

**Effect of 1 m and 1.5 m row spacing on yield and fibre quality of upland cotton in Warren, NSW, Australia**

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AFNR4102 Research Paper

2014

Faculty of Agriculture and Environment,  
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Number of words:	9025
Number of references:	52
Number of tables:	4
Number of figures:	21

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## **Effect of 1 m and 1.5 m row spacing on yield and fibre quality of upland cotton in Warren, NSW, Australia**

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### **Abstract**

Compaction caused by machinery traffic can have severe yield consequences. Compaction increases soil strength and reduces soil porosity, which hinders root growth, moisture and nutrient uptake, and plant growth. GPS-auto steer and modification of machines to 3 m wheel centres can minimise compaction of fields. Conventional 1 m cotton does not accommodate for 3 m wheel centres so row spacing can be altered to alleviate this issue. The aim of the experiment in this study was to test the hypothesis: is cotton yield and fibre quality in wide 1.5 m row the same as conventional 1 m rows? There were two main components to the experiment at Auscott Warren farm, a replicated plot experiment and a paddock scale whole block experiment. The replicated experiment was a RCB design with nine replicates of 1 m and 1.5 m row treatments. The paddock scale whole block was two large field blocks of 1 m and 1.5 m row treatments. 1.5 m cotton was 10 cm taller than 1 m cotton. There was little difference in harvest index (60%) between the two configurations. The 1 m cotton yielded 1.8 bales/ha and 3.6 bales/ha higher than the 1.5 m cotton in the machine picked and handpicked replicated experiment, respectively. Yield of 1 m cotton mainly came from fruiting nodes 1-8, position 1. In contrast, yield in 1.5 m cotton mainly came from vegetative fruiting branches. There was a strong positive correlation ( $R^2 = 0.99$ ) between the number of bolls/m<sup>2</sup> and yield, but only a weak correlation between lint per boll and yield ( $R^2 = 0.28$ ), and between number of bolls and lint per boll ( $R^2 = 0.21$ ). Only minor differences in fibre quality were observed. Gross margins of the two row configurations were very similar. Future research should quantify water usage to improve grower decision making.

**Keywords:**

Controlled traffic, fibre quality *Gossypium hirsutum*, gross margin, row configuration, wide row spacing, yield.

**Introduction**

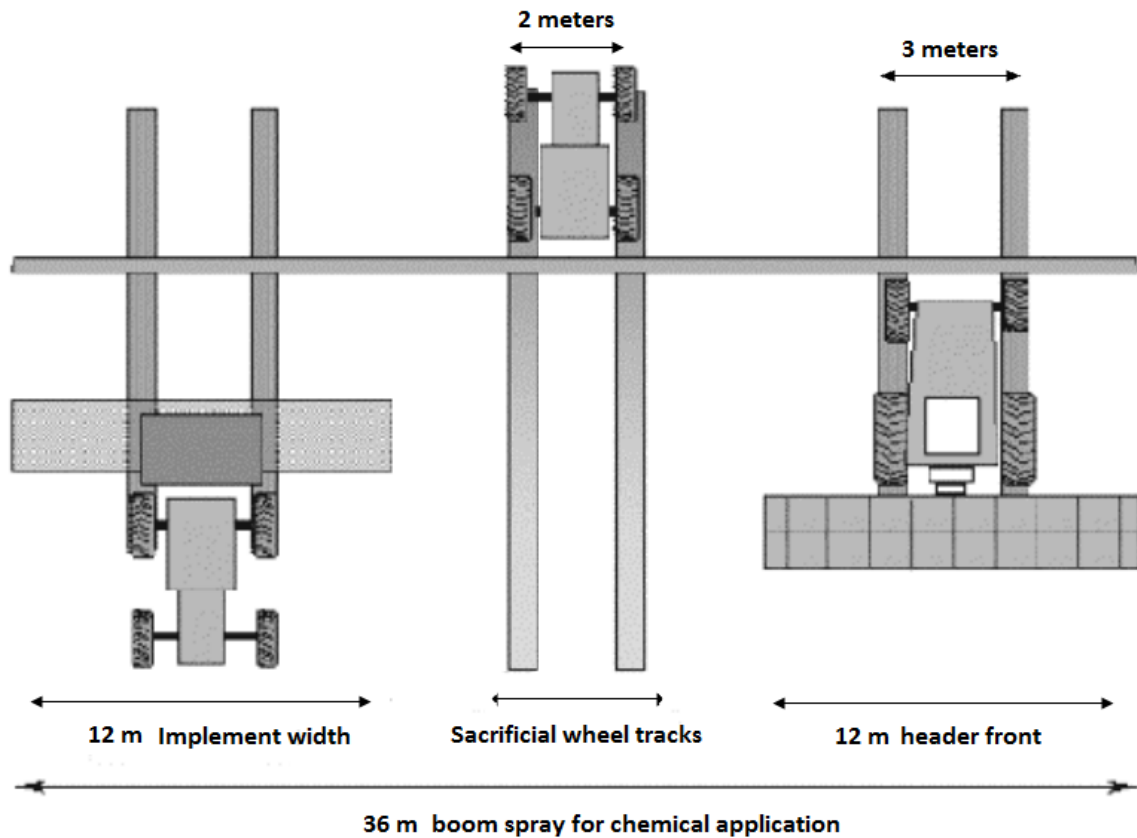
Soil compaction caused by machinery and implements is a globally recognised issue limiting agricultural production (Raghavan *et al.* 1990; Soane and Ouwerkerk 1994; Hamza and Anderson 2005; Chan *et al.* 2006). Soil compaction increases soil strength, restricting root growth, hindering the plants ability to respire and forage for moisture and nutrients.

Machinery usage in modern day agriculture is inevitable, and therefore some soil compaction must be tolerated, however it should be managed effectively to minimise its effects. If compaction is not managed effectively like a conventional farming system for example, up to 80-90% of the paddock can experience direct wheel traffic at least once a year (Soane and Ouwerkerk 1994; Radford *et al.* 2000; Chan *et al.* 2006).

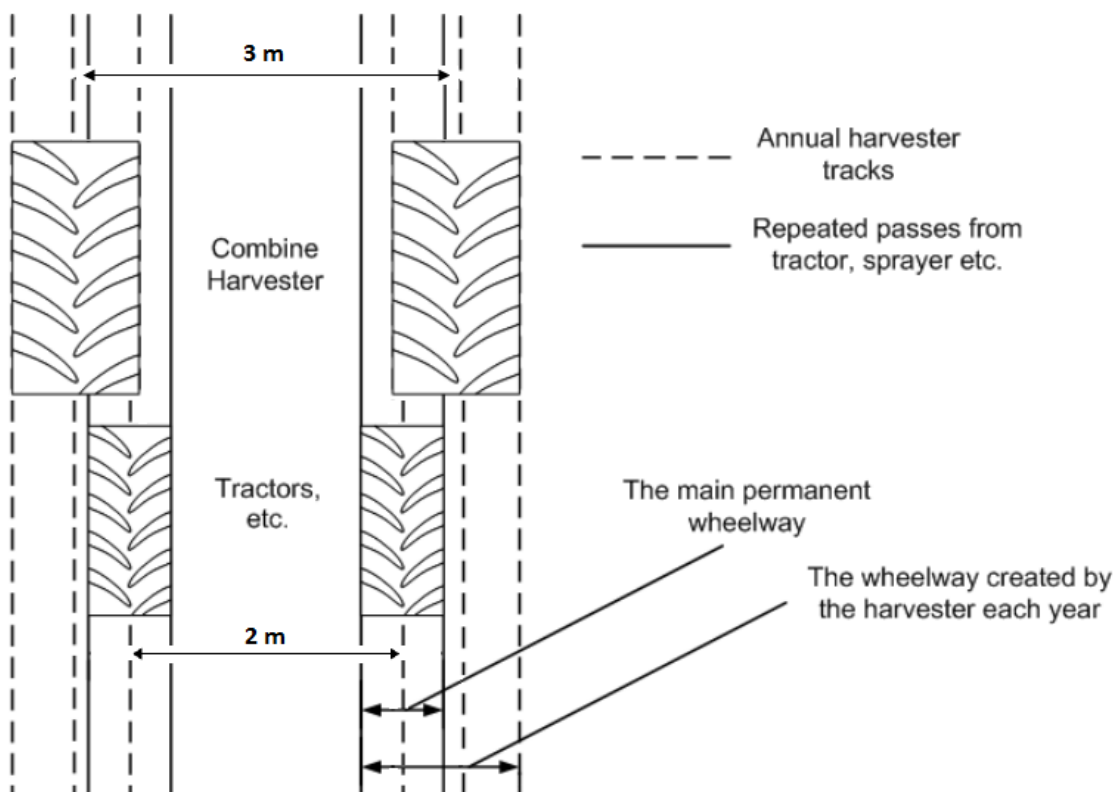
Technological developments including Global Positioning Systems (GPS) and Real Time Kinematic (RTK) have allowed steering aids and auto-steer systems on tractors and other farm machinery to be very accurate (to within 2 cm precision). Consequently a large number of broadacre dryland and irrigated farmers have converted their farming systems to controlled traffic systems. Controlled Traffic Farming (CTF) systems are systems that minimise soil compaction throughout a farm by confining all wheeled traffic to small designated wheel tracks that are sacrificed throughout the paddock, restricting compaction to only 15 – 20% of the total area (Tullberg 2000). This strategy allows for the remainder of the field to be

completely free of wheel traffic, providing noticeable improvements to soil structure with increased infiltration and plant growth (Campbell *et al.* 1986; Li *et al.* 2001; Chan *et al.* 2006). This CTF system is not only exceptionally beneficial for soil health, it also provides a firm base for machinery allowing operations to be completed sooner after rainfall, increased fuel savings, and increasing efficiencies by minimising overlaps (Hamza and Anderson 2005).

CTF systems involve implements that are multiple widths of each other to allow them to travel on the same wheel tracks, i.e. a 12 m air seeder and a 36 m boom spray and a 12 m header front (Fig. 1). This system is not quite perfect as sometimes farm machinery is produced on different wheel bases. Most row crop machinery travels on 2 m wheel centres (width from centre of tyre to centre of the other tyre) as standard. Wheat is the most common crop in Australia to be grown in a rotation with cotton, and the combine harvester is only produced on 3 m wheel centres, meaning that the combine harvester compacts soil outside of the designated wheel tracks (Fig. 2). A management strategy to avoid this and optimise CTF is to extend the axles of all machinery so that all wheels run on 3 m centres to minimise the portion of the field devoted to wheel tracks (Chan *et al.* 2006; Masek *et al.* 2010).



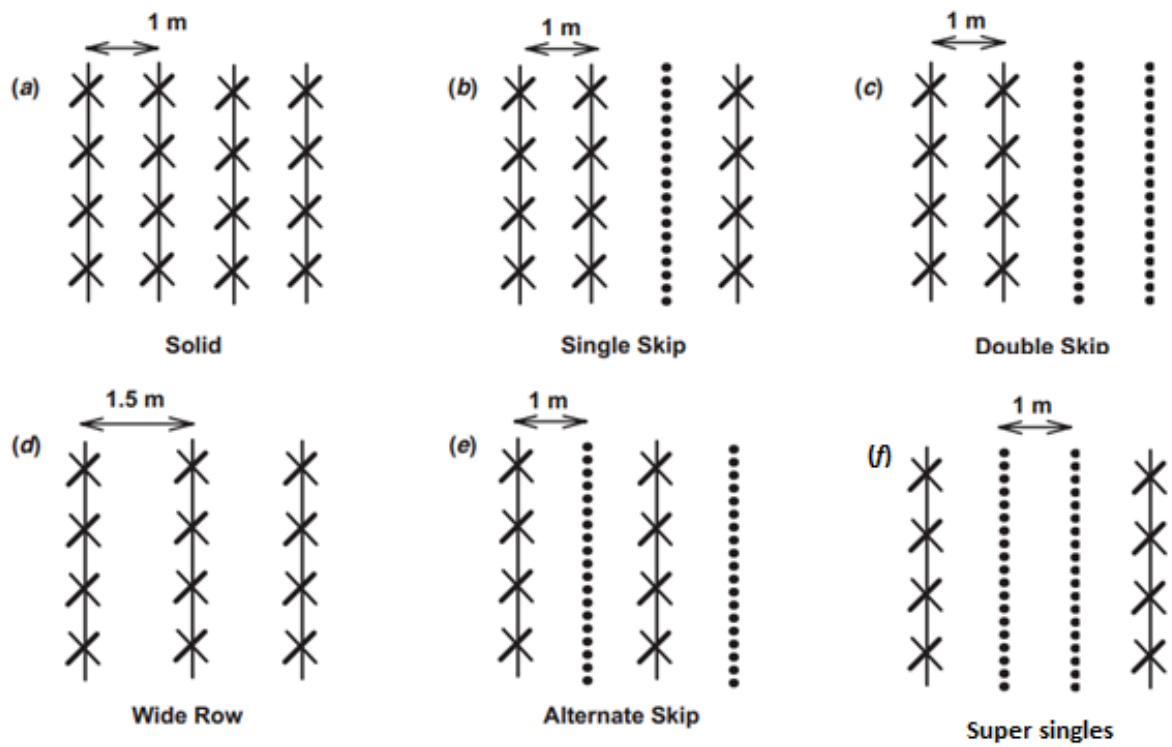
**Figure 1:** Diagram representing a 12 m controlled traffic farming system. All machines are equipped with auto steering technology to travel only on the designated wheel tracks (Masek et al. 2010).



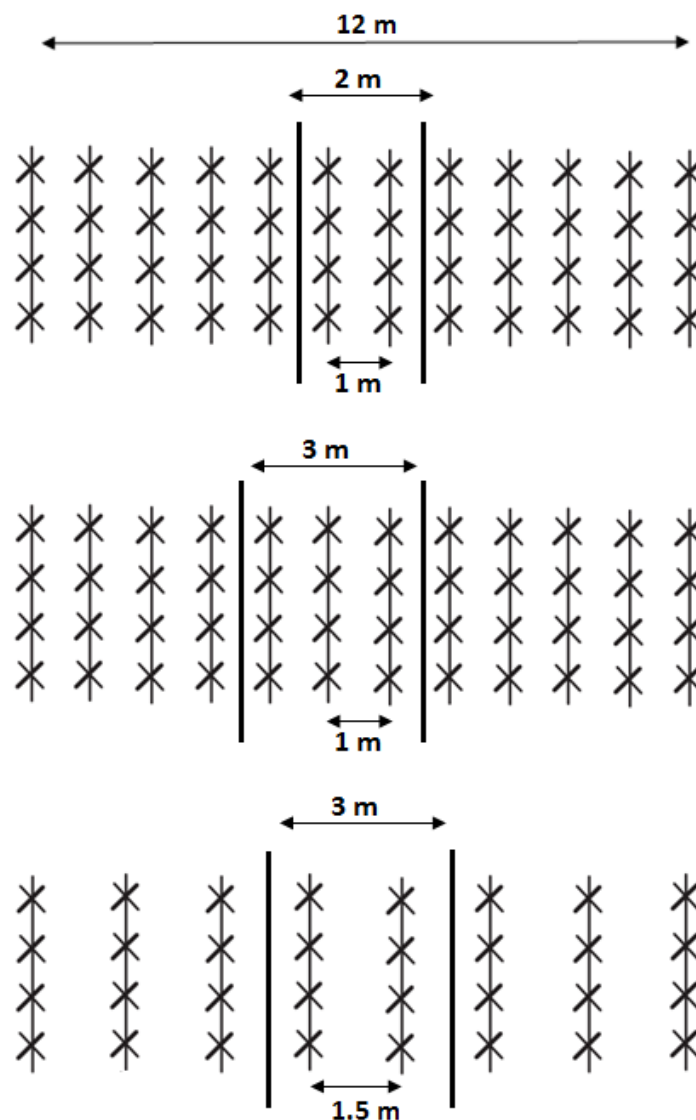
**Figure 2:** Diagram representing the different wheel tracks created by different farm machinery (Masek et al. 2010).

Row spacing can play a large role in performance of dryland and irrigated crops. In dryland situations wide row spacing and skipped rows can be used as a management technique to minimise production risk in dry years but limit top end yields in favourable conditions (Routley *et al.* 2003; Whish *et al.* 2005). Narrow row spacing increases yield in more favourable rainfed environments and in irrigated environments by increasing crop leaf area and associated light interception (Routley *et al.* 2003; Brodrick *et al.* 2010).

The vast majority of irrigated cotton in Australia is grown in solid configuration, on 1 m row spacing (Fig. 3a). There are a number of different row configurations that can be used in limited water or dryland scenarios such as single skip, double skip, super singles, alternate skip and wide row (Fig. 3) (Bange *et al.* 2005; Brodrick *et al.* 2012). The traditional row spacing in Australia of 1 m struggles to accommodate for 3 m wheel centres and a complete CTF system (Fig. 4). One method of ameliorating this problem is to alter the spacing between the planted rows to accommodate for the adjustments in tractor wheel widths to create a complete CTF system (as seen at the bottom of Fig. 4). These altered row spacing can include 1.5 m spacing (wide row cotton, Fig. 3d, Fig. 4) or narrow row (0.75 m) cotton. Both of these configurations allow for all machines within the farming systems to run 100% on the designated wheel tracks, in both summer and winter cropping rotations.



**Figure 3.** A diagram representing different planting configurations for irrigated and rainfed cotton production in Australia. The solid lines with x represent rows with plants, and the dotted lined represent skipped rows. Configurations are solid (a), single skip (b), double skip (c), wide row (d), alternate skip (e) and super singles (f) (Bange *et al.* 2005).



**Figure 4.** Solid 1 m cotton with 2 m wheel traffic (top); solid 1 m cotton with 3 m wheel traffic (middle); solid wide row (1.5 m) cotton with 3 m wheel centres (bottom). Straight parallel lines represent tractor wheel tracks; rows with x represent plant lines.

There has been a considerable research into Ultra Narrow Row cotton (<0.4 m) and narrow row cotton (0.75 m) (Lewis 1971; Constable 1977a, 1977b; Jost and Cothren 2000; Jost and Cothren 2001; Brodrick *et al.* 2010) and conventional 1 m cotton, but little is known about the performance of irrigated wide row (1.5 m) cotton.

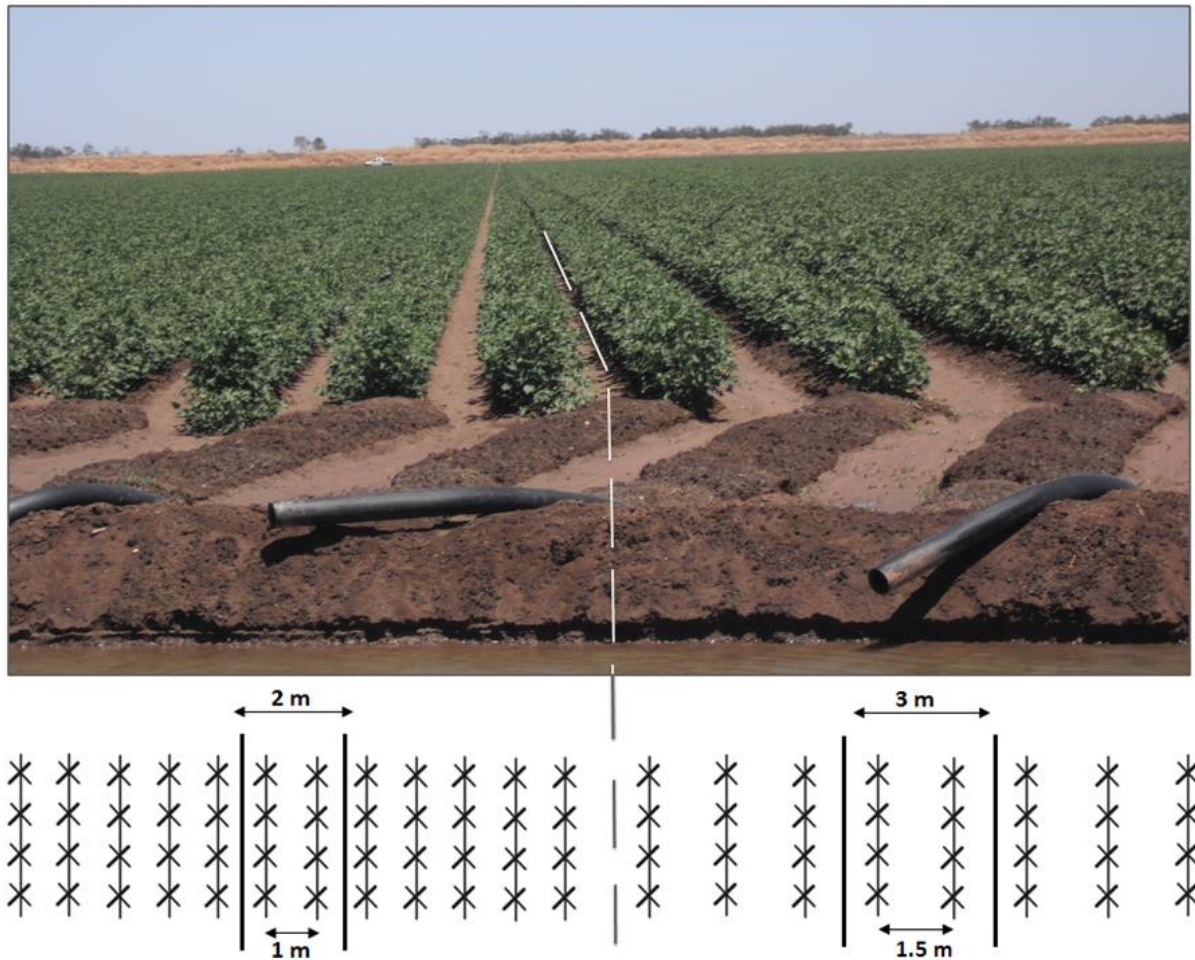
Auscott Limited are pioneers in the Australian cotton industry and often run a number of on-farm experiments for their own benefit and that of the wider cotton industry. The

management at Auscott Warren conducted a field experiment during the 2013/2014 cotton season in Field 12 with both 1 m and 1.5 m row cotton. Data from this experiment provided me with the opportunity to investigate yield and fibre quality of cotton grown in wide row configuration (1.5 m) compared with conventional 1 m farming systems.

This study will investigate the hypothesis: is cotton yield and fibre quality in wide 1.5 m row the same as conventional 1 m rows? The aim of the study is to compare the yield and fibre quality of wide row (1.5 m) and conventional (1 m) cotton grown under irrigated conditions. It will also provide a preliminary assessment of the economic outcomes of the two row configurations to improve the farmer's ability to make decisions. This research is important to support CTF which is an important component of modern agriculture in Australia as profit margins get slimmer and production needs to increase.

## **Materials and Methods**

There were two main components to the experiment at Auscott Warren farm (31°47'25" S 147°44'17" E, 195 m above sea level), a replicated plot experiment and a paddock scale whole block experiment. Auscott Warren is located 11 km south west of Warren in the central west area of NSW, Australia. The area is considered semi-arid, receiving an average rainfall of 490mm per annum, which is evenly split between summer and winter, of which 236 mm fall on average during the cotton growing season (October – February). Hot summers (mean daily maximum 33.4°C, and minimum 19°C) and mild winters (mean daily maximum 15.6°C and minimum 3.4°C) are typical of the area. Medium self-mulching grey Vertosols dominate the irrigation areas of the farm (Isbell 2002).



**Figure 5:** Cotton growing (top) and diagram representing (bottom) 1 m row spacing (left of centre) and 1.5 m row spacing (right of centre). Lines with x represent plant line; vertical solid lines represent machinery wheel tracks.

The replicated plot experiment was a randomised block experimental design with 9 replicates at the Auscott Warren farm (see Table 1). All experiments used the variety Sicot 74BRF (Bollgard II<sup>TM</sup> Roundup Ready Flex<sup>TM</sup>).

**Table 1: Experimental design;** “A” treatments represent 1 m row spacing, “B” treatments represent 1.5 m row spacing, X represents spraying wheel tracks

Treatment	Replicate	AB line		Description	Swath width (m)	Cumulative m
B		0		Buffer	12	12
B		1	X	Buffer	12	24
A	1	2		1 m	12	36
A	2	3		1 m	12	48
B	1	4	X	1.5 m	12	60
A	3	5		1 m	12	72
A	4	6		1 m	12	84
B	2	7	X	1.5 m	12	96
B	3	8		1.5 m	12	108
A	5	9		1 m	12	120
B	4	10	X	1.5 m	12	132
A	6	11		1 m	12	144
B	5	12		1.5 m	12	156
B	6	13	X	1.5 m	12	168
A	7	14		1 m	12	180
A	8	15		1 m	12	192
B	7	16	X	1.5 m	12	204
A	9	17		1 m	12	216
B	8	19		1.5 m	12	228
B	9	20	X	1.5 m	12	240

#### *Plant height was measured during the season*

Cotton height was measured three times during the season in two neighbouring paddocks (one with 1 m row spacing, and the other with 1.5 m row spacing) on similar soil types under the same agronomic management.

#### *Harvest index taken at full maturity*

One linear metre of above ground plant row was cut off and removed at ground level (at full maturity prior to defoliation) from all of the plots (experimental units) of the experiment. The segments were dried in a forced air oven at 80°C for four days until there was no change in mass. The contents were separated into stems, leaves and bolls and weighed and a harvest index was calculated. Areas were selected where plant stands were greater than 8 per linear metre.

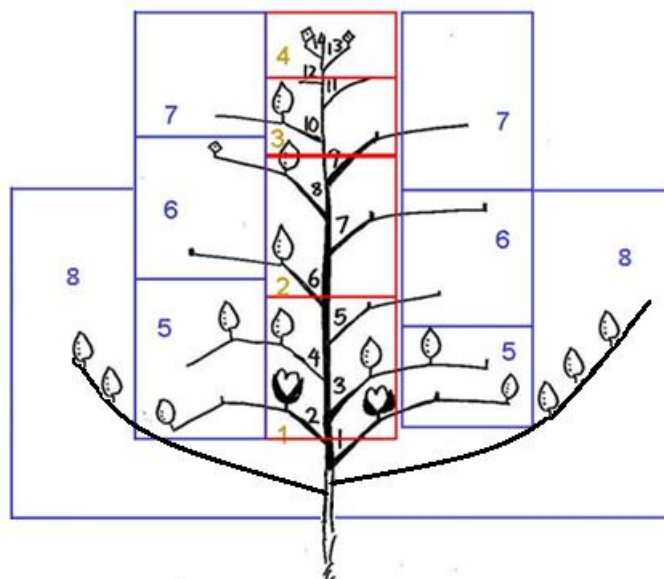
The term harvest index refers to the proportion of reproductive dry biomass (bolls that would contribute to yield) to total above ground dry biomass.

$$\text{Harvest index} = \frac{\text{Reproductive biomass}}{\text{total above ground biomass}} \times 100$$

### *Hand segment picked cotton*

One linear metre plant rows were selected to be handpicked from all eighteen plots (experimental units) of the experiment. The cotton from each linear metre was handpicked and grouped into different fruiting segments of the plant (see Fig. 6). Areas were selected where plant stands were greater than 8 plants per linear metre. Plant numbers were recorded per linear metre, and boll numbers recorded per segment. Samples from each segment were bagged with a total of 8 bags per treatment.

- 1) Main stem fruiting nodes **1-4** position **1**
- 2) Main stem fruiting nodes **5-8** position **1**
- 3) Main stem fruiting nodes **9-12** position **1**
- 4) Main stem fruiting nodes **13+** position **1**
- 5) Main stem fruiting nodes **1-4** position **2+**
- 6) Main stem fruiting nodes **5-8** position **2+**
- 7) Main stem fruiting nodes **9+** position **2+**
- 8) Vegetative fruit (identified by smooth stem on the other side of where a boll is formed)



**Figure 6:** Segment picking diagram outlining segments 1-8

Fibre quality parameters were measured using the High Volume Instrument (HVI) which is industry standard practice (Bange *et al.* 2009).

#### *Machine picked field experiment*

The Paddock scale experiment was conducted on a large 17.5 ha block which was divided into two whole blocks of 8.75 ha each for the 1 m, and the 1.5 m row configuration treatments (Table 1), which were separately machine harvested. The harvested seed cotton from each block was ginned separately to provide an infield broad scale comparison between 1 m and 1.5 m row spacing. A buffer zone of 24 m was located on the edge of the field to ensure border effects were not interfering with results.

Results for both the handpicked and machine picked yields will be displayed in bales/brown hectare and bales/green hectare (227 kg lint bales). The term brown ha refers to the total area taken to grow the wide row crop in hectares, whereas the term green ha refers only to the area covered by plant rows and does not account for the additional space between the rows. Brown

hectares are generally used in the Australian cotton industry as it represents the actual area required to grow the crop.

#### *Water use efficiency*

Water Use Efficiency (WUE) was calculated on farm by measuring the total irrigation water being supplied to the farm (via Mace meters), and estimating how much water was left in storage at the end of the season. WUE also takes into account growing season rainfall (October –February).

WUE refers to the amount of water it takes to produce a unit of harvestable product; In this case it refers to the amount of water applied to a field to produce a bale of cotton (Zwart and Bastiaanssen 2004).

$$\text{Water use efficiency} = \frac{\text{bales per hectare}}{\text{applied water} + \text{incrop rainfall}}$$

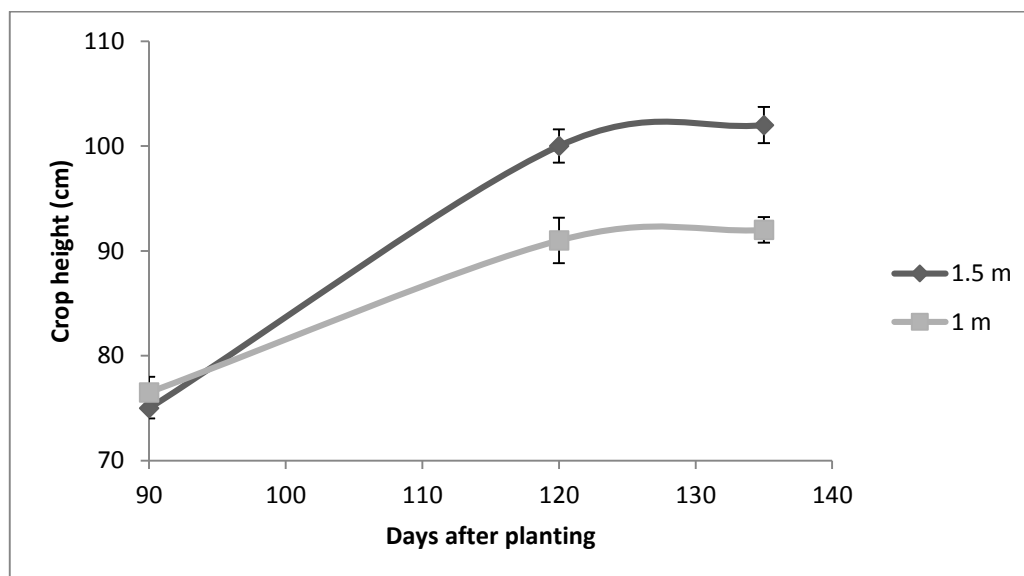
This equation simply takes into account the amount of marketable harvested product, divided by the amount of water that was applied to the crop and rainfall received in the growing season (October – February), to provide the amount of produce harvested per unit of water (Zwart and Bastiaanssen 2004).

#### *Data analysis*

Data was analysed using a one-way analysis of variance (ANOVA) in Genstat V16 for handpicked yield, bolls/m<sup>2</sup>, lint per boll, fibre length and fibre strength. Linear regressions were fitted between the number of bolls/m<sup>2</sup> and lint yield (227 kg bales/ha), lint per boll (g) and the number of bolls/m<sup>2</sup>, and lint per boll (g) and lint yield (227 kg bales/ha).

## Results

### *Plant height*

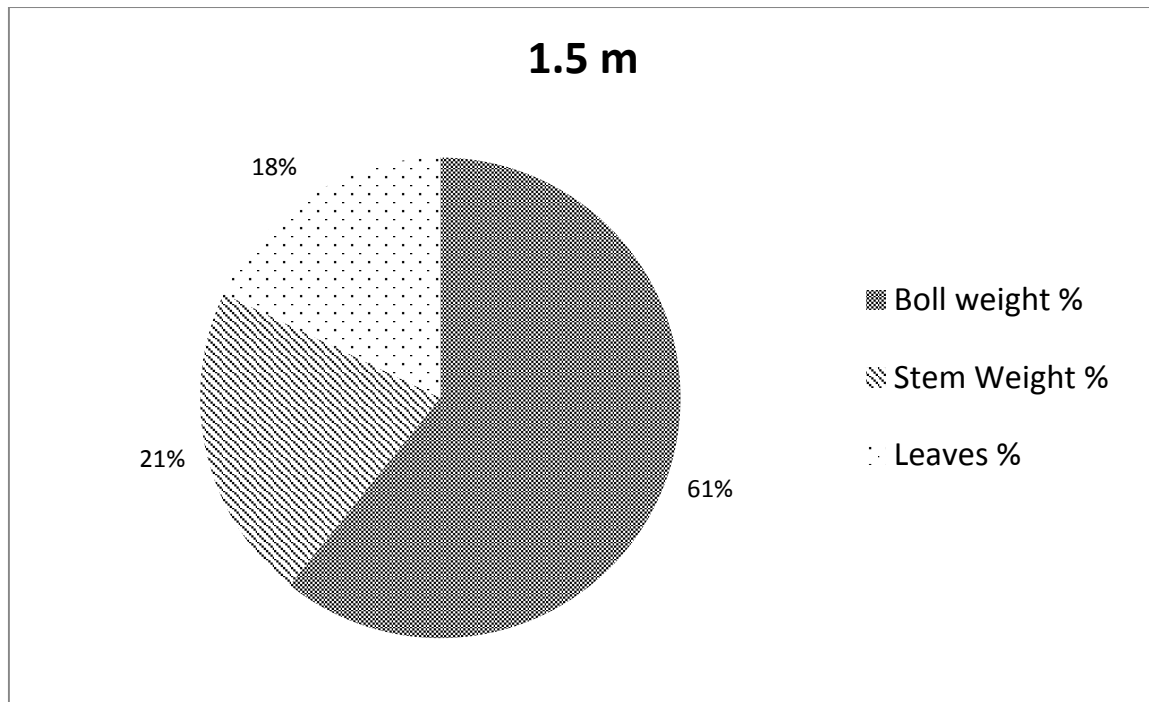


**Figure 7:** Plant height (cm) measured at 97, 127, and 142 days post planting. Error bars represent standard errors of the mean.

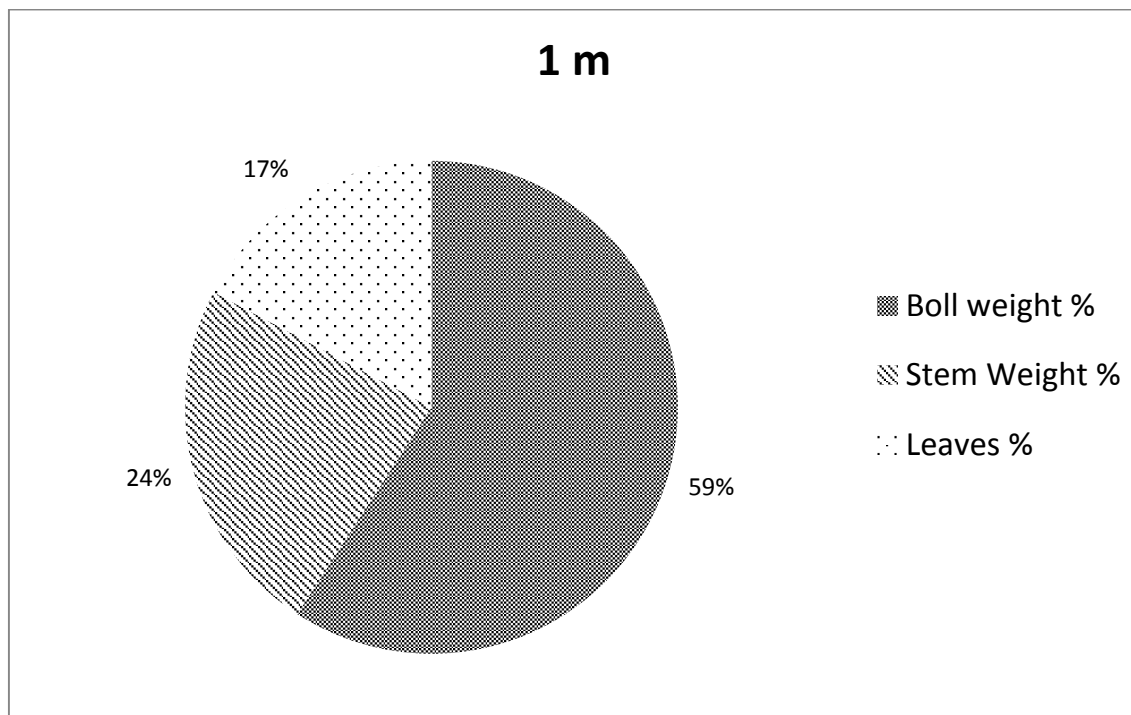
The 1.5 m cotton experienced more growth between 97 and 127 days post planting than the 1 m cotton (Fig. 7). The final heights were recorded at 92 cm for the 1 m cotton, and 102 cm for the 1.5 m cotton.

### *Harvest index*

The harvest index showed very little difference between the proportions of boll, stems and leaf weight for the two row configurations. There was slight increase in fruit percentage in the 1.5 m (Fig. 8) and a slight decrease in stem proportion compared with the 1 m row configuration (Fig. 9)



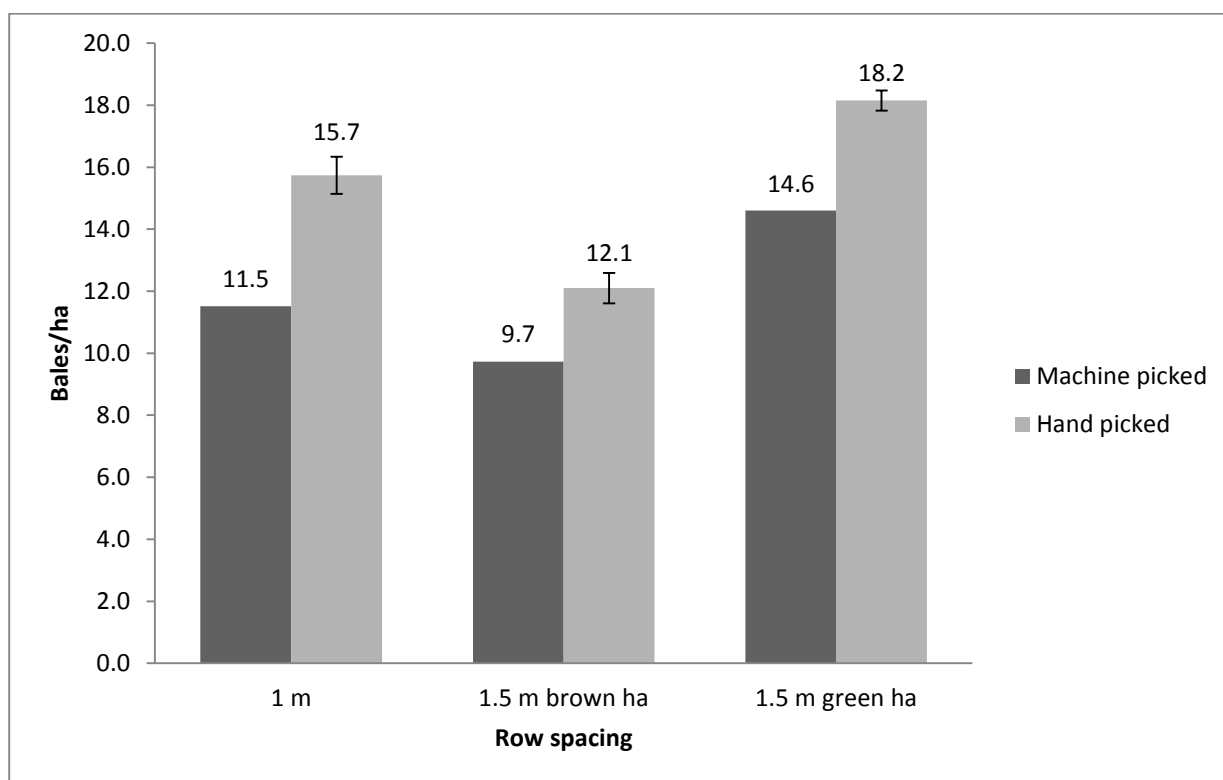
**Figure 8:** Proportion of the plant made up by bolls, leaves and stems in a linear 1 m row grown on 1.5 m row spacing.



**Figure 9:** Proportion of the plant made up by bolls, leaves and stem in a linear 1 m grown on 1 m row spacing.

*Machine picked and handpicked experimental yields (in 227 kg bales)*

The cotton grown on 1 m row spacing out yielded the 1.5 m cotton in both the handpicked ( $P < 0.001$ ) and the machine picked field experiments (Fig. 10) on a brown ha basis. Data from the machine picked fields revealed that the 1 m cotton out yielded the 1.5 m cotton by nearly 2 bales/ha, a 16% yield difference (note 227 kg cotton lint per ginned bale) (Fig. 10). A similar trend emerged with the handpicked data where the 1 m cotton out yielded the 1.5 m cotton by 3.6 bales/ha, a 23% yield reduction.



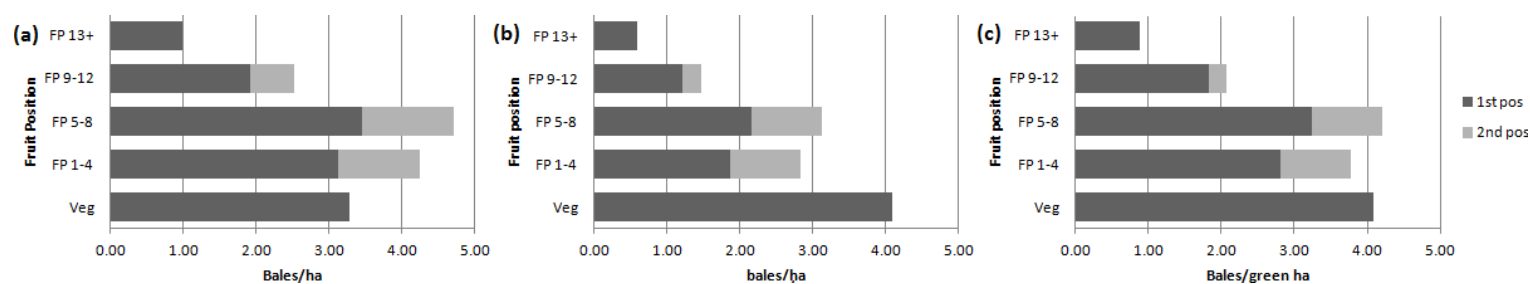
**Figure 10:** Cotton lint yields harvested (227 kg bales) by machine and by hand from cotton grown on 1 m and 1.5 m row spacing. The term brown ha refers to the total area taken to grow the wide row crop in hectares, whereas the term green ha refers only to the area covered by plant rows and does not account for the additional space between the rows. Error bars represent standard errors of the mean.

*Segment picked cotton*

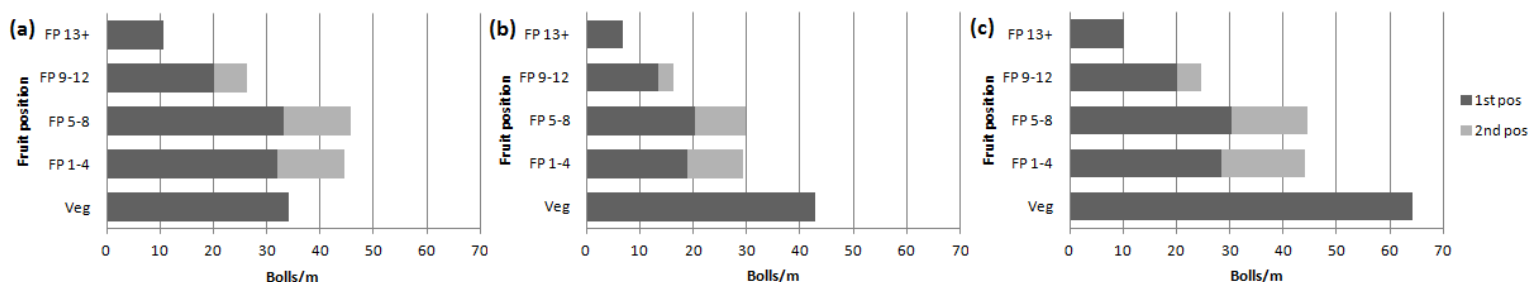
The two different row spacing resulted in different fruiting patterns of the plant. Yield on the 1 m row spacing was confined to mainly first position fruit on fruiting nodes 1-8, and some vegetative fruit. In contrast yield on the 1.5 m spacing was mainly derived from vegetative

branches, along with a smaller contribution from fruiting nodes 1-8 (Fig. 11). This theme was reinforced by the number of bolls per square metre from each fruiting segment of the plant, which told a very similar story (Fig. 12).

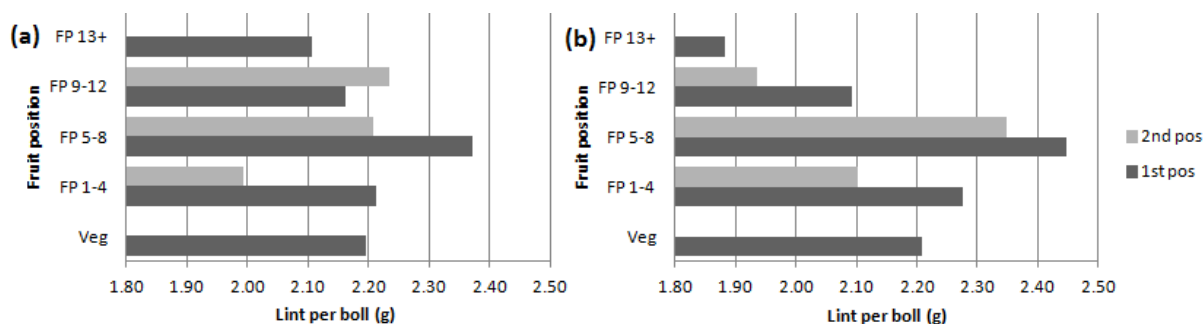
Average lint weight of individual bolls did not vary considerably, with most fruiting positions remaining above 2.1 g of lint per boll (Fig. 13). The only exception to this was the fruiting segment 13+ position 1 of the 1.5 m cotton which had only had a boll weight of < 1.9 g, whereas the same position on 1 m cotton was > 2.1 g.



**Figure 11:** Yield components of hand picked cotton separated into fruiting positions (227 kg lint bales); (a) 1 m row spacing, (b) 1.5 m row spacing (yield/brown ha), (c) 1.5 m row spacing (yield/green ha).

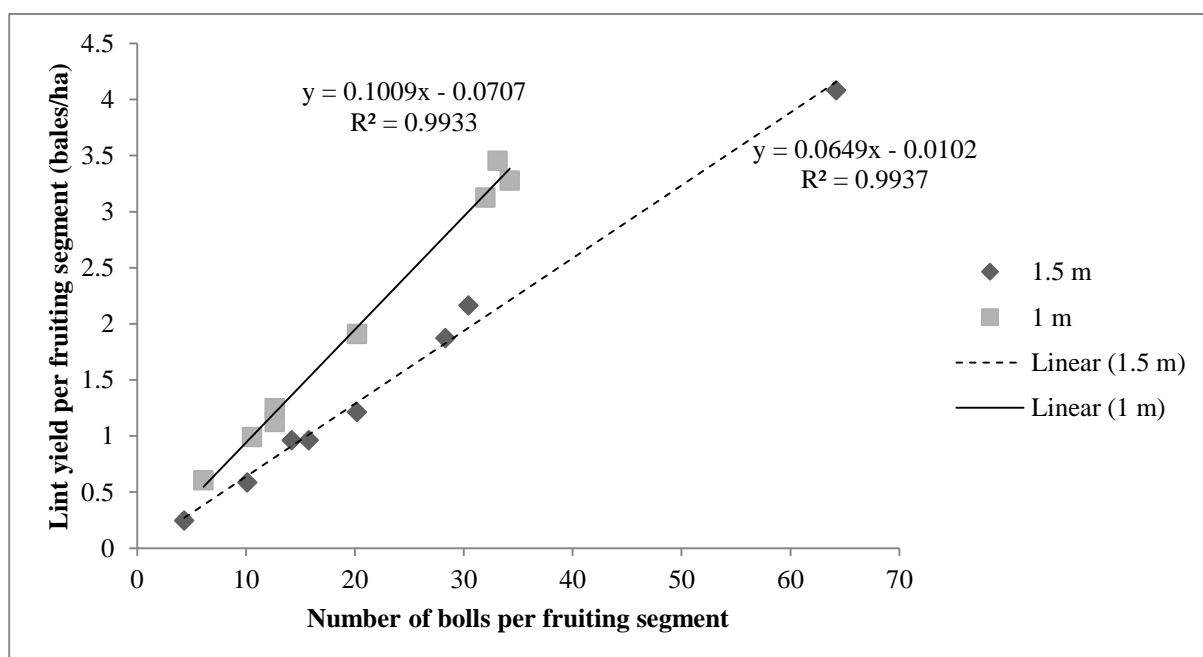


**Figure 12:** Number of bolls per metre of hand picked cotton separated into fruiting positions; (a) 1 m row spacing, (b) 1.5 m row spacing (bolls/m<sup>2</sup>), (c) 1.5 m row spacing (bolls/linear m).

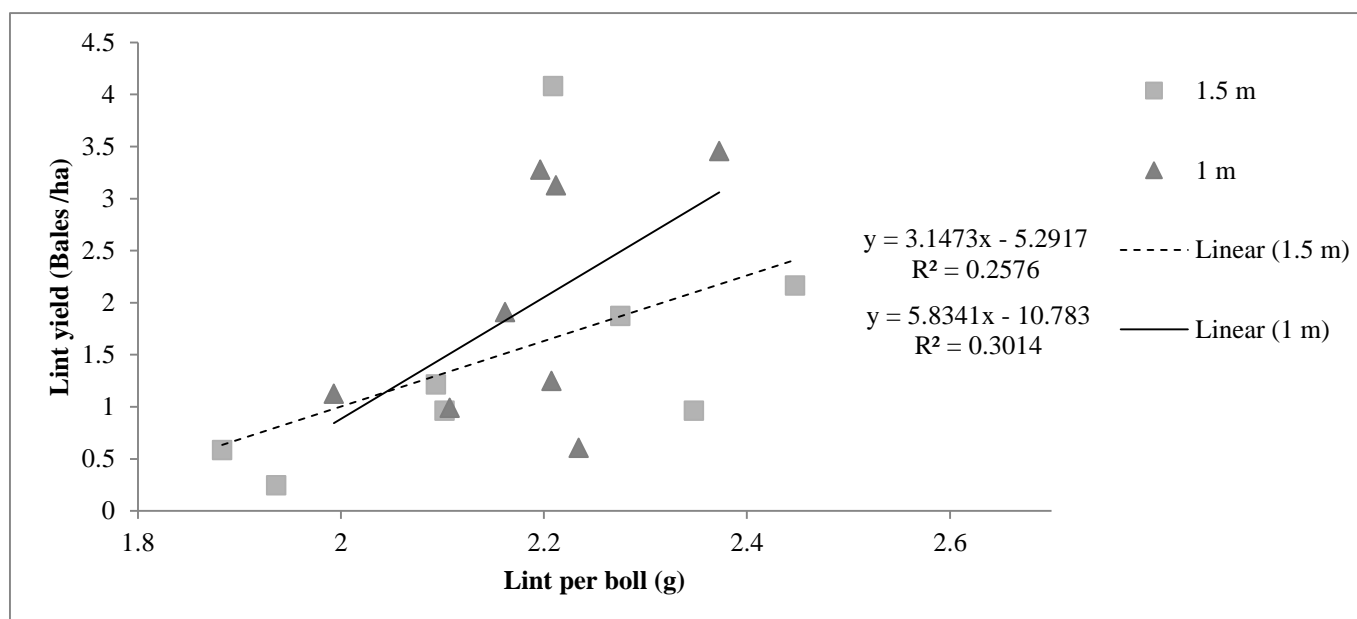


**Figure 13:** Average lint weight in grams per boll of cotton separated into fruiting positions; (a) 1 m row spacing, (b) 1.5 m row spacing

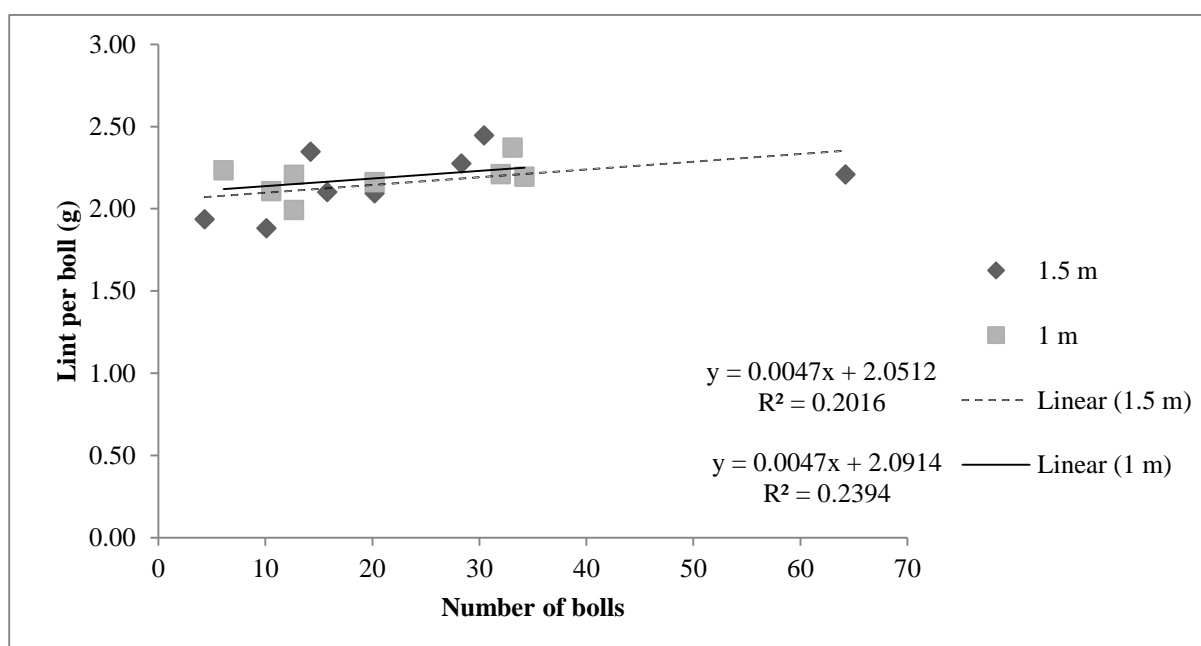
There was a very strong linear correlation between the number of bolls per m<sup>2</sup> and yield ( $R^2 = 0.99$ ) (see Fig. 14). There was only a poor correlation between the size of bolls and the number of bolls (see Fig. 15) and between the size of bolls and lint yield (see Fig. 16).



**Figure 14:** Relationship between the number of bolls (per m<sup>2</sup>) and yield (in 227 kg bales/ha) across all segments.



**Figure 15:** Relationship between number of bolls (per m<sup>2</sup>) and the amount of lint per boll lint per boll

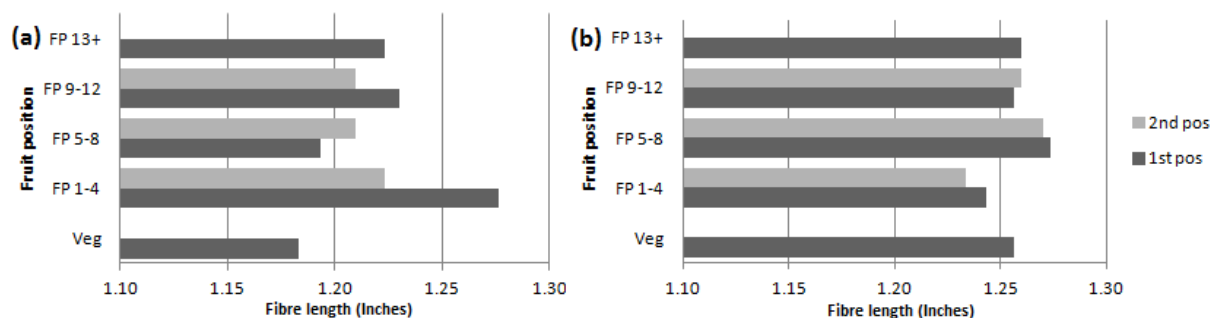


**Figure 16:** Relationship between lint per boll (g) and lint yield (in 227 kg bales/ha)

### *Fibre quality*

Fibre length was more consistently longer and less variable in the 1.5 m cotton compared with 1 m cotton ( $P < 0.031$ ) (Fig. 17). The 1 m cotton showed considerable variation in fibre length throughout the different fruiting positions. The 1.5 m cotton was consistently approximately 1.25 inches, whereas the 1 m cotton was approximately 1.2 inches, and

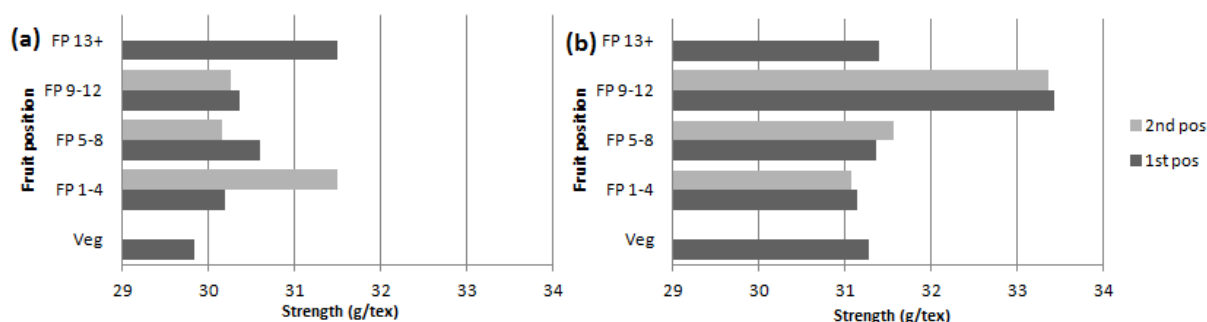
shorter in the vegetative branches (1.18 inches). Note that fibre length is measured in decimal inches by the High Volume Instrument (HVI) and 1 inch = 25.4 mm.



**Figure 17:** Fibre length (inches) of hand picked cotton shown in separate fruit positions; (a) 1 m row spacing and (b) 1.5 m row spacing. (1 inch = 25.4 mm)

Fibres from the 1.5 m cotton were slightly stronger than those of the 1 m cotton ( $P < 0.020$ ).

The 1.5 m cotton consistently took over 31 g/tex to break, whereas the 1 m cotton was slightly weaker at 30 g/tex except for the vegetative fruiting positions (under 30 g/tex) (Fig. 18).



**Figure 18:** Fibre strength (g/tex) of hand picked cotton shown in separate fruit positions; (a) 1 m row spacing and (b) 1.5 m row spacing.

### *Water use efficiency*

1.5 m cotton performed 8% and 18% better than 1 m cotton in total WUE and Applied WUE, respectively (see Table 2).

**Table 2: Water use efficiency (in 227 kg lint bales grown per ML) based on estimated applied water of 1 m and 1.5 m cotton.** In-crop rainfall including all October 2013 – February 2014 from Trangie BOM site (BOM 2014), rainfall for 1.5 m cotton was multiplied by 4/3 to reflect the 33% more soil available due to extract moisture from due to increased row spacing.

<b>Row spacing</b>	<b>1 m</b>	<b>1.5 m</b>
<b>Yield (bales/ha)</b>	11.52	9.73
<b>Applied water (ML/ha)</b>	10.43	7.27
<b>In crop rainfall (ML/ha)</b>	1.24	1.86
<b>Total water</b>	11.67	9.13
<b>Total WUE (bales/ML)</b>	0.99	1.07
<b>Applied WUE (bales/ML)</b>	1.10	1.34

## Discussion

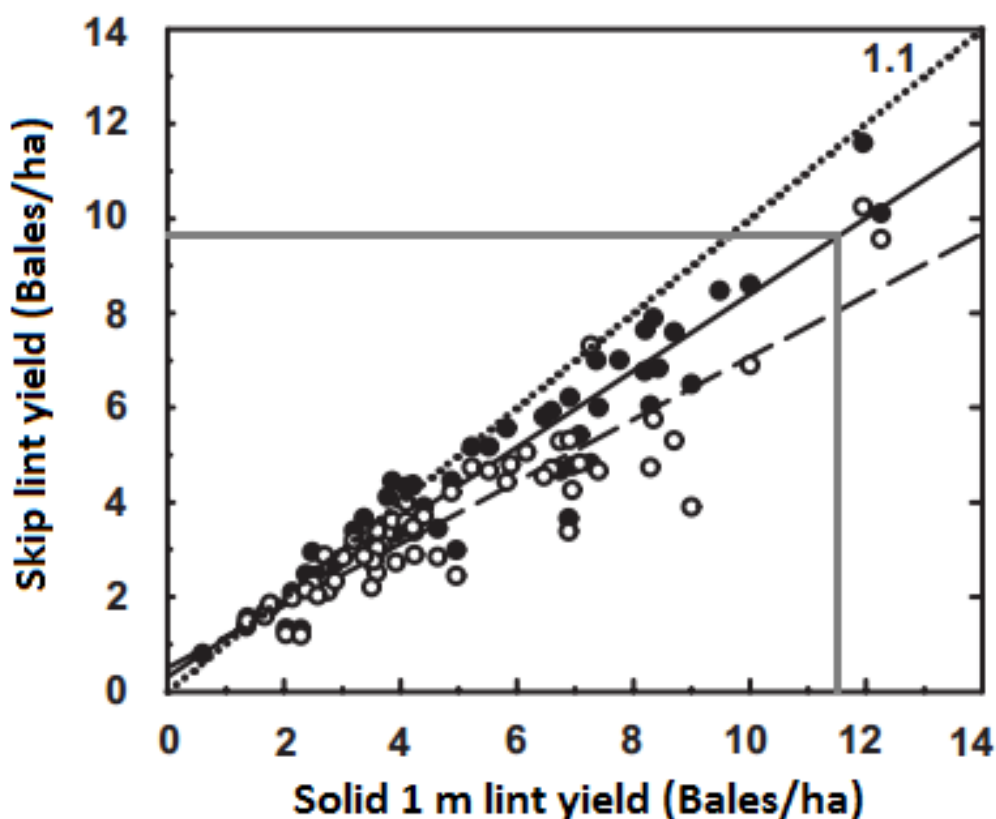
### *Yield*

Yield in terms of bales/ha is the most important aspect of production for a cotton grower.

Yield is a key profit driver in any farming system because gross income is simply equal to yield multiplied by price. As the price of cotton has remained relatively constant over an extended period, increased profitability is therefore driven by increasing production (yield) and minimising costs. A yield difference of 16% was observed between the two row spacing treatments in the machine picked experimental blocks, which at \$450 per bale equates to over \$800/ha difference.

The yields observed in my handpicked and machine picked experiments are consistent with a number of independent experiments investigating single skip cotton (Fig. 19) (Pyke 1991; Marshall *et al.* 1994; Goyne 2000; Bange *et al.* 2005). Single skip cotton is comparable to 1.5 m cotton to some extent as it represents the same area (brown area) planted per hectare (66.67%) as wide row cotton, just with different spacing between the planted rows (Fig. 3).

The experimental yields of my machine picked data of 1 m and 1.5 m cotton have been plotted against a combination of Pyke (1991), Marshall (1994) and Goyne's (2000) experimental data of high yielding dryland cotton experiments (grown in reasonably high rainfall seasons) (Pyke 1991; Marshall *et al.* 1994; Goyne 2000; Bange *et al.* 2005). My data follows almost exactly the same trend as their data (Fig. 19).



**Figure 19:** A combination of experimental data from Pyke (1991), Marshall (1994) and Goyne (2000) that shows the relationship of lint yield (227 kg bales/ha) between solid, single skip and double skip planting configurations in a high yielding dryland scenario. The solid line represents single skip, the dashed line represents double skip, and the 1:1 is represented by the dotted line (Pyke 1991; Marshall *et al.* 1994; Goyne 2000; Bange *et al.* 2005). The thick solid grey perpendicular lines plot the actual relationship between the 1 m cotton yield (11.5 bales/ha) and the 1.5 m cotton (9.7 bales/ha) yield in my data at Auscott Warren farm in 2014.

Cotton Seed Distributors (CSD) have also conducted field experiments comparing 1 m cotton with single skip (Fig. 3b) and alternate row cotton (Fig. 3e) in limited water environments at Bourke NSW, and Goondiwindi (QLD) (CSD 2010). This experiment received 5 irrigations and 400 mm of in-crop rain which were very favourable conditions. The solid crops went on

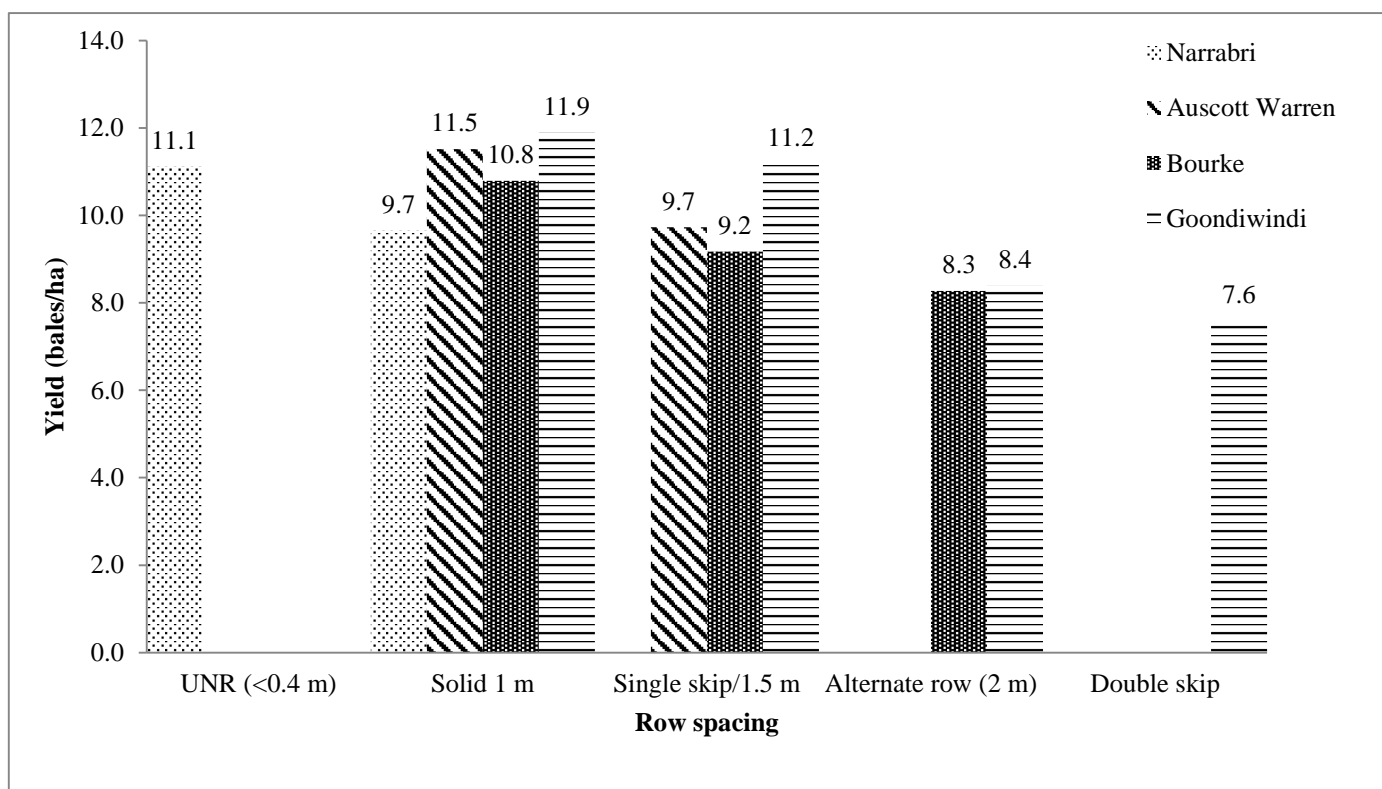
to yield well, with single skip (Fig. 20) yielding 85% and 94% of solid cotton, 77% and 71% for alternate row, respectively, at “Latoka” Bourke and “Kalanga” Goondiwindi (Fig. 21).

My data in the machine picked experiment followed this trend with 1.5 m cotton yielding 84% of the 1 m cotton.

In research on Ultra Narrow Row (UNR) cotton (< 0.4m), yield on average was 13 % higher than conventionally spaced (1 m) cotton over 5 experiments in different locations (Brodrick *et al.* 2010). Farming logistics in UNR are extremely difficult and as a result it has had limited uptake by the Australian cotton industry.



**Figure 20:** Single skip cotton being harvested at “Latoka” Bourke NSW (CSD 2010).



**Figure 21.** Comparison of data from Brodrick's UNR field experiments (Brodrick *et al.* 2010) and CSD field experiments (CSD 2010) with my data from the Auscott Warren machine picking experiment (2014) of UNR, skip row and 1.5 m cotton compared with 1 m cotton.

It is apparent that this yield decrease for 1.5 m cotton is directly related to the plants having reached their yield potential, as environmental conditions (predominately moisture) are not limiting. This concept was investigated by Gibb (1995) who produced similar data with a fully irrigated field experiment showing that plants had reached full fruiting capacity, and their potential yield was reached and could produce no more (Gibb 1995).

Yield in my data was driven by the number of bolls/m<sup>2</sup> with nearly a perfect positive correlation ( $R^2 = 0.99$ ) (see Fig. 14) which agrees with Worley *et al.* (1974) and Jones *et al.* (2014) working in South Carolina and Texas U.S.A. respectively (Worley *et al.* 1974; Jones *et al.* 2014). Furthermore bolls/m<sup>2</sup> is considered the primary factor to Australia's yields increasing throughout its history (Constable *et al.* 2001).

A considerable difference in yield is present between the handpicked cotton and the machine picked cotton. There are a number of factors that can account for this difference. Firstly plant establishment was an issue in the replicated plot field experiment, particularly in the cotton grown on 1.5 m row spacing. Therefore when selecting sites for handpicking, representative areas were chosen that had more than 8 plants per linear metre to try and represent a normal target plant population. Secondly the percentage of lint turnout (the percentage of lint cotton present after seed cotton is ginned) was considerably higher in the handpicked cotton (46%) compared with the machine picked cotton (41.5%), which continued to exacerbate the already high yields in the handpicked areas. Thirdly machine picking conditions in 2014 were tough due to a considerable amount of rain on ripening cotton, resulting in a considerable portion of cotton being lost in the harvest process. Brodrick *et al.* (2010) also observed that handpicked yields were approximately 10% higher than machine picked cotton in Australian irrigated cotton production (Brodrick *et al.* 2010).

Harvest issues may also arise from cotton grown on 1.5 m row spacing. Large, vegetative cotton plants can have reduced mechanical picking efficiency. A yield of 15 bales/ha in the row is a considerably large amount of cotton to be picked by each picking head in the cotton mechanical picker. The picking efficiency of individual spindles will decrease in such high yielding conditions in the row and harvest losses will increase as a result. Typically the 2013/14 cotton season was a low yielding season for the Macquarie Valley. Yields in the Valley can be as high as 14 bales/ha in conventional 1 m cotton, so yields in the row may be as high as 18 bales/ha in 1.5 m cotton exacerbating this issue.

*Harvest index, fruiting positions and boll weight.*

Comparing the harvest index of the two row spacings (1 m and 1.5 m) suggests that the plant was only marginally more efficient at converting carbohydrates generated by the plant into harvestable fruit in the 1.5 m row cotton (Figs. 8 and 9).

The two different row configurations grew fruit in a different pattern across the plant. The 1.5 m cotton had increased spatial area both above and below ground, and reduced plant competition for nutrients, water and sunlight. Hence the 1.5 m row spacing showed more variation of boll weights, especially in fruiting positions higher on the plant (Fig. 13). This may be a maturity related issue with bolls set higher (and hence later) on the plant were not able to fully mature before defoliation, or the plant may not have been able to fill its carbohydrate demands due to a wet cloudy February preventing full rates of photosynthesis reducing boll size.

The 1.5 m cotton grew was slightly taller than the 1 m cotton. This is consistent with Brodrick *et al.* (2010)'s work on Ultra Narrow Row cotton (< 0.4m) it was observed that the plants were considerably shorter and smaller on the narrow row spacing (Brodrick *et al.* 2010). Individual bolls rely almost solely on the leaf adjacent to them to generate carbohydrate to fill the fruit. A large closed canopy in crops grown on 1 m and < 0.4 m row spacings may cause self-shading and a reduction in size of lower bolls or lower fruit could be abscised (Wang *et al.* 2006).

*Water and water use efficiency*

Australian irrigators face significant amounts of uncertainty as to the availability of irrigation water, and it is widely accepted as the most limiting factor of production systems (Roth *et al.* 2013). This is likely to continue into the future as the agriculture sector continues to compete with environmental, domestic and industrial sectors for this finite resource (Zwart and Bastiaanssen 2004). Without irrigation water, cotton production is dramatically reduced, as it is likely that seasonal conditions are not appropriate for dryland cotton. Actual water usage is very difficult to measure in in-field surface irrigated experiments. Estimated water usage provided by Auscott implied that the 1.5 m cotton used 30% less water (7.27 ML/ha), compared with the 1 m cotton (10.43/ha).

Water is an expensive asset and water costs can vary considerably and can be valued at anywhere between \$50/ML in the Murrumbidgee/Murray Valley, and \$300/ML in the Namoi Valley as temporary transfer. The cost of irrigation water is one of the largest costs per ha in the gross margin of both 1 m and 1.5 m cotton (Table 3). The water saving of 3 ML/ha plays a large role in reducing costs of 1.5 m cotton to compensate for the reduction in yield and keep the gross margin competitive (Table 3). It is therefore very important that future research quantifies actual water use to allow for true cost comparison. Saved water would allow for more hectares of cotton to be grown and a more profitable farming system.

The water figures listed above refer to estimated applied irrigation water and growing season rainfall; it is important to note that the 1.5 m cotton has potentially 33% more soil water per plant to extract moisture from compared with 1 m cotton. Consequently this means that potentially 33% more soil moisture is available per hectare from stored soil moisture conserved in fallow conditions and 33% more water per hectare will be harvested from in

crop rainfall. The Bureau of Meteorology weather station at Trangie (30km south east) receives an average of 236 mm of in crop rainfall (Oct-Feb) or 2.36 ML/ha. In 1.5 m cotton this equates to 3.57 ML/ha, an increase of 1.2 ML/ha.

The ability of 1.5 m row systems to harvest stored soil moisture and growing season rainfall may be more suited to years of limited irrigation water, or northern cotton growing regions where higher average summer rainfall is expected, and a greater opportunity to harvest growing season rain is present. The 1.5 m cotton provides a viable option in years of reduced water allocation for these reasons (Bange *et al.* 2005).

### *Economics*

Estimated gross margins reveal that the two row configurations (1 m and 1.5 m) return a very similar amount, with gross margins differing by only \$46 between the two systems (see Table 3). The income of 1 m cotton is considerably higher than the 1.5 m cotton; however costs are also considerably higher in the 1 m cotton than the 1.5 m cotton. The main reductions in costs are due to irrigation water (\$474/ha), technology fees (\$133/ha), and ginning (\$107/ha) (Table 3).

The price per bale for cotton and cotton seed may fluctuate depending on supply and demand levels around the world (lint) and domestically (seed). \$450 a bale was chosen as a representative average price for lint, and \$250 per tonne for seed. For every bale of cotton, it was estimated 250 kg of fuzzy seed was produced as a by-product. Except for water, the cost of production was calculated using recorded inputs and costs calculated using the NSW DPI gross margin template (NSW DPI 2014).

Since the value of water purchased as temporary transfer (single use) can range considerably in all the river valleys in Australia, the Macquarie River is no exception with prices ranging from \$50/ML in years of excess water to over \$300/ML in years of tight supply. \$150/ML was used as an estimate of an average price for temporary transfer. Water is the largest cost saving of the 1.5 m cotton. If the price of water was to fluctuate lower than \$150/ML then the difference between the two gross margins would increase, and 1 m cotton would be more profitable. Alternatively if the price of water was to remain high, it would be more economic to grow cotton on 1.5 m row spacing.

The industry wide adoption of the genetically engineered Bollgard II™ and Roundup Ready Flex™ traits have meant that Monsanto technology fees have become a substantial cost in growing irrigated and rainfed cotton (\$400/ha). However the fees are charged based on the actual green hectares grown, i.e. 100% of the fees are applicable for solid cotton, 66.7% for 1.5 m cotton and skip row spacing as they represent only  $\frac{2}{3}$  of the total area planted. An additional saving of \$134/ha is taken into account. The third largest cost saving of 1.5 m cotton is ginning. The cost of ginning is \$60 per bale, the saving observed is that there are simply fewer bales of cotton per hectare to gin. Fertiliser usage for 1.5 m cotton was based at 84% of 1 m cotton to correspond with yield differences. One less defoliation is expected in 1.5 m cotton due to greater coverage and canopy penetration of defoliant.

**Table 3: Expected gross margins of 1 m and 1.5 m row spacing** (based on the NSW DPI gross margin template for North West NSW).

<b>Income</b>	<b>Yield</b>	<b>Price</b>		<b>Income 1 m (\$/ha)</b>	<b>Yield</b>	<b>Price</b>		<b>Income 1.5 m (\$/ha)</b>
<b>Lint income</b>	11.5	450.0		5184.0	9.7	450.0		4378.5
<b>Seed income</b>	2.9	250.0		720.0	2.4	250.0		608.1
<b>Total income</b>				<b>5904.0</b>				<b>4986.6</b>
<b>Operation</b>	<b>Volume</b>	<b>Cost</b>	<b>Application cost</b>	<b>Cost 1 m (\$/ha)</b>	<b>Volume</b>	<b>Cost</b>	<b>Application cost</b>	<b>Cost 1.5m (\$/ha)</b>
<b>Bed forming</b>	2.0		25	50.0	2.0		25	50.0
<b>MAP</b>	100	0.96		96.0	84	0.96		80.6
<b>Seed</b>	13.0	8.0	9	113.0	8.7	8.0	9	78.3
<b>Nitrogen fertiliser</b>	275.0	1.1		298.9	231.0	1.1		251.1
<b>Water</b>	10.43	150.0		1564.5	7.27	150.0		1090.5
<b>Herbicide</b>	4.0	9.0	6	60.0	4.0	9.0	6	60.0
<b>Insecticide</b>	1.0	15.0	15	30.0	1.0	15.0	15	30.0
<b>Defoliation</b>	3.0	25.0	15	120.0	2.0	25.0	15	80.0
<b>Picking</b>			272	271.8			272	271.8
<b>Module wrap</b>	11.52	6		69.1	9.73	6		58.4
<b>Ginning</b>	11.52	60.0		691.2	9.73	60.0		583.8
<b>Technology levies</b>	1.0	400.0		400.0	0.67	400.0		266.7
<b>Consultant</b>	11.5	4.5		51.8	9.73	4.5		43.8
<b>Total costs</b>		60.0		<b>3876.4</b>				<b>3005.0</b>
<b>Gross margin</b>				<b>2027.6</b>				<b>1981.6</b>

### *Fibre quality*

Overall there were no considerable differences in fibre quality of the two row configurations. Both 1 m and 1.5 m cotton exceeded the parameters adhered to by the Australian cotton industry (see Table 4) (Bange *et al.* 2009). There was however small changes in fibre quality in my handpicked experiments.

Fibre length of each boll is determined in the 25 days post flowering. Cell expansion and elongation are strongly driven by turgor pressure, therefore adequate soil moisture must be present (immediately after anthesis) for full elongation (Bange *et al.* 2009). Therefore if the plant suffers from water stress during the first third of the boll filling process (when fibres are elongating) fibre length will be compromised (Hearn 1976; Constable and Hearn 1981; Ramey Jr 1986; Hearn 1994; Palomo-Gil *et al.* 2004). My experimental data revealed that the 1.5 m cotton had longer fibre length with less variation as a result of having a larger soil moisture profile and volume to draw moisture from during the fibre elongation period.

Fibre strength refers to the amount of force it takes to break a specific number of fibres.

There is a direct correlation with fibre maturity and fibre strength, as the more mature a fibre is, the stronger is it likely to be. Water stress in the later two thirds of boll filling process will reduce fibre maturity and thickening (micronaire) (Constable and Bange 2007; Bange *et al.* 2009; Roth *et al.* 2013). This was observed in our fibre strength experimental data although micronaire data was not available.

**Table 4: Fibre quality parameters** (Bange *et al.* 2009)

<b>Fibre Trait</b>	<b>Ideal range</b>	<b>Premium range</b>
Length	> 1.125 inches	> 1.250 inches
Strength	> 29 g/tex	> 34 g/tex

#### *Other agronomic factors to consider*

There are some other agronomic factors to consider that may influence the choice of row spacing. To grow the same green area of 1 m cotton in 1.5 m row spacing, it will require 1/3 more area. This requires 1/3 of extra irrigation development to account for the row spacing change. Development of land for irrigation is an expensive operation, costing \$2,000 ha for surface irrigation (Roth *et al.* 2013).

Growing cotton on 1.5 m row spacing increases the ease of some farming operations.

Operations throughout the season are considerably easier when performed on wider row spacing such as; determining when water is flowing through in flood irrigation scenarios and having more space between rows allows for later herbicide and insecticide applications by ground rig and reducing the need for aerial application (Steele, S. pers. com. 2014).

Extension of machinery axles and modification to implements, combined with the cost of buying GPS auto-steer systems requires a significant amount of upfront capital, especially if a number of machines are involved (Reeder 2006). However a 15% return on investment will ensure management will be saving money after 6 years of installation (Masek *et al.* 2010).

Extension of axles can also increase the rate of wear on machinery and must be taken into account.

### *Compaction*

Reduction in compaction due to a complete CTF system of 1.5 m rows also adds significant value. Soil compaction caused by machinery traffic results in significant damage to soils including increased bulk densities, and increased mechanical impedance (Radford *et al.* 2000; Hamza and Anderson 2005; Chan *et al.* 2006). Increased soil bulk densities reduce soil porosity, a soil's ability to store moisture and limit the number of sites available for gas exchange. All of the above mentioned consequences of soil compaction can severely hinder root growth (Barley 1963; Taylor and Ratliff 1969; Atwell 1993), moisture uptake and plant growth as a result (Kirkegaard *et al.* 1992; Passioura 2002; Chan *et al.* 2006). Many studies have found yield decreases due to soil compaction in both dryland (Ellington 1986; Radford *et al.* 2001; Hamza and Anderson 2003; Sadras *et al.* 2005) and irrigated cropping systems (McGarry and Chan 1984; Daniells 1989; McGarry 1990; Braunack *et al.* 1995) across a large range of soil types, environments, and crop types (Chan *et al.* 2006).

Auscott Warren, having implemented a CTF system will confine these issues created by compaction to the smallest area possible. In theory it would be expected that increased crop and root growth, and consequently increased yield will be observed into the future (Hamza and Anderson 2005). It may take a period of time for past soil structural damage that has not been rectified, which may continue to impede root growth. Many cotton farms in Australia run on a form of CTF system, although most do not run on a complete CTF with all wheel traffic on 3 m centres due to the logistical difficulties. The reduction in compaction observed in a complete CTF system compared with a CTF system only reduces 1 pass by the combine harvester every time a rotation crop is grown. In a cotton, cotton, wheat rotation a complete CTF system will reduce only 1 single compaction event caused by the combine harvester (26 tonne full) once every three years.

Soil resilience refers to the time it takes for a soil to return to a normal state after it has been subject to some form of change. The rate of resilience differs between soil types, but is often very slow to self-repair. Vertosols are the most common soil types found in the cotton growing regions of Australia and have a relatively high level of resilience due to their swell/cracking nature. In saying this, the process is still slow and will take a number of years to self-repair, even with increased frequency of wetting and drying cycles observed in irrigation fields (Chan *et al.* 2006).

#### *Limitations*

This experimental work is limited as there is only one year's worth of data in only one location (Warren NSW), in one cotton growing region of Australia. This experiment needs to be repeated in the same location along with other locations with different climates for a more accurate indication of the effect of 1 m and 1.5 m row spacing on yield and fibre quality in all cotton growing regions. My data may not be applicable to cotton grown in a different cotton growing region with different climatic conditions. Estimated water usage also limits this experiment as it only gives a good indication to the actual water used by each row configuration, not exact water usage.

#### *Future research*

To more precisely compare the two row configurations (1 m and 1.5 m), water use must be quantified. As water is such a finite resource in all cotton growing regions of Australia, it is an important factor when making agronomic decisions. The same experiment should be replicated to increase the reliability of the data in this study, with the additional focus of

water use. Water use is typically very difficult to measure in flood irrigation experiments. Water use could be quantified by measuring total water onto the field (head ditch), and off the field (tail drain) with high volume flow instruments such as Mace meters to determine the total water applied to the whole experiment. Capacitance probes should also be used in each replicate to measure the total amount of water being used by each replicate of the experiment. This will provide information which will allow us to determine the proportion of water that is used by each replicate, and investigate if there are any differences between the two row configurations. Canopy temperatures could also be measured to observe moisture stress levels of the 1 m and 1.5 m cotton. When water data has been accurately captured it will provide all of the information needed to make an informed decision about the costs and benefits of the two row configurations. Future research should also take into the account the effects of compaction of one pass of a combine harvester every three years. This information would contribute to the decision making process with regard to the two row configurations. The machine picked experiment should be repeated in a replicated fashion instead of harvesting the whole field blocks to increase the reliability of the data and allow for statistical analysis.

## **Conclusion**

My experimental data showed that the 1 m cotton out yielded the 1.5 m cotton by 1.8 bales/ha (16%). The handpicked segments revealed that the majority of the fruit in 1 m cotton came from fruiting positions 1-8 position 1, whereas in the 1.5 m cotton the majority of fruit came from the vegetative fruiting branches. The gross margins of the two systems were remarkably similar, with 1 m cotton performing \$46/ha better than the 1.5 m cotton. Only minor differences in fibre quality were observed in my experimental data, of which all fibre parameters were better than the industry requirements. Future research needs to quantify water use to provide more information to improve decision making.

**Acknowledgements**

Firstly I would like to thank my supervisor, Dr Daniel Tan for his comments and advice throughout this whole experiment. Daniel has put tireless hours into editing and planning of this experiment. I would also like to acknowledge Dr Rose Brodrick of CSIRO Plant Industry for her advice and comments; her experience in cotton research was very helpful. I would also like to acknowledge Bob Ford of Cotton Seed Distributors (CSD) for his advice, comments, data analysis and help regarding segment picking and ginning of handpicked samples. I would also like to acknowledge Auscott Warren for their work in facilitating this experiment. Without them this experiment would not have been possible. I would also like to thank Auscott for their ongoing contributions to the cotton industry and their willingness to share information. Finally I would also like to thank the Cotton Research and Development Corporation for their generosity in funding an Honours Scholarship to help me undertake this research.

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