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Growth, yield and phenology of 2 hybrid papayas (*Carica papaya* L.) as influenced by method of water application

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Abstract. Highly variable, outcrossed papaya lines irrigated with overhead sprinklers were grown at Yarwun (151.3°E, 23.75°S) in Queensland, Australia. The inherent variability made scientifically based comparative studies impractical. The advent of uniform hybrid papaya lines allowed the testing of 2 of these hybrids under 3 irrigation methods, 2 of which had the potential to greatly reduce water use compared with overhead sprinklers. Yields of 92 t/ha.year were achieved by both papaya Hybrids 29 and 1E. Water application method did not influence yield. About 26% of plants were lost due to the phytoplasma diseases dieback, yellow crinkle and mosaic over the life of the trial. Downward yield fluctuations were related to poor fruit set in winter when pollinators (Family Sphingidae) were not present and growth was slow due to hot dry periods affecting fruit set. The resultant fruit (about 6 months later) were small and reduced in number.

Irrigation with overhead sprinklers using saline water (1400–4000 µS/cm) damaged leaves and reduced growth of plants. Winter spot was most severe in July, August and September, in Hybrid 29 with overhead irrigation.

Height of plants 13 weeks after planting was greater under trickle irrigation due to less damage from the saline water supply than in the overhead sprinkler treatment. Hybrid 29 set fruit at 94.3 cm above ground compared with 117.6 cm for Hybrid 1E.

Additional keywords: papaya, growth, hybrids, yield, trickle irrigation, phenology, salinity.

Introduction

The papaya (papaw) industry is based on dioecious outcrossed varieties developed by growers because of the higher yields obtained under Queensland (Australia) climatic conditions. These varieties were extremely variable in such characteristics as fruit shape, taste, size, flesh-colour, firmness and yield. This is in contrast to the more homozygous hermaphrodite lines grown in Hawaii (Nakasone *et al.* 1972). This extreme variability made scientific field experimentation unattractive due to the difficulty in obtaining statistically reliable results (Kuhne and Alan 1970) while at the same time induced 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 selfing seasonally male plants with suitable characteristics. Male plants usually produce bisexual flowers in spring and subsequently fruit in autumn. Inbred lines developed from male plants could be crossed to produce hybrids with relatively uniform characteristics. The availability of these uniform lines enabled 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 observations and grower records. Papayas can be grown on a wide range of soils with a pH of 5.5 to 6.7 and are regarded as being a moderately

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salt-sensitive crop particularly in the seedling stage (Marler *et al.* 1994). This study was undertaken to provide information on yield, crop phenology and irrigation methods under field trial conditions and with 2 of the hybrids being utilised by industry.

Materials and methods

Trial site layout, pre-plant preparation and planting

The trial site was located in the Yarwun–Targinnie district of Central Queensland about 10 km north-west of Gladstone (151.3°E, 23.75°S). It was planted on 22 September 1992 and continued until 2 November 1994.

The soil was a Haplic, Eutrophic, Red Kandosol (red earth) with a uniform dark sandy clay loam surface grading to a massive sandy clay overlaying granite. In addition there was an 8 m wide strip of Haplic, Eutropic Brown Chromosol (yellow podzolic) running through the site. It had a dark sandy clay loam surface with a clear change to brown medium clay subsoil. It was probably indicative of an old stream (creek) line.

A randomised split-plot design with 2 replicates, 3 main plot treatments (irrigation) and 2 subplot treatments (papaya hybrids) was used. The 3 main plot treatments were overhead irrigation, mini sprinklers and T-tape trickle irrigation. The parentage of the 2 hybrids (female by male) was: Hybrid 1E, GD3-1-19 × ER6-2 and Hybrid 29, GD3-1-9-1 x TVL7 (Anon. 1998).

The trial site was spread over 3 bays between contour banks with 3 main plots and 2 replicates down the slope and 4 subplots (2 for each replicate) across the slope. The seedlings were planted in double rows on a 2.0 by 1.8 m (in row) grid with 84 plant sites in each plot (sub area of an irrigation treatment containing plants all of the same hybrid). There was an average of 4.35 m between centres of the double rows. The double rows were on 30 cm high raised beds. All plots were mulched with coarse grass hay to a depth of 10–15 cm, 2 months after planting.

The trial site was fertilised before planting based on results of soil analyses (Anon. 1994*b*). The edges of all blocks were planted to bana grass (*Pennisetum purpureum* × *P. glaucum*), to provide windbreaks up to 4 m in height.

Papaya seedlings were produced in 100 mm pots. The seedlings were planted out when they were about 15 cm high. Each plant site had 4–5 plants (Storey 1952) later thinned to 1 plant when flowering was initiated (90% female).

Irrigation and water salinity

Watering was undertaken to maintain soil water tension below 15 kPa indicated by 30-cm deep tensiometers. In practice, because of extreme drought conditions in 1994, this was not always achievable and water was supplied at a lower level depending on availability. However, the same level of irrigation was supplied across the site and records were kept of the volume of water applied. Water quality was measured in micro seimens per cm (µS/cm).

Because of the belief that papaya would be damaged at saline water levels above 1500 µS/cm, regular conductivity measurements were made of the irrigation water. Each plant was rated for salt damage: 0, no damage; 1, 1–25% of leaves showing some damage; 2, >26–50% of leaves with some damage; 3, >51–75% of leaves with some damage; 4, >75% of leaves damaged.

Nutrition

Soil and leaf samples were taken and analysed (by Incitec) at 6-monthly intervals to determine nutrient requirements (Anon. 1994*a*, 1994*b*). The fertiliser program consisted of potassium nitrate and, at times, urea applied through the irrigation system at the rate of about 20 g KNO_3/plant.week during the growing months, September to May.

Crop disease and insect protection

Diseases were controlled with the appropriate fungicide (benomyl or mancozeb for black spot and triadimenol for powdery mildew). Plants showing symptoms of the diseases yellow crinkle, mosaic and dieback were recorded and cut out on a weekly basis. Crops were monitored for banana-spotting bugs [(*Amblypelta lutescens lutescens* (Distant) (Hemiptera: Coreidae)]. They were controlled with endosulfan as required.

Plant growth

Plant stem diameters (± 2 mm) at 300 mm above ground level and plant heights (± 50 mm) of the tallest plant in each plant position were recorded at 6 weeks, 13 weeks and 8 months. The height (± 5 mm) to the first flower was measured. Just before first harvest, the number of fruit per female plant was counted. Fruit were counted if the petals had fallen off.

Yield and fruit quality

Fruit were harvested by the grower/cooperator twice weekly in summer and weekly in winter. Because male plants produce commercially unacceptable fruit during a restricted period of the year, these fruit were not included in the yield data. Individual fruit weights (± 1 g) and diameters (± 1 mm) were recorded. At the same time each fruit was rated for winter spot and the number of black spots (*Asperisporium caricae*) counted. Winter spot was rated according to the following scale: 1, no winter spot; 2, winter spot on up to 25% of fruit; 3, winter spot on 26–50% of fruit; 4, winter spot on 51–75% of fruit; 5, winter spot on >75% of the fruit surface. Because of the high value of fruit to the grower and the destructive sampling required we were unable to obtain a sample of fruit at suitable intervals from each plot to test for total soluble solids (°Brix). However, at any one time 3 fruit per hybrid were tested by taking a lengthwise slice and then dividing the slice into 3 equal sections (stem end, middle and flower end) and testing hand squeezed juice with a hand-held refractometer.

Statistical analyses

Plant height, stem diameter, height to first fruit, number of fruit set, total fruit weight, average fruit weight, number of fruit, winter spot and black spot incidence were analysed by standard analysis of variance (ANOVA). Residuals from the analyses were checked and no analyses were considered to have violated the variance and normality assumptions. Pair-wise comparisons of means were conducted using a protected least significant difference (l.s.d.) test at $P = 0.05$. Winter spot and black spot data were analysed on specific dates when incidence was at a maximum rather than bulked across time because of the seasonal nature of both. Both are at very low levels in the warmer months.

Salt damage rating and the number of plants removed due to disease were analysed using a log-linear model (interactions can be fitted when replication is included).

Results

Growth and fruit setting

There were no height differences ($P>0.05$) among the hybrid sources or between the irrigation sources of variation, 6 weeks post planting. Overall mean height was 26.5 cm.

Thirteen weeks post planting there were no height differences (P>0.05) among hybrids. Plants were 28% taller (P = 0.055) in the trickle irrigation plots (135.9 cm) than in the overhead (106.3 cm). The mini sprinkler plots (115.3 cm) were intermediate in height but not different (l.s.d. 22.3 cm, P = 0.05) to either the overhead or the trickle irrigation treatments. There were no stem diameter differences (P>0.05) due to hybrid or irrigation treatments. Mean stem diameter was 2.63 cm.

Eight months after planting there were no differences (P>0.05) in plant height among irrigation treatments while Hybrid 29 (258 cm) was shorter (P = 0.07) than Hybrid 1E (268 cm). Stem diameter at 30 cm in the mini sprinkler treatment (12.4 cm) was significantly (P<0.05) larger than the overhead (11.4 cm) or the trickle irrigation (11.1 cm) irrigation treatments. The height of Hybrid 29 first fruit set was significantly (P<0.05) lower (94.3 cm) than Hybrid 1E (117.6 cm).

There were no differences (P>0.05) in the number of fruit set per plant among irrigation treatments or between hybrids. Mean number of fruit set was 29.3 ± 1.5 (mean ± s.e., n = 12). The first fruit were picked 8 months after planting.

There were differences (P<0.001) between the irrigation treatments for salt damage. In the overhead sprinkler treatment, 91.4% of plants had greater than 25% of leaves showing damage while the mini sprinkler and the trickle irrigation treatments had 17.3 and 10%, respectively.

Hybrid 29 suffered greater plant losses due to disease than Hybrid 1E (146 plants *v.* 102; P<0.01). The diseases involved were dieback, yellow crinkle and mosaic.

Fruit yield over 16 months — number of fruit and total fruit weight

The pattern of the number of fruit picked (Fig. 1) and the total fruit weight were almost identical. They both declined over 16 months until the plants were ratooned because of severe hail on 2 November 1994. Hybrid 29 gave mainly higher yields than Hybrid 1E and the overhead irrigation was usually lower than the other 2 irrigation treatments. However, there were no differences (P>0.05) between irrigation treatments or among hybrids for both total number (plot mean = 936) and total mass of fruit (plot mean = 1166 kg) produced. Yields were equivalent to 92 t/ha.year.

Fruit size over 16 months — fruit circumference and average fruit weight

From July 1993, weight (Fig. 2) and fruit circumference showed similar patterns. They increased slightly in the first 2–3 months of picking and then

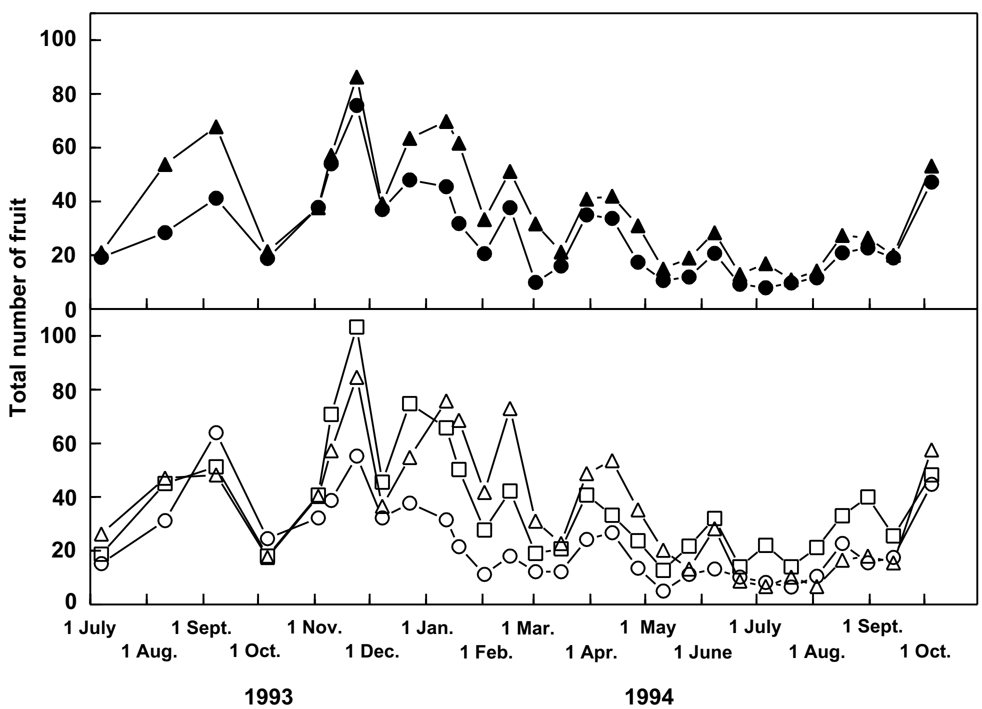

Figure 1. Total number of papaya fruit harvested for 2 hybrid (▲ Hybrid 29, ● Hybrid 1E) and 3 irrigation (○ overhead, □ mini sprinklers, △ T-tape trickle) treatments over a 16-month period, 1993–94.

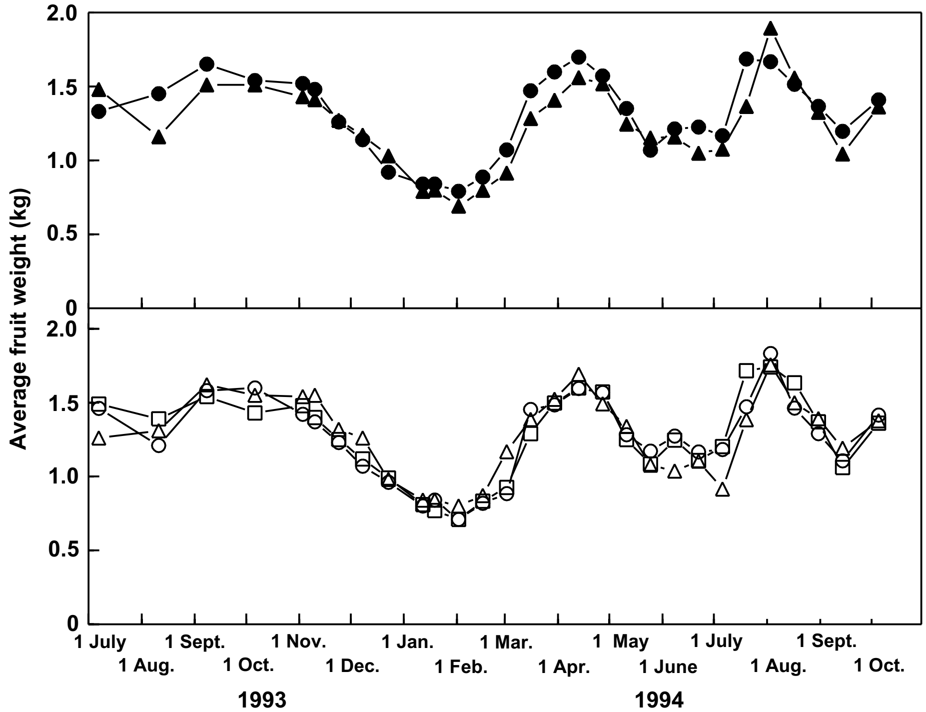

Figure 2. Average weight of papaya fruit harvested for 2 hybrid (▲ Hybrid 29, ● Hybrid 1E) and 3 irrigation (○ overhead, □ mini sprinklers, △ T-tape trickle) treatments over 16 months, 1993–94.

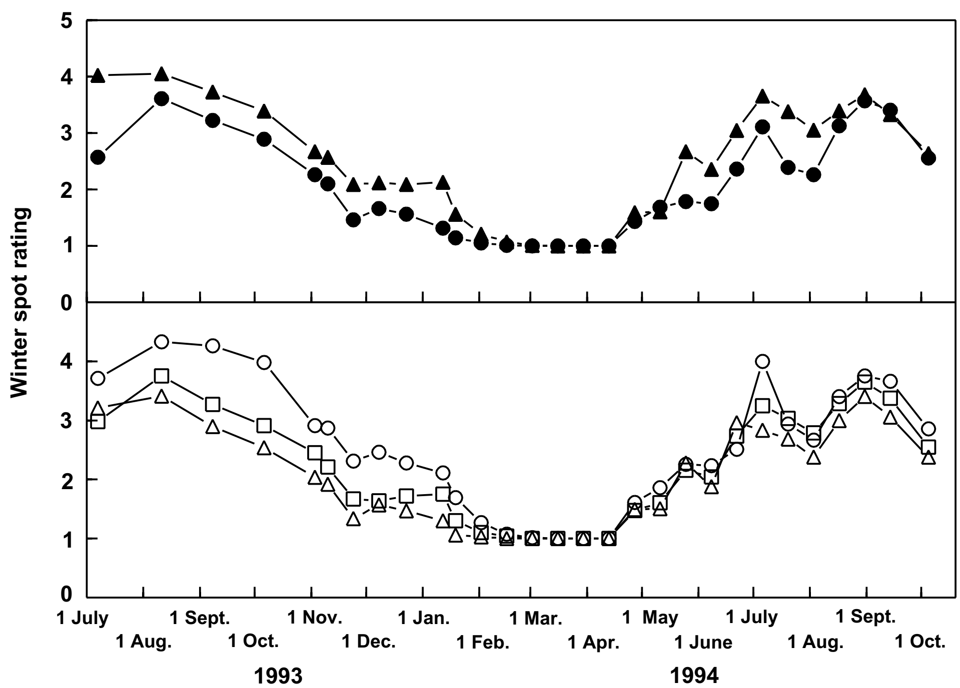

Figure 3. Winter spot incidence on papaya fruit harvested for 2 hybrid (▲ Hybrid 29, ● Hybrid 1E) and 3 irrigation (○ overhead, □ mini sprinklers, △ T-tape trickle) treatments over a 16-month period, 1993–94.

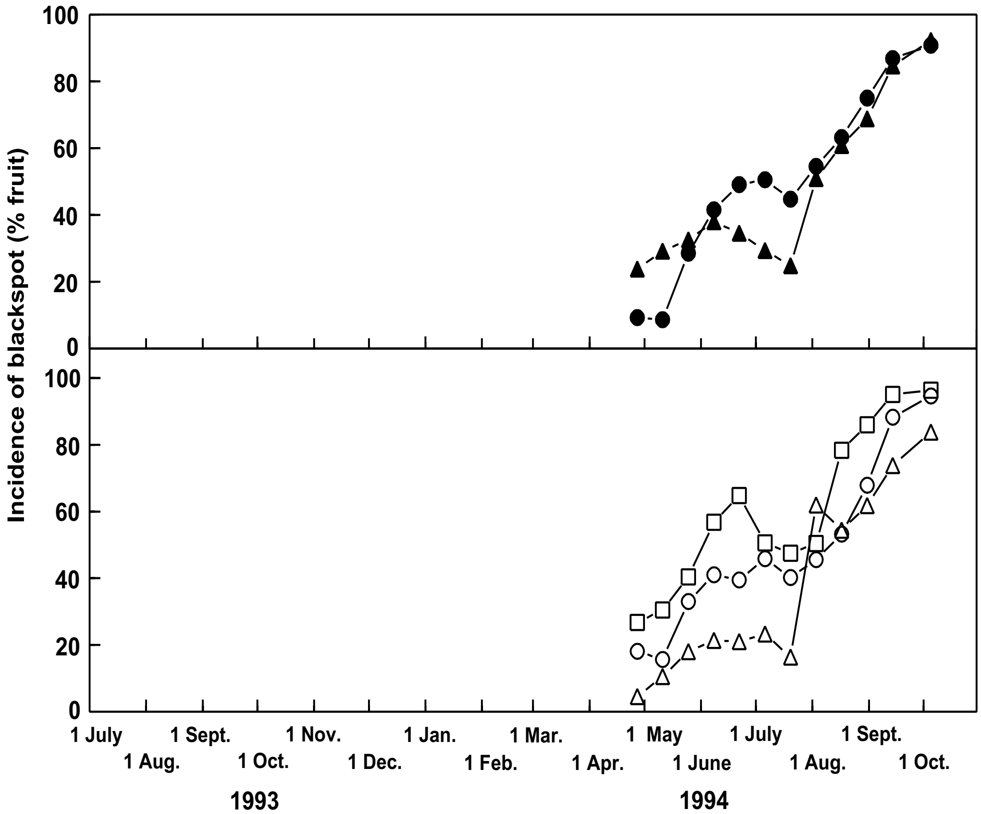

Figure 4. Black spot incidence on papaya fruit harvested for 2 hybrid (▲ Hybrid 29, ● Hybrid 1E) and 3 irrigation (○ overhead, □ mini sprinklers, △ T-tape trickle) treatments over a 16-month period, 1993–94.

declined to a low in February. Size then increased to a peak in April–May followed by a decline in June–July and another peak in August (Fig. 2). Average fruit weights varied between 1.8 and 0.7 kg. However there were no differences (P>0.05) between irrigation treatments or among hybrids for both average (for 16 months) fruit weight (mean = 1.27 kg) or circumference (mean = 40.52 cm).

Winter spot incidence

Winter spot in 1993 and 1994 was highest in the months of July, August and September (Fig. 3). In the first 10 months of the study period overhead irrigation gave worse winter spotting than the mini or trickle irrigation treatments. Hybrid 29 tended to have more spotting than Hybrid 1E in the cooler months and similar spotting to Hybrid 1E in December to June at a time when levels were low. Analysis of the data for 14 September 1994 indicated no differences (P>0.05) in winter spot rating among hybrids or between irrigation treatments (mean = 3.36). Observations indicated that winter spot appeared as the fruit approached maturity and was usually more prevalent on the exposed part of the fruit away from the stem.

*Black spot (*Asperisporium caricae*) incidence over 16 months*

Black spot was still to enter Central Queensland from northern Queensland when the trial layout was designed. Black spot incidence increased from autumn to very high levels by September (Fig. 4). There were no significant (P>0.05) differences in black spot ratings due to irrigation or hybrid treatments on 7 September 1994. Weekly applications of mancozeb did not control the disease. Poor control was due to the bana grass windbreaks preventing effective spray coverage of leaf and fruit surfaces (R. A. Peterson pers. comm.).

Brix levels in fruit over a 10-month period

Both hybrids had large variations in total soluble solids at any one time and throughout the year (Fig. 5). The values were initially low for Hybrid 1E (6.2–7.4°Brix) and high for Hybrid 29 (8.8–9.0°Brix). By mid February 1E was similar to Hybrid 29 and the relatively high levels

(7.5–10.6°Brix) were maintained through to June. They declined progressively from July to late October to as low as 5.6°Brix, although some fruit still had levels of between 8.5 and 10.4°Brix in October. If the above data is representative for most seasons then Hybrid 29 shows a rapid increase in Brix between late October and 1 January each year whereas in Hybrid 1E the Brix remained low until mid February. Fruit of Hybrid 1E and some Hybrid 29 fruit had an unacceptable taste to an informal group buying the fruit in the September–January period. During the rest of the year both were acceptable although Hybrid 29 was preferred.

Water use and salinity

Water use in the trickle irrigation treatment was increased initially by running an extra line between the paired rows and later by increasing the application time. Trickle irrigation used about 50% less water than mini sprinklers and mini sprinklers about 50% less water than overhead irrigation (Table 1). Yields were not significantly (P<0.05) different for any of the irrigation treatments (Fig. 1) although there was a consistent trend for yields to be higher in the trickle and mini sprinkler treatments.

Papayas were grown with irrigation water conductivity (salinity) levels far above the maximum of 1300 µS/cm (recommended by Anon. 1994*a*) i.e. up to 4510 µS/cm (Table 2). Conductivity levels dropped after 2 February 1994 to 200 µS/cm after substantial rain and run off into the dam. Yields of 92 t/ha were achieved in spite of the high salinity levels and at times inadequate amount of water applied.

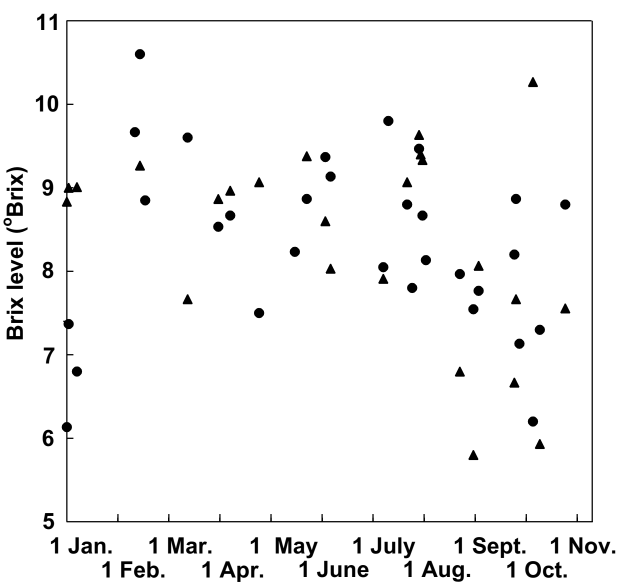

Figure 5. Brix levels for papaya Hybrid 29 (▲) and Hybrid 1E (●) over a 10-month period in 1994.

Table 1. Weekly water use from September 1992 to February 1994 at the trial site

Treatment	Water use (L/plant.week)		
	Sept. 92–March 93	March 93–Oct. 93	Oct. 93–Feb. 94
T-tape trickle	50	65	86
Mini sprinkler	80	180	180
Overhead	360	360	360

Discussion

While there were no growth differences at 6 weeks, trickle irrigation gave by far the best plant growth over the 13 weeks from planting. This was probably due to fewer weeds, no salt damage to the leaves and no physical damage to the plants from splashing. A change from water with a conductivity of 1870 to 1410 µS/cm (1420 µS/cm) was thought to be the reason for an observed marked improvement in plant growth in the last 10 days before sampling.

The mini sprinkler treatment produced plants with larger diameters at 30 cm height than the other 2 treatments by 8 months post planting. This treatment had the advantage that it used much less (50%), in this case poor quality irrigation water (conductivity greater than 3500 µS/cm) than the overhead sprinkler treatment. Mini sprinklers therefore reduced the effect of salt build up in the soil. Mini sprinklers (as compared with trickle irrigation) also assisted with the uptake of broadcast fertiliser applications because there was little rain. The area was severely drought affected. Plants in both the mini sprinkler and trickle irrigation treatments had lower overall salt damage ratings than the overhead sprinklers as water was not sprayed on leaves.

Hybrid 29, regarded as a semi-dwarfed hybrid, set fruit at a lower height than Hybrid 1E. This is a useful trait as it

Table 2. Water conductivity at the trial site on five occasions, 1992–94

Date	Electrical conductivity (µS/cm)
16 October 1992	1420
20 January 1993	2700
16 April 1993	4140
6 July 1993	3430
2 February 1994	200[A]

[A]Value measured following drought-breaking rain.

means that the plant will be in economic production for a longer period due to ease of harvesting. The heights to first set fruit of 92.3 cm for Hybrid 29 and 117.6 cm for Hybrid 1E compare unfavourably with those of Drew and Vogler (1993). They obtained values of between 42.7 and 79.2 cm for height to first flower with tissue cultured and seedling material planted at various times. However, in their work the first flower may not have set.

Production of first fruit after 8 months of growth was a major improvement over the current 10–12 months for the district. This was due largely to the use of vigorous hybrids and better irrigation and fertiliser techniques. These practices combined to provide early production and faster growth. This means that fruit production for a given planting will be compressed into a shorter time period (e.g. 1.5 instead of 2.5 years). Plants are usually replaced or ratooned when they become too high to pick from the ground and faster growth causes plants to reach the ratooning/replacement height sooner. This means that a grower could manage a smaller area to obtain the same production or manage the same area for a larger output.

A reduced area for the same or greater production has obvious labour advantages and cost savings for irrigation, harvesting, pesticide, fertiliser and mulch application. If this earliness could be achieved with an autumn planting, first harvest in the following autumn could catch the early market with potentially better market prices.

The windbreaks around the block markedly reduced the wind within the block compared with outside. It is believed that this has reduced physical damage to the plants and fruit as well as reducing water stress.

Yields of 102 t/ha.year (1200 plants/ha) of marketable hermaphroditic fruit have been obtained under irrigated conditions in Hawaii (Awada and Ikeda 1957) and up to 62 t/ha for dioecious lines in India (Singh *et al*. 1967). Yields of 92 t/ha achieved in this study compare favourably.

The low fruit size in January to March, declining size in October to December and increasing size from April and May can be attributed directly to poor pollination of flowers 6–7 months previously. Garrett (1995) showed by light trapping counts that in a nearby district (Rockhampton) about 100 km to the north, the Sphingid (hawk) moth-pollinators of papaya (6 species from the Family: Sphingidae) were absent in the winter of 1993 (mid June to mid August). These insects were the only insect pollinators of papaya and pollination due to other factors (e.g. wind) was of very limited importance. Garrett (1995) also showed that seed set had a substantial effect on papaya size, each seed increasing fruit size by an average of 0.78 g. Her work on Hybrid 29 and Hybrid 1D (1D has similar parentage to 1E studied here) showed that they could be successfully hand pollinated during this winter period. Hybrid 29 in particular had above average pollen viability and production even during cold winter and hot summer periods when other papayas had much lower pollen production.

Winter spot (star spot, freckle) is believed to be associated with damage to the lenticels and surrounding area during cold windy weather (Peterson *et al.* 1993; Kaiser *et al*. 1996). The extremes of temperature and plentiful soil moisture are believed to increase the turgor of plants and hence rupturing of the fruit lenticels. This is supported by the above data that indicates that overhead irrigation resulted in greater incidence of winter spot. The appearance of winter spot late in the life of individual fruit and on the exposed side may indicate that some form of protection such as bagging may be useful in reducing the disorder. The incidence of winter spot was greatest in Hybrid 29. This leads to the possibility of a breeding program targeted at developing hybrids less susceptible to winter spot.

In other types of fruit, Brix was the variable best correlated with eating quality (Guthrie and Walsh 1997). Other variables examined by them included acidity, pH, Brix : acid ratio, and ester concentrations. Brix levels of 14° and above were industry standards for market acceptability for mangoes. Pineapples have an industry standard of 12°. Informal taste assessments of the 2 papaya hybrids were undertaken at the same time that Brix measurements were made. Hybrid 29 was consistently regarded as having a superior flavour to Hydrid 1E over the sampling period despite the relatively small differences in Brix levels. The relatively low and variable Brix levels found in this study indicate that further breeding work to isolate parent lines with high and stable Brix levels was important if the industry was to compete with other fruit in the marketplace.

T-tape trickle irrigation gave a 50 and 75% reduction in water use over mini sprinklers and overhead irrigation methods respectively while producing similar fruit yields. It also lowered pumping costs by the same percentages. Water conductivity (salinity) levels increased above the usual levels due to severe drought. The results suggest that papayas can be grown in the short term using water with conductivity levels as high as 4510 μS/cm.

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