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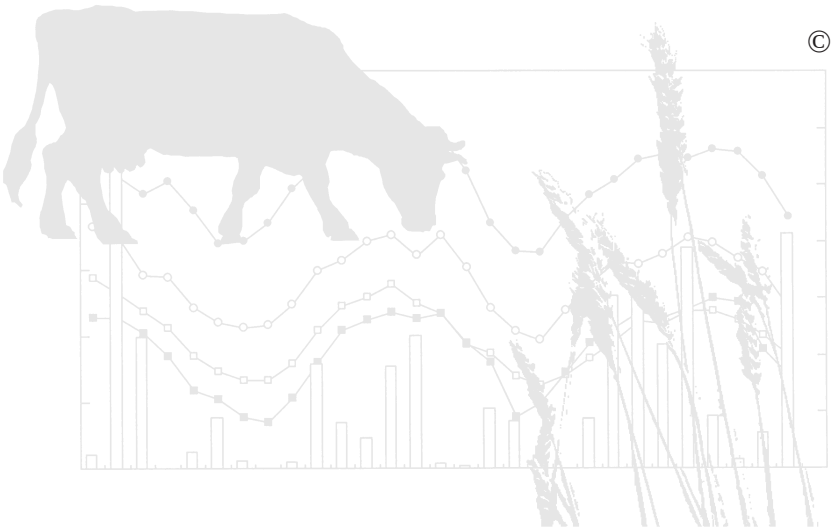

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Growth and yield of 3 hybrid papayas (*Carica papaya* L.) under mulched and bare ground conditions

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Abstract. At Yarwun (151.3°E, 23.75°S), Australia, papaya Hybrid 29 yielded twice as much fruit as Hybrid 11 and 30% more than Hybrid 13. The plots mulched with coarse grass hay yielded 50% more fruit than the plots with bare ground. The highest yielding treatment, Hybrid 29 + mulch, averaged the equivalent of 81 t/ha.year over the 16.5-month harvest period. The yields were achieved in spite of inadequate water supply due to drought and the loss of 877 plants from 1441 plant positions (4 plants per position) due to the 3 phytoplasma diseases; dieback, yellow crinkle and mosaic.

Hybrid 29 produced higher yields than the other hybrids by flowering early on shorter plants with thicker stems and setting more fruit that commenced lower down on the stem. Hybrid 13 was intermediate in size and the amount of fruit setting between Hybrid 29 and Hybrid 11 but was the slowest to flower and set fruit. Hybrid 11 had the thinnest and tallest stems, flowered at an intermediate time between the other 2 hybrids and produced fewer flowers and fruit resulting in the lowest yield.

Mulching increased stem height and thickness, promoted earlier flowering and increased fruit set, yield and average fruit weight.

Introduction

The Queensland papaya (papaw) industry was based on dioecious outcrossed varieties developed by growers because it was believed that they produced higher yields than hermaphrodite varieties under Queensland's (Australia) climatic conditions. This is in contrast to the more homozygous hermaphrodite varieties grown in Hawaii (Nakasone *et al.* 1972). Open-pollinated, dioecious varieties exhibit extreme variability in such characteristics as fruit shape, taste, size, flesh-colour, firmness and yield. In the past, this extreme variability made scientific field experimentation unattractive due to the difficulty in obtaining statistically reliable results (Kuhne and Allan 1970) and induced a perception in the market place that papayas were an unreliable product. Hofmeyr (1953) and Aquilizan (1987) developed a method of fixing breeding lines by self-fertilising male plants with suitable characteristics. Male plants usually produce bisexual flowers and subsequently fruit in autumn. The availability of these inbred lines that could be crossed to produce hybrids with relatively uniform characteristics encouraged the field trial described in this paper.

Due to the variability in outcrossed varieties, information on yield and crop phenology available to the industry was extremely limited and based on casual observations and grower's records. Elder *et al.* (2000) studied the effect of 2 hybrids (Hybrid 1E and Hybrid 29) and 3 irrigation methods (trickle, mini-sprinklers and overhead sprinklers) on the yield of papaya when mulched with coarse grass hay. They showed that fruit yields of 92 t/ha.year could be achieved independent of hybrid or irrigation method. The study from planting to ratooning outlined in this paper was undertaken to provide information on the yield and crop phenology of 3 new hybrids, with or without the use of mulch.

Materials and methods

Site description and experimental design

The experiment was conducted on a commercial papaya property at Yarwun (151.3°E, 23.75°S), Queensland, Australia where it was sited on the north-west side of a hill with an average slope of about 25% and spread over 4 contour bays down the slope.

The soil at the site was a Haplic, Eutrophic, Red Dermosol

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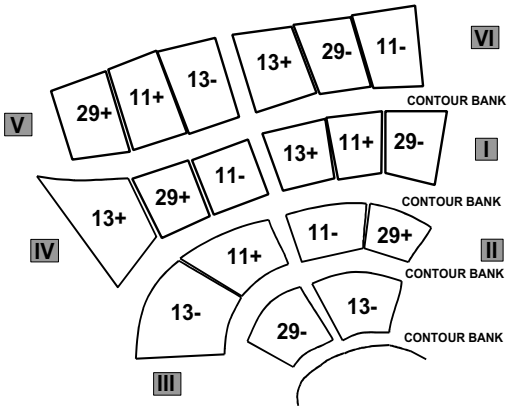
(prairie soil) developed on andesite, an intermediate volcanic rock. The soil varied in depth and surface texture depending on the topographic position.

Two soil surface treatments, mulched and bare ground, and 3 hybrids, Hybrid 29 (GD3-1-9 × TVL7)(female × male), Hybrid 11 (GD3-1-9 × ER6-4) and Hybrid 13 (BB5H × ER6-2) (Anon. 1998) were compared. These 6 treatments were arranged in a randomised incomplete block design with 3 replicate blocks and 2 small blocks within each replicate making a total of 6 small blocks. Each small block consisted of 3 plots (Fig. 1). Plant positions were in double rows on a 2.0 by 1.8 m (in row) grid with an average of 5.5 m between centres of the double rows. There were 80 plant positions in each plot resulting in a plant population of about 2000 plants/ha. The edges of all plots were planted to bana grass (*Pennisetum purpureum* × *P. glaucum*) to provide windbreaks up to 4 m in height. The mulched plots were covered to a depth of 10 cm with coarse grass hay just before planting and subsequently topped up at about 6-monthly intervals to maintain a 10 cm depth of mulch. Weeds were controlled as required in the mulched and bare ground plots by spraying with glyphosphate-ipa (Roundup, Monsanto Australia).

Crop establishment

Papaya seedlings were produced in 7.5 or 10 cm pots by planting up to 6 seeds per pot. The potting mix consisted of a mixture of equal parts peat and vermiculite plus slow release NPK fertiliser (Osmocote, NPK ratio 16:3.5:10, Scotts Europe, Heerlen, Netherlands) and had a pH of 6.5. In addition, the seedlings were fertilised fortnightly with a complete foliage fertiliser at 1 g/L (Thrive, NPK ratio 27:5.5:9, Yates Australia). The trial site was fertilised before planting using rates as determined from soil analyses (Anon. 1994*b*).



Replicate	Block	Hybrid		
		29	11	13
1	I	–	+	+
1	II	+	–	–
2	III	–	+	–
2	IV	+	–	+
3	V	+	+	–
3	VI	–	–	+

Figure 1. Layout of plots and treatments (+ mulched; – bare ground) in the trial site at Yarwun. Blocks V and VI are on a lower contour than IV and I which in turn are on a lower contour than III and II.

Seedlings were planted in the field on 7 June 1994 when they were about 15 cm in height. As the hybrids used were dioecious, 4 or 5 plants were planted at each plant position to enable the establishment of 90% females in each plot as sex can only be determined at flowering. The mulch in the mulched plots was brought up against the plants to reduce weed growth as much as possible. Because of losses due to frost in sub-blocks V and VI and some drought-encouraged kangaroo grazing damage over the whole block, misses were replanted on 10 August 1994. There had been little growth in the intervening period due to cold conditions.

Plants were thinned out to 1 per position 5 months after planting to retain 90% females in each plot. Thinning involved cutting back unwanted plants to stumps about 15 cm in height. These stumps regrew slowly but were available to replace the main plant if it was itself cut out due to disease.

Crop management and measurements

The area was irrigated uniformly using T-tape trickle irrigation. Irrigation was scheduled to maintain soil water tension below 15 centibars in 30 cm deep tensiometers. Because of extreme drought conditions in 1994–96, this was not always achievable and water was supplied at a lower level depending on availability.

Soil and/or leaf samples were taken at 6-monthly intervals in each plot with sampling procedures as given by Anon. (1994*a*, 1994*b*). Samples were analysed by Incitec (Gibson Island, Queensland), to determine nutrient requirements that allowed the appropriate fertilisers to be applied. The basis of the fertiliser program was potassium nitrate applied through the trickle irrigation system at the rate of about 20 g KNO_3/plant site.week during the growing months of September to May.

The number of dead and live plants were counted at each plant position 3 weeks after field planting. Diseases were controlled with the appropriate fungicide, mancozeb (Nufarm Mancozeb Fungicide, Nufarm Pty Ltd, West Perth) for black spot and triadimenol (Bayfidan 250 EC, Bayer Pty Ltd, Pymble) for powdery mildew. Plants showing symptoms of the phytoplasma diseases dieback, yellow crinkle and mosaic (Peterson *et al.* 1993) were recorded and cut out on a weekly basis. Plants were monitored for banana-spotting bugs [*Amblypelta lutescens lutescens* (Distant) (Hemiptera: Coreidae)] and when required were controlled with endosulfan (Thiodan, Agrevo Pty Ltd, Glen Iris).

Five months after planting, stem diameters (– 0.2 cm) of plants 30 cm above ground level and heights (– 0.5 cm) of the tallest plant in each plant position were recorded. In addition, the sex of the largest plant at each position was determined if flower initiation had commenced. Seven months after planting the presence or absence of male or female flowers on all plants at each position was determined. In addition, whether plants had reached the bud, flowering or fruiting stage, independent of sex, was recorded. Just before first harvest (10.5 months after planting) the number of fruit per female plant was counted. Fruit were deemed to have formed and were counted if the petals had fallen off. Plant height, height of the first fruit from ground level (– 0.5 cm) and stem circumference at 30 cm were also measured at this time.

Fruit were harvested by the grower/cooperator from female plants twice weekly in summer and weekly in winter, and individual fruit weights (– 1 g) were recorded. While male plants produce fruit during a restricted period of the year, these fruit were regarded as inferior to those produced on female plants and were discarded.

The yield data reported in this paper are from first fruit pick (16 April 1995) through to ratooning the first group of plants

(29 August 1996). The yield results from the first ratoon crop will be reported in a subsequent paper.

Statistical analyses

Circumference measurements at 10.5 months were converted to diameters for analysis and to facilitate comparison with the diameters at 5 months. Plant growth characteristics up to 10.5 months (stem diameter and height), fruit set (height of first fruit and number of fruit set) at 10.5 months and yield up to ratooning were analysed by analysis of variance. Foliar nutrient levels at 10.5 months were also analysed by analysis of variance. The proportion of dead plants and the proportion of positions without plants 3 weeks after field planting were analysed by residual maximum likelihood (REML; Patterson and Thompson 1971), with the total number of plants and plant positions, respectively, used as weighting variables in the analysis. Hence, more weight is given in the analyses to proportions based on larger denominators (i.e. those with more overall plants or plant positions). The proportion of mature plants at 5 and 7 months after planting were also analysed by REML, with the total number of plants used as a weighting variable. The proportion of plant positions with evidence of phytoplasma affected plants (dieback, yellow crinkle and mosaic) between 25 October 1994 and 29 August 1996 were analysed by analysis of variance. Distributional assumptions for all analyses were assessed by inspection of residual and normal probability plots. No analyses appeared to violate the variance and normality assumptions so transformations were not necessary. Pairwise differences between means were tested using a protected l.s.d. procedure at $P = 0.05$. It should be noted that the nature of the incomplete block design partially confounded mulching and the hybrid by mulching interaction with blocks resulting in efficiency factors of 0.89 and 0.56, respectively. The efficiency factor represents the proportion of information available to estimate a term, this having been reduced due to the confounding. All information (i.e. efficiency = 1.0) was available for estimating hybrid effects.

Results

Growth

There was no interaction ($P>0.10$) between mulching treatments and hybrids for any of the growth parameters.

Five months after planting, plants in the mulched plots were larger ($P<0.01$) than in the bare ground plots with 44% greater stem diameters (Table 1). By 10.5 months, mulched plants were still larger ($P<0.05$) than those without mulch with the stem diameters being 14% and 18% greater for females and males, respectively (Table 1). Both female and male plants in the mulched plots were also taller ($P<0.05$) than those in the bare ground plots (Table 1).

Stem diameters at 5 months after planting differed ($P = 0.069$) among hybrids. Hybrid 29 plants were larger than Hybrid 13 plants with Hybrid 11 being intermediate in diameter (Table 1). By 10.5 months after planting, there were no differences ($P>0.10$) in stem diameter among hybrids for either male or female plants (Table 1). However, at 10.5 months Hybrid 29 plants (male and female) were shorter ($P<0.05$) than either Hybrid 11 or Hybrid 13 plants (Table 1).

Flowering and fruit set up to 10.5 months

Five months after planting a greater ($P<0.001$) proportion of Hybrid 29 had flowered compared with Hybrid 11 which in turn was greater than Hybrid 13 (66.5, 45.6 and 13.2%, respectively). A greater ($P = 0.053$) percentage of plants in the mulched treatment had flowered compared with the bare ground treatment (48.4% and 35.1%, respectively). There were no differences ($P>0.10$) between the treatments in the ratio of males to females (largest plant at any 1 position only). The overall ratio was 1.08 male to female.

At 5 months, immature (non-flowering) plants were smaller ($P<0.01$) than males and females with mean stem diameters of 1.95 (immature), 2.72 (male) and 2.85 (female) cm.

By 7 months (13 January 1995), both mulched and bare ground treatments for Hybrid 29 and Hybrid 11 and the mulched treatment for Hybrid 13 had only a small proportion of plants that had not flowered (<8%), while the bare ground treatment for Hybrid 13 still had almost 40% immature plants ($P<0.05$; Fig. 2).

Female plants from Hybrid 11 and Hybrid 13 set the first fruit 55% higher ($P<0.05$) on the stem than Hybrid 29 (Table 1). By 10.5 months Hybrid 29 had set almost 2.5 times more ($P<0.05$) fruit than Hybrid 11 with

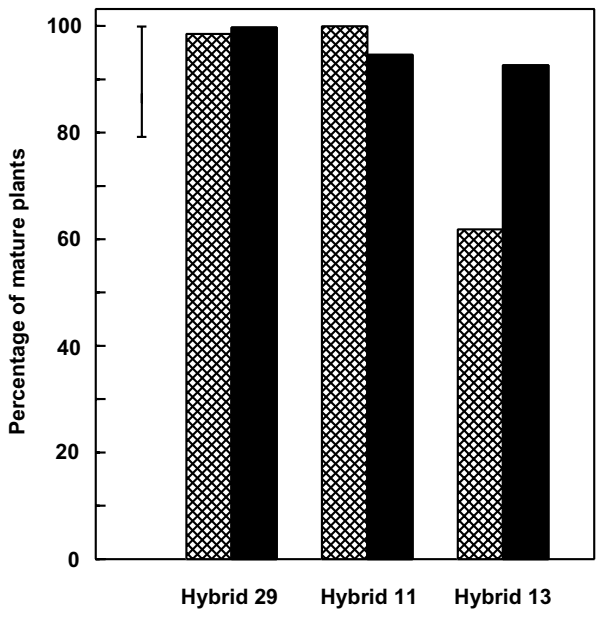


Figure 2. Percentage of mature (flowering) plants for 3 papaya hybrids in either bare ground (shaded bars) or mulched plots (solid bars) 7 months post planting. The vertical bar indicates the average l.s.d. ($P = 0.05$) for the interaction.

Hybrid 13 intermediate (Table 1). There was also evidence ($P = 0.071$) that plants in mulched plots had set more fruit by 10.5 months than plants in bare ground plots (Table 1).

Soil and foliar nutrient analyses 10.5 months post planting

Foliage analyses 10.5 months after planting indicated that nitrogen, copper and zinc in all plots were below optimum (Table 2). Nitrogen was applied at the rate of 10 g urea/plant.week over the following 3 weeks and copper and zinc sulfate once at 7 g/plant.site to correct low levels of these nutrients. Sodium was variable with a number of plots slightly above optimum (Table 2).

Differences in foliar nutrients due to treatments were limited but total nitrogen differed ($P<0.05$) among hybrids (Hybrid 29>Hybrid 11>Hybrid 13) while sulfur, phosphorus, potassium and boron levels were greater ($P<0.05$) for the mulched treatment compared with the bare ground treatment (Table 2).

Soil pH at 6.5 was in the optimal range for nutrient availability while soil nutrients were at medium to high levels except for nitrogen which was low. Sodium and chloride levels in the soil were below the critical level at which phytotoxicity may occur.

Diseases

Three weeks after planting, a number of plants had died mainly due to rotting at or close to ground level. The disease organism was identified as *Rhizoctonia* sp. (R. G. O'Brien pers. comm.). The mulched treatment had more ($P<0.01$) dead plants (9 *v*. 1%) and more ($P<0.01$) positions without plants (11 *v*. 2%) than the bare ground treatment. There were no differences ($P>0.10$) among hybrids in the proportion of dead plants or the number of plant positions without plants and there were no trends based on spatial position (e.g. bottom or top of hill).

Of 1441 plant positions with 1–4 plants per position, there were 611, 195 and 71 plants (total of 877) exhibiting symptoms of dieback, yellow crinkle and mosaic, respectively, between 25 October 1994 and 29 August 1996 which represented 37%, 13% and 5% of positions respectively. There were no differences ($P>0.10$) among hybrids or between mulching treatments.

Yield up to ratooning

There were no interactions ($P>0.10$) between mulch treatments and hybrids for each of total yield, total number of fruit and mean fruit weight over the 16.5-month harvest period to the commencement of ratooning. However, both total yield and total number of fruit varied ($P<0.01$) among hybrids and between mulching and bare ground treatments (Table 3). Hybrid 29 produced 30% greater yield than Hybrid 13 and double the yield of Hybrid 11. Furthermore, mulching increased yield by 50% compared with bare ground. The highest yielding treatment, Hybrid 29 + mulch, averaged the equivalent of 81 t/ha.year over the 16.5 month harvest period. There was no difference ($P>0.10$) among hybrids in average fruit weight but mulching tended ($P = 0.068$) to increase average fruit weight compared with bare ground (1.21 *v*. 1.15 kg, respectively).

Figures 3 and 4 depict the fortnightly harvest data for hybrids and mulching treatments, respectively. Similar trends over time were evident in fortnightly fruit yield, fruit number and average fruit weight for each of the 3 hybrids and for the 2 mulching treatments. There was a tendency for greater yields and more fruit to be harvested in winter and spring than in the summer. For most of the time, Hybrid 29 had the greatest fruit yield and number of

Table 1. Effect of mulching on growth and fruit set of three papaya hybrids up to 10.5 months after planting

Means within a treatment not followed by a common letter are significantly different ($P<0.05$)

	Stem diameter at 5 months (cm)	Stem diameter at 10.5 months (cm)		Plant height at 10.5 months (cm)		Height of first fruit (cm)	No. of fruit set at 10.5 months
		Female	Male	Female	Male		
Mulching (M)	***	*	*	*	*	n.s.	$P = 0.071$
Bare	1.97b	8.43b	8.31b	210.4b	210.1b	101.6	10.2
Mulched	2.83a	9.64a	9.84a	223.2a	225.9a	96.1	14.5
Hybrid (H)	$P = 0.069$	n.s.	n.s.	***	***	***	**
29	2.62	8.69	8.82	192.3b	195.6b	72.2b	17.2a
11	2.40	9.69	9.68	234.3a	232.7a	111.5a	7.2b
13	2.18	8.72	8.72	223.7a	225.8a	112.8a	12.5ab

*$P<0.05$; **$P<0.01$; ***$P<0.001$; n.s., not significant ($P>0.10$).

Table 2. Average nutrient levels from foliar analyses 10.5 months after planting

The optimum nutrient levels (Anon. 1994*a*) are presented for comparison
Means within a treatment not followed by a common letter are significantly different (P<0.05)

	Total N (%)	NO_3-N (mg/L)	S (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)
Mulching	n.s.	n.s.	*	*	*	n.s.	n.s.	n.s.
Bare	0.79	83	0.33b	0.19b	3.38b	1.67	0.78	0.16
Mulched	0.82	65	0.41a	0.25a	4.10a	1.73	0.79	0.13
Hybrid	*	n.s.	n.s.	n.s.	P = 0.066	n.s.	n.s.	P = 0.065
29	0.86a	82	0.39	0.24	4.17	1.65	0.80	0.19
11	0.81ab	73	0.37	0.21	3.65	1.66	0.76	0.13
13	0.76b	68	0.35	0.21	3.39	1.80	0.80	0.12
Optimum levels	1.30–2.50	n.a.	0.3–0.6	0.2–0.4	3–6	1.0–2.5	0.5–1.5	<0.2

	Cl (%)	Cu (mg/L)	Zn (mg/L)	Mn (mg/L)	Fe (mg/L)	B (mg/L)	Al (mg/L)
Mulching	P = 0.082	n.s.	n.s.	n.s.	n.s.	P = 0.052	n.s.
Bare	2.83	2.36	6.43	52.4	26.0	24.9	12.0
Mulched	3.13	3.53	8.01	52.2	20.4	26.1	9.0
Hybrid	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
29	2.95	3.33	8.17	56.0	26.7	24.8	11.0
11	2.91	3.33	8.17	48.8	22.7	25.7	11.2
13	3.08	2.17	5.33	52.2	20.3	26.0	9.3
Optimum levels	<4	4–10	10–30	25–150	20–80	20–50	n.a.

*P<0.05; n.s., not significant (P>0.10). n.a., not available.

fruit each fortnight while Hybrid 11 had the least. The mulched treatment tended to have a greater yield and more fruit each fortnight than the bare ground treatment. Hybrid and mulching treatment differences were also more evident during the winter and spring harvests. In addition to seasonal fluctuations there appeared to be a general decline in average fruit weight over time, from about 1.4 kg in April–May 1995 to about 1.0 kg by late 1996. Fruit from mulched plots were consistently larger than those from the bare-ground plots.

Table 3. Effect of mulching on total yield (kg), total number of fruit and average fruit weight (kg) per plot of three papaya hybrids over 16.5 months before ratooning (16 April 1995 to 29 August 1996)

Means not followed by a common letter are significantly different (P<0.05)

	Weight (kg)	Number of fruit	Average fruit weight (kg)
Mulching	**	**	P = 0.068
Bare	2129b	1840b	1.149
Mulched	3201a	2615a	1.211
Hybrid	**	**	n.s.
29	3536a	2878a	1.222
11	1748c	1488c	1.170
13	2711b	2316b	1.149

**P<0.01; n.s., not significant (P>0.10).

Discussion

The fungal organism *Rhizoctonia* sp. is common in soil, particularly in heavily mulched situations, and attacks a number of different plants (Persley and Stirling 1994). Plant damage is usually more common in the warmer months. Accordingly, mulch should always be kept at least 30 cm away from young papaya plants. Where mulching is used it should be put down before planting as there is less damage to the small plants compared with mulching after planting. Also the young plants have the benefit of reduced moisture loss from the upper soil levels and reduced weed growth in the establishment phase.

The growth rate of all plants was slow for much of the first 5 months due to an extended cool winter with 2 episodes of damaging frost. Frost was more severe on the

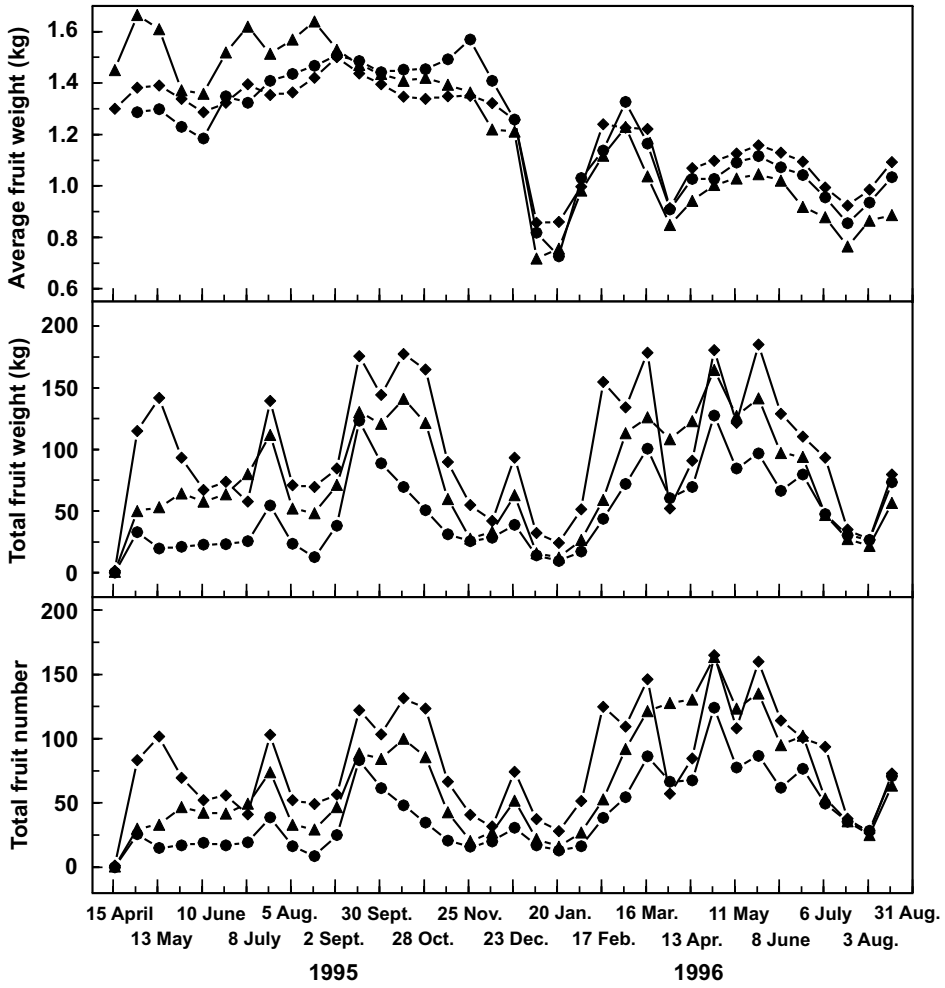


Figure 3. Average fruit weight (kg), total fruit weight (kg) and total number of fruit per plot for 3 papaya hybrids (◆ Hybrid 29; ● Hybrid 11; ▲ Hybrid 13) on a fortnightly basis. The dates indicated are the starting dates for every second fortnight.

mulched plots in block III while the other blocks further up the slope were relatively unaffected. Mulching also decreased the time to flowering for all hybrids.

Mulching increased stem growth (diameter) and plant height of papaya compared with bare-ground plants up until the commencement of harvest at 10.5 months post planting. This response to mulching was probably due to a number of factors including better use of the total soil volume, lower soil temperatures in the first few centimetres, reduced soil and water loss, improved conditions for soil mychorrhiza and decreased nematode populations. These will be examined in a subsequent paper that covers the post-ratoon yield results.

Hybrid 29 exhibited its dwarfed habit (Anon. 1998) by reduced plant height compared with Hybrid 11 and Hybrid 13 and its lower height of first fruit set (72 cm compared with 112 cm for the other 2 hybrids). Hybrid 29 also matured earlier than the other 2 hybrids.

At 5 (pre-flowering) and 10.5 months (post flowering) it was not possible to distinguish male and female plants on size. Therefore, removal of excess plants cannot be done until flowering.

There was a marked difference in fruit set with Hybrid 29 setting much more fruit followed by Hybrid 13 and Hybrid 11. The fruit set occurred under conditions of occasional inadequate water supply and, as a result, the set was 'gappy' because some flowers, spaced at irregular intervals, failed to set fruit. One of the parents of Hybrid 11 (ER6-4) is a known poor fruit setter under dry conditions (Anon. 1998). As periods of dry are known to happen on

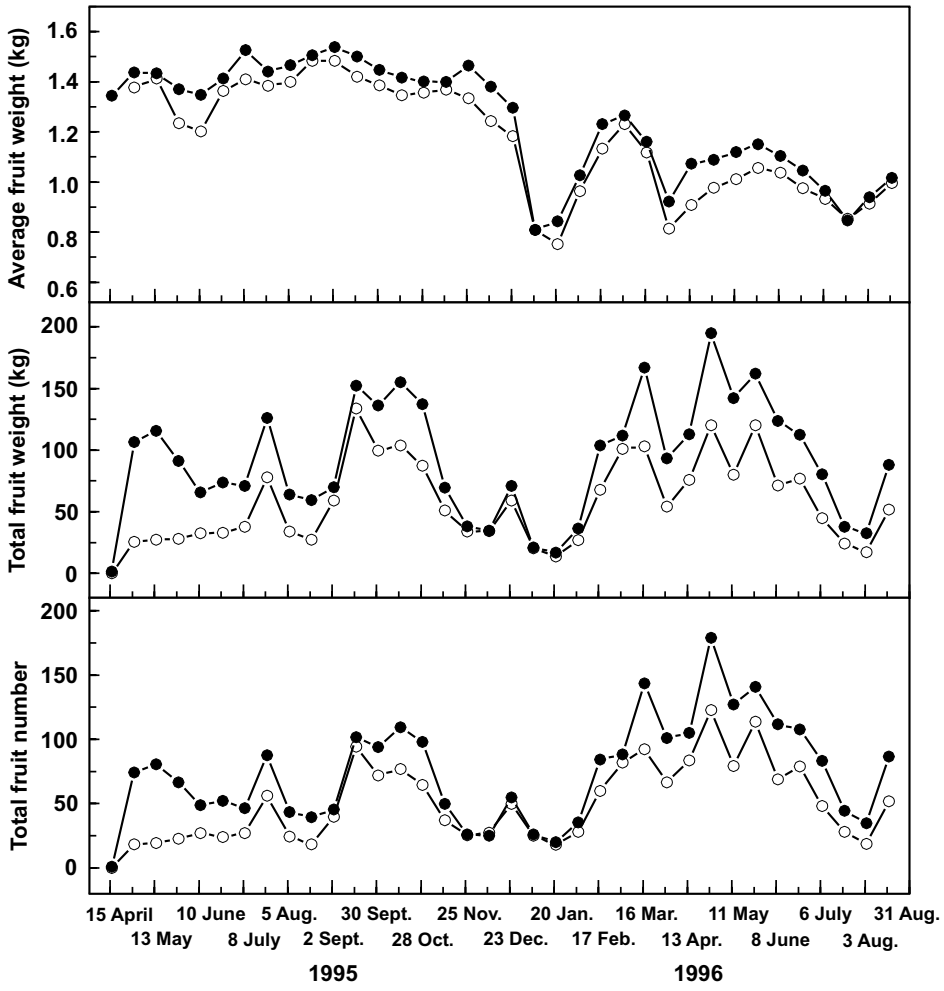


Figure 4. Average fruit weight (kg), total fruit weight (kg) and total number of fruit per plot for mulched (●) and bare soil (○) treatments on a fortnightly basis. The dates indicated are the starting dates for every second fortnight.

most properties throughout the growing areas of Australia, even in the wet tropics (P. Ross pers. comm.), Hybrid 11 has real commercial limitations.

Nitrogen, copper and zinc were below optimum in the foliar analyses. Apart from total nitrogen, and to some extent potassium and sodium, there were no differences among hybrids in foliar nutrient levels. The reason for the lower total nitrogen level in the Hybrid 13 treatment is not known. The higher levels of sulfur, phosphorous, potassium and boron in the mulched compared with the bare soil treatment may be due to improved soil water retention through the whole soil volume under the mulch, allowing the plant to access more nutrients. This may have contributed to the better growth as indicated by stem diameter and plant height in the mulched treatments. Mulching of avocado trees is known to improve root growth and this was reflected in improved yields and increased fruit size (Moore-Gordon *et al.* 1996).

The greater initial fruit set in Hybrid 29 than in Hybrid 13, which in turn was greater than in Hybrid 11, was reflected in the much higher yield in Hybrid 29 followed by Hybrid 13 and then Hybrid 11. Given the yield advantage of Hybrid 29, it may not be worthwhile to plant Hybrid 13 or Hybrid 11 commercially. The drop in average fruit weights and yield in January (Figs 3 and 4) is an annual event and follows the reduced pollination in the winter months of July and August by moths from the family Sphingidae (Garrett 1995; Elder *et al.* 2000). Garrett (1995) showed that fruit weight is dependent on the number of fertile seeds and that hand pollination

during the July–August period when the moths are absent has the potential to significantly increase fruit weights at picking in the following January. The commercial viability of hand pollination is unknown.

The incidence of the 3 phytoplasma diseases, particularly dieback, was quite high. Disease incidence was independent of mulching treatment and hybrid and therefore represents a level experienced by producers in the growing area. Although the effects of these diseases will have depressed potential yields, the yields reported are indicative of likely commercial yields. Furthermore, by utilising the regrown stumps when plants were cut out due to dieback, the number of lost plant positions was kept to a minimum.

This trial has shown that mulching in papaya is a valuable management practice producing plants with thicker stems, promoting earlier flowering and increasing fruit set, yield and average fruit weight. Of the 3 hybrids grown in this trial, Hybrid 29 had thicker stems, was shorter, flowered earlier, set more fruit commencing lower down the stem and produced the best yields.

Acknowledgments

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