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The influence of planting density on the production of 'Goldfinger' (*Musa* spp., AAAB) in the subtropics

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Abstract

'Goldfinger', a tetraploid banana produced from the Fundación Hondureña de Investigación Agrícola (FHIA) breeding program, was released to the Australian industry in 1995. It was promoted as an apple-flavoured dessert banana with resistance to Fusarium wilt race 1 and subtropical race 4, as well as resistance to black and yellow Sigatoka (*Mycosphaerella fijiensis* and *M. musicola*, respectively). This study was initiated to provide agronomic information to the banana industry, which was under threat from Fusarium wilt, on a new cultivar which could replace 'Williams' (AAA, Cavendish subgroup) or 'Lady Finger' (AAB, Pome subgroup) in those areas affected by Fusarium wilt. Also few studies had reported on the production characteristics of the new tetraploid hybrids, especially from subtropical areas, and therefore two field sites, one a steep-land farm and the other a level, more productive site, were selected for planting density and spatial arrangement treatments. The optimum density in terms of commercial production, taking into account bunch weight, finger size, length of the production cycle, plant height and ease of management, was 1680 plants/ha on the steep-land site where plants were planted in single rows with 2.5 m × 2.5 m spacings. However on the level site a double-row triangular layout with inter-row distances of 4.5 m to allow vehicular access (1724 plants/ha) gave the best results. With this arrangement plants were in an alternate, triangular arrangement along a row and a spacing of 1.5 m between plants at the points of each triangle and between each block of triangles.

Keywords: Banana; FHIA-01; Spacing; Plantation establishment

1. Introduction

In 1995 the Australian banana industry released a new banana variety in the market. 'Goldfinger' (AAAB) was one of the earlier cultivars released from the Fundación Hondureña de Investigación Agrícola (FHIA) breeding program and was first sold commercially in South Africa in 1992 (Whiley, 1996). 'Goldfinger' has a sweet acid or 'apple' flavour, with similarities to 'Lady Finger' (AAB, Pome subgroup), but is highly resistant to race 1 and race 4 of *Fusarium oxysporum* f.sp. *cubense* (*Foc*), which limit 'Lady Finger' production in the Australian subtropics (Pegg et al., 1996). Under subtropical conditions that exist at Wamuran in southeast Queensland, 'Goldfinger' plants were taller than 'Williams' (AAA, Cavendish subgroup) but shorter than 'Lady Finger', and showed greater cold tolerance (Smith et al., 1998). They also reported that at a density of 1333 plants/ha, 'Williams' was the most productive cultivar at 35.8 t/ha/yr, followed by 'Goldfinger' (34.8) and 'Lady Finger' (20.9).

Robinson (1996) states that the spacing of bananas is a complex matter in plantation establishment and major determinants of density choice are prevailing climate, plantation vigour and plantation longevity. For instance a mild, subtropical climate with cold winters requires that a lower ratoon density be used (<2000 plants/ha) to allow light penetration, enhance growing temperatures and accelerate the cycling time. Conversely shorter plantation cycles (i.e. the period from planting to plough-out) can tolerate higher planting densities. It is very important that the appropriate planting density be chosen because it is one of the major determinants of annual yield per hectare and, once the density is initially chosen, it cannot be easily adjusted at a later stage.

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The work presented in this paper reports on the effect of planting density and spatial arrangement on growth and performance of 'Goldfinger' bananas planted in two locations in southeast Queensland. Measurements were made for both plant and ratoon crops. The Wamuran site (27°S, 153°E) was on steep land (average 20° slope) and of medium to low vigour with respect to soil type and ease of management. The site was typical of the hillside environment in which Cavendish banana cultivars were succumbing to subtropical race 4 of Fusarium wilt and the study was to examine the best planting strategy for commercial production where plantation longevity extends to over 10 ratoon crops. Bundaberg Research Station (25°S, 152°E), on the other hand, has well-drained soils on a flat, deeply weathered volcanic plain. The purpose of selecting this site was to study the performance of 'Goldfinger' in an area that offered greater prospects for mechanisation and crop rotation and therefore more profitable, sustainable production.

2. Materials and methods

2.1. Plant materials

'Goldfinger' (*Musa* spp., AAAB) tissue cultured material were kindly supplied by P. Rowe of Fundación Hondureña de Investigación Agrícola, and used to establish a field block at South Johnstone Research Station (SJRS; 17.6°S, 146°E). Suckers collected at SJRS from 'Goldfinger' and 'Williams' (*Musa* spp., AAA, Cavendish subgroup), the Australian industry standard, were subsequently used to re-establish tissue cultured plants. These plants were micropropagated and established in the field for experimental work when they reached a height of 20 cm in 2.5 L planter bags (Smith and Hamill, 1993).

2.2. Establishment and maintenance of field trials

The Wamuran site (27°S, 153°E) previously formed part of a commercial Cavendish plantation and was characteristic of many of the steep-land farms in subtropical areas of the eastern coast of Australia. The soil is classified as a yellow ferrosol (gleyed podzolic soil) and is a heavy clay–clay loam. The slope varied from 10° to 40° and had a north-east aspect. The experiment was planted in October 1994 in single rows with the following four plant crop spacings: 1.8 m × 1.8 m (3086 plants/ha), 2.5 m × 2.5 m (1680 plants/ha), 3.0 m × 3.0 m (1111 plants/ha) and 3.6 m × 3.6 m (772 plants/ha). One sword sucker was selected for each plant on the uphill side about 6 months after planting. In one treatment plants were initially spaced at 1.8 m × 1.8 m but thinned to 3.6 m × 3.6 m by removing every second row and every second plant in the remaining rows for the ratoon crop. There were two datum rows per treatment and guard rows of the same spacing bordered each treatment.

The Bundaberg Research Station site (25°S, 152°E) was level and on a deep, friable, red loam (krasnozem). The experiment was planted in October 1996 in double rows with inter-row distances of 4.5 m to allow vehicular access. Plants were spaced at either 1.5 or 2.0 m between rows with either 1.5 m (2222 plants/ha) or 2.0 m (1538 plants/ha), respectively, between plants along a row in a rectangular arrangement. In one treatment (Fig. 1) plants were in an alternate, triangular arrangement along a row and a spacing of 1.5 m between plants at the points of each triangle and between each block of triangles (1724 plants/ha). 'Williams' planted at 1.5 m × 1.5 m (2222 plants/ha) was introduced as a fourth treatment.

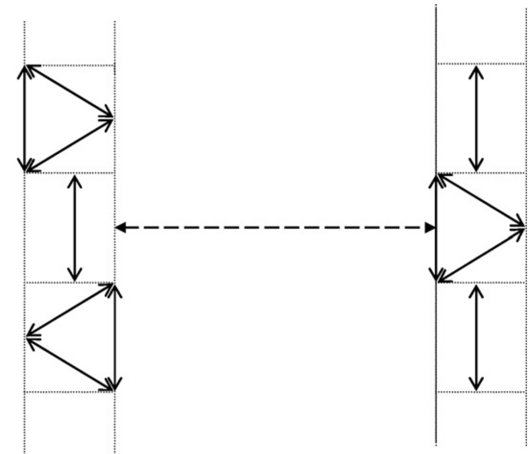

Fig. 1. Triangular planting arrangement used at Bundaberg Research Station. The field trial was planted in October 1996 in double rows with inter-row distances of 4.5 m (dashed arrow) to allow vehicular access. Plants were in an alternate, triangular arrangement along a row and a spacing of 1.5 m (solid arrows) between plants at the points of each triangle and between each block of triangles (1724 plants/ha).

On average the Wamuran site experienced winters 2.4 °C colder (mean daily minimum temperature of 8.8 °C during winter) than Bundaberg, whereas the summer daily maxima was 29.0 °C for Wamuran and 29.8 °C for Bundaberg. The Bundaberg site also experienced consistently windy conditions throughout the year where monthly wind speeds averaged 14.2 km/h, ranging from a high of 15.2 km/h in April to a low of 13.1 km/h in August. Although wind speeds were not recorded at the Wamuran site, it was more sheltered than the Bundaberg site and not exposed to the south-easterly trade winds.

Plants at both experimental sites were grown using standard commercial practices (Broadley et al., 2004). Fertiliser as N, P, K plus trace elements (Nitrophoska) was broadcast by hand at the Wamuran site every 3 months at the rate of 150–200 g per plant, while the Bundaberg site received a basal dressing of dolomitic limestone at 1.2 t/ha, 35 kg P/ha as superphosate, 51 kg N/ha as ammonium nitrate and 100 kg K/ha as potassium chloride that was broadcast in the drill just before planting. Side dressing of the same rate broadcast on rows with a Vicon mechanical spreader every 6 months for dolomitic limestone and P, and each month for N and K. Water was supplied through overhead sprinklers at Wamuran and through undercanopy microsprinklers at Bundaberg. Weeds were controlled by hand hoeing at Wamuran but at Bundaberg this was only necessary for the first 3 months. After this, paraquat or glyphosate was sprayed as required. 'Goldfinger' has resistance to Sigatoka leaf spot, but 'Williams' at the Bundaberg site had to be treated with mancozeb and miscible oil every 5–6 weeks during summer and early autumn. Detrashing to remove old necrotic leaves was performed by hand at each site every 4–6 weeks to keep stools clean. Lorsban® (chlorpyrifos 500 g/L ai.) for banana weevil borer (*Cosmopolites sordidus*), was applied at the recommended rate twice yearly at both sites.

2.3. Measurements

Blocks were visited weekly and when banana plants started bunching, pseudostem height (from the soil surface to the point of intersection of the 2 upper-most leaves) and pseudostem circumference (at 30 cm above ground) were measured. The height of the follower was also measured. At harvest the following parameters were recorded: date, number of leaves produced from post planting (tissue culture) to harvest, number and total area of green leaves at harvest (calculated using the formula of Robinson and Nel (1985) where leaf length × maximum leaf width was multiplied by a conversion factor of 0.83), bunch weight, bunch stalk weight, number of hands, number of fingers in bunch, number of fingers in third proximal hand, and length of middle finger of the outer whorl of the third proximal hand.

2.4. Experimental design and statistical analysis

Both sites used a randomised complete block design with 6 replicates and 5 treatments at Wamuran and with 5 replicates and 4 treatments at Bundaberg. At Wamuran there were a total of 150 datum plants for the 1.8 m × 1.8 m spacing, 108 plants for the 2.5 m × 2.5 m spacing, 93 for the 3.0 m × 3.0 m spacing and 82 for the 3.6 m × 3.6 m. In the treatment where the plants were thinned there were 148 datum plants for the plant crop but 64 for the ratoon harvest. Likewise at the Bundaberg site there were 90 datum plants for the 'Williams' and 86 for the 'Goldfinger' planted at the 1.5 m × 1.5 m spacing and 89 plants and 68 plants, respectively, when planted at 1.5 m × 2.0 m spacing or in the alternate, triangular arrangement. Unequal plant numbers were due to the practice of thinning one treatment and differences in availability of planting material. Data was analysed by ANOVA and tested using the significance level of $P = 0.05$.

Productivity was calculated using the actual times of harvest of plant and ratoon bunches from each plant. The bunch weights of the plant and ratoon crops for each plant were added and converted to an average 'per annum' yield figure from planting to ratoon harvest. These individual plant yields were then added to give a production figure for the whole plot and converted to a per hectare basis. At Wamuran and at the high densities there were still a few plants that had not produced a mature ratoon bunch at the conclusion of the experiment (1446 days).

3. Results

At the Wamuran site, increasing the planting density resulted in significant differences in Goldfinger's stature, cycling times and bunch characteristics (Table 1). As the density increased from 772 to 3086 plants/ha, the plants became significantly taller (2.50–2.81 m in the plant crop; 2.97–3.64 m in first ratoon) and the time from planting to bunch harvest became significantly longer (577–690 days for the plant crop; 896–1246 days for first ratoon). An examination of bunch weight, number of hands, number of fingers and finger length found that they were generally greatest at a planting density of 1111 plants/ha, although there were few significant differences in these parameters at the lower planting densities (772, 1111 and 1680 plants/ha). However the bunches harvested from the highest density planting (3086 plants/ha) were significantly smaller with reduced finger length.

At the Bundaberg site, the triangular spacing arrangement gave results marginally better than the standard 2-row rectangular arrangement (Table 2), even though in terms of density it was intermediate (1724 plants/ha) between the high and low planting densities (2222 and 1538 plants/ha, respectively). The plants under the triangular planting arrangement

Table 1
A comparison of agronomic traits of 'Goldfinger' in a plant and ratoon crop at 4 different spacing densities at Wamuran experimental site

Treatment (plants/ha)	Pseudostem height (m)	Pseudostem circum (cm)	Days to bunch emergence	Total no. leaves	No. of green leaves at harvest	Leaf area at harvest (cm^2)	Days to harvest	Bunch weight (kg)	No. of hands	No. of fingers on 3rd hand	Finger length (cm)[a]
Plant crop											
3086	2.81 a	82.3 a	492 a	46.2 a	4.78 b	8,930 a	690 a	18.7 b	9.0 a	14.3 a	18.9 b
1680	2.64 b	82.9 a	450 b	45.6 a	5.26 b	9,130 a	629 b	20.7 ab	9.0 a	14.5 a	20.0 a
1111	2.56 bc	81.8 a	445 b	45.4 a	6.98 a	9,170 a	604 bc	21.7 a	8.9 a	14.3 a	20.5 a
772	2.50 c	80.4 a	434 b	45.5 a	7.85 a	8,990 a	577 c	21.4 a	8.9 a	14.3 a	20.4 a
Ratoon crop											
3086	3.64 a	98.7 a	1125 a	34.6 a	7.22 a	12,820 a	1246 a	24.8 a	10.5 a	14.5 b	19.9 a
3086–772[b]	3.23 c	100.0 a	955 b	31.6 bc	9.02 a	12,960 a	1116 b	29.2 a	10.3 a	15.9 a	20.6 a
1680	3.39 b	101.2 a	914 b	33.2 ab	7.65 a	12,890 a	1079 b	28.1 a	10.9 a	15.9 a	20.1 a
1111	3.18 c	97.2 a	826 c	30.9 bc	7.98 a	11,490 b	972 c	28.0 a	10.9 a	15.4 a	20.4 a
772	2.97 d	94.1 a	762 d	29.8 c	8.32 a	10,880 b	896 d	26.2 a	10.0 a	15.2 ab	20.4 a

Experiment was established in October 1994 from micropropagated plants. Means within each plant crop or ratoon crop column followed by a common letter are not significantly different at $P = 0.05$.

[a] Finger length was measured from the middle finger of the outer whorl of the third hand from the proximal end.

[b] Plants in block were planted at 6 m × 6 m spacing and thinned to 12 m × 12 m spacing after plant crop harvest.

Table 2
A comparison of agronomic traits of 'Goldfinger' and 'Williams' in a plant and ratoon crop at 3 different spacing densities at Bundaberg experimental site

Treatment (cultivar, plants/ha)	Pseudostem height (m)	Pseudostem circum (cm)	Follower height (cm)	Days to harvest	No. of green leaves at harvest	Leaf area at harvest (cm^2)	Bunch weight (kg)	Stalk weight (kg)	No. of hands	No. of fingers on 3rd hand	Finger length (cm)[a]
Plant Crop											
'Williams', 2222	2.05 d	61.0 c	160 b	474 b	3.12 c	5470 a	18.2 ab	1.37 b	8.1 a	16.3 a	19.0 b
'GF', 2222	2.44 b	71.0 ab	244 a	492 a	4.42 ab	5630 a	17.1 bc	1.36 b	7.4 b	12.8 b	19.1 ab
'GF', 1724[b]	2.51 a	72.0 a	253 a	496 a	5.22 a	6020 a	18.8 a	1.73 a	7.6 ab	13.2 b	19.8 a
'GF', 1538	2.32 c	69.2 b	247 a	478 b	4.17 b	5490 a	16.2 c	1.40 b	7.1 b	13.2 b	18.4 b
Ratoon Crop											
'Williams', 2222	2.42 c	73.7 c	164 b	808 b	5.12 c	8890 a	22.1 c	1.58 c	8.5 c	15.7 a	18.6 b
'GF', 2222	3.11 b	90.8 a	238 a	816 b	6.94 ab	9300 a	26.9 ab	2.08 b	9.5 ab	14.3 c	18.9 ab
'GF', 1724[b]	3.24 a	93.1 a	239 a	838 a	7.50 a	9660 a	29.2 a	2.18 ab	9.8 a	14.6 bc	19.4 a
'GF', 1538	3.05 b	86.6 b	230 a	768 c	6.18 b	7870 b	24.9 b	2.31 a	9.2 b	14.8 b	18.4 b

Experiment was established in October 1996 from micropropagated plants in double-rows. Means within each column followed by a common letter are not significantly different at $P = 0.05$.
[a] Finger length was measured from the middle finger of the outer whorl of the third hand from the proximal end.
[b] Plants were in an alternate, triangular arrangement along a row and a spacing of 1.5 m between plants at the points of each triangle and between each block of triangles.

Table 3
Productivity of 'Goldfinger' in two subtropical Australian environments and at different planting densities

Wamuran					
Density (plants/ha)	3086	3086–772[a]	1680	1111	772
Productivity (t/ha/yr)	31.2 a	20.2 c	25.2 b	19.9 c	14.1 d
Bundaberg					
Density (plants/ha)	'Williams', 2222	'GF', 2222	'GF', 1724[b]	'GF', 1538	
Productivity (t/ha/yr)	34.0 ab	37.7 a	29.7 bc	27.2 c	

Values are the means of 5–6 plots. Means within each row followed by a common letter are not significantly different at $P = 0.05$. Productivity was calculated by combining the bunch weights of plant and ratoon crops and converting to an overall 'per annum' figure for each plant and then summed to give a production figure for the whole plot (converted to a per hectare basis).
[a] Plants in block were planted at 1.8 m × 1.8 m spacing and thinned to 3.6 m × 3.6 m spacing after plant crop harvest.
[b] Plants were in an alternate, triangular arrangement along a row and a spacing of 1.5 m between plants at the points of each triangle and between each block of triangles.

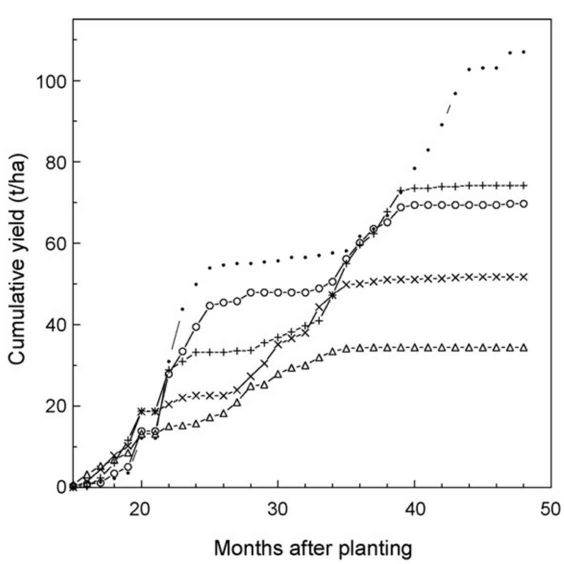

Fig. 2. The relationship between productivity and planting density of 'Goldfinger' in a plant and ratoon crop at 4 different spacing densities at Wamuran experimental site. Cumulative yield (t/ha) was calculated as the production over the whole trial period, from planting to when the trials were terminated at 1446 days. Legend (plants/ha): ● (3086), ○ (3086–772)[a], + (1680), × (1111) and △ (772). [a]Plants in block were planted at 6 m × 6 m spacing and thinned to 12 m × 12 m spacing after plant crop harvest.

were more robust and had significantly heavier bunch weight in the plant crop, while overall; the plants from this treatment had individuals with the greatest number of hands and longest finger length compared to the other 'Goldfinger' treatments.

Bundaberg was the most productive site (Table 3), so even at lower planting densities the tonnes of fruit harvested per hectare per unit time tended to be higher than those at the Wamuran site. As expected higher planting density gave a higher cumulative yield (Figs. 2 and 3), but this has to be balanced against other features such as plant height at bunching, length of time to harvest and large finger size at harvest which are also important to consider in a commercial banana production system. Also at the one site where 'Williams' and 'Goldfinger' were compared (Bundaberg at 2222 plants/ha, Table 2), 'Goldfinger' was as productive as 'Williams'.

4. Discussion

'Goldfinger' is intermediate in height between 'Williams' (AAA) and 'Lady Finger' (AAB), but capable of yields approaching and even surpassing Cavendish cultivars (Daniells et al., 1995a,b; Whiley, 1996; Smith et al., 1998). However there are few published reports of the performance or productivity of 'Goldfinger' in large-scale field experiments

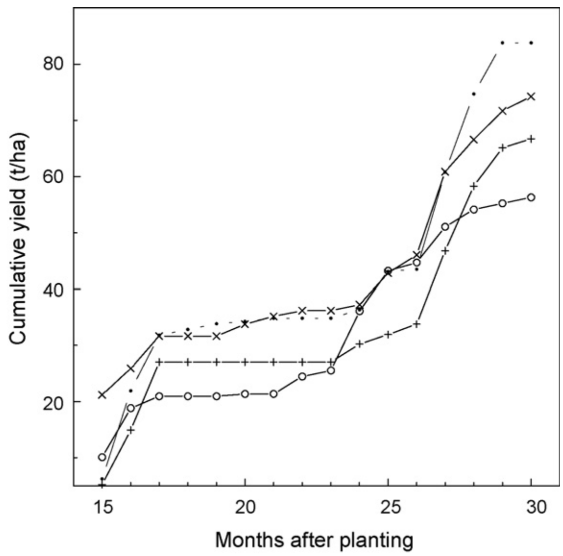

Fig. 3. The relationship between productivity and planting density of 'Goldfinger' and 'Williams' in a plant and ratoon crop at 3 different spacing densities at Bundaberg experimental site. Cumulative yield (t/ha) was calculated as the production over the whole trial period, from planting to when the trials were terminated at 918 days. Legend (cultivar, plants/ha): ● ('GF', 2222), ○ ('GF', 1538), + ('GF', 1724)[a] and × ('Williams', 2222). [a]plants were in an alternate, triangular arrangement along a row and a spacing of 1.5 m between plants at the points of each triangle and between each block of triangles.

and at various planting densities and spatial arrangements. Most reports are comparative studies of FHIA hybrids and tend to focus on responses to pests, diseases and marginal growing conditions where 'Goldfinger' has generally been found to be more productive than local selections or reference cultivars (Alvarez, 1997; Eckstein et al., 1998; González et al., 2003).

At both Australian subtropical sites productivity, as measured by tonnes of fruit (as bunches) produced per hectare per unit time, increased as planting density increased (Table 3). In the more limiting growing conditions experienced at Wamuran the upper limit of productivity was being approached with standard commercial practices. Further increases in productivity could be achieved in Bundaberg by increasing planting density. However other plant characters are as important in determining the most suitable density and arrangement in terms of production of marketable fruit and ease of management.

As the density increased the plants competed more for light and became taller. Therefore bagging and harvesting fruit was more difficult and took more time. Fortunately 'Goldfinger' plants are robust, required little propping or tying and were resistant to leaf-spot caused by *Mycosphaerella musicola*, unlike Cavendish where high planting densities can lead to taller, thinner plants and increased spray costs to control leaf diseases. It is worth noting however that with high-density plantings at Wamuran there was increasing incidence of leaf speckle caused by *Mycosphaerella musae*. Daniells et al. (1995a,b) have indicated that under certain circumstances damage to 'Goldfinger' caused by *M. musae* could be sufficient to reduce yield/quality if fungicides are not applied. Therefore high-density plantings may not only exacerbate development of leaf diseases but their control is made more difficult due to lack of penetration of sprayed fungicides.

Fruit size also decreased at the higher densities, and fruit colour became paler (results not shown), and this can affect the packout of first-grade fruit leading to further financial losses during marketing. Excessive shading in high-density plantings also creates problems with sucker selection. For instance the ability of the parent plant to produce suckers in high-density plantings at Wamuran was reduced and this delayed follower selection. As a result, the harvest of fruit from the ratoon crop continued over a longer period of time and bunches were still being harvested from the high-density treatment (3086 plants/ha) 4 years after planting. Robinson (1996) gives a full account of the disadvantages of both high and low densities, and concludes that it is better to choose a density too low rather than one that is too high.

The Wamuran site was characteristic of the steep-land farms in southeast Queensland and northern New South Wales. Access to these farms is often difficult and maximum use is made of land with a suitable north-easterly aspect. In these situations a spacing of 2.5 m × 2.5 m and a planting density of 1680 plants/ha was considered optimal in terms of commercial production. Certainly, at the highest density plants were very tall at harvest and more difficult to manage.

Newer areas of farming land in the Australian subtropics are being opened as an alternative crop to sugar cane. The Bundaberg site was characteristic of many of these areas and it opens up the possibility of increasing accessibility and mechanisation of banana production based on cultivars suited to the cool subtropics. It is not only the density of plants per hectare which is important but also the way they are spaced in relation to each other. Based on plantation design of semi-tropical banana production in north Queensland (Daniells et al., 1987), wide interrows were included in the design because it allowed complete access to each plant by tractor and trailer which had distinct advantages in managing and harvesting the crop. We considered that the triangular spacing arrangement within the double-row layout optimized light interception, although this needs to be verified, and the plants were superior in stature and yield compared to the other spacings, particularly in the plant crop. This arrangement was considered the best planting density and arrangement for more level sites in subtropical areas.

These results indicate that 'Goldfinger' is productive in adverse conditions where poor soils which go from saturated to cracking many times during a production cycle and low winter temperatures, both encountered at the Wamuran site, can combine to shorten or interrupt the active growing period. However 'Goldfinger' is also productive in more favourable subtropical growing conditions with yields comparable to 'Williams', the Australian industry standard, at the same planting density.

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