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Relationship between canopy density and fruit quality of kiwifruit

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Abstract The influence of canopy density on fruit quality was investigated during 2 years in two commercial kiwifruit (*Actinidia deliciosa* 'Hayward') orchards in Te Puke, New Zealand. One orchard had a history of producing fruit which store well, whereas the other tended to have a dense canopy, and high losses of fruit during coolstorage. In each orchard we adjusted pruning regimes to produce open, or dense canopies, with mean leaf area index (LAI) values ranging from 3.0 to 5.5. There was a tendency for vines with dense canopies to have more premature fruit drop and more soft fruit on the vine at harvest; reduced accumulation of dry matter in fruit during maturation; fruit with lighter, more vivid, more yellow/brown skin; lighter, less vivid, and less green flesh; reduced fruit firmness after long-term storage; increased fruit losses during storage because of stem end rots; and fruit with different textural properties, but similar flavour and aroma. However, in many instances differences were found between fruit from the two orchards which could not be attributed to variations in canopy density. Although some of the effects related to canopy density were statistically significant, most were small and probably not of commercial importance.

Keywords kiwifruit; fruit quality; postharvest storage; leaf area index; maturity; fruit colour; sensory quality

INTRODUCTION

Premature softening of kiwifruit (*Actinidia deliciosa* (A Chev.) C. F. Liang et A. R. Ferguson) during storage can result in fruit being too soft to transport, or market. Such losses can significantly reduce orchard profitability, particularly when the likelihood of such losses is not predictable. It is popularly believed (Ombler 1991; McLeod 1992; Mulligan 1993) that the way kiwifruit vines are managed can affect fruit quality, and fruit softening. There is a widespread belief that vines with a dense leaf canopy tend to produce fruit which soften prematurely on the vine and which have high levels of fruit loss during commercial storage. However, pruning vines so that the canopy is very open can also reduce fruit quality. Tombesi et al. (1994) have shown that a leaf area index (LAI) of 1.8 can reduce fruit size, and the fruit soluble solids concentration, at harvest.

Shading within trees has been shown to reduce fruit quality in many fruit species, including satsuma mandarin, peach, grapes, and raspberries (Palmer 1989). Of the species reviewed, grapes had the lowest within-canopy irradiance, with photosynthetically active radiation (PAR) levels as low as 1% of those above the vine. Grapes which were exposed to high light levels were generally higher in sugar and anthocyanin, and lower in titratable acidity, all

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characteristics which enhance the quality of wine. Removal of leaves near the fruit clusters to allow more light onto the fruit and improve fruit quality, is used commercially in vineyards in California and Europe (Kliewer & Smart 1989).

Kiwifruit vines can produce a dense canopy which results in low light levels in the fruiting zone at the bottom of the canopy (Tombesi et al. 1994). Within-vine shading has been shown to reduce the diameter of individual canes, fruit size, and fruit starch concentration, but not sugar levels of kiwifruit (Grant & Ryugo 1984a). Davison (1977) observed differences in fruit firmness, soluble solids concentration, colour, and taste between fruit from well-shaded and exposed positions on individual vines. Tombesi et al. (1993) showed that fruit from the shaded parts of the canopy were smaller and had a lower chlorophyll concentration at harvest. During storage these fruit were consistently less firm, and had a lower soluble solids concentration than fruits which had grown in exposed positions. Artificial shading of individual fruits of kiwifruit similarly reduces flesh firmness, soluble solids concentration, and dry matter (DM) concentration at harvest (Tombesi et al. 1993). However, the data of Smith et al. (1994) imply that low light levels do not always reduce fruit quality of kiwifruit. In that study, fruit with the highest soluble solids concentration (after 12 weeks of storage) were located near the cordon, in the denser parts of the canopy.

The effects of light microclimate appear to be moderated by crop load (Lakso et al. 1989; Snelgar et al. 1991), so that on low-cropping plants any effect of shading is essentially undetectable, but on high-cropping plants shading severely reduces fruit size. Similarly, the soluble solids concentration of grapes is most severely reduced by shading when vines are carrying a heavy crop (Lakso et al. 1989).

The influences of LAI and crop load on vine productivity were investigated by Snelgar & Martin (1995) on two commercial orchards in Te Puke during 2 years. Orchard A had a history of producing fruit which stored well, whereas Orchard B tended to have a dense canopy, and high losses of fruit during coolstorage. In each orchard we pruned canes and leaves to produce vines which had "open" or "dense" canopies, so that the LAI of individual vines ranged from 2.5 to 6.0. High values of LAI were found to decrease mean fruit size at a rate of 5.8 g per unit LAI, but only in the second season, when crop loads were high (21–70 fruit/m^2). In the present study we report on the fruit quality aspects of this trial.

MATERIALS AND METHODS

Trial layout and pruning treatments

The trial was undertaken in two adjacent commercial orchards in Te Puke, Bay of Plenty, New Zealand (37°49′S, 176°19′E), each with mature vines trained on pergola support systems. Pruning and crop load treatments were randomly assigned, in a 2 × 2 × 2 factorial design (orchard × LAI × crop load), to a total of 40 experimental vines. It was initiated in late winter 1991, after winter pruning had already been completed. Orchard B had more canes tied down per metre of row than Orchard A, and we did not modify these differences in cane density. Summer pruning regimes were: (1) "normal" summer pruning, resulting in a **open** canopy. Shoots were tipped in mid October, followed by summer pruning on four occasions, at approximately monthly intervals. Summer pruning consisted of tipping shoots back to 2–4 leaves beyond the fruit and removing some vegetative shoots; and (2) no summer pruning, resulting in a **dense**, more shaded and tangled canopy.

The LAI varied between orchards (Orchard B, with more canes per metre, tended to have higher LAI than Orchard A) and between years, as well as between pruning treatments. Thus the terms open and dense are relative, rather than absolute.

Single vines were used as experimental plots, but half of each of the surrounding guard-vines was pruned to the same LAI. In this first season, crop loads on all vines were not high, so we did not modify crop loads.

In the second season, winter pruning was adjusted so that more cane was tied down on the dense vines in both orchards (3.3 canes per metre of row cf. 2.4 on the open-canopied vines). The same summer pruning regimes were applied to the vines as the previous season. In addition, two nominal crop loads were imposed on vines by thinning fruit. Crop loads were relative ("low" and "high") because vines with fewer canes (low LAI) carried fewer fruit, so it was difficult to set high crop loads on these vines.

A combination of natural pollination by bees, and artificial pollination using hand held sprayers was used in each orchard. Standard commercial practices were applied throughout the trial. Hydrogen cyanamid was applied to Orchard A in spring 1991 and to both orchards in 1992 to increase budburst.

Orchard measurements

From mid February onwards, each experimental vine was visually assessed for leaf condition and leaf drop at c. 2-weekly intervals. Fruit drop was estimated by counting the number of fruit on the ground under each vine.

Measurements of LAI were made under clear sky conditions on four occasions in 1992 and seven occasions in 1993 during the growing season. A Decagon sunfleck ceptometer, with a sensor 800 mm long and composed of 80 individual photodiodes, was used to measure the transmission of PAR through the canopy. With the ceptometer held horizontally, and perpendicular to the main cordon of the kiwifruit vine, the operator walked along under each side of the vine, sampling at c. 0.2 m intervals. Thus each plot was sampled 30–50 times, and the arithmetic mean of these 2400–4000 readings was stored.

At the same time, incident radiation 1.5 m above ground level was measured using a cosine-corrected PAR sensor (Palmer 1987) located on a meteorological site within c. 0.5 km of the research plots. A shade band (Horowitz 1969) at the same site was used to measure diffuse radiation. The PAR sensors were scanned at 5 s intervals and mean values recorded every 60 s. The light transmission for each experimental plot was calculated using the mean under-canopy PAR measured by the ceptometer, and the incident radiation at the meteorological site. These values were used to estimate the LAI using the equations supplied by Decagon.

In addition, the relationship between light transmission through the canopy and measured LAI was determined in a total of 21 calibration plots, each c. 3.6 m^2 and with LAI ranging from 1.3 to 6.8, during the two growing years. This range of LAI was obtained by varying the pruning of the vines as described above. The LAI of these plots was firstly estimated using the ceptometer and then, within 7 days, all leaves from the plots were harvested and the total leaf area was measured on a LICOR 3100 leaf area meter. An empirical regression was fitted to correct the Decagon calculation to measured LAI. Values estimated using this correction were highly correlated with the measured LAI (r^2=0.78). However, at very high LAI (6.8), there was so little light transmitted through the vine that the ceptometer underestimated LAI.

Fruit maturation and storage quality

At 2–4-week intervals from mid February to mid May each season, 20 fruit per treatment were harvested from similar positions on each experimental vine (Snelgar & Hopkirk 1988) and assessed for fruit firmness, soluble solids, DM, starch concentration (1992 only), and seed colour.

In both years, fruit which were soft to the touch at harvest were recorded but were not stored with the bulk of the fruit. Before the 1993 harvest, any fruit on shoots which had lost their leaves were marked so they could be identified during grading and storage.

Fruit from all experimental vines were harvested at a soluble solids concentration of c. 7% (10–12 May) and sorted on an electronic grader which recorded individual fruit weights. Export-quality fruit of count size 36 (99–107 g) were packed into standard, single-layer kiwifruit trays (36 fruit per vine in 1992 and 216 in 1993), and placed into coolstorage at 0°C 24 h after harvest. The DM concentration of fruit was assessed at harvest. At harvest, and after 2, 4, 6, 10, 15, 20, and 25 weeks of storage 2 fruit per vine (6 fruit per vine in 1993) were assessed for fruit firmness, and soluble solids concentration after fruit had been held at 20°C for 1 day. In 1993, additional assessments were undertaken: (1) the skin and flesh colour of 36 fruit per vine were measured the day after harvest; and (2) the proportion of fruit with stem end storage rot was assessed in 108 fruit per vine after 10 weeks of storage.

Specific methods

Fruit firmness was measured using an Effegi penetrometer, and soluble solids concentration of the juice was measured using a hand-held refractometer (Snelgar & Hopkirk 1988). DM was measured by drying equatorial slices from each fruit (with skin removed) at 65°C to constant weight. Seed colour was scored as the percentage of dark seeds assessed visually on a transverse cut near the equator of the fruit. Starch content of freeze-dried flesh was measured using the Boehringer Mannheim starch kit (Bowen et al. 1987).

Skin colour was measured on the flat side of the fruit, then the skin was removed, and flesh colour measured, using a Minolta chromameter CR-200b in the tristimulus L*a*b* mode. Since a* and b* are not independent and it can be misleading to compare them directly (Hirst et al. 1990), lightness, chroma, and hue values were calculated according to McGuire (1992).

Sensory evaluation

At the time of grading, 14 fruit per vine (44 in 1993) for sensory assessment were randomly selected from 36 count size. The packed fruit were coolstored at 0°C. After 1–7 days half of the fruit were treated with 100 ppm ethylene overnight at 20°C, then held at 20°C until eating ripe, when fruit were assessed by panellists. The remaining fruit were held in coolstorage for a further 8 weeks, then removed and left to ripen at 20°C until evaluation .

Panels trained in the descriptive analysis of kiwifruit were used to assess the fruit (28 members in 1992 and 24 in 1993). All sensory assessments of fruit were completed in individual temperature and light-controlled booths. At the time of sensory evaluation, fruit firmness and soluble solids concentration were measured on each fruit to be evaluated, and individual panellists were presented with three fruit of similar firmness, matched within a range of 0.5 to 0.9 kgf, one from each of three treatments. Each treatment was assessed 21 times (1992) or 27 times (1993). Panellists were asked to rate the intensities of the following 13 attributes, using 150 mm unstructured line scales with verbal anchors at each end—(1) aroma: initial aroma intensity, characteristic kiwifruit aroma, acidity, sweetness, and grassiness; (2) flavour: initial flavour intensity, characteristic kiwifruit flavour, acidity, sweetness; and (3) texture: juiciness, softness/firmness, smoothness/coarseness, fibrousness.

Statistical analysis

The influence of canopy density, crop load and orchard were analysed by multifactorial ANOVA. In analyses each vine was treated as an experimental unit. Percentage data were transformed to the angular scale before analysis.

RESULTS

Vine observations

Light levels under the vines typically ranged from 0.1% to over 6% of the incident light level. Under the most dense canopies, PAR levels averaged only 1 $\mu E\ m^{-2}\ s^{-1}$, the minimum level detectable by the ceptometer at midday when the incident PAR was 1500 $\mu E\ m^{-2} s^{-1}$. In both years, LAI reached a maximum during mid summer, and declined before harvest (data not presented). Average mid summer values (February 1992, March 1993) were calculated for each treatment, and were used in subsequent analyses (Table 1). In 1992, mean LAI for the treatments imposed ranged from 3.0 to 4.4, whereas in 1993 a greater range was obtained (3.0–5.5), by maintaining very dense canopies on some vines (Table 1). Crop loads were only moderate at c. 30 fruit/m^2 in 1992 (Table 1; cf. Richardson & McAnenny 1990), but ranged from 25 to 60 fruit/m^2 in 1993.

In Orchard A there were gaps in the canopy where no canes had been tied down, and thus extra light was available to some areas of vines, even when canopies were dense. In both years, vines in Orchard A with open canopies had little leaf or fruit drop before harvest. Vines with a dense canopy had a small amount of leaf drop by mid February in the areas of high LAI, and in each year <1% of fruit fell before harvest (Table 2).

Generally, vines in Orchard B had denser canopies than those in Orchard A (Table 1), despite being pruned to a uniform cane density during winter 1992. Vines with an open canopy dropped a small number of leaves and fruit between mid April and harvest. On vines with dense canopies, leaves began to drop in mid February, and many had fallen from the shoots bearing the fruit by late March, so that most of the leaves remaining by late April were on next season's replacement canes. Withering of some fruit stalks was noticeable in mid March and fruit

Table 1 Mean leaf area index and crop load on experimental kiwifruit vines (*Actinidia deliciosa* 'Hayward'). (LAI = leaf area index.)

Year	Orchard	Canopy	LAI (m^2/m^2)	Crop load (fruit/m^2)
1992	A	Open	3.0	32
	A	Dense	4.1	30
	B	Open	3.5	27
	B	Dense	4.4	32
1993	A	Open	3.0	26
	A		3.0	36
	A	Dense	4.6	45
	A		4.4	60
	B	Open	3.8	25
	B		4.1	38
	B	Dense	5.5	35
	B		5.4	47

began dropping in late March. In each year c. 3% of fruit dropped before harvest.

In both years, Orchard B had a higher proportion of soft fruit than Orchard A, and there were more soft fruit on vines with dense canopies (Table 2). The high level of leaf drop meant that, when averaged over both orchards, vines with dense canopies bore 14% of their fruit on shoots which had no leaves at harvest (Table 2). However, as only 1% of the fruit on these vines was soft at harvest, this suggests that most of the fruit found on leafless shoots did not soften prematurely.

Table 2 Influence of canopy and orchard on fruit softening and fruit drop of kiwifruit (*Actinidia deliciosa* 'Hayward'). The influence of crop load was assessed in 1993, but as this factor was not significant, data are not presented. Data are summarised as the overall mean, and the size of the change induced by the main effects. Significant interactions are noted in footnotes. Canopy:orchard refers to the canopy by orchard interaction. All percentage data have been transformed to the angular scale. Data can be backtransformed to percentages as $(\sin(\text{angular}\%))^2$. (LAI =leaf area index.)

				At harvest			After 10 weeks of storage
Year	Contrasts	LAI (m^2/m^2)	Fruit drop (%)	Soft fruit (%)	Fruit on leafless shoots (%)	Soft fruit on leafless shoots (%)	Stem end rot (%)
1992	Mean	3.8	6.5	5.1	–	–	–
	Canopy	1	4.9	1.9*	–	–	–
	Orchard	0.4	7.1	10.2	–	–	–
	Canopy:orchard		−0.2	1.9	–	–	–
	LSD ($P = 0.05$)		1.3	1.2	–	–	–
1993	Mean	4.2	5.4	4.3	13.8	21.8	6.6
	Canopy	1.5	6.2†	3.8	16.8‡	30.0	3.3
	Orchard	1	5.6	4.3	11.5	16.9	3.5
	Canopy:orchard		1.3	0.2	3.6	3.3	0.8
	LSD ($P = 0.05$)		1.2	1.2	2.6	11.9	2.7

*Increasing canopy density significantly increased the percentage of soft fruit, but only in Orchard B. Orchard A had no soft fruit.
†Fruit drop was greater from a dense canopy than a light canopy in both orchards, but the magnitude of this effect was greatest in Orchard B.
‡Percentage of fruit on leafless shoots was greater under a dense canopy than a light canopy in both orchards, but the magnitude of this effect was greatest in Orchard B.

Table 3 Influence of canopy and orchard on the fruit maturation and fruit quality of kiwifruit (*Actinidia deliciosa* 'Hayward'). The influence of crop load was assessed in 1993, but since this factor was not significant, the data are not presented. Data are summarised as the overall mean, and the size of the change induced by the main effects. Significant interactions are noted in footnotes. Canopy:orchard refers to the canopy by orchard interaction. (LAI = leaf area index, SSC = soluble solids concentration, DM = dry matter.)

				At harvest			After 20 weeks of storage	
Year	Contrasts	LAI (m^2/m^2)	Date of 6.2% SSC	Firmness (kgf)	SSC (%)	DM (%)	Firmness (kgf)	SSC (%)
1992	Mean	3.8	3 May	7.65	7.58	15.4	1.15	12.28
	Canopy	+1	0	0	−0.15	−0.4	−0.02	−0.35*
	Orchard	+0.4	+3	−0.20	−0.55	−0.7	−0.24	−0.45*
	Canopy:orchard		−2	0.10	−0.05	0.10	0.04	−0.55
	LSD ($P = 0.05$)			0.24	0.32	0.3	0.07	0.28
1993	Mean	4.2	4 May	8.03	7.18	15.6	1.10	12.46
	Canopy	1.5	−1	−0.35	0.20	0.0	−0.11	0.03
	Orchard	1	+6	−0.50	−0.25	−1.0	−0.13	−0.78†
	Canopy:orchard		−3	0.10	0.20	0.10	0.02	0.38
	LSD ($P = 0.05$)			0.25	0.24	0.4	0.06	0.32

*Dense canopies decreased SSC , but only in Orchard B. Orchard B had lower SSC than Orchard A, but only under dense canopies .
†Orchard B had lower SSC than Orchard A, but only when canopies were light.

Fruit maturation

Fruit firmness

Canopy density had no effect on fruit firmness in 1992. In 1993 fruit from vines with dense canopies were 0.35 kgf softer at harvest than fruit from vines with open canopies (Table 3). However, the difference in firmness between fruit from the different orchards was even greater with fruit from Orchard B being 0.5 kgf softer than fruit from Orchard A.

Carbohydrate accumulation

During fruit maturation, soluble solids concentrations of all fruit increased exponentially from c. 4.2% soluble solids in late February to 7% soluble solids in early May, as is typical for kiwifruit (Beever & Hopkirk 1990). The date that fruit from each experimental treatment reached commercial harvest maturity (6.2% soluble solids) was estimated by linear interpolation between the observed values. The date of commercial maturity differed by up to 6 days between orchards (Table 3). At the time of harvest, when soluble solids concentrations were c. 7%, fruit from the various canopy and crop load treatments contained similar soluble solids concentrations, but at this time fruit from Orchard A had slightly higher levels than fruit from Orchard B (Table 3).

Dry matter levels in all fruit increased as fruit matured. Fruit from vines with dense canopies had a lower percentage of DM at harvest in 1992 but not in 1993 (Table 3). In both years, the orchard had a greater effect on DM levels than either canopy density or crop load. At harvest, fruit from Orchard A had DM levels 0.7% higher than fruit from Orchard B in 1992 and 1% higher in 1993.

In the months before harvest, seed colour changed from light cream to black, and starch levels increased to a maximum and then decreased, each in the pattern typical of kiwifruit maturing on the vine (Beever & Hopkirk 1990). There were no differences between fruit from the different canopy and crop load treatments (data not presented).

Skin and flesh colour

In both years, the skin of fruit from vines with dense canopies was lighter (high L*), more vivid (high chroma), and more yellow (increased hue) than that of fruit from vines with open canopies (Table 4). In 1992, an increase of 1 unit LAI increased L* by 1.6 (3%), chroma by 0.9 (3%), and hue by 1.9 (2%). These changes as a result of canopy were consistent in both orchards. In both years there were also significant differences in skin colour between fruit from the two orchards. Although these differences in were inconsistent, they were sometimes large. In 1993, for instance, the between-orchard differences were larger than those due to the increase in LAI .

The colour of the flesh also varied with canopy density (Table 4). Under dense canopies the flesh

Table 4 Influence of canopy and orchard on the skin and flesh colour of kiwifruit (*Actinidia deliciosa* 'Hayward'). Measurements were made at harvest. The influence of crop load was assessed in 1993, but as this factor was significant for only one variate, this is noted in a footnote. Data are summarised as the overall mean, and the size of the change induced by the main effects. Significant interactions are noted in footnotes. Canopy:orchard refers to the canopy by orchard interaction. (LAI = leaf area index.)

			Skin			Flesh		
Year	Contrasts	LAI (m^2/m^2)	L value	Chroma	Hue	L value	Chroma	Hue
1992	Mean	3.8	51.2	29.2	85.8	64.8	36.9	112.0
	Canopy	1	1.6	0.9	1.9	1.5	−2.0*	−0.7
	Orchard	0.4	−0.5	0.7	0.4	−1.4	0.2	0.1
	Canopy:orchard		0.6	0.6	0.3	0.7	−0.9	−0.2
	LSD ($P = 0.05$)		0.8	0.7	1.0	1.1	0.8	0.3
1993	Mean	4.2	51.0	29.5	84.5	65.9	37.3	110.8
	Canopy	1.5	2.0	1.7	2.3‡	2.4	−2.1	−0.8
	Orchard	1	2.3	2.5†	2.6	1.0	−1.6	−0.7
	Canopy:orchard		0.1	−0.1	0.0	−0.3	0.0	0.0
	LSD ($P = 0.05$)		0.4	0.3	0.8	0.5	0.7	0.2

* Flesh chroma was reduced under a dense canopy, but only in Orchard B.
† Skin chroma was increased on vines with a high crop load, but only in Orchard B. Crop load was significant as a main effect (−0.4). Orchard:crop load interaction is also significant (0.4).
‡ Skin hue was increased under a dense canopy at both low and high crop loads, but high croploads reduced skin hue only under a dense canopy. Crop load:canopy interaction (−1.0) is significant.

was lighter, less vivid, and less green. Consequently, under open canopies the skin of fruit was much less vivid than the flesh, but under dense canopies these values tended to converge. This may be the result of the skin being less opaque under dense canopies, thereby allowing the flesh colour to more strongly influence the skin colour. There were some between-orchard differences in flesh colour in both years, but these differences were not consistent.

Postharvest fruit quality

During storage at 0°C, the firmness of all fruit decreased rapidly at first and then more slowly as firmness values approached 1.0 kgf (data not shown). Fruit from vines with open canopies were slightly firmer than fruit from vines with dense canopies during the early stages of storage in both orchards in both years (data not presented). In 1993, after 20 weeks of storage, fruit from vines with open canopies tended to be firmer than fruit from vines with dense canopies (0.11 kgf, Table 3). However, we believe that the differences attributed to canopy density are unlikely to be large enough to be commercially significant, even when fruit approach 1.0 kgf, the minimum firmness permitted for export fruit. In both years, fruit from Orchard B were less firm after 20 weeks of storage than fruit from Orchard A (0.24 kgf in 1993; 0.13 kgf in 1993). Crop load did not influence fruit firmness after 20 weeks of storage.

Soluble solids concentrations increased during the first 6 weeks of storage and then remained relatively constant (data not presented). There was no clear effect of canopy density on soluble solids concentrations during storage, although in 1993 there was an interaction between canopy density and orchard (Table 3). When the canopy was open fruit from Orchard A had a soluble solids concentration of 13%, whereas fruit from Orchard B attained only 11.9%. Under a dense canopy soluble solids values were low and the between-orchard differences were smaller (12.5% cf. 12.1%). There was no significant effect of crop load on mean soluble solids concentrations after 20 weeks of storage.

In 1993, when fruit were assessed after 10 weeks of storage, fruit from vines with a dense canopy had a higher incidence of stem end storage rots than fruit from vines with an open canopy (Table 2). When vines had an open canopy only 0.3% of the fruit developed rots. However, the incidence of rots increased to 3% under a dense canopy. There was similar difference between orchards, with Orchard A having only 0.3% rots compared with 3% in Orchard B. These observations corroborate the results of more detailed studies of the effects of LAI on storage rot (H. Pak & M. Manning pers. comm.).

Sensory quality

Aroma

In 1992, the aroma of freshly harvested fruit from Orchard A grown under dense canopies was significantly sweeter than that of fruit from Orchard B grown under an open canopy (data not presented). This sweeter aroma may have been due to the high soluble solids concentration (13.4% cf. 12.3%) of these fruit. In 1993, we found no differences in the

Table 5 Influence of canopy and orchard on sensory characteristics of kiwifruit (*Actinidia deliciosa* 'Hayward'). Fruit were assessed after 8 weeks of coolstorage at 0°C. The influence of crop load was assessed in 1993, but as this factor was not significant data are not presented. Data are presented as the overall mean, and the size of the change induced by the main effects. Significant interactions are noted in footnotes. Canopy:orchard refers to the canopy by orchard interaction. (LAI = leaf area index, SSC = soluble solids concentration.)

				Aroma		Flavour			Texture			
Year	Contrast	LAI (m^2/m^2)	SSC (%)	Acid*	Grassy*	Kiwi†	Acid*	Sweet*	Juicy*	Smooth*	Soft flesh*	Soft core*
1993	Mean	4.2	12.69	59.9	46.5	77.3	69.5	61.3	87.3	49.8	44.8	60.8
	Canopy	1.5	–0.03	3.3	–3.0	–5.5	–3.0	–1.0	–6.5	0.5	0.0	1.5
	Orchard	1	–0.73	–5.8	–6.5	–7.5	–5.0	–2.0	–5.0	–5.5	–6.5	–8.0¶
	Canopy:orchard		0.07	1.8	5.5	1.5	7.0‡	–8.5§	–1.0	0.5	2.0	3.0
	LSD (P = 0.05)		0.38	5.5	6.5	5.7	5.7	5.6	4.5	5.0	5.1	7.0

*0 = absent and 150 = extreme.
†0 = not kiwifruit and 150 = distinctively kiwifruit.
‡Acid flavour was highest on Orchard A, but only under a light canopy.
§ Sweet flavour was increased under a dense canopy in Orchard A, but reduced in Orchard B.
¶ Soft core was highest in Orchard A, but only when crop loads were low. Orchard:crop load interaction (–8.5) was significant.

aroma of fruit at harvest, but after 10 weeks of storage, fruit from Orchard A had a more acid, more grassy aroma (Table 5). Canopy density had no significant effect on any aroma attribute in 1993.

Flavour

The flavour attributes of fruit were not affected by canopy density in 1992 (data not presented). In 1993 sweet flavour showed an interaction between canopy density and orchard. Dense canopies increased this characteristic in Orchard A, but **reduced** it in Orchard B. In 1992, fruit from the two orchards were similar, whereas in 1993, fruit from Orchard A had a more intense characteristic kiwifruit flavour after storage than fruit from Orchard B (Table 5). Acid flavour was also highest on Orchard A, but only on vines with an open canopy.

Texture

At harvest in 1992, fruit from vines with open canopies had a significantly firmer flesh texture than fruit from vines with dense canopies (data not shown). However, this fruit also had higher penetrometer readings, which indicates that this fruit was not fully ripe at the time of tasting. Thus the differences in firmness perceived by the sensory panel may have been partially due to fruit from the various treatments being at different stages of ripeness. At harvest in 1993, fruit grown under open canopies was significantly more coarse in texture, and had firmer, more fibrous flesh than fruit grown under a dense canopy. These differences were not apparent after storage, but at this time fruit from vines with open canopies were juicier than those grown under dense canopies (Table 5).

In 1993, fruit from the two orchards did not differ in texture at harvest, but after storage, fruit from Orchard A were significantly juicier, with a less smooth, firmer flesh, and a coarser core, than fruit from Orchard B. Some of these between-orchard differences may have been because of the high LAI in Orchard B. In both years, mean intensities for all texture attributes except juiciness, were lower after storage than in freshly harvested fruit.

Crop load had no significant effect on any of the aroma, flavour, or texture attributes measured in 1993. However, after 20 weeks of storage there was a significant interaction between orchard and crop load. The score for soft core was greatest in Orchard A, but only when crop loads were low.

DISCUSSION

Canopy density and shading

During our 2-year trial, we were unable to show large differences in fruit quality due to differences in LAI, even though our experimental vines had a relatively large range of LAI, from 3 to 5.5. An LAI of 3 is typical of a well managed kiwifruit orchard, whereas 5.5 indicates an extremely dense canopy. These LAI values are similar to those reported for other horticultural crops, such as apple trees (0.5–4, Palmer 1989) and grapes (1.5–5.5, Grantz & Williams 1993). In contrast, the LAI of forests can be as high as 12 (Bolstad & Gower 1990). However, the light levels under our kiwifruit vines were very low (0.1% of the incident light) compared with other crops. Forest trees with an LAI of 6 transmit 0.6–12% of the incident light, whereas orange trees with LAI greater than 6 still transmit more than 1% of the incident light. The comparatively low light levels under kiwifruit vines suggest that the kiwifruit vine canopies are unusually effective at absorbing light, and this may be partially because of the very large leaves of kiwifruit (average area 130 cm^2, Snelgar & Thorp 1988), and the compact nature of the canopy (<1 m deep). The combination of high LAI, and low transmission results in the fruit on kiwifruit vines being more intensely shaded than the fruit of other horticultural crops such as apples .

Canopy density and fruit quality

The high rate of leaf drop observed in our study was probably related to the low light levels under kiwifruit vines with dense canopies. This loss of leaf area, and the low levels of PAR available for photosynthesis, is likely to limit the carbohydrate supply available to many fruit for some weeks before harvest. Grant & Ryugo (1984b) noted the low rates of photosynthesis found in shaded leaves of kiwifruit. This limited carbohydrate supply may be responsible for the observed effects of high LAI on fruit quality: small delays in commercial harvest maturity, lower DM concentrations at harvest in one season, and lower soluble solids levels in ripe fruit. Our findings contrast with those of Tombesi et al. (1994) who found that **low** LAI (1.8–2.6) reduce the soluble solids concentrations of fruit at harvest. However, at an LAI of 1.8 fruit development was probably limited by the low amount of leaf area available per fruit (330 cm^2). Thus their findings are likely to be due to the indirect effect of LAI on the leaf to fruit ratio (crop load), rather than to the direct effects of LAI on within-vine shading. The moderate to high LAIs used in our trial corresponded to between 730 and 1600 cm^2 leaf area per fruit, and this should be sufficient to maximise the soluble solids concentrations of fruit (Snelgar & Thorp 1988). Under these conditions, crop load was shown to have no significant effect on fruit firmness, soluble solids concentrations or sensory quality of the fruit.

Canopy density had only a small effect on fruit firmness. A higher proportion of fruit grown on vines with dense canopies dropped from the vine before harvest or were soft at the time of harvest and "normal" fruit were slightly softer at harvest, and after 20 weeks of storage. The only differences in sensory quality attributed to canopy density were small difference in fruit texture: coarseness, firmness and fibrousness of the flesh, and juiciness. Colour development of the skin and flesh were reduced under dense canopies.

The lack of strong, or consistent, relationships between fruit quality and canopy density in our study suggests that the fruit of kiwifruit are less sensitive to variations in light level than the fruit of crops such as apples or grapes.

Importance of canopy density

In this study we measured fruit quality on two contrasting orchards and attempted to evaluate the importance of canopy density in modifying fruit quality. Although our findings partially support the suggestion that vines with a dense canopy produce fruit of poorer quality, many of the effects related to canopy density were small or inconsistent, and they did not often result in differences which were of commercial significance. It is also evident that other differences between the two orchards, which are still undefined, have an important effect on fruit quality. It is possible that if the trial had been continued for several more years, cumulative effects of canopy density may have become more evident.

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