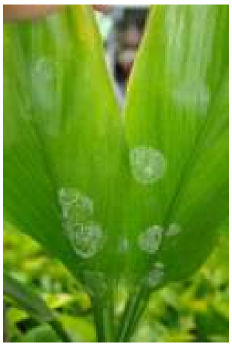
Banana rust thrips

Rust thrips feeding injury
Photo: Scot Nelson, Flickr

Banana rust thrips (*Chaetanaphothrips signipennis)* lives in colonies in sheltered places on the banana plant, especially behind the bases of leaf stalks. When they infest flower or fruit bunches their feeding blemishes the fruit. Rust thrips occurs in coastal areas of Queensland and northern New South Wales.

Spiralling whitefly

Spiralling whitefly (*Aleurodicus disperses*) is not a fly, but related to the aphids. The name is derived from the silken spirals that females produce when laying eggs on foliage and fruit. Spiralling whitefly is present in Queensland and Darwin in the Northern Territory. The pest has natural enemies such as the parasitic wasp *Encarsia* which is effective in an integrated management approach.

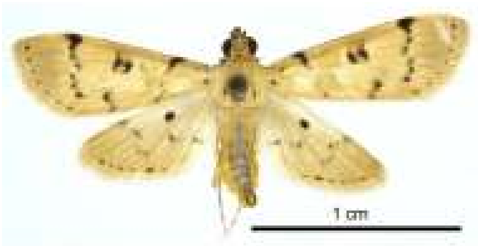


Spiraling whitefly on *Cordyline fructicosa*
Photo: Scot Nelson, Flickr

Spiralling whitefly colony
Photo: David Cappeart, Michigan State University, Bugwood.org

Banana scab moth

Banana scab moth (*Nacoleia octasema)* is a serious pest in Queensland. Cultural and biological control methods have not yielded any positive results to date, and the only effective chemical control is by injection of insecticide into emerging banana bells.



Adult dorsal view
Photo: B Rhode, PaDIL

Adult wing
Photo: B Rhode, PaDIL

Panama disease

Panama disease (also known as *Fusarium* wilt) is a serious wilt caused by the soil-borne fungus, *Fusarium oxysporum* f.sp. *cubanense*. There are four races of the fungus with Race 4 posing the greatest threat to the Western Australian banana industry. Race 4 has two 'sub races', Subtropical Race 4 and Tropical Race 4. Tropical Race 4 has the potential to be particularly damaging as it can attack unstressed plants. Subtropical race 4 is present in south-eastern Queensland and north-eastern New South Wales. Tropical Race 4 is present in most banana growing areas of the Northern Territory.

Outbreaks of Race 1 have been recorded in Carnarvon since 1949 on plantain bananas that were used as windbreaks. Regulations were introduced in 1966 that resulted in removal of the plantain windbreaks. Further regulations were introduced in 1993 prohibiting the movement of banana planting material and soil out of the Carnarvon Horticultural Area.

Panama disease invades plants through the roots and blocks the vascular tissue, cutting off the supply of water and nutrients. The first symptoms are yellowing and dying of leaf edges, often mistaken for effects of water stress. Vertical splitting of the corm at ground level may also be an early indicator. Internally, the water conducting tissue becomes discoloured turning a reddish brown to maroon colour.

If any symptoms such as these are noted when harvesting and cutting down plants please contact the Pest & Disease Information Service on 1800 084 881.

Internal necrosis of banana pseudostem
Photo: Scot Nelson, Flickr

Wilt of Panama disease
Photo: Scot Nelson, Flickr

Splitting of the base of the pseudostem
Photo: L Gasparotto, PaDIL

Symptoms on rhizome
Photo: LJ,Smith PaDIL

Pests and disease of local biosecurity importance

Yellow sigatoka

Yellow sigatoka leaf spot is a serious fungal (*Mycosphaerelia musicola*) disease present in NSW, Queensland, NT and also Kununurra.

The first signs of infection are pale yellow streaks about 10mm long on the third or fourth youngest leaves. These change to brown, and enlarge to oval spots. Later they develop into grey spots with a thin brown or black border and yellow halo. If infection is severe, the leaves become brown with black and grey streaks.

Symptoms of black sigatoka are similar to yellow sigatoka, except the streaks are rusty red to brown developing to black. Yellow sigatoka can mask any outbreak of the exotic disease black sigatoka, as both look similar. This means effective controls on yellow sigatoka lower the potential threat posed by an outbreak of black sigatoka.

Yellow sigatoka on leaf
Photo: Bill Farnsworth, Flickr

Banana leaves with yellow sigatoka lesions. Photo: Bill Farnsworth, Flickr

Banana leaves infected with severe yellow sigatoka. Photo: Bill Farnsworth, Flickr

Banana leaf infected with advanced sigatoka. Photo: Bill Farnsworth, Flickr

Yellow sigatoka is more widespread than black sigatoka as it can proliferate at lower temperatures and lower relative humidity.

Yellow sigatoka is very difficult to control under hot wet conditions. An integrated disease management program involving both cultural and chemical measures is required for effective control. Cultural controls include keeping the plant growing vigorously and deleafing throughout the year.

Integrated pest management

Integrated pest management or IPM is an integrated program that involves less reliance on chemicals by using all or several complementary control measures.

- Use pesticides only if pest monitoring indicates there is a need.
- Use cultural control methods such as crop hygiene and insect-free planting material.
- Allow beneficial species to build up — use chemicals sparingly and carefully target all chemical treatments.
- Apply chemicals properly — using the correct equipment that is calibrated and maintained to avoid crop damage and excess residues.

Apply cover sprays to the whole plant only if essential — sprays should be used only after careful selection of an appropriate chemical with minimal adverse effect on beneficial insects.

Monitoring of plantation for pests and diseases

Pest monitoring is a critical component of IPM and is based on pest action or critical threshold levels. The action level is the point at which damage is roughly equivalent to the cost of control.

Climatic conditions, insect mobility, duration of life cycle, potential crop damage and crop stage determine the frequency of monitoring.

Biological control of banana pests

Banana plantations can be home to a large number of beneficial organisms that provide a degree of pest control. Predatory ladybird beetles, lacewings, bugs, ants and parasitic flies and wasps are the main beneficial insect groups active in banana plantations. Spiders and frogs are other major groups of predators of banana pests.

Within the plantation different species of pests and beneficial occupy different habitats. Some prefer the leaves, others on bunches, while others are more common on the ground amongst the leaf litter.

Garden orb weaver in banana patch
Photo: DAFWA

Transverse ladybirds, predators of soft-bodied insects, such as aphids
Photo: DAFWA

Green lacewing, a general predator of a wide range of pests including aphids, moth eggs and small larvae, scales and whiteflies.
Photo: Bill and Mark Bell, Flickr

Lizard in banana patch
Photo: Sweeter Banana

Farm biosecurity

Six simple, routine farm practices that can reduce the threat of new pests entering and establishing on your property are:

1. Make sure you, your farm workers and contractors are familiar with the most important banana pest threats. Conduct a biosecurity induction session on your farm to explain hygiene practices for people, equipment and vehicles.

2. Obtain clean planting and propagation material from reputable sources to reduce the risk of introducing new pests and diseases to your property. Keep records of your farm inputs.

3. Good sanitation and hygiene will help prevent the entry and movement of pests onto your property. Workers, visitors, vehicles and equipment can spread pests, so make sure they are decontaminated before they enter and leave your farm. Have a designated visitor's area and provide vehicle and personnel disinfecting facilities.

4. Monitor your crop frequently. Knowing its usual appearance will help you recognise new or unusual events and pests. Keep written and photographic records of all unusual observations. Constant vigilance is vital for early detection of any exotic plant pest threat.

5. Support and be aware of laws and regulations established to protect the banana industry, Australian agriculture, and your region.

6. If you suspect a new pest – report it to the Exotic Plant Pest Hotline 1800 084 881.

Harvesting and postharvest

Harvesting

Bunches are harvested when the fruit has lost its angular appearance. When fruit begins ripening after harvest the sugar levels in the pulp increase. As this happens water is drawn from the skin into the pulp, the pulp swells and the skin gets thinner. This causes fruit that is too full at harvest to split. Fruit which looks round at harvest is too advanced to survive the commercial ripening process intact.

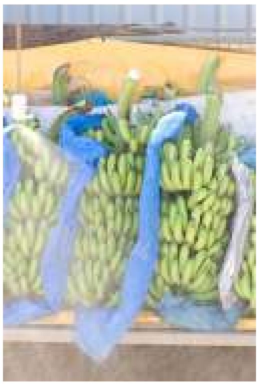
Harvesting is best done by teams of two people, with one person cutting and the other carrying the bunch. Banana bunches are harvested by nicking the pseudostem at about head height to allow the bunch to fall slowly to the carrier’s shoulder. After cutting, the bunch should be handled carefully to avoid damage to the fruit. Using a soft shoulder pad and good padding on the banana trailer will help avoid fruit damage. Wetting of this padding will soften flower bracts and also reduce damage. Some growers de-hand bunches in the field into padded bulk bins to minimise fruit damage.

After harvest the remaining pseudostem should be cut down at a height of 1.5-2 metres or greater. Research in Queensland has shown that cutting at this height results in yield increases of up to 12 per cent compared with cutting the stem at less than 0.5 metre high.

In summer, it is often wise to leave harvested plants standing to avoid exposure of adjacent bunches to direct sun which will result in sunburnt fruit. These spent plants should be removed at the end of summer to allow more light and warmth during the cooler months.

Postharvest handling

Protecting bananas from heat after harvest is important as it greatly improves quality and shelf life. Temperatures over 28°C have been shown to decrease the life of a banana by one-half. It is preferable to harvest bananas in the cool of the day; they should not be left in the sun and should be placed in cool storage as soon as possible. Storage under shade with a mist or sprinkler system will allow for evaporative cooling ad preserve shelf life. The ideal storage temperature for bananas is 13°C.



Processing bananas at the Sweeter Banana shed
Photos: Sweeter Banana

Quality

The visual appeal of the banana is the most important factor in its sale. Blemishes result in the downgrading of fruit at the market place and blemished fruit should not be packed. To increase the pack-out of quality fruit, operations detailed above should be practised in the plantation. Many growers pack on-farm however the Sweeter Banana Co-operative provides packing and marketing services for their members. This minimises the need for additional labour on-farm. Packing specifications will vary according to market and are not covered in this publication.

Packaged lunch box bananas
Photo: Sweeter Banana

Some useful resources for subtropical banana production

1. Banana growing guide – Cavendish Bananas, from NSW DPI
   dpi.nsw.gov.au/__data/assets/pdf_file/0007/251899/Banana-growing-guide-cavendish-bananas-1.pdf
2. Banana growing basics, from NSW DPI
   dpi.nsw.gov.au/__data/assets/pdf_file/0008/223010/Banana-growing-basics-for-NSW.pdf
3. Soil and water best management for Banana, from NSW DPI
   dpi.nsw.gov.au/__data/assets/pdf_file/0007/242359/soil-and-water-best-management-practices-for-nsw-banana-growers.pdf
4. Subtropical banana information kit from Qld DPIF http://era.deedi.qld.gov.au/1966/
5. Sweeter Banana Environmental Best Management guide.
   dustupprojects.com.au/uploads/files/Sweet_Best_Practice_Manual_09____v5.pdf
6. Using tensiometers for effective banana irrigation in Carnarvon from DAFWA
   agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/irr/fn009_1993.pdf
7. Banana root and soil health manual from QLD DPIF
   daff.qld.gov.au/documents/Environment/BRASH-SOIL-health-kit-users-manual-final.pdf
8. Biosecurity manual from Plant Health Australia
   planthealthaustralia.com.au/industries/bananas/
9. Crop Evapotranspiration; Guidelines for computing water requirements. Food and Agriculture Organisation of the United Nations
   fao.org/docrep/x0490e/x0490e00.htm#Contents

Banana bell
Photo: Sweeter Banana

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Robinson JC (2012) Report on a consultation visit to: Carnarvon, Western Australia, to evaluate banana trials and banana growing practices. *Pers Comm*

Subtropical banana growers Best practice guide – Banana nutrition Part 2 Leaf analysis as a guide. NSW Department of Primary Industries.

Further details on the information contained in this bulletin are available from horticultural officers at the Carnarvon District Office of the Department of Agriculture and Food.