

## CHAPTER 6

# FRUIT SIZE, YIELD AND STARCH CYCLING IN RELATION TO DELAYED HARVEST OF EARLY AND LATE MATURING AVOCADO CULTIVARS

## 6.1 EFFECT OF DELAYED HARVEST ON SUBSEQUENT YIELD AND FRUIT SIZE OF EARLY ('Fuerte') AND LATE ('Hass') MATURING AVOCADO CULTIVARS

### 6.1.1 Introduction

Competition with other trees in forest stands during evolution has increased the complexity of woody perennials to the extent that they have developed life-cycle strategies which optimise competitive fitness within the plant community (Dickson 1991). The storage of minerals and carbohydrates surplus to current requirements and their remobilisation during periods of critical demand, enhance the tree's competitiveness in terms of growth and reproduction. Avocados have the capacity to store significant quantities of minerals and carbohydrates which are largely recycled during flowering, fruit set and spring growth (Cameron and Borst 1938; Cameron *et al.* 1952; Scholefield *et al.* 1985). While mineral nutrients are essential for vegetative growth, the requirements for avocado fruit development are comparatively small (Wolstenholme 1991). However, there is large investment of "energy" to produce oil-rich fruit with large carbohydrate-rich seeds, compared with sugar-storing species, e.g.. apples, citrus, peaches, mangoes (Wolstenholme 1986; 1987). Avocado fruiting therefore places high demand on the carbon-based products of photo-assimilation.

During a current cropping cycle, biotic and abiotic factors can have a substantial impact on tree performance. Biotic factors such as shoot vigour, leaf to fruit ratios and the incidence of pests and diseases (Quinlan and Preston 1971; Chacko *et al.* 1982; Whiley *et al.* 1986), and the environmental variables such as temperature (particularly in relation to critical phenological events), humidity, light, wind and storms (Proctor and Creasey 1971; Sedgley and Annells 1981; Whiley and Winston 1987; Issarakraisila and Considine 1994; Crane *et al.* 1994) all contribute to the quality and quantity of the harvest.

The inability of mature avocado fruit to ripen while attached to the tree (Schroeder 1952) has been widely utilised as a “tree storage” strategy to take advantage of marketing opportunities. As lipids continue to accumulate in fruit well after horticultural maturity (Eaks 1990; Kaiser and Wolstenholme 1994), this practice undoubtedly will have some impact on the total carbon economy of the tree. In some circumstances, delayed harvest of late maturing cultivars such as ‘Hass’, may result in the tree simultaneously carrying mature fruit while flowering and setting the following season’s crop. In cooler climates where ‘Hass’ is grown, e.g. California, Israel and New Zealand, simultaneously carrying two seasons crops on trees is a “normal” event and may be the main cause of the pronounced alternate bearing experienced in these countries.

While currently there are no published reports on the long-term effect of delayed harvest of avocado on subsequent productivity, the consequences of this practice have been reported for ‘Valencia’ orange. This fruit may also be “stored” on trees in cool areas for up to eight months after legal maturity has been reached, with several months overlap of successive crops. The consequences are reduced yields of smaller fruit in subsequent crops, with the likelihood of the onset of alternate bearing (Hilgeman *et al.* 1967; Monselise and Goldschmidt 1982).

Fruit size of avocado is also an important component of yield as premium prices are often paid for larger fruit, and small size can be problematic with some cultivars, e.g. ‘Hass’ (Lahav and Adato 1990; Köhne 1991; Cutting 1993). This study investigates the impact of delayed harvesting on starch cycling within the tree, and the subsequent effect on fruit size and yield of early and late maturing cultivars growing in Australia.

### **6. 1. 2 Materials and Methods**

Avocados growing in commercial orchards at Childers (latitude 25°S, altitude 40 m) and Maleny (latitude 26.5°S, altitude 520 m) in S.E. Queensland were used in this study over six seasons from 1988 until 1994. The research was carried out with the two most important avocado cultivars grown in Australia - the early maturing ‘Fuerte’ and the late maturing ‘Hass’. The ‘Fuerte’ experiment was located at Childers which has a warm, subtropical climate best suited to this cultivar. There were two ‘Hass’ experiments, one located at Childers and the other at Maleny. The

climate at Childers is considered marginally too warm for 'Hass', with small fruit at maturity consequently a serious commercial problem. This cultivar is much more suited for production in the cool, mesic subtropical climate of Maleny. At Childers, seven-year-old 'Fuerte' and 'Hass' trees grafted to seedling Guatemalan rootstock spaced at 9 x 7 and 8 x 6 m respectively, were chosen while at Maleny 10-year-old 'Hass' trees grafted to seedling 'Velvick' spaced at 12 x 8 m were used. The 'Hass' at Maleny had previously been affected by hail and had developed a strong alternate bearing pattern prior to starting the experiment. At each location, fertilisation and pest and disease control were according to recommendations of Whiley *et al.* (1988a) and Banks (1992). Irrigation at Childers was by under-tree sprinklers (two per tree each delivering 14 l hr<sup>-1</sup>) and was scheduled with tensiometers to supplement rainfall (annual average of 900 mm) while at Maleny trees relied solely on rainfall (annual average of 2000 mm).

Percentage dry mass of fruit flesh was selected as the maturity index for harvest. As maturing avocado fruit maintain a constant relationship between the percentage oil and water in the flesh (Swarts 1976; Lee 1981a; Lee *et al.* 1982), the determination of flesh dry matter is a reliable method of judging maturity with respect to the previously defined oil content standard (Lee 1981b). In Australia and South Africa this (or the reciprocal, flesh moisture percentage) has been commercially utilised for some time for determining minimum fruit maturity standards (Swarts 1978; Brown 1984). In Australia the minimum maturity standard for avocados is 21% dry matter (Brown 1984) though commercially 'Hass' is generally harvested when it reaches 23 to 25% dry matter. In many instances fruit is stored on trees for market opportunities, so that pulp dry matter may exceed 30 to 35% when harvested. Thus treatments selected spanned those of normal commercial practice and were:

***for 'Fuerte'***

1. All fruit harvested at 21% dry matter (21%);
2. All fruit harvested at 24% dry matter (24%);
3. Half of the fruit harvested at 21% and half at 30% dry matter (21/30%);
4. Half of the fruit harvested at 24% and half at 30% dry matter (24/30%);
5. All fruit harvested at 30% dry matter (30%); and

***for 'Hass'***

1. All fruit harvested at 25% dry matter (25%);
2. All fruit harvested at 30% dry matter (30%);

3. Half of the fruit harvested at 25% and half at 35% dry matter (25/35%);
4. Half of the fruit harvested at 30% and half at 35% dry matter (30/35%);
5. All fruit harvested at 35% dry matter (35%).

To determine the correct stage of maturity for harvesting, random fruit samples were periodically collected for pulp dry matter determination. In addition, at harvest pulp dry matter of five fruit from each tree was measured to establish the actual maturity of fruit from each treatment when picked.

Tree phenology was detailed by recording the date of floral bud-break; the duration of anthesis and the periods of active shoot growth. Wood samples were collected from trunks and the most recently produced shoots at regular intervals for starch analyses. Samples of wood were taken from five sites on each tree by first removing a plug of bark and then drilling 40 mm into the trunk with a 9 mm bit. The shavings were collected for analysis. Approximately 6 cm samples were removed from mature summer grown shoots and the leaves discarded. Ten non-fruiting shoots were randomly collected from each tree and sampling continued until the completion of anthesis. The procedures for processing and analysing the samples for starch content were as described in Chapter 2.

Data from each experiment were analysed by ANOVA, and covariance analysis was used to separate the effect of yield on fruit size. Where applicable, the relationship between trunk starch concentration in July and subsequent yield was established using linear regression analysis (TableCurve™, Jandel Scientific, Calif., USA).

### 6. 1. 3 Results

#### *'Fuerte' at Childers*

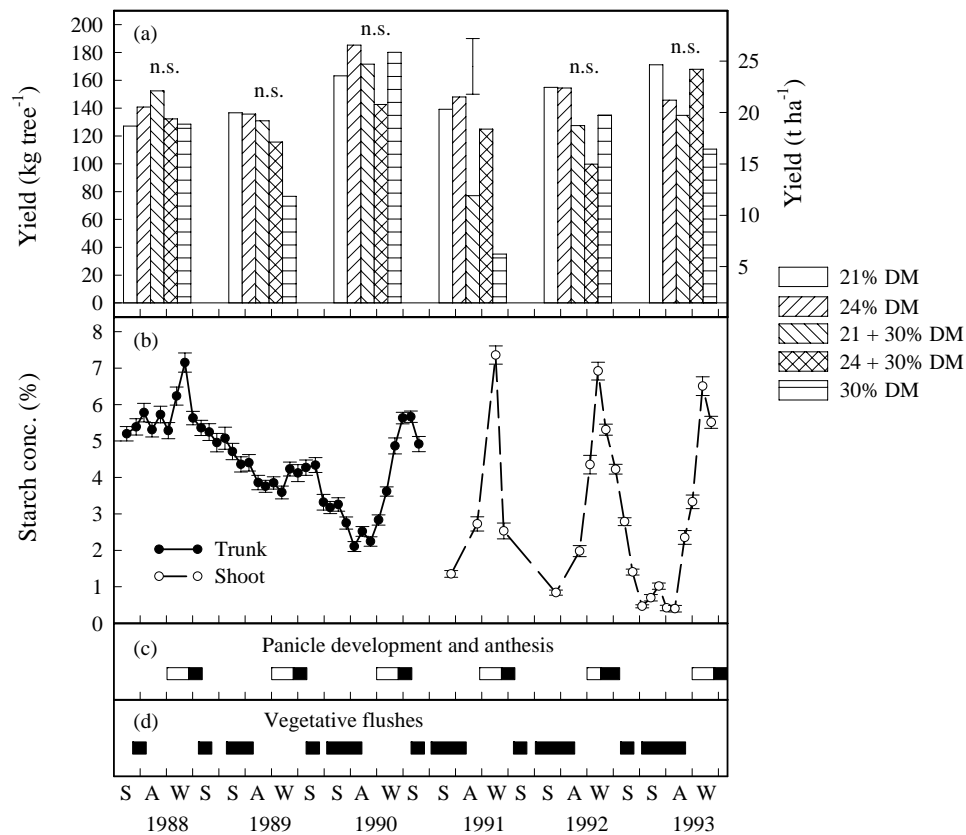
Depending on the year, fruit reached 21% dry matter from late March until mid-April; 24% dry matter from late April until mid-May and 30% dry matter from late May until mid-June (Table 8). All fruit over the duration of the study were harvested within  $\pm 1\%$  of the target dry matter for the respective treatments.

**Table 8** Maturity of cv. Fuerte fruit at Childers indicated by dry matter at the different times of harvest in 1988 to 1993. Data are the means  $\pm$  SE (n = 5) from each treatment when harvested at their respective maturity times.

1st Harvest		2nd Harvest		3rd Harvest	
Date	Dry matter (%)	Date	Dry matter (%)	Date	Dry matter (%)
14.04.88	21.5 $\pm$ 0.3	06.05.88	24.6 $\pm$ 0.4	17.06.88	31.1 $\pm$ 0.3
28.03.89	21.1 $\pm$ 0.2	26.04.89	24.9 $\pm$ 0.5	08.06.89	29.8 $\pm$ 0.4
24.04.90	21.4 $\pm$ 0.3	15.05.90	25.4 $\pm$ 0.4	19.06.90	29.7 $\pm$ 0.3
11.04.91	21.7 $\pm$ 0.1	09.05.91	24.8 $\pm$ 0.2	21.05.91	30.4 $\pm$ 0.4
09.04.92	21.2 $\pm$ 0.2	29.04.92	24.6 $\pm$ 0.2	18.06.92	30.6 $\pm$ 0.3
14.04.93	21.7 $\pm$ 0.2	04.05.93	25.7 $\pm$ 0.6	24.05.93	30.0 $\pm$ 0.5

On an annual basis, there was no significant treatment effect on yield except in 1991 where trees that were strip-harvested at 21% and 24% or picked at 24/30%, had significantly higher yield than trees where fruit was harvested at 21/30% or 30% (Fig. 26a). Due to carry-over effects and natural tree to tree variation, it is unusual to demonstrate yield responses from agronomic treatments in tree crops over an annual cycle (Schaffer and Baranowski 1986). In this case significant

differences were likely due to pre-conditioning of the trees following the application of treatments over a number of years.



**Fig. 26** Relationship between yield, seasonal starch concentration flux and tree phenology of cv. Fuerte at Childers where: (a) is yield of fruit which were harvested at different stages of maturity as judged by dry matter (DM), vertical bar indicates LSD ( $P \leq 0.05$ ); (b) is the mean starch concentration of all treatments ( $n = 30$ ), SEs are represented by vertical bars; (c) is periods of panicle growth represented by open horizontal bars, and periods of anthesis represented by closed horizontal bars; (d) is periods of vegetative growth represented by closed horizontal bars.

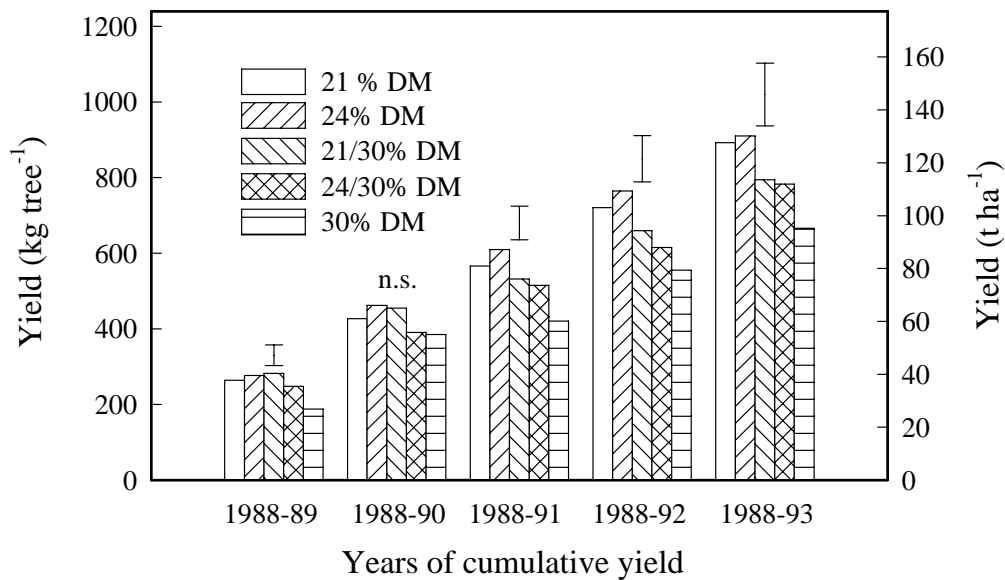
Trunk and shoot starch concentration data have been pooled as there were no significant differences between treatments. The concentration flux of trunk starch over three years was in the order of 5% (from ca. 2 to 7%) (Fig. 26b). Starch levels peaked during each winter and declined

after flowering. The lowest trunk starch concentrations were during the summer and autumn of 1990 when trees were carrying their heaviest crop (Figs. 26a & 26b). The seasonal concentration flux of starch in summer grown shoots was higher than in the trunks of trees (ca. 8% varying from < 1% to > 7%) and followed a defined seasonal pattern (Fig. 26b). Peak concentrations of starch accumulated during the autumn/winter period when shoot growth had ceased and the tree was in a relatively quiescent phase (Figs. 26b, 26c & 26d). During the flowering and spring flush periods shoot starch levels dropped rapidly to < 1% by the end of spring.

There were two periods of shoot growth activity in trees during a cropping cycle, viz. in spring and summer (Fig. 26d). Spring shoot growth was synchronised by flowering with most terminals flushing simultaneously in early September. Shoot growth was relatively quiescent after 60 days, followed by more sporadic summer and autumn flush growth from late December through to late April-May when all shoot growth activity ceased.

Mean fruit size was dependent on the time of harvest although significant differences were not apparent for every year of the study (Table 9). In general fruit size increased in those treatments where harvest was delayed, either by removing part of the crop early and the balance later or leaving the fruit until they had reached 30% DM. In three years out of six for example, fruit size of the 21/30% and 30% DM treatments were significantly larger than the 21% DM treatment.

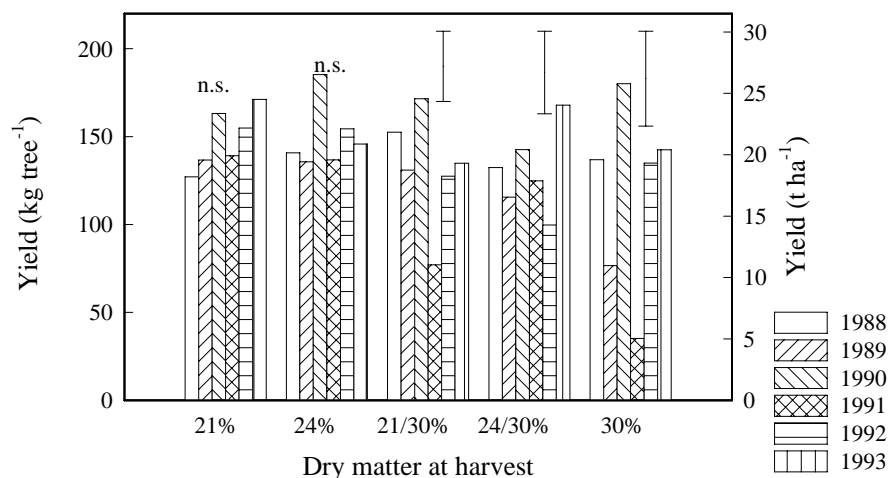
From the second year of the study treatments began to affect the cumulative yield of trees (Fig. 27). Treatments with the earliest harvest times, i.e. 21% and 24% DM, had significantly higher yields than where fruit was allowed to hang until 30% DM. The yield increment increased with time, though the earliest harvested treatments never significantly out-yielded those where fruit were harvested at 21/30% or 24/30% DM. Expressed differently, split harvests did not prejudice cumulative yields over the six seasons.



**Fig. 27** Effect of time of harvest, based on fruit dry matter (DM), on the cumulative yield of cv. Fuerte avocado trees at Childers over six consecutive years. Columns are treatment means ( $n = 6$ ) and vertical bars indicate LSDs ( $P \leq 0.05$ ).

The effect of the time of harvest on yield becomes more apparent when the annual patterns for each treatment are examined over the duration of the study (Fig. 28). In the first year of this experiment treatments had no significant effect on yield, indicating absence of bias in the experimental population (Fig. 26a). The continued early harvesting of fruit at 21 and 24% for six years resulted in cropping patterns wherein annual variation was insignificant, and limited to fluxes which most likely expressed environmental conditions at critical periods of development (Fig. 28). In contrast, delayed harvesting of fruit, either 50% or all of the crop, resulted in the development of an alternate bearing cycle where the amplitude increased with time. Examination of the data show that the cycle was atypical from 1992 to 1993 where yields for the 21/30% and 30% treatments were almost identical (Fig. 28). This may be explained by the severe tropical storm experienced in the orchard in February 1992 when a significant portion of the crop was lost when fruit was about 60% grown. This effectively amounted to an unscheduled early harvest across all treatments allowing a similar sized crop to be carried the following year.





**Fig. 28** Effect of time of harvest on the sustainability of yield of cv. Fuerte avocado trees at Childers over six consecutive years. Columns are mean values ( $n = 6$ ) and vertical bars indicate LSDs ( $P \leq 0.05$ ).

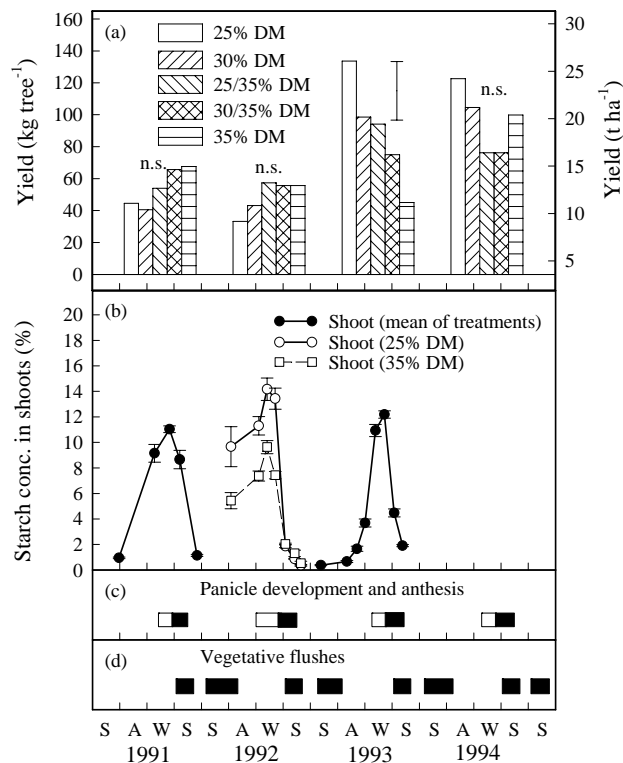
### *'Hass' at Childers*

'Hass' fruit at Childers reached 24% dry matter from mid to late May over the duration of the study (Table 10). From mid- to late July, fruit had accumulated 30% dry matter with 35% being reached from late August to mid-September. All fruit were harvested within  $\pm 1\%$  of the target dry matter for the respective treatments.

**Table 10** Maturity of cv. Hass fruit at Childers indicated by dry matter at the different times of harvest in 1991 to 1994. Data are the means  $\pm$  SE ( $n = 5$ ) each of treatment when harvested at their respective maturity times.

1st Harvest		2nd Harvest		3rd Harvest	
Date	Dry matter (%)	Date	Dry matter (%)	Date	Dry matter (%)
12.05.91	24.8 $\pm$ 0.2	03.07.91	31.6 $\pm$ 0.4	22.08.91	35.1 $\pm$ 0.4
18.05.92	24.7 $\pm$ 0.3	06.07.92	30.6 $\pm$ 0.3	07.09.92	34.8 $\pm$ 0.3
25.05.93	24.9 $\pm$ 0.4	27.07.93	29.4 $\pm$ 0.3	17.09.93	35.2 $\pm$ 0.4
30.05.94	24.7 $\pm$ 0.4	04.07.94	30.7 $\pm$ 0.4	28.08.94	34.8 $\pm$ 0.4

There was an increase in crop load from the start to the finish of the study, particularly in the last two years of the experiment (Fig. 29a). However, fruit yield was lower than expected in 1992 due to the effects of a tropical cyclone. There were no significant differences between treatments in annual yield except for 1993 when trees harvested at 25%, 30% and 25/35% DM out-yielded those in which harvest was delayed until 35% DM. In this case, carry-over effects from the storm may have enhanced the magnitude of treatment effects thereby precipitating a conclusive result.



**Fig. 29** Relationship between yield, seasonal starch concentration flux and tree phenology of cv. Hass at Childers where: (a) is yield of fruit which were harvested at different stages of maturity as judged by dry matter (DM), the vertical bar indicates LSD ( $P \leq 0.05$ ); (b) is starch concentration of shoots of all treatments (●,  $n = 15$ ), or 25% DM (○,  $n = 3$ ), or 35% DM (□,  $n = 3$ ), SEs are represented by vertical bars; (c) is periods of panicle growth represented by open horizontal bars, and periods of anthesis represented by closed horizontal bars; and (d) is periods of vegetative growth represented by horizontal closed bars.

There were no significant differences in fruit size between any of the treatments in each of the four years of the study (Table 11). However, there were trends present, stronger in some years than others, which indicated the potential for fruit size to increase the longer it is left on the tree.

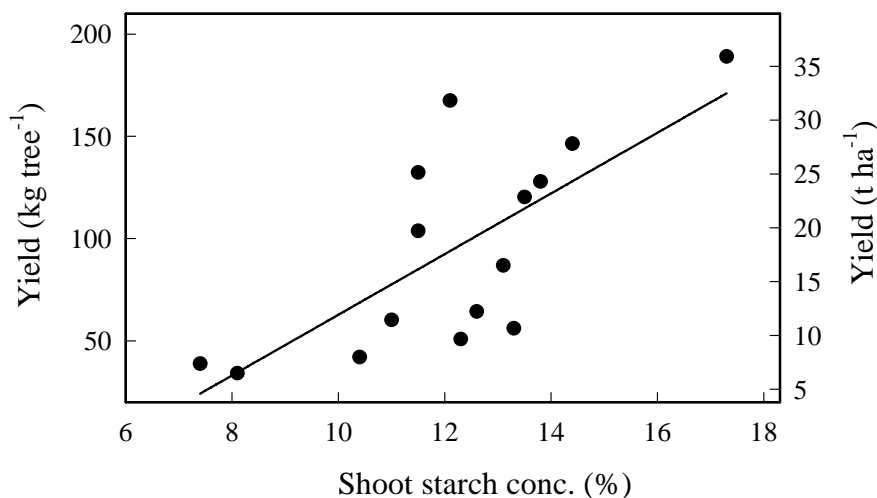
**Table 11** Effect of time of harvest on fruit size of cv. Hass growing at Childers. Data are mean of 6 trees for each treatment for each year of the study and have been subjected to covariance analysis adjusting for yield. Figures in parenthesis are the unadjusted fruit size means. There were no significant differences between values in columns as tested by ANOVA.

Treatment	Fruit size (g)			
	1991	1992	1993	1994
25% DM	172.9 (179.8)	169.1 (164.8)	230.2 (203.8)	188.9 (183.8)
30% DM	178.6 (188.3)	146.5 (144.7)	239.6 (241.5)	194.0 (195.2)
25/35% DM	186.2 (186.4)	160.3 (163.0)	244.8 (240.4)	192.5 (195.5)
30/35% DM	185.4 (177.6)	162.7 (164.6)	236.4 (242.5)	192.8 (195.8)
35% DM	202.1 (193.0)	176.3 (178.2)	238.5 (253.2)	206.9 (205.7)
Regression coefficient	-0.692**	0.253	-0.553**	-0.174

With respect to seasonal starch concentrations in shoots, there were no significant differences during 1991 and 1993 so data for all treatments were pooled. However, in 1992 shoot starch concentrations were significantly different and data have been presented separately for the 25% and 30% DM treatments (Fig. 29b). Starch levels for the 30%, 25/35% and 30/35% DM treatments in 1992 fell between concentrations for the 25% and 35% DM treatments and were not significantly different (data not presented). Starch concentrations in the shoots followed similar seasonal patterns for the first three years of the study when they were measured. Levels were initially low at the completion of summer shoot growth but increased rapidly as shoots entered a period of quiescence and peaked prior to flowering (Figs. 29b, 29c & 29d). Concentrations declined rapidly during flowering and spring shoot growth.

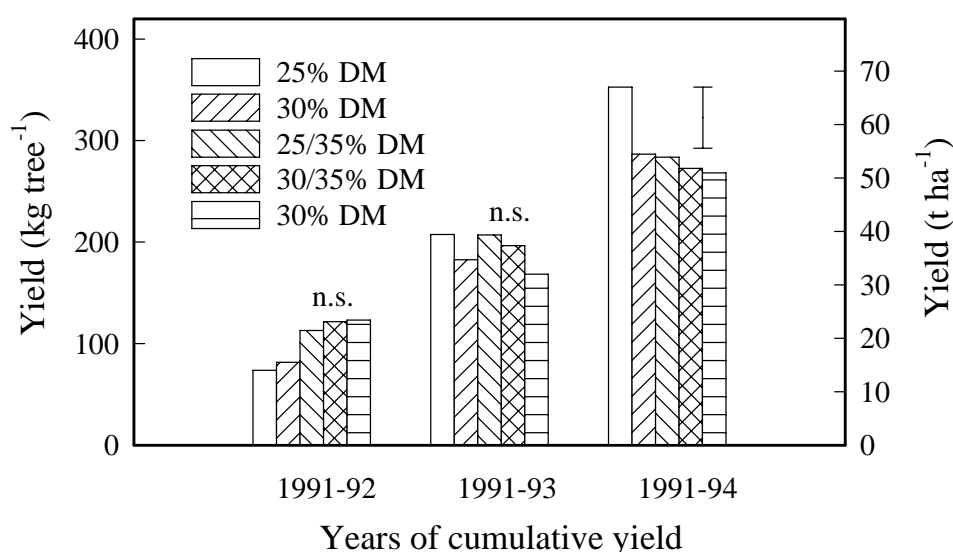
Shoot growth occurred during two periods over each cropping cycle; a relatively short term of activity in the spring concomitant with the termination of flowering followed by intermittent growth during the summer. The spring flush was generally concluded by mid- to late November while shoot growth during summer began in early January and had ceased by mid-March.

The light crop due to storm damage and the different harvesting times of fruit are the factors most likely contributing to higher accumulation of starch in the 25% DM treatment in 1992. While all treatments lost a considerable percentage of their crop in February, the earlier harvesting of the 25% treatment (18.05.92) provided these trees with a greater period without strong sinks to accumulate starch in shoot tissues. The 1992 starch concentration in shoots was positively related to fruit yield in 1993 (Fig. 30).



**Fig. 30** Relationship between yield (1993) and July shoot starch concentration (1992) of cv. Hass growing at Childers. The regression is represented by the equation  $y = 14.84x - 85.63$ ,  $r^2 = 0.52^*$ .

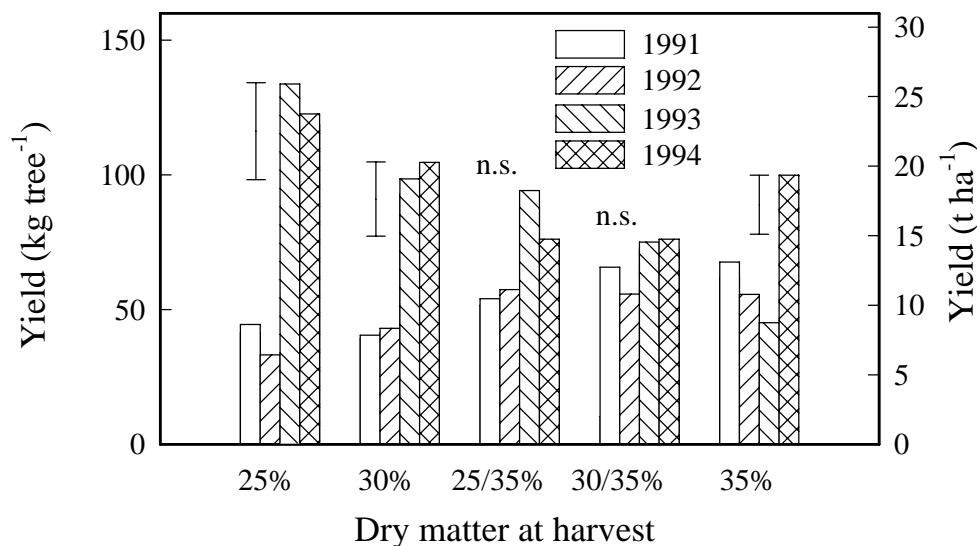
While there were no significant differences in cumulative fruit yield until the fourth year of the study, the combined yield of the first and second years was higher for treatments which were harvested late (Fig. 31). This was undoubtedly due to the non-significant trend for an increase in size of late harvested fruit (data not presented) and before any impact was made by these fruit on the following year's crop. By the end of 1993 (three years) this trend was changing slightly favouring the earlier harvested fruit and after four years, those trees harvested at 25% dry matter produced more fruit than all the other treatments (Fig. 31).



**Fig. 31** Effect of time of harvest, based on fruit dry matter (DM), on the cumulative yield of cv. Hass avocado trees at Childers over four consecutive years. Columns are mean values of 6 trees for each treatment and vertical bar represents LSD ( $P \leq 0.05$ ) determined by ANOVA..

With respect to the sustainability of production there was little impact made on yield by any of the treatments during the first two years of the study (Fig. 32). This in part may be due to the storm damage to the trees during the 1992 season. However, in the third and fourth years there is an indication that treatments were beginning to affect production sustainability. Where fruit were harvested at 25% and 30% DM, yield increased substantially in 1993 and 1994 and was similar for both of these years. There were no significant differences in yield from year to year in those

treatments harvested at 25/35% and 30/35%. However, in those trees where all fruit were harvested at 35% there was a reduction in the 1993 yield compared with production in 1994. It is suggested that this may be the beginning of a biennial fruiting pattern similar to that induced with 'Fuerte' growing in the same orchard.



**Fig. 32** Effect of time of harvest, as judged by fruit dry matter (DM), on the sustainability of yield of cv. Hass at Childers. Columns represent mean values of 6 trees for each treatment and vertical bars LSDs ( $P \leq 0.05$ ) determined by ANOVA.

### ***'Hass' at Maleny***

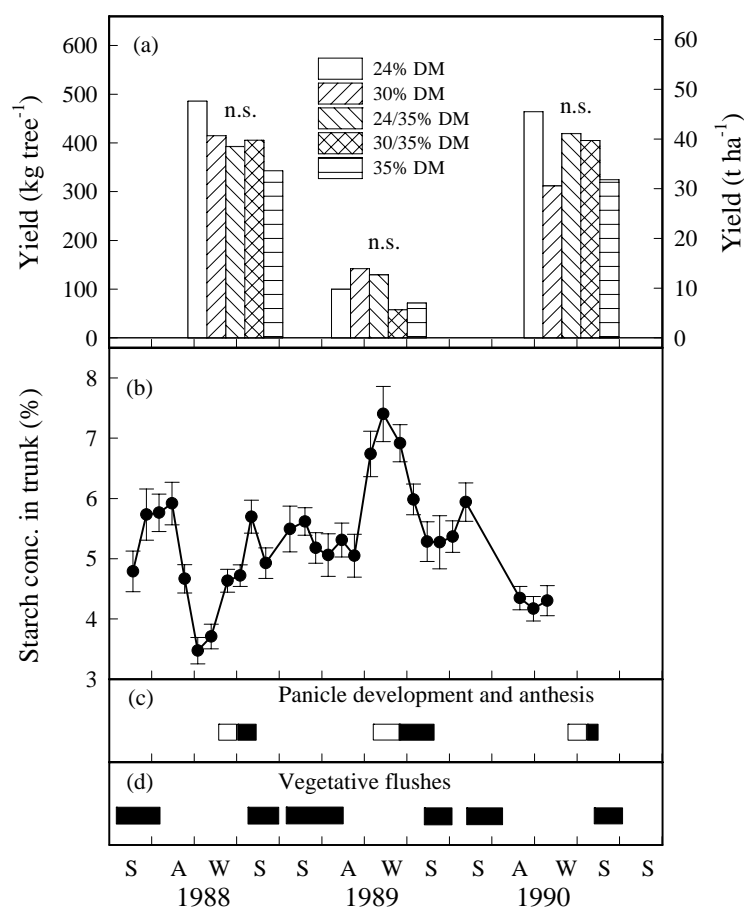
At Maleny fruit reached 25% dry matter from late June to mid-July; 30% from early August to late September; and 35% in early November (Table 12). For the most part treatments were harvested within 1.5% of their defined maturity, the exceptions being the November 1989 and September 1990 harvests at which fruit were slightly more mature than planned. Some fruit were tree-stored for over 4 months, well into a second growing season.

**Table 12** Maturity of cv. Hass fruit at Maleny indicated by dry matter at the different times of harvest in 1988 - 1990. Data are the means  $\pm$  SE of five fruit from each of the trees when harvested at their respective maturity times.

1st Harvest		2nd Harvest		3rd Harvest	
Date	Dry matter (%)	Date	Dry matter (%)	Date	Dry matter (%)
14.07.88	24.5 $\pm$ 0.3	28.09.88	31.6 $\pm$ 0.4	09.11.88	35.5 $\pm$ 0.3
28.06.89	24.2 $\pm$ 0.4	02.08.89	31.1 $\pm$ 0.5	01.11.89	37.4 $\pm$ 0.3
18.07.90	25.0 $\pm$ 0.2	19.09.90	32.6 $\pm$ 0.5	07.11.90	35.4 $\pm$ 0.5

There were no significant differences among treatment yields in any of the three years of the study (Fig. 33a). However, there was a very strong biennial effect across all treatments with high yields in the first and third years of the experiment (equivalent to 39.2 and 37.0 t. ha<sup>-1</sup>, respectively) and low yield (equivalent to 9.6 t. ha<sup>-1</sup>) in the second year.

As there were no significant differences in trunk starch concentrations between treatments throughout the three years of the study data have been pooled. Seasonal fluctuations in trunk starch levels ranged from ca. 3.5 to 7.4% and maximum concentrations occurred just prior to (1988 & 1990) or during flowering (1989) (Figs. 33b & 33c). Starch concentrations tended to be relatively stable during shoot growth and were in the vicinity of 5 to 6% (Figs. 33b & 33d). The low starch concentrations in 1988 and 1990 were likely due to very heavy crop loads which were not harvested until June/July or later for some of the treatments. The highest concentration of starch occurred during winter 1989 after shoot growth had ceased and when the crop load was light (Fig. 33a & 33b).



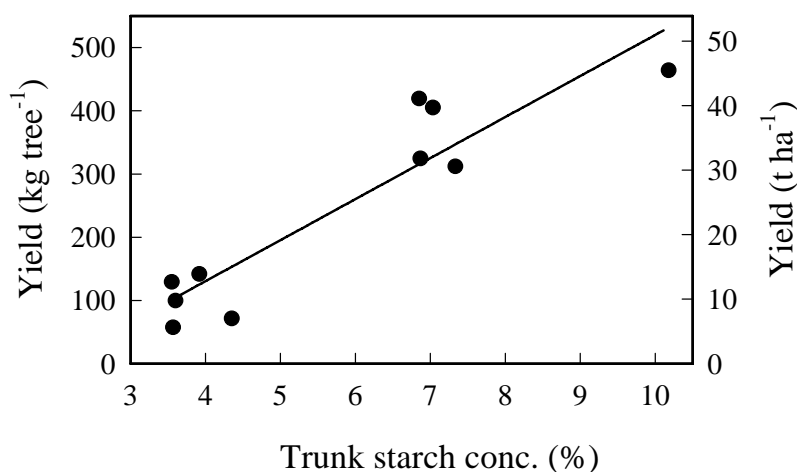
**Fig. 33** Relationship between yield, seasonal starch concentration flux and tree phenology at Maleny where: (a) yield of fruit which was harvested at different stages of maturity as judged by dry matter (DM); (b) is starch concentration ( $n = 30$ ), of all treatments, SEs are represented by vertical bars; (c) is periods of panicle growth represented by open horizontal bars, and periods of anthesis represented by closed horizontal bars; and (d) is periods of vegetative growth represented by horizontal closed bars.

Panicle emergence began in mid- to late July each year with anthesis mainly during September and extending into October (Fig. 33c). The flowering intensity was noticeably greater and extended for longer in the spring of the off-year preceding heavy cropping. Shoot growth occurred in two major periods over each crop cycle (Fig. 33d). In spring growth was synchronised by flowering and began near the conclusion of anthesis in early October. By late November of each year shoots had matured and following a short rest, sporadic flushing occurred over the summer months. In 1989,



summer growth began in mid-December and extended through until mid-April while in 1990 summer growth had ceased by the middle of March.

Trunk starch concentration in July of 1988 and 1989 were directly related to the yields in 1989 and 1990, respectively (Fig. 34). These data show “low” yields of ca. 100 kg tree<sup>-1</sup> (10 t ha<sup>-1</sup>) after July trunk starch concentrations of ca. 3 to 4%, rising to ca. 500 kg tree<sup>-1</sup> (50 t ha<sup>-1</sup>) at ca. 9 to 10% trunk starch the previous July.



**Fig. 34** Relationship between July trunk starch concentration and next season's yield of cv. Hass growing at Maleny. The regression is represented by the equation  $y = 64.90x - 129.04$ ,  $r^2 = 0.86^{**}$ .

The effect of harvest time on fruit size is detailed in Table 13. General trends for each year indicate that delayed harvest increased fruit size, however a near significant ( $P \leq 0.06$ ) increase was only recorded in the low crop year of 1989. In this season fruit which was allowed to hang late on the tree were 23% heavier than the earliest fruit harvest. This increase in fruit size was achieved without any significant reduction in fruit yield, either in the 1989 or 1990.

**Table 13** Effect of time of harvest on fruit size of cv. Hass growing at Maleny. Data are means of 6 trees for each treatment for each year of the study and have been subjected to covariance analysis adjusting for yield. Values in parenthesis are the unadjusted fruit size means. Means in columns not sharing a common letter were significantly different at  $P \leq 0.06$  as tested by ANOVA.

Treatment	Fruit mass (g)		
	1988	1989	1990
25% DM	219.8 a (214.0)	259.3 a (255.2)	219.2 a (214.3)
30% DM	233.5 a (233.0)	227.2 ab (214.5)	217.9 a (222.5)
25/35% DM	222.5 a (223.7)	251.2 a (243.4)	230.3 a (228.1)
30/35% DM	225.3 a (225.5)	210.3 b (214.7)	210.8 a (209.6)
35% DM	217.3 a (222.2)	236.7 ab (240.5)	237.7 a (241.4)
Regression coefficient	-0.075	-0.167*	-0.062

#### 6. 1. 4 Discussion

##### *Yield and fruit size*

Results presented in this Chapter have shown that avocado yields are strongly influenced by the synergism of fruit load and duration of the crop on the tree. With early and late maturing cultivars growing at Childers, removal of fruit within reasonable time of reaching maturity maintained yield performance over a number of seasons. However, prolonged delayed harvesting of fruit caused strong alternate bearing cycles to develop. This was particularly evident with 'Fuerte' which began this cycle the first year after starting treatments, i.e. shown in the 1989 yields. The development of the alternate bearing pattern at Childers was delayed with 'Hass', as yields were relatively low across all treatments over the first two years of the study. This was most likely due to the previous history of the trees which had suffered from Phytophthora root rot and boron deficiency prior to starting the treatments, and damage caused by the tropical storm in 1992. Nevertheless, in the final two years of the study there were signs that a biennial cycle had developed in trees where delayed

harvesting was practiced. This result contrasts with that reported by Kaiser and Wolstenholme (1994) who found that late harvesting of 'Hass' in the cool, mesic, subtropical Natal midlands did not depress yields the following year. There are three possible reasons why results differ: the length (number of years) of the Kaiser and Wolstenholme experiment was insufficient to induce biennial patterns; theft of fruit from trees distorting yield data which was suggested by the authors to explain unexpected results; or environmental differences between the sites significantly changing comparative tree and fruit performance. With respect to the latter, the Childers site in Queensland is significantly warmer than Everdon in Natal. Higher mean temperatures would increase the 'cost of fruiting' at Childers through increased respiratory losses (Blanke and Whiley 1995) thereby limiting photo-assimilates for fruit growth and subsequent crops.

Picking date is also reported to have affected yield in other tree crops. In a study with apples, fruit were picked over an eight week period from when they were judged to attain maturity until they had begun to fall naturally from the trees (Williams *et al.* 1980). It was shown that fruit set the following spring was highly correlated to the harvest dates of the previous year. Early picking promoted more flower clusters which consequently set more fruit. Similarly, harvest time has been shown to affect cropping patterns of 'Valencia' oranges. After a 14-year study, Jones and Cree (1954) concluded that late picking decreased the following year's yield and increased the severity of alternate bearing. Later studies showed a curvilinear relationship between harvest date and the size of the next year's crop and suggested that 'Valencia' oranges crop to the limit of their available carbohydrates (Jones *et al.* 1964b).

'Hass' trees at Maleny were in a hail-induced biennial bearing cycle when treatments were started and this cycle, represented by "on", "off", "on" years continued for the duration of the study. Climatic stresses have been reported responsible for biennial bearing in other fruit species. For instance, spring frosts which destroy bloom have caused synchronised alternate cropping over large areas in apples, pecans and mangoes (Singh *et al.* 1974; Williams and Edgerton 1974; Sparks 1975). Unseasonably cool temperatures during flowering have also led to large scale failure of fruit set of 'Valencia' oranges in Australia thereby initiating an alternate cropping cycle (Gallasch *et al.* 1978).

The crop at Maleny in the first year (ca. 39 t. ha<sup>-1</sup> averaged across treatments) was extremely high by physiological standards for avocados (Wolstenholme 1986; 1987). It was associated with depletion of trunk starch content as the crop matured during winter, which contrasts with previously described patterns (Cameron and Borst 1938; Rodrigues and Ryan 1960; Scholefield *et al.* 1985; Kaiser and Wolstenholme 1994). Flowering, which led to a small crop in 1989, was of low intensity and short duration compared with the same event in 1989 which subsequently produced a 37 t. ha<sup>-1</sup> crop (averaged across treatments). In this case the effect of harvest time on yield had no apparent impact on the pre-determined cycle, and it appears that more rigorous procedures earlier in the crop cycle of an “on” year will be necessary to break strong alternate bearing patterns. For instance, Jones *et al.* (1974) were able to influence the cropping cycle of alternate bearing ‘Valencia’ oranges by thinning fruit at different stages of development in an “on” year. The subsequent crop was directly related to the amount and time after set that fruit was removed, e.g. removal of 66% of the current crop three months after anthesis produced more fruit the following year than the removal of 33% of the current crop seven months after anthesis. Similarly, El-Zeftawi and Thornton (1975) showed that stripping fruit from ‘Valencia’ trees within four months of setting their first commercial crop, moderated alternate bearing for six years without decreasing total yield over that period. Strategic pruning of trees may also be an alternative practice to modulate biennial cropping patterns in avocado. There is currently no information available on this topic but severe pruning (topping along with tree removal) of large trees in Florida improved yield compared with non-pruned crowded trees (Crane *et al.* 1992).

There was a trend of increased fruit size with delayed harvest though results were not significant in all years or at all sites. For ‘Fuerte’, fruit size increased in the order of 8 to 18% with later harvested treatments. However, these gains must be balanced against lower yields as small fruit are generally not an issue in well managed ‘Fuerte’ orchards. There was no significant difference in fruit size with ‘Hass’ grown at Childers once data had been adjusted for yield, though there was a consistent trend each year suggesting larger fruit with delayed harvest. Although delayed harvest at Maleny increased fruit size by ca. 23% in the “off” year ( $P \leq 0.06$ ), no differences were recorded when heavy crops were carried on the trees. This may be due to assimilate limitation due to overloading trees with fruit. Other studies have reported increased fruit size when harvesting was delayed. For instance, the size of ‘Bramley’s Seedling’ apple improved appreciably with late harvesting (Williams *et al.* 1980), and Kaiser and Wolstenholme (1994) found larger ‘Hass’ fruit

when harvesting was delayed. This is consistent with the well-known fact that cell division continues as long as avocado fruits are firmly attached to the tree, with effects likely to be greater in fruit in which seed coats do not abort prematurely (Schroeder 1952; Valmayor 1967).

It is worth noting the difference in 'Hass' fruit size between Childers and Maleny after adjustment for yield at both sites (Tables 11 & 13). At Childers the mean fruit size over the four years of the study was  $195.0 \pm 6.5$  g while for the three years at Maleny mean fruit size was  $227.9 \pm 3.6$ . This represents an increase of ca. 17% in the size of the fruit at Maleny. Due to different time frames for the two experiments statistical analysis cannot be applied to the data, however these results support industry perceptions that in warmer climates the 'Hass' small fruit problem is more severe. During the first 12 weeks of fruit ontogeny (October/December) the mean min/max temperature at Childers was  $3.5^{\circ}\text{C}$  higher than at Maleny. This is the period of most rapid cell division and growth (Valmayor 1967) when respiration rates of fruit are highest (Whiley *et al.* 1992; Blanke and Whiley 1995). Blanke and Whiley (1995) have suggested that the high rates of  $R_d$  measured for 'Hass' fruit may be a contributing factor to their smaller size in warmer climates.

### ***Seasonal starch cycling***

Starch is the most common and ubiquitous reserve carbohydrate in plants and there are numerous reports on its role in alternate bearing in fruit crops (Grochowska 1973; Davis and Sparks 1974; Jones *et al.* 1975; Goldschmidt and Golomb 1982; Scholefield *et al.* 1985). It has been repeatedly confirmed that starch levels are higher during the winter of the "off" year compared to levels when the tree has cropped heavily. The three year study of Scholefield *et al.* (1985) clearly indicated a direct relationship between winter starch levels and subsequent yield of 'Fuerte' avocado trees growing in a cool, dry Mediterranean climate in southern Australia. In this six year study with 'Fuerte' there was no clear correlation between starch concentrations (measured in the trunk or shoots) and yield, although in all years trunk or shoot levels declined rapidly during flowering and early fruit development. The small seasonal change in starch concentration relative to yield compared with that reported by Scholefield *et al.* (1985), suggests a low dependence on reserve carbohydrate of 'Fuerte' trees to maintain yield in subtropical climates. It is suggested that carbohydrates from current photo-assimilates play a proportionally more important role in cropping than is the case in cooler regions where avocados are grown. Observations at Childers

indicated the trees retained most summer grown leaves through until spring shoot growth was fully developed, thereby ensuring continuity of photo-assimilate supply during the flowering and fruit set period. However, Scholefield *et al.* (1985) reported that summer grown leaves were shed from March onwards at a rate faster than new ones were produced, probably as a consequence of salinity and environmental stress. Thus the assimilation surface was substantially reduced at flowering (a period of critical demand) and setting fruit were largely dependent on storage carbohydrate until the sink/source transition of the spring growth occurred.

Starch concentrations in either the trunk or shoots of trees were a better indicator of crop performance for 'Hass'. At Childers, a direct relationship between shoot starch concentrations in July and the subsequent crop was established for the 1992/93 cycle when large differences in treatment yields were recorded. Similarly, at Maleny trunk starch and subsequent yield were directly related across two seasons when strong biennial bearing was present. Shoot starch concentrations at Childers reached higher levels in 'Hass' (ca. 14%) than 'Fuerte' (ca. 7%). The reasons for this are not clear but may be associated with magnitude and temporal differences in phenology. 'Fuerte' showed more vegetative vigour than 'Hass' and flushed longer during summer (Figs. 26 & 29). Although 'Fuerte' fruit were harvested earlier in the year, floral bud development and anthesis were also advanced compared with 'Hass'. Strong root growth could also be expected from the cessation of summer flushing through to anthesis (see Chapter 2) and this combination of sinks together with decreased CO<sub>2</sub> assimilation efficiency during the winter, may have produced the lower peak concentrations.

The reduced yields detailed in these experiments cannot be solely attributed to threshold concentrations of starch at critical phenological stages. Crop failure was most often related to poor flowering with either a reduced number of floral sites or expression of flowering intensity (observed but no data recorded). The reasons for flowering failure are beyond the scope of data presented in this chapter, but can possibly be explained by the theory of "multifactorial control" which postulates that several compounds - assimilates and known phytohormones - participate in floral induction (Bernier *et al.* 1981; Bernier 1988). Bernier *et al.* (1993) suggest a complex series of physiological signals between shoots and roots which precipitate floral induction. Roots are the primary source of cytokinins which participate in the floral stimulus at apical buds. Root studies presented in this thesis (Chapter 2), clearly show suppression of root growth during the

autumn/winter period, a time of floral induction in avocado (Davenport 1982; Whiley *et al.* 1988a), when trees carry heavy crop loads. Poor root growth resulting in reduced cytokinin supply may well be a factor contributing to the diminished flowering observed in trees where delayed harvesting reduced the subsequent yield.

### **6.1.5 Conclusions**

Alternate bearing in fruit crops disrupts continuity of supply to markets and reduces farm cash flow. Results reported herein indicate that harvesting time with respect to avocado fruit maturity, is an important criteria with respect to maintaining productivity on a yearly basis. Early removal of fruit from trees between 21 to 24% ('Fuerte') or 25 to 30% ('Hass') flesh dry matter sustained production levels in otherwise well managed orchards, but markedly delayed harvesting of fruit precipitated strong alternate cropping patterns. Early harvesting of 'Hass' where biennial bearing was entrenched, did not release the tree from this cropping pattern and more extreme practices such as fruit thinning or pruning may be needed to moderate the cycle. Indeed, where storm damage effectively removed crop load five months after fruit set, cropping patterns were modified in cv. Fuerte (see Childers data). In both cultivars the concentration flux of starch closely followed changes in phenological events and generally peaked in winter during an extended quiescent period. Although heavy fruiting depressed winter starch accumulation which resulted in reduced yield, production is more likely to be constrained by other environmental, resource and management bottlenecks at critical phenological stages.