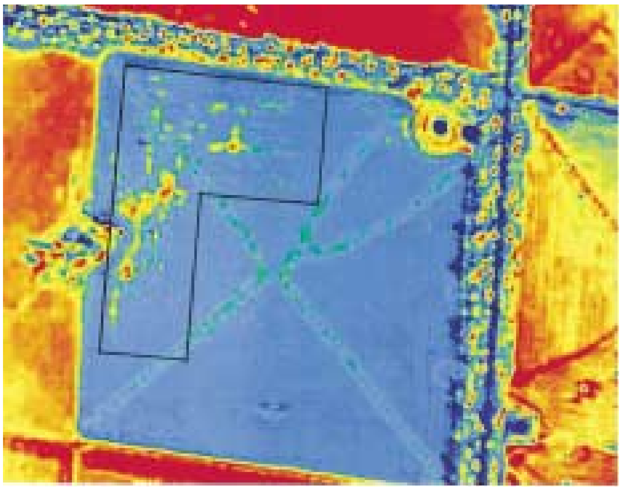
CSIRO Publishing

Australian Journal of Experimental Agriculture



Volume 42, 2002

. . . a journal publishing papers at the cutting edge of applied agricultural research

All enquiries and manuscripts should be directed to:

Australian Journal of Experimental Agriculture
CSIRO Publishing
PO Box 1139 (150 Oxford Street)
Collingwood, Vic. 3066, Australia

Telephone: +61 3 9662 7614
Fax: +61 3 9662 7611
Email: publishing.ajea@csiro.au

CSIRO PUBLISHING

Published by CSIRO Publishing
for the **Standing Committee on Agriculture and Resource Management (SCARM)**

www.publish.csiro.au/journals/ajea

Australian Journal of Experimental Agriculture, 2002, **42**, 71–81

Post-ratoon growth and yield of three hybrid papayas (*Carica papaya* L.) under mulched and bare-ground conditions

R. J. Elder[A], *D. J. Reid*[AD], *W. N. B. Macleod*[AC] *and R. L. Gillespie*[B]

[A]Department of Primary Industries, PO Box 6014, Rockhampton, Qld 4702, Australia;
e-mail: Rod.Elder@dpi.qld.gov.au
[B]Department of Natural Resources, PO Box 485, Biloela, Qld 4715, Australia;
e-mail: Roy.Gillespie@dnr.qld.gov.au
[C]Golden Circle Ltd, PO Box 106, Virginia, Qld 4014, Australia; e-mail: nmacleod@gcl.com.au
[D]Author for correspondence; e-mail: David.Reid@dpi.qld.gov.au

Abstract. At Yarwun (151.3°E, 23.75°S), a trial was conducted to compare 3 papaya hybrids (Hybrid 29, Hybrid 11 and Hybrid 13) under mulching with grass hay or in bare ground. The viability of ratooning a papaya crop was also investigated. After a 16-month cropping season plants were cut to a 750-mm stump (ratooned) about monthly over a 3.5-month period and, following a 4.5-month regrowth period, were harvested for a period of 11 months (post-ratoon). Hybrid 29 yielded (by weight) 54% more than Hybrid 11 and 92% more than Hybrid 13 during the 3.5-month ratooning period. At the commencement of ratooning, Hybrid 29 plants were 41–58 cm shorter than Hybrid 11 and 13 plants, allowing the Hybrid 29 plants to be retained for longer before being ratooned. Hybrid 29 also returned to fruiting more quickly with a greater proportion of plants (97%) with fruit at the first post-ratoon harvest compared with Hybrid 11 (87%). Following regrowth (post-ratoon) the 3 hybrids produced similar yields. All 3 hybrids were equally susceptible to the 3 phytoplasma diseases and to nematodes. The plots mulched with coarse grass hay yielded 70% more during the ratooning period and 116% more post-ratoon than the plots with bare ground. This difference was attributed in part to fewer root-knot nematodes, the roots being more heavily infected with vesicular arbuscular mycorrhiza, the use of the complete upper soil profile by the roots, reduced rainfall run off and less soil loss in the mulched treatment. The highest yielding treatment, mulched Hybrid 29, averaged the equivalent of 55 t/ha.year during ratooning, 43 t/ha.year over the 11-month post-ratoon harvest period and 65 t/ha.year over the entire plant–ratoon cycle. These yields were achieved in spite of drought conditions and quite severe outbreaks of the phytoplasma diseases, dieback, yellow crinkle and mosaic, with 60% of plant positions infected with dieback during the post-ratoon period. Theoretical yield estimations using the data from the plant and post-ratoon crops indicated that ratooning may give superior average monthly yields compared with 2 successive plant crops because of the reduced time required for the ratooned crop to return to production. The study demonstrated the benefits of mulching, the superiority of Hybrid 29 and that ratooning may be successfully used in papaya. In environments similar to Yarwun, Hybrid 29, or similar hybrids, with mulching is recommended for commercial production. If land, time or finances are limiting, consideration should be given to ratooning the plant crop based on monthly cut outs over a 3–4-month ratooning period with vacant plant positions replanted during ratooning.

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 hermaphroditic varieties under Queensland (Australia) climatic conditions. This is in contrast to the more homozygous hermaphroditic lines grown in Hawaii (Nakasone *et al.* 1972). Open-pollinated dioecious lines were grown also in South Africa. These varieties were extremely variable in characteristics such as fruit shape, taste, size, flesh colour, firmness and yield. This extreme variability made scientific field experimentation unattractive due to the difficulty in obtaining statistically reliable results (Kuhne and Allan 1970), while at the same time inducing a perception in the market place that papayas were unreliable to purchase. 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. These inbred lines could be crossed to produce hybrids with relatively uniform characteristics. The availability of these lines encouraged the field trial described in this paper.

Due to the variability in outcrossed varieties, information on yield, crop phenology and irrigation methods available to the industry was extremely limited, being based on casual

 10.1071/EA01032 0816-1089/02/010071

observations and grower's records. Elder *et al.* (2000*a*) 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 yields of 92 t/ha.year could be achieved independent of hybrid or irrigation method. A study by Elder *et al.* (2000*b*) provided information on the yield and crop phenology of Hybrid 29 and 2 new hybrids, with and without the use of grass-hay mulch. The plots mulched with coarse grass hay yielded 50% more fruit by weight than the plots with bare ground, with the highest-yielding treatment, mulched Hybrid 29, averaging the equivalent of 81 t/ha.year over the 16.5-month harvest period. These yields were achieved despite less-than-satisfactory conditions due to drought and the loss of 877 plants from 1441 plant positions due to the phytoplasma diseases, dieback, yellow crinkle and mosaic (Elder *et al.* 2000*b*). Basso-Figuera *et al.* (1994, 1995) obtained papaya-yield increases in an experiment where municipal solid-waste compost was incorporated in soil before planting.

Ratooning of papaya by cutting plants back to 750-mm height once they are too tall to easily pick fruit is used by some growers in Queensland. Ratooning is used also as a means of control for dieback. Ratooning apparently allows the plant to rid itself of the causal organism and the regrowth is healthy (Elder *et al.* 2002). Ratooning does not control yellow crinkle and mosaic, the other 2 phytoplasma diseases. Growers believe that ratooning is more economical than replanting because land preparation and irrigation lines are already in place. Also, the plants return to production 2 (or more) months sooner than if replanting was undertaken (W. N. B. Macleod pers. comm.). This paper extends the results from the plant crop (7 June 1994 to 4 September 1996) reported in Elder *et al.* (2000*b*) by determining the effects of ratooning (commencing on 4 September 1996) on regrowth and yield of the 3 hybrids under conditions of bare ground and mulching with grass hay.

Materials and methods

Site description and experimental design

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

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 (Elder *et al.* 2000*b*). 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 79–81 plant positions in each plot resulting in a total of 1441 plant positions, which equates to 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 glyphosate-ipa (Roundup, Monsanto Australia).

Crop management and measurements

Because the hybrids used were dioecious, each plant position was planted with 4 or 5 plants on 7 June 1994. They were thinned to 1 plant per position 5 months after planting to retain 90% female plant positions in each plot (Elder *et al.* 2000*b*).

The area was irrigated uniformly using T-tape trickle irrigation to maintain soil water tension below 15 centibars in 30-cm-deep tensiometers. Due to extreme drought conditions in 1996–98, this was not always achievable and water was supplied at a lower level depending on availability. Records were kept of the volume of water applied.

Soil and leaf petiole samples were collected at appropriate intervals and sent to Incitec (Gibson Island, Queensland) for analysis to determine nutrient requirements that allowed the appropriate fertilisers to be applied (Anon. 1994*a*, 1994*b*). The basis of the fertiliser program was potassium nitrate and at times urea applied through the irrigation system at the rate of about 20 g KNO_3/(plant position).week during the growing months of September–May. Following petiole analyses on 23 June 1997, a mixed fertiliser (Crop King 55, NPK ratio 11.9 : 14.1 : 9.9, Incitec, Gibson Island, Queensland) was applied at a rate of 400 kg/ha. Potassium nitrate was applied at a rate of 20 g/(plant position).week. Extra nitrogen, supplied as urea, was applied at a rate of 10 g/(plant position).week over the following 3 weeks.

Soil loss was measured following a storm in January 1996 yielding about 15 mm of rain over 30 min. Run off was collected in 6 m by 10 cm troughs placed across the slope below 2 mulched and 2 bare-soil plots. Soil was removed from the troughs after the event and oven-dried before weighing. The annual soil loss per hectare was estimated by multiplying the soil washed into the troughs by the estimated average number of storms of similar magnitude per year and converting to a per hectare basis. The number of storms per year was estimated from the Rainfall Intensity Diagram, Yeppoon 1989, contained in the Soil Conservation Handbook, Queensland Department of Primary Industries Soil Conservation Branch.

Diseases were controlled with the appropriate fungicide — i.e. mancozeb (Nufarm Mancozeb Fungicide, Nufarm Pty Ltd, West Perth, Western Australia) for black spot and triadimenol (Bayfidan 250 EC, Bayer Pty, Ltd, Pymble, New South Wales) 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. Crops were monitored for banana-spotting bugs [*Amblypelta lutescens lutescens* (Distant) (Hemiptera: Coreidae)] and, when required, controlled with endosulfan (Thiodan, Agrevo Pty Ltd, Glen Iris, Victoria).

Nematode samples were taken on 25 September 1996 by collecting 10 soil subsamples per plot and then bulking the 10 subsamples. The nematodes were extracted using a Baermann tray (Whitehead and Hemming 1965). Briefly, 200 mL of soil was spread on a tissue in a mesh basket, the basket was placed in a tray and water was added to saturate the soil. Nematodes migrated through the tissue into the water below and after 2 days they were concentrated on a 38-µm sieve. The nematodes were separated into root-knot (*Meloidogyne* spp.), spiral (*Helicotylenchus dihystera*) and a mixture of bacterial- and fungal-feeding nematodes.

On 4 September 1996, the plant height (± 5 cm) of the tallest plant in each plant position was recorded before ratooning the first plants. Crop-ratooning occurred over 4 occasions (4 September, 3 October, 7 November and 19 December 1996) reflecting commercial practice.

On the first 3 occasions, plants were cut out if their fruit were too high to pick easily from the ground and if the fruit were 3 months from picking, while all remaining plants were cut out on 19 December. The first harvest following final ratooning occurred on 8 May 1997. The number of stems with fruit, the number of fruit, the total number of stems at each plant position and the sex of stems at each plant position were recorded for plants in replicates 1 and 2 only. At the end of the study on 27 April 1998, the number and sex of remaining stems per plant position was recorded.

Fruit were harvested by the grower and/or cooperator twice weekly in summer and weekly in winter and individual fruit weights (± 1 g) were recorded from first ratooning (4 September 1996) until the last pick (2 April 1998), a period of 19 months. The 19 months include a 3.5-month ratooning period with harvesting continuing, a 4.5-month regrowth period with no yield and 11-month post-regrowth period of harvesting. The yield results from the pre-ratoon crop were reported by Elder *et al.* (2000*b*).

Statistical analyses

Plant height at the beginning of ratooning, the number of fruit and the number of stems per remaining female plant position at the first post-ratoon harvest and the number of stems per remaining female plant position at the end of the trial were analysed by residual maximum likelihood (REML; Patterson and Thompson 1971). The proportion of remaining plant positions that were female and the proportion of these female plant positions with fruit at the first post-ratoon harvest were also analysed by REML. Models included the fixed effects of hybrid, mulching treatment and their interaction and the random effects of replicate, blocks, plots and plant position (except for analysis of proportions). If the variance component estimate of any random effect was negative, the random effect was removed from the model. If the interaction was not significant (i.e. $P>0.05$) then it was removed from the model to allow testing of the main effects. An approximate F-test derived from the Wald-statistic was used in assessing significance of fixed effects.

The proportion of plants cut out at each of the 4 ratooning times, the number of remaining plant positions per plot at the end of the trial and the proportion of these that were female were analysed by analysis of variance. Yield from the ratooning phase (4 September–19 December 1996), from the post-ratoon harvests (8 May 1997–2 April 1998) and from first plant-crop harvest to the last post-ratoon harvest (16 April 1995–2 April 1998) were also analysed by analysis of variance. Foliar nutrient levels, nematode counts for each of the 3 types of nematodes and the proportion of plant positions with plants on 4 September 1996 that had at least 1 occurrence of dieback, yellow crinkle and mosaic between the commencement of ratooning and 19 March 1998 were analysed by analysis of variance. Pairwise differences between means were tested using a protected least significant difference (l.s.d.) procedure at $P = 0.05$.

Distributional assumptions for all analyses were assessed by inspection of residual and normal probability plots. The nematode counts, the number of fruit and the number of stems per remaining female plant position at the first post-ratoon harvest and the number of stems per remaining female plant position at the end of the trial were square-root transformed [$\sqrt{(x + 0.5)}$] before analysis to stabilise variance. Nitrate-nitrogen levels were log-transformed [$\ln(x + 1)$] and Al levels were square-root transformed. The proportion of female plant positions with fruit at the first post-ratoon harvest were arcsine transformed. All other data did not appear to violate the variance and normality assumptions.

It should be noted that the nature of the incomplete-block design partially confounded mulching and the hybrid by mulching interaction with blocks in the analysis of variance 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

Soil loss, on an oven-dry weight basis, due to the January 1996 rainfall event was 5.14 t/ha in the bare plots and 0.43 t/ha in the mulched plots, equating to an estimated annual loss of 12.85 t/ha in the bare plots and 1.08 t/ha in the mulched plots. Although not measured directly, water run off was greater in the bare-ground plots than in the mulched plots as, after minor rainfall events, there was usually water in the soil collection troughs of the bare-ground plots but less or none in the troughs of the mulched plots indicating greater infiltration rates in the mulched plots.

Ratooning phase (*4 September–19 December 1996*)

Of the original 1441 plant positions, 1158 positions still had plants at the start of the ratooning phase on 4 September 1996. The height of the tallest plant at each plant position was greater in the mulched plots than the bare-ground plots ($P<0.01$; 278 *v.* 248 cm, respectively) and for Hybrid 11 and Hybrid 13 plants compared with Hybrid 29 plants ($P<0.001$; 288 and 271 *v.* 230 cm, respectively).

There were no interactions or mulching effects ($P>0.10$) on the proportion of plants cut out on any of the 4 ratooning occasions. At the first and third ratooning occasions there were no differences ($P>0.10$) among hybrids in the proportion of plants cut out (Fig. 1). However, at the second ratooning on 3 October 1996 there were proportionally fewer ($P<0.05$) Hybrid 29 and Hybrid 11 plants cut out than

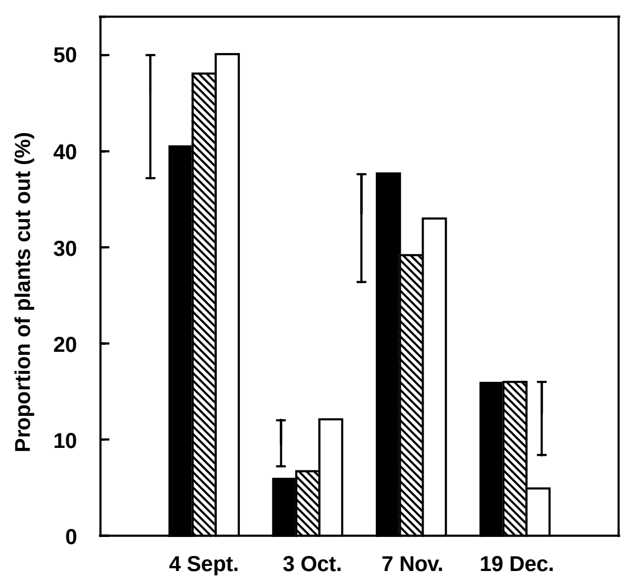


Figure 1. The proportion of plants cut out at each of the 4 ratooning times in 1996 for Hybrid 29 (solid bars), Hybrid 11 (shaded bars) and Hybrid 13 (open bars) averaged over the mulched and bare-ground treatments. The lines at each ratooning time indicate the l.s.d. at $P = 0.05$.

Hybrid 13 plants. This resulted in a greater proportion of Hybrid 29 and Hybrid 11 plants cut out on the final ratooning when height and fruit number were ignored and all remaining plants were cut out.

Foliar chemical analyses 9.5 months after the commencement of ratooning

Foliage analyses on 23 June 1997 indicated that nitrogen and potassium were low and phosphorous was marginal in all plots (Table 1). The sodium and chloride levels were satisfactory but still higher than desirable.

Foliar total nitrogen and zinc differed (P<0.05) among hybrids (Hybrid 11>Hybrid 13, Hybrid 29) as did nitrate-nitrogen (Hybrid 11>Hybrid 29) and potassium (Hybrid 29>Hybrid 13, Hybrid 11). Total nitrogen, nitrate-nitrogen, chloride and potassium were greater (P<0.05) for the mulched treatment than for the bare-ground treatment, while the reverse applied for magnesium and zinc.

Plant characteristics at the first post-ratoon harvest (*8 May 1997*) *and at the end of the trial* (*27 April 1998*)

At the first post-ratoon harvest, female plants occupied 74% of the remaining plant positions and this was independent of mulching treatment and hybrid. Of these female plant positions, almost 94% were carrying fruit with a greater (P<0.05) proportion of plants in the mulch treatment with fruit than in the bare-ground treatment (97 *v.* 89%, respectively). Also, Hybrid 29 (97%) had a greater (P<0.05) proportion of plants with fruit than Hybrid 11 (87%) with Hybrid 13 intermediate (95%). Mulched female plants had more (P<0.01) fruit than those in bare ground (31 *v.* 12) but there was no difference (P>0.10) among hybrids. Female plant positions averaged 2.9 stems per plant position and this was independent of mulching treatment and hybrid.

At the end of the trial, only 689 (59%) of the 1158 plant positions existing at the commencement of ratooning, or 48% of the 1441 plant positions at planting, remained with active plants with an average of 38 plant positions per plot independent of mulching treatment and hybrid. Of these, 75% were female with no difference (P>0.10) between mulching treatments or among hybrids. Each female plant position had an average of 1.8 stems again independent of mulching treatment and hybrid.

Phytoplasma diseases and nematodes

Of 1158 plant positions at the commencement of ratooning, 935, 255 and 53 plants from 689, 227 and 51 plant positions exhibited symptoms of dieback, yellow crinkle and mosaic, respectively, between 4 September 1996 and 19 March 1998. Sixty per cent of positions exhibited dieback during this period, almost all occurring in an outbreak in October–December 1997, with no differences (P>0.10) among hybrids or between mulching treatments. Overall, 19% of positions had yellow crinkle, primarily resulting from 2 outbreaks (January–March in 1997 and 1998), with some evidence that mulched plots were more susceptible than bare-ground plots (P = 0.058; 23 *v.* 16%, respectively) while there was no difference among hybrids. The proportion of positions affected by mosaic was influenced (P<0.05) by the combination of hybrids and mulching treatments with Hybrid 13 mulched plots more susceptible than Hybrid 13 bare-ground plots, while there was no difference between bare-ground and mulched plots for Hybrid 29 and Hybrid 11.

There were considerably (P<0.01) more *Meloidgyne* spp. nematodes in the bare-ground treatment than in the mulch treatment (118 *v.* 15 nematodes, respectively) while there was no difference (P>0.10) among hybrids. For *Helicotylenchus dihystera*, there was an interaction (P<0.05) between the mulching treatment and hybrid. There were more *H. dihystera* for Hybrid 29 under mulch than bare soil (463 *v.* 48), while the mulching treatment had no effect on the other 2 hybrids (182 *v.* 262 and 224 *v.* 368 for Hybrid 11 and 13 in mulched and bare-soil treatments, respectively). There were no

Table 1. Papaya plant nutritional status from foliar analyses on 23 June 1997

Back transformed values, where applicable, are given in parentheses
Means within a treatment not followed by a common letter are significantly different at P = 0.05
The optimum nutrient levels (Anon. 1994*a*) are presented for comparison

	Total N (%)	S (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Nitrate N[A] (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)	B (ppm)	Al[B] (ppm)
Mulching	**	n.s.	n.s	*	n.s.	**	P = 0.094	**	*	n.s	*	P = 0.073	n.s.	n.s.	n.s.
Bare	0.80b	0.46	0.18	2.13b	2.89	1.42a	0.18	2.48b	3.60b (36)	4.2	16.3a	131.5	46.1	25.2	2.69 (7.2)
Mulched	0.89a	0.47	0.19	2.72a	2.78	1.16b	0.28	3.37a	4.47a (86)	4.9	13.2b	111.9	39.6	26.3	2.25 (5.0)
Hybrid	**	P = 0.066	n.s.	*	n.s.	n.s.	n.s.	n.s.	*	n.s.	**	n.s.	n.s.	n.s.	n.s.
29	0.79b	0.41	0.18	2.88a	2.68	1.28	0.24	3.14	3.45b (30)	3.8	13.8b	127.0	40.5	26.3	1.82 (3.3)
13	0.78b	0.49	0.20	2.20b	2.87	1.23	0.27	2.75	3.99ab (53)	4.8	12.2b	110.3	50.2	25.8	2.79 (7.8)
11	0.97a	0.49	0.17	2.19b	2.94	1.37	0.19	2.88	4.67a (106)	5.0	18.3a	127.8	38.0	25.2	2.79 (7.8)
Optimum level	1.3–2.5	0.3–0.6	0.2–0.4	3.0–6.0	1.0–2.5	0.5–1.5	<0.2	<4.0	n.a.	4–10	10–30	25–150	20–80	20–50	n.a.

[A]Data were log-transformed. [B]Data were square-root transformed.
*P<0.05; **P<0.01; n.s, P>0.10. n.a., not available.

mulching or hybrid differences (P>0.10) in the number of free-living nematodes that feed on bacteria and fungi.

Yield during the ratooning phase
(*4 September–19 December 1996*)

For each of total yield, total number of fruit and average fruit weight during the 3.5-month ratooning process there were no interactions (P>0.10) between mulch treatments and hybrids. Hybrid 29 produced 54% greater yield by weight than Hybrid 11 and 92% greater than Hybrid 13 (Table 2). Furthermore, mulching increased (P<0.01) yield by 70% compared with bare ground. Similar results were observed for fruit number with Hybrid 29 yielding 53 and 73% more fruit than Hybrids 11 and 13, respectively, and mulching increasing fruit number by 63% compared with bare ground (Table 2). The best-yielding treatment, mulched Hybrid 29, averaged the equivalent of 55 t/ha.year over the 3.5-month ratooning period. Hybrid 29 produced larger (P<0.05) fruit than Hybrid 11, which in turn produced larger fruit than Hybrid 13. Mulching tended (P = 0.071) to increase average fruit weight compared with bare ground (Table 2).

Yield post-ratooning (*8 May 1997–2 April 1998*)

No fruit were harvested over the 4.5-month period from the final ratoon on 19 December 1996 to 7 May 1997, while plant regrowth was occurring.

For each of total yield, total number of fruit and average fruit weight over the 11-month post-ratoon harvest period there were no interactions (P>0.10) between mulch treatments and hybrids. The 3 hybrids produced similar (P>0.10) yields and numbers of fruit. Mulching increased yield by 116% (P<0.001) and number of fruit by 104% (P<0.01) compared with bare ground (Table 2). The best-yielding treatment, mulched Hybrid 29, averaged the equivalent of 43 t/ha.year over the 11-month post-ratoon harvests. Hybrid 29 and Hybrid 11 produced fruit that were about 10% larger than those for Hybrid 13 (P<0.01), while mulching increased average fruit weight by 4% compared with bare ground (P<0.05; Table 2).

Figures 2 and 3 depict the fortnightly post-ratoon 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. Hybrid 29 tended to have the greatest fruit yield and greatest number of fruit each fortnight while Hybrid 11 had the smallest. The mulched treatment had consistently greater yield and produced more fruit each fortnight than the bare-ground treatment. Average fruit weight of about 1 kg was maintained from May to August and then declined to about 0.6 kg in December. It increased again to almost 1 kg per fruit by February–March. Fruit from mulched plots were larger than from the bare-ground plots in June–August and February–April, but were otherwise similar in size.

Total crop yield — pre-ratoon, ratooning and post-ratoon harvests

There were no interactions (P>0.10) between mulch treatments and hybrids for any of the yield parameters over the 31-month period from first harvest after planting to last harvest post-ratooning (16 April 1995–2 April 1998). The 31 months excludes both the plant establishment and the 4.5-month post-ratooning periods when no fruit were available for harvest.

Hybrid 29 produced 29% greater fruit weight than Hybrid 13, which in turn produced 40% greater than Hybrid 11 (P<0.01; Table 2). Mulching increased yield by 65% (P<0.01) and number of fruit by 68% (P<0.01) compared with bare ground. The best-yielding treatment, mulched

Table 2. Yield and number of fruit per plot and average fruit weight of female plants from harvest during the ratooning phase (4 September 1996–19 December 1996), the post-ratoon harvests (8 May 1997–2 April 1998) and the total crop harvest — pre-ratoon (Elder *et al.* 2000*b*), ratooning and post-ratoon harvests

Means within a treatment not followed by a common letter are significantly different at P = 0.05

	Ratoon harvest			Post-ratoon harvest			Total of pre-ratoon, ratoon and post-ratoon harvests		
	Weight (kg/plot)	Number of fruit	Average fruit weight (kg)	Weight (kg/plot)	Number of fruit	Average fruit weight (kg)	Weight (kg/plot)	Number of fruit	Average fruit weight (kg)
Mulching	**	**	P = 0.071	***	**	*	**	**	n.s.
Bare	275b	257b	1.04	611b	696b	0.89b	3015b	2793b	1.08
Mulched	467a	419a	1.12	1317a	1419a	0.93a	4985a	4453a	1.11
Hybrid	**	*	*	n.s.	n.s.	**	**	**	*
29	513a	454a	1.13a	1113	1166	0.95a	5162a	4498a	1.14a
11	334b	297b	1.11b	767	837	0.92a	2850c	2622b	1.09ab
13	267b	263b	1.00c	1011	1170	0.85b	3989b	3749a	1.05b

*P<0.05; **P<0.01; ***P<0.001; n.s., P>0.10.

Hybrid 29, averaged the equivalent of 65 t/ha.year over the 31-month harvest period. Hybrid 29 produced fruit that were about 9% heavier ($P<0.05$) than those for Hybrid 13 while Hybrid 11 was not different from either Hybrid 29 or Hybrid 13. Mulching did not increase average fruit weight ($P>0.10$).

Figure 4 depicts the average fortnightly yield from first pick after planting until the last ratoon harvest reported in this paper averaged over all treatments. The post-ratoon yield from male trees is presented separately from female and/or bisexual trees to show the restricted period (late February–July) when these fruit are present. Yield from mulched Hybrid 29 male trees totalled about 800 kg/ha for the 6-month period they were present. In addition to seasonal fluctuations, there was a general decline in average fruit weight over time, from about 1.4 kg in April–May 1995 to about 1.0 kg by 1998. Also post-ratoon yield was considerably less than pre-ratoon yield.

Discussion

Hybrid 29 was superior to Hybrids 11 and 13

Hybrid 29 yielded twice as much as Hybrid 11 and 30% more than Hybrid 13 in the pre-ratoon plant crop (Elder *et al.* 2000*b*). During ratooning, Hybrid 29 yielded 54–92% more than Hybrid 11 or 13 with post-ratoon yields similar for all 3 hybrids. Over the complete plant–ratoon cycle, Hybrid 29 yielded 81% more than Hybrid 11 and 29% more than Hybrid 13 (Table 2). Hybrid 29 had the largest fruit during each phase of the crop (1.22 kg pre-ratoon, 1.13 kg during ratooning and 0.95 kg post-ratoon) with an average of 1.14 kg over the entire plant–ratoon cycle (Elder *et al.* 2000*b*; Table 2).

In this study, Hybrid 29 again exhibited its reduced internode length by being 41–58 cm shorter at the commencement of ratooning than Hybrids 11 and 13. The reduced height after 16.5 months of harvest allowed the

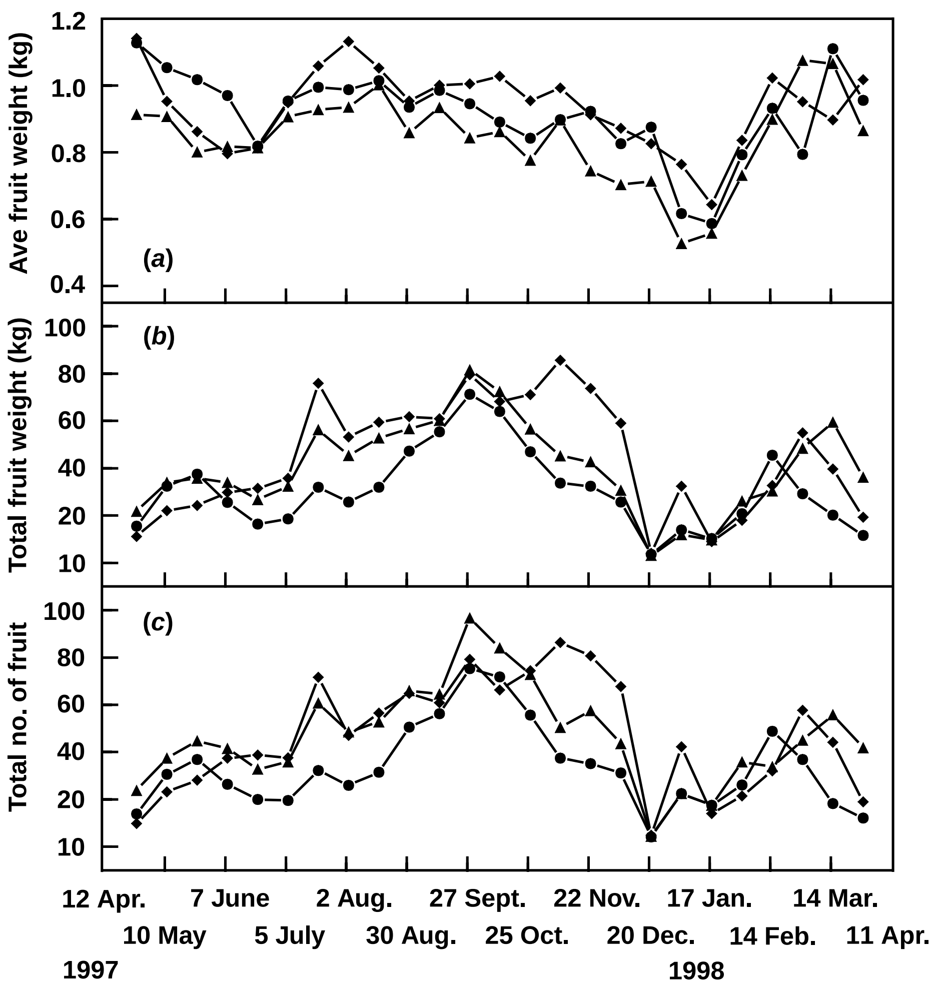


Figure 2. (*a*) Average fruit weight (kg), (*b*) total fruit weight (kg) and (*c*) total number of fruit per plot on a fortnightly basis for three papaya hybrids (Hybrid 29 ◆; Hybrid 11 ●; Hybrid 13 ▲) following ratooning. The data are averaged over the mulched and bare-ground treatments. The dates indicated are the starting dates for every second fortnight.

plants to be retained for longer before being ratooned (Fig. 1) and therefore extended the plant-crop production. The shorter nature of Hybrid 29 plants allowed ratooning to be more evenly spread across the 3.5-month ratoon period, with about 50% in the first 2 ratooning times and 50% in the last 2 ratooning times. Thus, Hybrid 29 maintained reasonable production over the entire ratooning phase. Hybrid 29 also returned to fruiting faster with a greater proportion of plants (97%) with fruit at the first post-ratoon harvest compared with 87% for Hybrid 11 and 95% for Hybrid 13. All 3 hybrids were equally susceptible to the 3 phytoplasma diseases and to nematodes. Therefore, Hybrid 29 is the preferred hybrid (of the 3 studied) for ratooning in this environment.

Mulching was superior to bare ground

Mulching increased yield by 50, 70 and 116% for pre-ratoon, ratooning and post-ratoon harvests, respectively, resulting in a 65% yield advantage over the plant–ratoon cycle (Elder *et al*. 2000*b*; Table 2). Mulched plants also returned to fruiting more quickly than those in bare ground, with a greater proportion of mulched plants with fruit (97 *v.* 89%), and with more fruit (31 *v.* 12), at the first post-ratoon harvest. However, mulching increased plant height at the first ratooning date by 12% (30 cm) but this did not impact on the proportion of plants cut out at each ratooning date.

The substantially greater number of root-knot nematodes (*Meloidgyne* spp.) in the bare-soil treatment than in the mulched treatment (118 *v.* 15, $P<0.01$) would presumably have impacted on yields. *Meloidgyne* spp. are pests of papaya and cause a gradual decline in flowering, fruit set and vigour (Persley 1993). The effect on yield of the nematode *H. dihystera* is less clear because of the interaction where there were more in the mulched treatment than in bare soil for Hybrid 29 while mulching had no effect for Hybrids 11 and 13. Mulching did not increase the likelihood of dieback

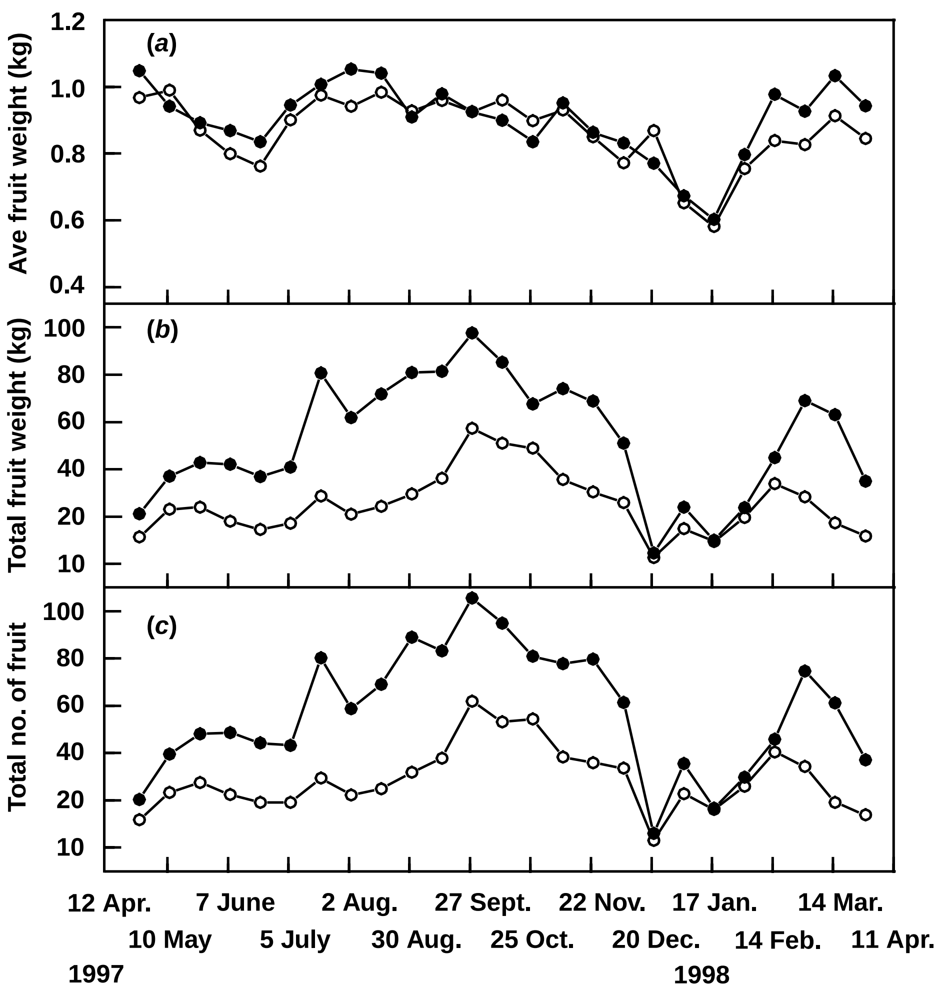


Figure 3. (*a*) Average fruit weight (kg), (*b*) total fruit weight (kg) and (*c*) total number of fruit per plot on a fortnightly basis for mulched (●) and bare soil (○) treatments following ratooning. The data are averaged over the three hybrids. The dates indicated are the starting dates for every second fortnight.

or mosaic but plants were slightly more susceptible to yellow crinkle.

Other studies have shown the beneficial effect of mulch on yield and plant growth on a wide variety of crops. Increases in yield and plant growth were observed in papaya with the use of grass straw (Elder *et al.* 2000*b*), in apples (*Malus domestica*) using hay straw mulch (Merwin and Stiles 1994) and in avocado (*Persea americana*) with composted pine bark (Moore-Gordon *et al.* 1996). These studies attributed the beneficial effect to better use of the total soil volume, lower soil temperatures, reduced water and soil loss, improved conditions for soil mychorrhiza, reduced root-knot nematode populations, improved root activity, reduced tree stress, increased soil levels of potassium, phosphorus and boron and leaf levels of potassium, weed control and increased soil water availability.

We expected that leaf petiole nutrient levels would be greater in the mulched plots because mulching allowed the plants to access the upper levels in the soil profile, including the soil surface, unlike the bare plots where the upper levels were usually dry. In addition, the estimated 12.5 t/ha.year soil loss from the surface of the bare plots, some 12 times the estimated loss of 1.05 t/ha.year for the mulched plots was expected to reduce the nutrients available to the plants and hence their petiole nutrient concentrations. This occurred for nitrogen, nitrate nitrogen, potassium and chloride but not for magnesium and zinc. These results are somewhat different from those obtained in the plant crop where higher levels of sulfur, phosphorous and boron were obtained in the mulched plots (Elder *et al.* 2000*b*). Higher water infiltration levels in the mulched plots would allow the crop to make best use of rainfall, particularly under drought conditions where irrigation water was limited and of poor quality.

Ragupathy *et al.* (1998) published data collected during the experiment showing that mulching improved vesicular arbuscular mycorrhizal (VAM) infectivity by a factor of 2.4 and decreased endomycorrhizal species diversity by a factor of 1.5 compared with bare ground. The species included the

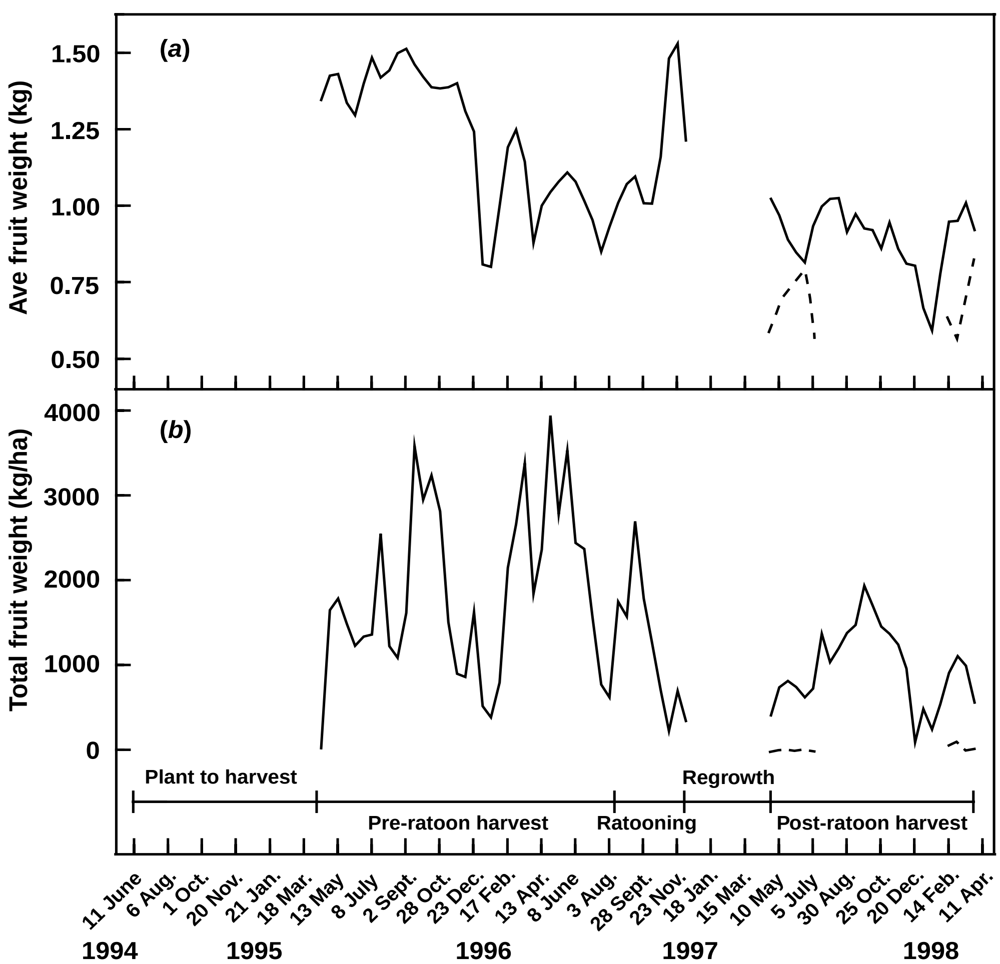


Figure 4. (*a*) Average fruit weight (kg) and (*b*) total fortnightly fruit weight (kg/ha) of female (solid line) and male (dotted line) fruit throughout the experiment averaged over all treatments. The dates indicated are the starting dates for every fourth fortnight.

genera *Glomus*, *Acaulospora*, *Gigaspora*, *Sclerocystis* and *Scutellospora*. The effect of these organisms on nutrient uptake by papaya in this experiment is not known.

Therefore, mulching of papaya is recommended as it increases yield, reduces time to production after ratooning, reduces root-knot nematode populations, does not increase susceptibility to dieback or mosaic, reduces soil loss, improves VAM activity and improves uptake of nitrogen (post-ratoon), phosphorus (pre-ratoon) and potassium. However, mulching does increase plant height but not to such an extent that plants are ratooned earlier than those on bare ground. Another limitation of mulching is that it increases chloride concentrations but levels in this study were not detrimental to plant growth.

As the hybrid and mulching effects were generally independent (i.e. no interaction) and as Hybrid 29 was the superior hybrid while mulching was superior to bare ground, the combination of Hybrid 29 with mulching is recommended for commercial production in central Queensland and is suitable for ratooning.

Ratooning as a crop management strategy

The management system of about monthly cut-outs over a 3–4-month ratooning period allows significant yield during the ratooning process as it takes into account the varying stages of cropping from plant to plant. Yields of up to 55 t/ha.year (mulched Hybrid 29) were observed during the 3.5-month ratooning period in this study. Following ratooning, there was a period of 4.5 months without yield. Once production recommenced there was a gradual increase in fortnightly production over a 6-month period through winter as more and more plants recommenced production.

There are obvious advantages of the ratoon cropping system. These include not having to move and/or relocate irrigation mains and submains, no loss of the T-tape, no loss of any residual mulch and mulch effects on soil physical properties at the end of the plant crop, not having to replant except possibly for vacant plant positions and continued use of any earthworks such as contour banks. These advantages need to be balanced against the possible decrease in average fruit weight between the plant crop and the ratoon crop, as observed in this study (Fig. 4). About 20% of plant positions were vacant (i.e. without any actively growing plants) at the start of ratooning. It is not clear as to how greatly this loss of plant positions affected production, but replanting vacant positions at the start of ratooning may be an option. By replanting lost positions at ratooning it may be possible to continue ratooning over a number of cycles with yield similar to that achieved in the plant crop. Root-knot nematodes may increase under ratooning but the evidence from this study is that mulching contains the problem.

This experiment was not designed to compare yields of a management system based on a plant crop followed by a ratoon crop (ratoon system) with yields of 2 plant crops (double-cropped system). However, as no other relevant data on ratooned papaya is currently available, a theoretical scenario was developed using the plant- and ratoon-crop yield data from this study to compare the 2 systems as a preliminary guide for growers and experimenters.

The scenario was based on data from the best treatment, mulched Hybrid 29, and on the following assumptions. First, it was assumed that the second plant crop in the double-cropped system would be planted in the same area as

Table 3. Comparison of the mulched Hybrid 29 crop phases and yields (kg/ha) for the plant–ratoon crop (ratoon system) considered in this study, with those estimated when a crop is cleared and the area replanted (double-cropped system)

Average monthly yield (kg/ha.month) is given in parentheses

Crop phase	Ratoon system		Double-cropped system	
	No. of months	Yield (kg)	No. of months	Yield (kg)
Land preparation	2.0	Nil	2	Nil
Planting to 1st harvest	10.0	Nil	10	Nil
1st harvest to ratoon start or last harvest	16.5	128000	20	143975[A]
Ratooning period	3.5	15975	—	—
Land preparation	—	—	2	Nil
Regrowth to 1st harvest or planting to 1st harvest	4.5	Nil	10	Nil
1st harvest post-ratoon or 2nd crop to last harvest	20.0	71409	20	143975[B]
Total yield (kg/ha) — unadjusted	56.5	215384 (3812)	64	287950 (4499)
Adjustment for the major dieback outbreak[C]	—	—	—	less 52562
Total yield (kg/ha) — adjusted	56.5	215384 (3812)	64	235388 (3678)

[A]Based on the total of the actual plant crop yield and the ratooning yield.
[B]Based on the previous 20-month plant-crop yield.
[C]Adjustment for the major dieback outbreak in 1997, which would have substantially reduced yields in the ratoon crop. As the plant crop suffered 37% incidence of dieback overall while the ratoon crop suffered 60%, the yield for the second plant crop in the double-cropped system is reduced by 143975 × (60–37)/(100–37).

the first plant crop. In practice, the same area would not normally be cultivated and planted as soon as possible after the last harvest but rather a new area would be used. Second, it was assumed that the environmental conditions for the second plant crop would be similar to those of the first plant crop and hence yield would be similar to the first plant crop. Third, as ratooning commenced before the completion of the 20-month plant-crop harvests, it was assumed that the total plant-crop yield was the sum of the 16.5-month plant-crop harvests and the 3.5-month ratooning harvests. This may have underestimated the real plant-crop yield but, given the ratooning criterion used (based on plant height and stage of fruiting), many of the ratooned plants may not have been commercially harvested anyway. Furthermore, the trial concluded after only 11 months of post-ratoon harvests and so the yield was multiplied to give a 20-month post-ratoon yield.

From the scenario presented in Table 3, the total yield from the ratoon system, unadjusted for the major dieback outbreak in 1997, produced almost 700 kg/ha.month less than the double-cropped system. However, the ratoon system took only 56.5 months whereas the double-cropped system took 64 months, although this could be reduced by planting the second crop in another area on the farm to provide any crop overlap desired. Overlapping of plant crops by using 2 separate areas allows the planting of the second crop at such a time that it will begin production during the period of least yield (December–February), which usually coincides with the period when market prices are greatest.

The above comparison assumed that conditions for the second plant crop would be similar to the first plant crop. Undoubtedly, conditions such as rainfall, temperature and watering would have differed. However, one dramatic difference was the large dieback outbreak that occurred in October–December 1997. Some 60% of plant positions had dieback during the post-ratoon period in this study, of which almost all occurred during this major outbreak, the most severe for at least 20 years (Elder *et al.* 2002). In contrast, only 37% of plant positions were infected with dieback during the plant crop that experienced 3 outbreaks (Elder *et al*. 2000*b*). As the yield of the second crop was based on the first crop, which experienced only 37% loss due to dieback over the entire plant crop, the yield estimate is mostly likely to be an over-estimate. Based on the scenario for the double-cropped system, the major dieback outbreak in 1997 would have occurred at the time the second plant crop began fruiting. It is likely that any plant crop would have suffered similar or even greater losses during the outbreak. Elder *et al.* (in press) demonstrated this in a plant crop monitored for disease on the same property and at the same time as the study described in this paper in which 78% of plant positions were lost during the 1997 dieback outbreak. Therefore, the yield for the second crop in the double-cropped system was adjusted to accommodate the extra 23% (37 *v.* 60%) of positions infected with dieback. This is given as the adjusted yield in Table 3 and indicates a 134 kg/ha.month yield advantage for the ratoon system compared with the double-cropped system, reversing the unadjusted yield results. It is difficult to draw any definitive conclusions from this as there are many underlying assumptions, but the scenario presented in Table 3 demonstrates that yields from a ratoon system may be similar to yields from a double-cropped system.

Conclusion

This study demonstrated the benefits of mulching, the superiority of Hybrid 29 and that ratooning can be successfully used in papaya. It follows that commercial producers in environments similar to Yarwun should grow Hybrid 29, or similar hybrids, with mulch. Consideration should be given to ratooning the plant crop based on monthly cut outs over a 3–4-month ratooning period with vacant plant positions replanted during ratooning particularly if land, time or finances are limiting.

Acknowledgments

Thanks are due to Denis and Heather Hall who provided the trial site on their property and helped with the day to day running of the sites. Queensland Department of Primary Industries Biometrician, Kerry Bell, designed the layout of the trial site treatments. Debbie Gultzow and Robert Buckley undertook much of the day to day data accumulation. Calliope Land Care and The Yarwun and Targinnie Fruit Growers Association provided labour and/or funds. The Queensland Fruit and Vegetable Growers, Horticultural Research and Development Corporation and Department of Primary Industries (Queensland) provided funds. Graham Stirling, formally of Department of Primary Industries, undertook the nematode field sampling and laboratory extractions and identifications. James Drinnan provided useful comment and guidance on the manuscript.

References

Anon. (1994*a*) 'Analysis systems. Plant tissue analysis interpretation manual 362.' (Incitec Ltd: Brisbane)

Anon. (1994*b*) 'Analysis systems. Soil analysis interpretation manual 362 for Queensland and Northern New South Wales.' (Incitec Ltd: Brisbane)

Anon. (1998) 'Papaya varieties for Queensland.' Queensland Department of Primary Industries, Brisbane, ISSN 0727 6907.

Aquilizan FA (1987) Breeding systems for fixing stable papaya inbred lines with breeding potential for hybrid production. In 'The breeding of horticultural crops'. pp. 101–106. (Food and Fertiliser Technology Center for the Asian Pacific Region: Taipeh)

Basso-Figuera C, Schaffer B, Crane JH, Colls AM, Bryan HH (1994) Effects of municipal solid waste compost and trench depth on papaya (*Carica papaya* L.) yield and fruit quality. *Proceedings of the Florida State Horticultural Society* **107**, 334–337.

Basso-Figuera C, Schaffer B, Crane JH, Colls AM, Bryan HH (1995) Mineral nutrient content, growth, and yield of papaya (*Carica papaya* L.) as influenced by trench depth and municipal solid waste compost. *Tropical Agriculture* (*Trinidad*) **72**, 231–235.

Elder RJ, Macleod WNB, Bell KL, Tyas JA, Gillespie RL (2000*a*) Growth, yield and phenology of 2 hybrid papayas (*Carica papaya* L.) as influenced by method of water application. *Australian Journal of Experimental Agriculture* **40**, 739–746.

Elder RJ, Macleod WNB, Reid DJ, Gillespie RL (2000*b*) Growth and yield of 3 hybrid papayas (*Carica papaya* L.) under mulched and bare ground conditions. *Australian Journal of Experimental Agriculture* **40**, 747–754.

Elder RJ, Milne J, Reid DJ, Guthrie J, Persley D (2002) Temporal incidence of 3 phytoplasma associated diseases of *Papaya carica* and their potential hemipteran vectors in central and south-east Queensland. *Australasian Plant Pathology* (in press).

Garrett A (1995) The pollination biology of papaw (*Carica papaya* L.) in Central Queensland. PhD Thesis, Central Queensland University.

Hofmeyr JDJ (1953) Sex reversal as a means of solving breeding problems of *Carica papaya* L. *South African Journal of Science* **49**, 228–232.

Kuhne FA, Allan P (1970) Seasonal variations in fruit growth of *Carica papaya* L. *Agroplantae* **2**, 99–104.

Merwin IA, Stiles WC (1994) Orchard groundcover management impacts on apple tree growth and yield, and nutrient availability and uptake. *Journal of the American Society for Horticultural Science* **119**, 209–215.

Moore-Gordon C, Wolstenholme BN, Levin J (1996) Effect of composted pinebark mulching on *Persea americana* Mill. cv. Hass fruit growth and yield in a cool subtropical environment. *Journal of the South African Society for Horticultural Science* **6**, 23–26.

Nakasone HY, Crozier JA, Ikehara DK (1972) 'Evaluation of 'Waimanalo', a new papaya strain.' Technical Bulletin 72, Hawaii Agricultural Experimental Station, University of Hawaii.

Patterson HD, Thompson R (1971) Recovery of inter-block information when block sizes are unequal. *Biometrika* **58**, 545–554.

Persley DM (1993) Common diseases in many perennial fruit crops. In 'Diseases of fruit crops'. (Ed. DM Persley) (Department of Primary Industries: Brisbane)

Peterson RA, Coates LM, Persley DM (1993) Papaw (papaya). In 'Diseases of fruit crops'. (Ed. DM Persley) (Department of Primary Industries: Brisbane)

Ragupathy S, Macleod N, Elder R (1998) Effect of straw mulching on papaya production. In 'Managing our future for innovation sustainability, continuity — 4th Australian horticulture conference, Melbourne (14–17 October)'. p. 69.

Whitehead AG, Hemming JR (1965) A comparison of some quantitative methods of extracting small vermiform nematodes from soil. *Annals of Applied Biology* **55**, 25–38.

Received 10 February 2001, accepted 1 June 2001