'HASS' AVOCADO TREE PHENOLOGY 2004-2009 IN THE WESTERN BAY OF PLENTY

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ABSTRACT

Avocado growers require a good understanding of the variability in the timing of phenological events in 'on' or 'off' flowering years so that orchard management practice could be fine tuned for best results. To formulate a hypothesis of how to manage avocado phenology to achieve regular crops well managed young trees on two orchards in the Western Bay of Plenty were monitored over the course of five years to establish the variation in phenological events and to correlate these events with each other and orchard factors. The least amount of visible growth was in winter, for this reason the general description of the fruit producing cycle had as its starting point 1 July. There are clear differences in the timing of growth patterns each year depending whether the trees are in the 'on' or 'off' flowering years of the alternate bearing cycle. In general, in the 'on' flowering year flower numbers were high and the spring shoot flush is complete before flower opening is complete. The summer shoot flush is weaker than the spring shoot flush and over winter there is a general decline in feeder roots. In the 'off' flowering year there are root flushes in winter. Flower numbers are low and flowering is complete before the spring shoot flush is finished. The summer shoot flush can be as strong as the spring shoot flush. Root flushes occur from summer to winter. The percentage of flowers setting fruit is similar in 'on' and 'off' flowering years. Therefore, fewer flower numbers in the 'off' flowering year may be the most important factor for low numbers of fruit. Analysing a combination of the shoot growth, flowering and fruit set growth patterns could be used as a method to predict the likely yield outcome each year. Phenological events differed by a few weeks from one year to the next sufficiently to affect the timing of tree management decisions. A simple working hypothesis from this study was that for consistent crops the tree needs to produce similar numbers of flowers each year. This requires the trees to grow the right amount of new shoots every year. Alternate bearing is then due to not enough shoot growth in the 'on' flowering year and too much shoot growth in the 'off' flowering year. The timing of phenological events varying from year to year and from orchard to orchard indicates that avocado growers could manage their trees according to the growth cycles. Orchard differences in the growth cycle may explain why orchards side by side can appear to need different management inputs. Although considerable gaps in our knowledge of avocado trees growth cycle still exist this study gives a basic foundation from which to develop a robust model of tree growth for productivity.

Keywords: tree growth cycles, flowering, roots, shoots, weather

INTRODUCTION

Phenology is a technical term used to describe the growth cycles of shoots, roots and flowers of plants. Avocado growers require a good understanding of avocado phenology in order to plan the best time for orchard management activities. For example, application of fertilizer is best done when the tree has new active roots that can absorb the nutrients. The general phenology of avocados is well known in other countries (Arpaia *et al*., 1996; Whiley and Saranah, 1995; Graham and Wolstenholme, 1991) and in the Western Bay of Plenty, New Zealand (Thorp *et al*., 1995). The phenology of avocados in New Zealand is similar to the phenology of avocados in other countries.

While the general phenological cycle is understood, the timing of important phenological events such as flowering and spring shoot growth can vary each year. A key skill for New Zealand avocado growers is to recognise the growth stages on the tree and to determine if any management activities need to be altered. An example is the introduction of bees for pollination purposes should occur when there is between 10% to 15% open flowers. Early or late flowering would suggest bees should be introduced early or late for best pollination success. It is not known if flower opening differs from year to year by a number of weeks or is very consistently the same. Depending on the timing of flower development, in some years, it may be prudent for an avocado grower to introduce bees into the orchard earlier than would be usual. Such an appreciation of the phenology allows orchard management practice to be fine tuned for best results. Utilising knowledge of the variability of phenological events could greatly assist in establishing best practice for regular cropping.

For New Zealand avocado growers to achieve consistent crops negative changes in the tree growth cycle need to be detected early enough to allow corrective management activities to be implemented. For example, research in South Africa (Graham and Wolstenholme, 1991) and in Australia (Whiley *et al.*, 1996) has indicated hanging fruit for several months, after reaching maturity, before harvest alters the timing of flowering, growth flushes and the amount of starch in the tree. These changes could then affect the cropping potential of the trees in subsequent years. Understanding the effects of hanging fruit late then allows avocado growers to compensate by altering their management.

To monitor the phenology of avocado trees the development of tools that accurately describe and measure the degree of variation in tree growth events are required. Using scales to assess growth allows the strength of phenological events to be determined. Identifying the differences in tree growth that lead up to 'on' and 'off' flowering years could suggest possible orchard management activities to achieve regular cropping. Careful observation over several years will also allow the examination of many assumptions that are considered to describe how 'Hass' avocado trees grow and crop in New Zealand. The potential therefore exists to improve knowledge of avocado trees growth cycles to improve yield potential.

As a first step towards formulating a hypothesis of how to manage avocado phenology to achieve regular crops a detailed and accurate description of phenological events building on previous observations (Thorp *et al.*, 1995) is required. Well managed young trees on two orchards in the Western Bay of Plenty were selected to be monitored over the course of several years to establish the variation in phenological events each year and to correlate these events with each other and orchard factors.

MATERIALS AND METHODS

Orchards

Five trees similar in size (about 3m tall and 4m wide), hemispherical shape and age (5 years) from each of two orchards were selected for regular measurement throughout the years 2004 to 2008. Orchard 1 was located in Te Puna and was regularly irrigated in 2004 and 2005 but irregularly irrigated from 2006 to 2008. Orchard 2 was located in Tauranga and was not irrigated. The trees in Orchard 1 were located in a group of trees planted at 7m x 7m and had several large (15m+ tall) Zutano trees within 30m while the trees in Orchard 2 also planted at 7m x 7m had pollinizer trees planted within the shelter belts. The soil type for each orchard was similar, as a recent volcanic ash with high organic matter content of 12% for Orchard 1 and 7.4% for Orchard 2. The trees were five years old when the phenological measurements began. Initially both orchards were fertilised and kept free from pests and diseases according to typical industry practice with adjustments in the amount of minerals required determined by leaf and soil tests conducted in April/May each year. In late 2005 Orchard 1 was sold and the new owners reduced fertiliser inputs to low levels in 2007 and 2008.

Shoots

Four branches per tree, one each on the North, West, South and East aspects, 20 branches per orchard were selected for measurement of shoot growth over spring and summer in the years 2004 to 2006. In 2007 and 2008, twelve branches per tree, three each on the North, West, South and East aspects, 60 branches per orchard were selected for measurement of shoot growth over spring and summer. New branches were selected each June, for the years 2004 to 2006, as this was when there was minimal shoot growth on the trees. In 2007 new shoots were selected in June for measurement in both 2007 and 2008, following the growth from the same shoots over two years. When selected in June the length of the dormant shoot was measured back to the nearest bud ring. Branches were selected at 1.5m to 2m height from the ground. The length of the new growth was measured to the nearest 5 mm from the bud ring closest to where the new shoot emerged to the shoot tip. The length of a flower panicle was measured separately from the vegetative shoot in 2004 and 2005. In 2006 to 2008 the combined panicle and shoot length was measured. Total shoot length of both the flower panicle and vegetative shoot is reported here. Shoot length was measured approximately every two weeks during the spring and summer flush until growth stopped. In addition to the shoot length the development of the flower buds was rated on a 1-10 scale (Dixon *et al.*, 2005) and if the shoot was determinate or indeterminate. The length of flush was measured for both the spring and, when present, summer flush. Shoot type, proleptic or sylleptic, was not recorded.

Roots

For individual trees root growth was measured as changes in the total root length. The length of new roots at the soil mulch interface in a 0.5m x 0.5m square (0.25m^2) quadrat inside the drip line of a tree. At the location of each quadrat the mulch was scraped away to reveal the soil at the soil-mulch interface. Each quadrat was pegged to the ground and covered with a coarse mesh windbreak cloth on top of which was placed the normal tree mulch. There were two quadrats per tree, one each on the north and south facing sides of the tree. When the roots were measured the cloth and mulch were carefully removed to reveal the roots that may be present at the soil-mulch interface. The length of roots was measured every two weeks to the nearest mm for the duration of the project.

Flowering and fruit set

In the years 2004 to 2006, on each tree, two indeterminate and two determinate flowering branches were selected for counting open flowers and fruit numbers. Four indeterminate flowering branches were selected on all trees from both orchards in 2007 and 2008. As many determinate flowering branches as was available, up to a maximum of four branches per tree, were selected in 2007 and 2008. The branches used for counting flowers and fruit set were different to the branches used for shoot growth measurement. The development of flower buds from bud break until the end of flower opening was rated on a scale of 1-10 (Dixon *et al.*, 2005). Just before flower opening at stage 5 or 6, all of the flower buds were counted on each flowering branch. Once the first flower had opened (stage 6), the number of open flowers and fruitlets were counted every three to four days. Flowers and fruit were not counted on weekends nor was the gender of the flowers recorded. A newly emerged fruit was counted once the new fruit was clearly visible through the sepals, at about 3 to 4 mm in diameter. Once flower opening was complete the fruit were counted every three to four days until the fruit number remained the same for three consecutive counts.

Weather

The shade air temperature and soil temperature at 100mm depth for one tree on each orchard was recorded using temperature microloggers (HortPlus, Cambridge, New Zealand). The microloggers recorded the temperature once every 30 minutes. The microloggers within the trees were placed within a Stevenson's screen while the microloggers in the soil were buried inside a sealed plastic bag to prevent exposure to moisture. The soil moisture matrix potential under one tree on each orchard was measured each time the orchard was visited using 30cm and 60cm Irrometer tensiometers. The tensiometers were positioned within the drip line of the trees with the tensiometers depth set at the soil mulch interface. The soil moisture matrix potential was measured under the mulch layer of the tree. Rainfall outside of the trees was measured using a 150mm capacity rain gauge. The amount of rain was recorded each time the orchard was visited.

Data Analysis

The data collected was collated and simple statistics calculated using MicroSoft® Office Excel® 2007. The graphs were produced using Microcal™ Origin® version 6.0.

Table 1. Cropping history of the whole of Orchard 1 with crop to be harvested and yield in the following year, mean annual temperature and total rainfall each year of the study.

Year	Crop to be harvested (t/ha)	Crop set in the current year (t/ha)	Mean Annual Temperature (°C)	Rainfall (mm)
2004	0.8	24.1	-[1]	521.0[2]
2005	24.1	0.0	13.1	1695.0
2006	0.0	21.5	12.9	1020.5
2007	21.5	8.4	13.5	1183.5
2008	8.4	15.1[4]	12.8	1469.5
2009	15.1[4]			730.5[3]

[1]Missing data, [2]Total rainfall from June to December, [3]Total rainfall from January to June, [4]Estimate

RESULTS

Orchard 1

The trees in Orchard 1 exhibited an alternate bearing pattern where the 'on' flowering years were 2004, 2006 and 2008 while the 'off' flowering years were 2005 and 2007 (Figures 2 and 3a). There were good crops set in 2004 and 2006 of over 20 tonnes/ha, no crop set in 2005 and moderate crops of about 8 tonnes/ha set in 2007 and a 15 tonnes/ha crop in 2008 (Table 1). The mean annual temperature was over 13°C in 2005 and 2007, 'off' flowering years, and was below 13°C in 2006 and 2008, 'on' flowering years. The annual rainfall ranged from about 840mm in the driest year to over 1600mm in the wettest year (Table 1). The 'on' or 'off' flowering years did not appear to be related to the rainfall each year.

Phenology

Shoot Growth

There were up to three shoot flush periods each year roughly corresponding to spring, summer and autumn that occur at a similar time each year (Figures 1 and 3b). The first flush was in spring and generally starts during September and finishes between mid-December and mid-January (Figure 1). The second flush is in summer from mid-January to the end of February/mid-March period (Figure 1). There may be a short period of shoot growth in autumn from mid-March to May (Figure 1). The greatest amount of shoot growth was in spring followed by summer growth with a weak flush in autumn.

Over the five years the average start of spring flush was the 6th of October and finished on the 6th of December. The start of the spring flush was early or late by one to three weeks from the average each year. The start and stop of the spring flush did not follow the same pattern as the 'on' and 'off' flowering cycle. In the years 2006 to 2008 the spring flush occurred within the same relative week but was 11 days late and in 2005 was 10 days early compared to the average (Table 2). When shoot growth stopped was a reflection of when the shoot growth started in 2005, 2007 and 2008. In 2004 the growth stopped late as there was a late start to the flush.

The greatest amount of shoot flush was in 2005 when there was no fruit set compared to 2004 when there was a heavy crop set. In 2008, the spring flush was about the same as in 2004, 2006 and 2007 with a weak summer flush. After 2005 the spring shoot flush was weaker each year with the summer shoot flush about the same (Figure 3b).

Table 2. Dates when the phenological events of spring flush and flowering occurred each year 2004-2008.

Spring flush Year	Earliest shoots	Growth ceased	Duration of flush (days)	Range of growing days
2004	17/10/2004	16/12/2004	60.1	49-85
2005	26/9/2005	5/12/2005	69.2	38-98
2006	5/10/2006	30/11/2006	52.2	32-71
2007	11/10/2007	9/12/2007	59.4	28-105
2008	5/10/2008	4/12/2008	60.0	34-106
Flowering Year	**First flower bud break**	**Average time of first open flowers**	**Flowering complete**	**Peak fruit number**
2004	6/10/2004	5/11/2004	16/12/2004	13/12/2004
2005	5/9/2005	28/10/2005	11/11/2005	No fruit
2006	15/9/2006	19/10/2006	8/12/2006	29/11/2006
2007	6/9/2007	24/10/2007	23/11/2007	28/11/2007
2008	4/9/2008	22/10/2008	16/11/2008	26/11/2008

The spring flush grew for an average of 52.2 to 69.2 days (Table 2) with the length of time individual spring flush shoots grew being variable and ranged from 28 days up to 106 days. The duration of spring shoot growth changes each year but there was no pattern with the 'on' and 'off' cycle.

Flowering

There was an obvious alternate bearing pattern on the trees monitored in this study. Fruit set in 2004, 2006 and 2008 was heavy and fruit set was absent in 2005 with a poor fruit set in 2007 (Figure 2). Flower bud break varied from year to year with bud break in 2005, 2006, 2007 and 2008 in early to mid-September but was a month later in early October in 2004 (Table 2). The time from bud break to the first open flower varied each year and was in 2004 and 2006, 30 and 34 days, respectively (Table 3). The time from flower bud break to the first open flower was 53 days in 2005 and 48 days in 2007 and 2008 (Table 3).The time taken to the first open flower was two to three weeks longer in the 'off' flowering years 2005 and 2007 compared to the 'on' flowering years 2004 and 2006. In 2008 the time taken from flower bud break to the first open flower was similar to the 'off' flowering years 2005 and 2007. In the years 2005 to 2008 the average time of the first open flowers differed by only nine days at the end of October. In contrast, the flowers in 2004 opened later in early November. Flowering was complete later in the 'on' flowering years 2004 and 2006 in mid-December than in the 'off' flowering years 2005 and 2007 in mid-November. In 2008 flowering was complete at a similar time to the 'off' flowering years. With respect to the initial fruit set peak fruit number was reached at almost the same time in the years 2006, 2007 and 2008 (Table 2). In 2004 peak fruit number was reached about mid-December reflecting the late flowering in that year. The number of days from flower bud break to the completion of flowering varied by 16 days between the years 2006 (84 days) and 2005 (68 days).

The time from flower bud break to the earliest spring shoots increased from 2004 to 2005 and from 2006 to 2007 (Table 3). In the years 2007 and 2008 the time from flower bud break to the earliest spring shoots had increased by as much as 24 days. The time from the earliest spring shoots to the first open flower was similar in the years 2004, 2006, 2007 and 2008 ranging from 19 to 13 days (Table 3). In 2005 the time between the appearance of the earliest shoots and flower bud break was about twice as long as in the other years. In the 'on' flowering year, 2004, flower opening finished at the same time as the cessation of spring shoot growth and in 2006 flower opening continued

Table 3. Calculated time in days from flower bud break to earliest spring shoots, flower bud break to first open flower, earliest spring shoots to flower opening and completion of flowering to cessation of spring shoot growth each year 2004 to 2008.

Year	Flower bud break to earliest spring shoots	Flower bud break to first open flower	Period of flower opening	Flower bud break to end of flowering	Earliest shoots to first open flower	End of flowering to cessation of shoot growth
2004	11	30	41	71	19	(0)*
2005	21	53	14	68	32	24
2006	20	34	50	84	14	(8)
2007	35	48	30	78	13	16
2008	31	48	25	73	17	18

*Flowering continued after shoot growth had ceased, **Shoot growth started before flower bud break.

Table 4. Average number of flower, maximum percentage initial fruit set and fruit number of two determinate and two indeterminate flowering shoots each year 2004 to 2008.

	Number of flowers		Maximum % fruit set		Maximum fruit number	
Year	D[1]	I[2]	D	I	D	I
2004	1074	854	5.6	8.7	38	42
2005	0	0	0.0	0.0	0	0
2006	887	401	8.2	5.7	64	21
2007	344	210	5.5	5.3	18	11
2008	1144	594	6.4	5.1	69	25

[1]Determinate flowering shoot, [2]Indeterminate flowering shoot

after the cessation of shoot growth (Table 3). By contrast, in the 'off' flowering years 2005 and 2007 shoot growth ceased up to three weeks after flower opening stopped.

The average number of flowers on determinate and indeterminate flowering shoots in the 'on' flowering years, 2004, 2006 and 2008 was generally greater than average flower numbers in the 'off' flowering years, 2005 and 2007 (Table 4). Flowering was very weak in 2005 with no flowers or fruit set recorded on the tagged shoots used for this study. The percentage of flowers that initially set a fruit was variable each year ranging from about 9% to 5%, when flowers were present. The maximum fruit number for initial fruit set was lowest in 2005 when flowering was absent and in 2007 an 'off' flowering year compared to the 'on' flowering years 2004, 2006 and 2008 (Table 4). Percentage fruit set appeared to be similar between indeterminate and determinate flowering branch types. The maximum fruit number of the initial fruit set was lower on indeterminate flowering branches in 2006, 2007 and 2008 while the maximum fruit number was similar in 2004 (Table 4).

Root Growth

Feeder roots were present all year round with flushes of new roots occurring throughout the year, including winter (Figures 1 and 3c). The general pattern was for there to be an underlying increase in roots at the soil mulch interface with flushes of feeder roots of varying strength occurring throughout the year but for there to be a general increase and decrease with the 'on' and 'off' flowering cycle (Figure 3c). The number and timing of root flushes each year varied with four distinct flushes in 2004, 2005 and 2006, five in 2007 and

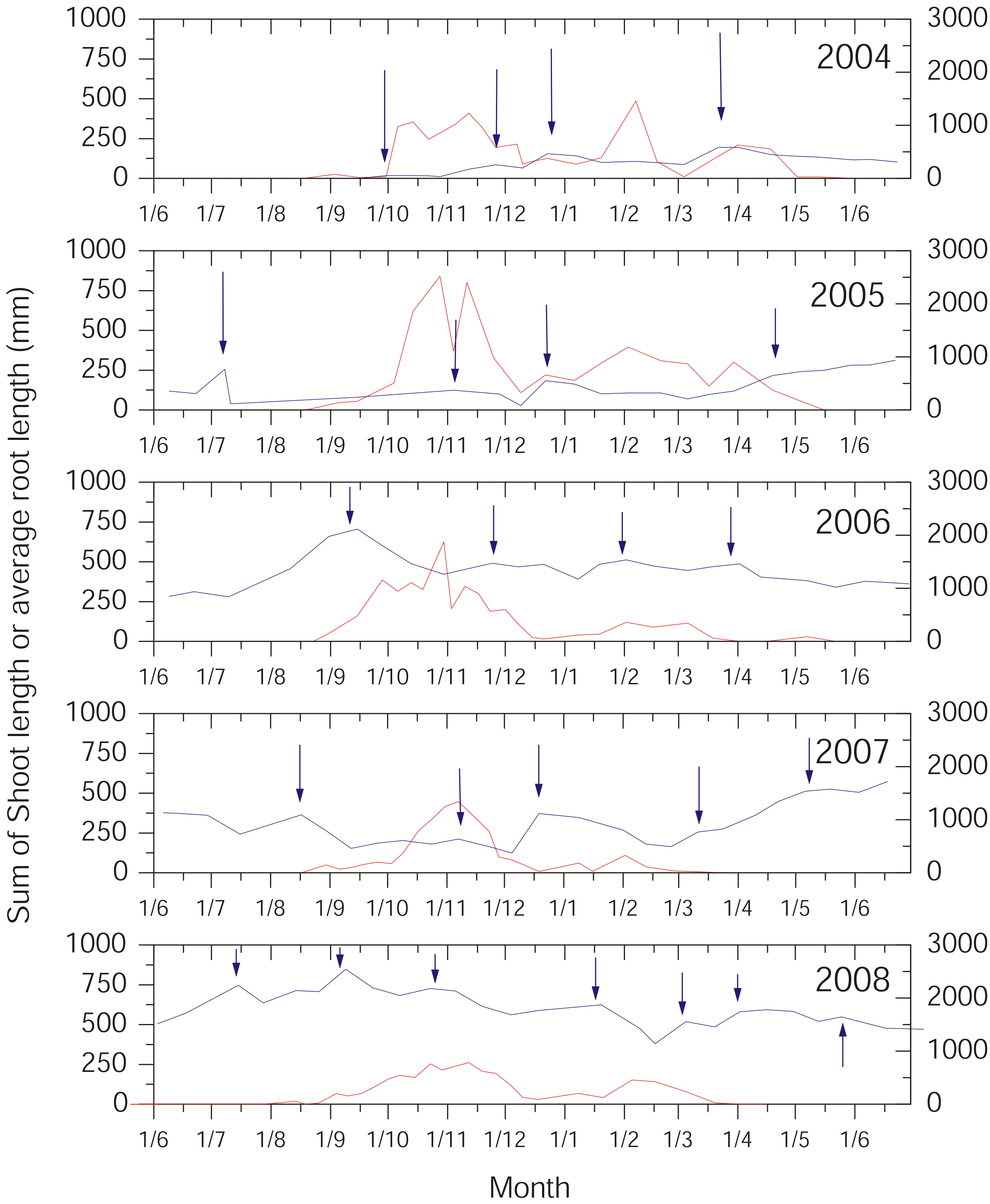

Figure 1. Total shoot and root length of five 'Hass' avocado trees from Orchard 1 for each year 2004 to 2008. The red lines represent the length of new shoots while the blue lines represent the root length of feeder roots at the soil mulch interface. Blue arrows indicate periods of root flush.

seven in 2008 (Figure 1). In general, there was a root flush in spring either before the shoot flush in 2004, 2006 and 2008 or during the spring shoot flush in 2005 and 2007. In 2008, there were two root flushes, one before the spring shoot flush and one during the spring shoot flush. Each year there were also root flushes in the period between the end of the spring shoot flush, usually mid-December to mid-January, and the beginning of the summer shoot flush. In winter, July and August, there were root flushes in the 'off' flowering years 2005 and 2007 but not in the 'on' flowering years 2004 and 2006 (Figure 1). In 2008, an 'on' flowering year, there was a winter root flush in July.

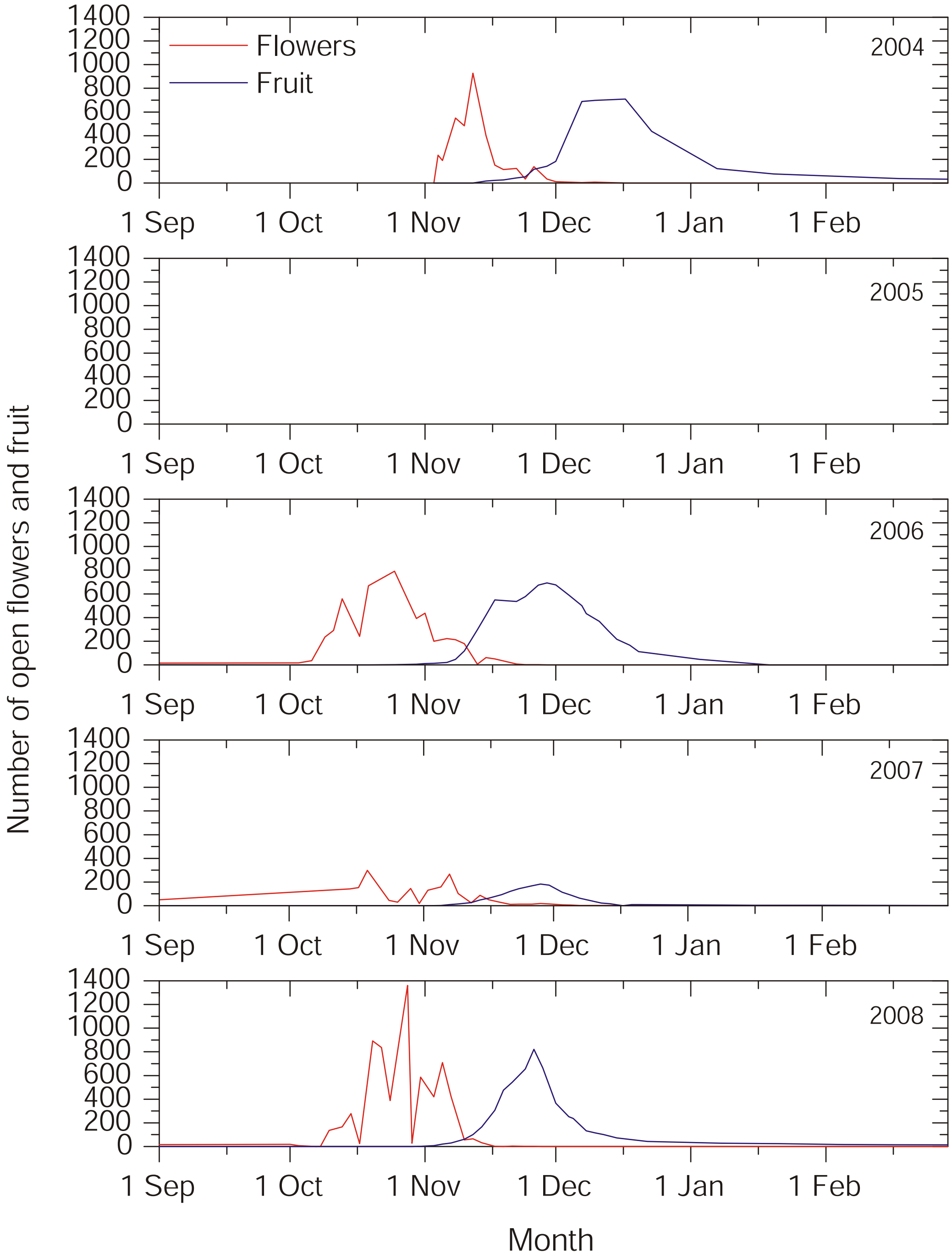

Figure 2. Total number of open flowers and fruit recorded on up to 40 flowering shoots over 5 'Hass' avocado trees from Orchard 1, 2004 to 2009.

Weather

Air Temperature

The general temperature profile each year was similar with the coldest months being June and July and the warmest month February (Figure 4). The diurnal fluctuation in temperature (the difference between the maximum and minimum temperature) is about 10°C. The months September to January had a rising temperature trend while the months March to June a decreasing temperature trend. In June and July average temperature was about 8°C to 10°C with the maximum between 12°C to 14°C and the minimum between 4°C to 7°C and there was a high risk of frost. In February the daily average temperature was around 17°C to 19°C with the maximum between 25°C to 22°C and the

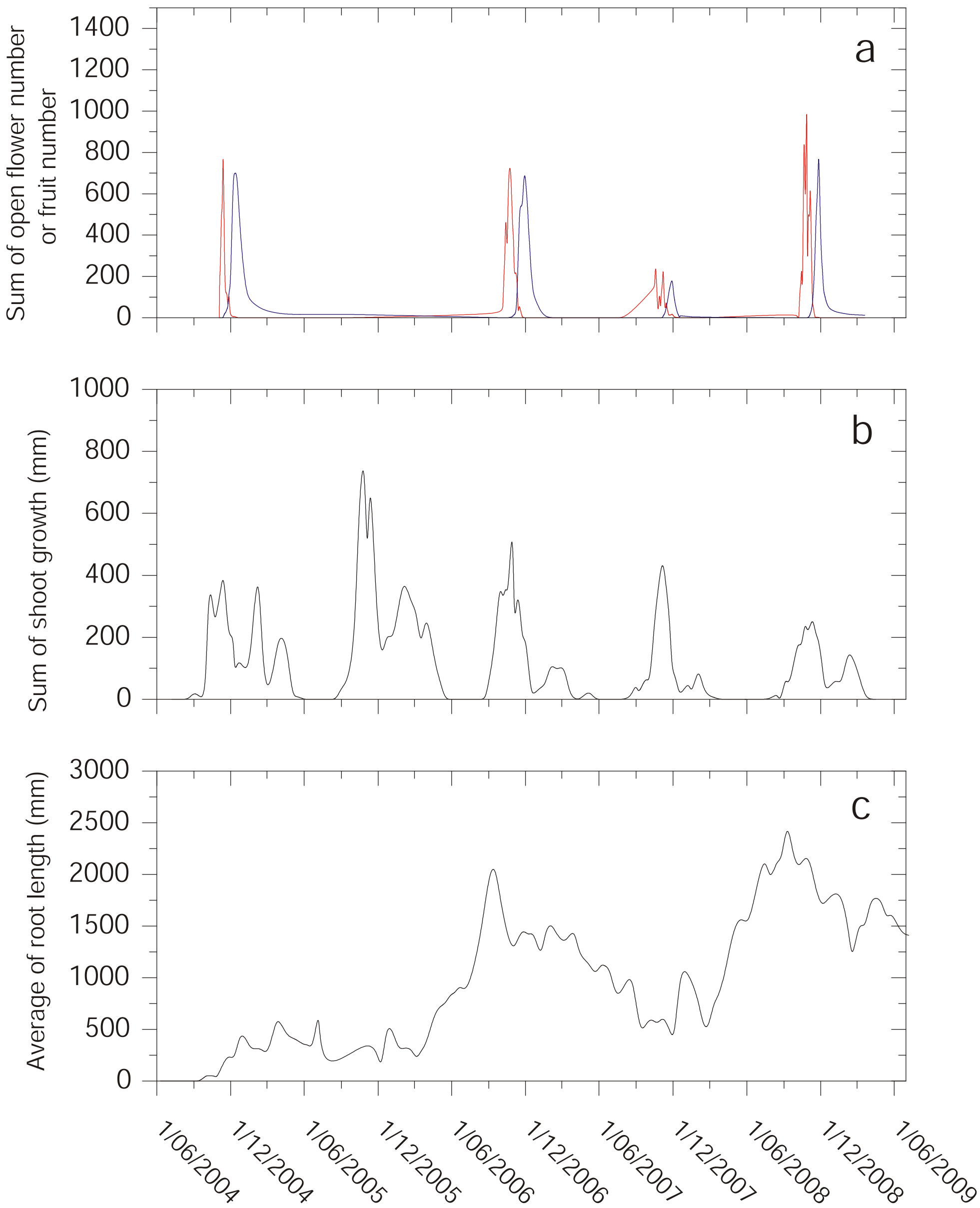

Figure 3. The sum of (a) open flower number and fruit numbers, (b) shoot length and (c) average feeder root length in $0.25m^2$ for the years 2004 to 2008.

minimum between 15°C to 13°C. The daily temperatures each year were very variable (Figure 4). During the period of flower bud break, flowering and fruit set, September to the end of December, there were many periods when the minimum temperature was below 10°C (Figure 5). There was no clear pattern of the number of days where the minimum was below 10°C or the maximum was greater than 17°C with the 'on' and 'off' flowering years. In the 'on' flowering years, 2004, 2006 and 2008, the number of days the minimum was below 10°C was 72, 82 and 64, respectively. In the 'off' flowering years, 2005 and 2007, the number of days the minimum was below 10°C was 58 and 73, respectively. In the 'on' flowering years, 2004, 2006 and 2008, the number of days the maximum was above 17°C was 69, 81 and 71, respectively. In the 'off' flowering years, 2005 and 2007, the number of days the maximum was above 17°C was 82 and 78, respectively. During the flower opening period the number of days when the minimum was below 10°C was in the 'on' flowering years 2004, 2006 and 2008, 16, 31 and 14. In the 'off' flowering years, 2005 and 2007, the number of days when the minimum was below 10°C was 4 and 19.

The average daily temperatures over the period of selected phenological events for each year of the study are presented in Table 5. For the period of the start to finish of spring flush there was no clear pattern across the years 2004 to 2008 of warm temperatures being associated with the 'on' and 'off' flowering pattern. The average temperature was not related to the duration of the spring flush. There was a general trend for the shortest times from flower bud break to first open flower to be associated with the warmer temperatures. The longest flower opening time was at an average temperature of 13.8°C and was shorter both above and below 13.8°C. The average temperature during the period of flower bud break to the completion of flowering was not related to the number of days taken to complete flowering.

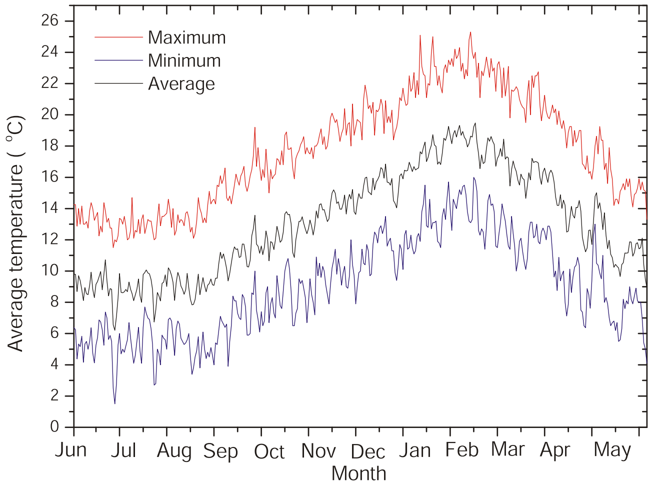

Figure 4. Average daily shade air temperature, average daily maximum and minimum daily shade air temperature for 'Hass' avocado trees in Orchard 1, 2004-2008.

Rainfall and soil moisture matrix potential

Rainfall was very variable from month to month and day to day and tended to be reasonably evenly distributed through the seasons each year. Generally, there was less rain in spring and summer (December, January and February) than in autumn or winter (March to August) (Figure 6). Overall 2006 was the driest year and 2005 the wettest (Table 1).

The average soil moisture matrix potential each month was relatively constant from June 2004 to December 2005 and was above -25 kPa (Figure 6), indicating that the trees were unlikely to have been under moisture stress. In 2006 when there was less irrigation the average soil moisture matrix was lower in summer than other months despite the reasonable rainfall that fell during the summer. In 2007 and 2008 the trees were only erratically irrigated and the average soil moisture matrix potential decreased from October until March. During these months the soil moisture was well below -25 kPa at 30cm, the common trigger level for irrigation. This would suggest the trees could have experienced moisture stress in the springs of 2007 and 2008. There was little difference in soil moisture matrix potential at 30 or 60 cm depth except in spring 2007 (Figure 6).

Table 5. Average temperature (°C) during specific growth events during flowering and spring shoot flush each year 2004 to 2008.

Year	Start to finish of spring flush	Growth events Flower bud break to first open flower	Period of flower opening	Flower bud break to the completion of flowering
2004	13.8	13.2	14.2	13.8
2005	13.5	12.1	14.7	12.5
2006	13.3	12.3	13.8	13.2
2007	13.7	11.5	13.3	12.1
2008	13.7	11.9	13.2	12.3

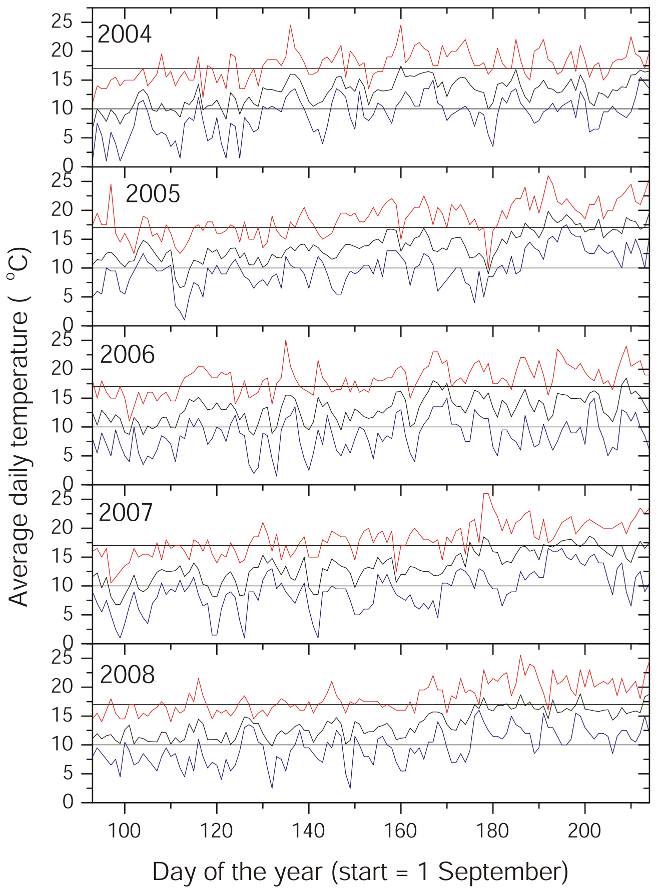

Figure 5. Daily average, maximum and minimum shade air temperatures for the period 1 September to 31 December of the years 2004 to 2008. The lower horizontal line on each graph represents 10°C and the upper horizontal line represents 17°C.

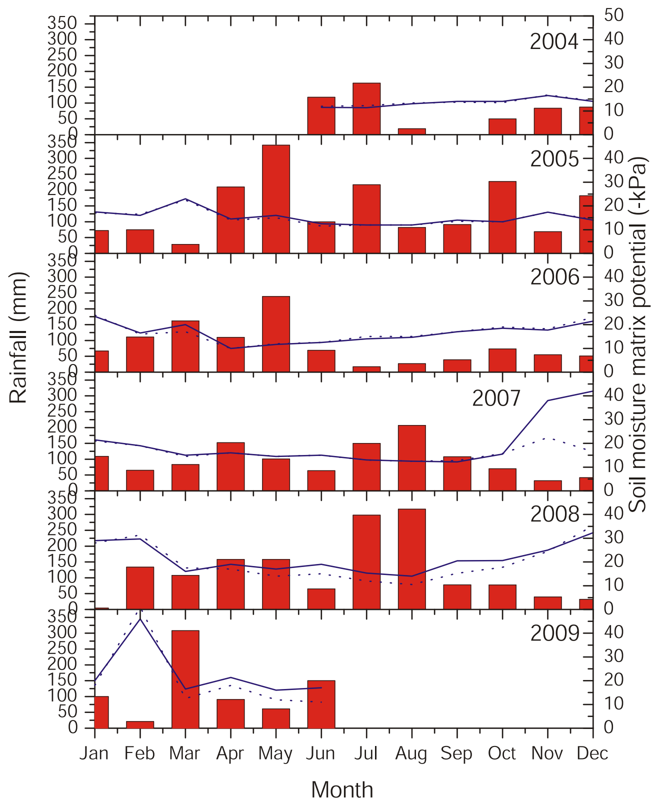

Figure 6. Average monthly soil moisture matrix potential at 30cm (blue line) and 60cm (dotted blue line) and total monthly rainfall (red columns) for Orchard 1 in 2004-2009. In 2004 and 2005 the trees were irrigated with 9.5mm of water every week. The amount of irrigation was not added to the rainfall values.

Soil Temperature

Averaged across the five years of the project, the lowest soil temperatures were in June, July and August where the soil temperature could fall below 10°C but was often between 10 to 11°C (Figure 7). From August the soil temperature rose steadily until February when it reached between 18 to 20°C before declining again. The general pattern of change in soil temperature each month was similar each year (Figure 8). The coldest winter soil temperatures were in June and July 2006 and the warmest winter soil temperatures were in 2004 (Figure 8). The winter soil temperatures were low for the longest in the years 2005, 2006 and 2007. In 2007 there was the longest period of warm summer soil temperatures while 2006 had the coolest summer soil temperatures (Figure 8). The years 2004, 2005 and 2008 has similar summer soil temperatures.

Orchard 2

The trees in Orchard 2 exhibited an alternate bearing pattern in the years 2004 to 2007 where the 'on' flowering years were 2004 and 2006 while the 'off' flowering years were 2005 and 2007 (Figures 10 and 11a). There were good crops of over 20 t/ha set in 2004 and 2006, a moderate crop of 8.7 t/ha set in 2005 and another moderate crop of 13.5 t/ha set in 2007 (Table 6). In 2008 the trees had a flowering and fruit set typical of an 'on' flowering year but the crop harvested was more typical of an 'off' flowering year at 12.5 t/ha. The

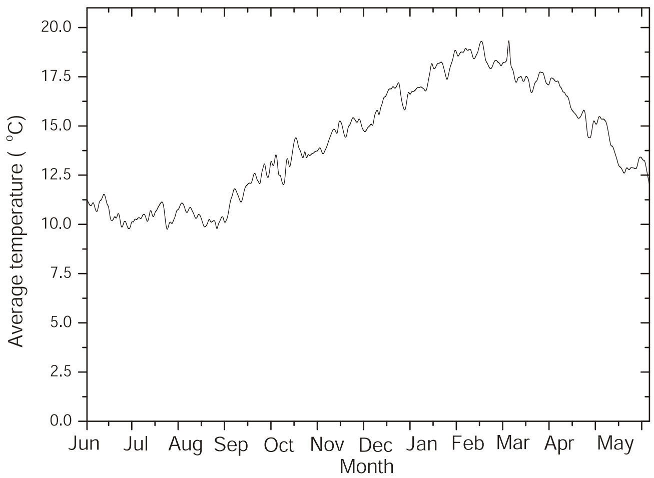

Figure 7. Average daily soil temperature (100mm depth) for 'Hass' avocado trees in Orchard 1, 2004-2009.

Table 6. Cropping history of the whole of Orchard 2 with crop to be harvested and yield in the following year, mean annual temperature and total rainfall each year of the study.

Year	Crop to be harvested (t/ha)	Crop set in the current year (t/ha)	Mean Annual Temperature (°C)	Rainfall (mm)
2004	19.9	21.3	13.1	663.0[1]
2005	21.3	8.7	13.7	1444.0
2006	8.7	24.1	13.5	832.5
2007	24.1	13.5	14.5	1121.5
2008	13.5	12.5[2]	13.5	1055.0
2009	12.5			618.0[3]

[1]Total rainfall from June to December, [2]Estimate, [3]Total rainfall from January to June

mean annual temperature was over 13°C each year with the warmest year 2007 and the coolest year 2004. The 'on' flowering years 2004, 2006 and 2008 were the coolest with the warmest years the 'off' flowering years 2005 and 2007 (Table 6). The annual rainfall ranged from about 830mm in the driest year to over 1400mm in the wettest year (Table 6). The 'on' or 'off' flowering years did not appear to be related to the rainfall each year.

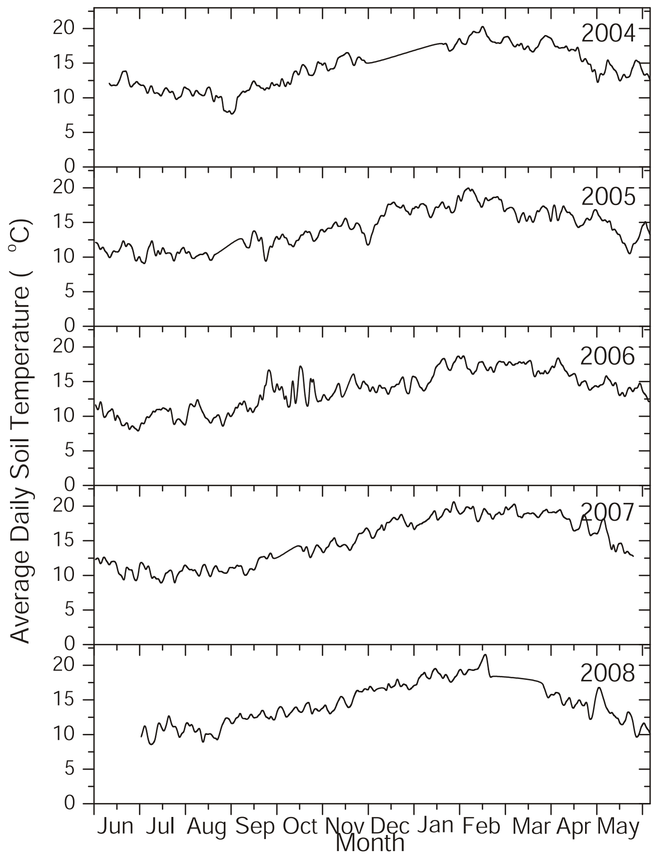

Figure 8. Average daily soil temperature at 100mm depth for 'Hass' avocado trees each year from 2004 to 2008.

Phenology

Shoot Growth

There were two distinct shoot flush periods each year roughly corresponding to spring and summer (Figures 9 and 11b). The first flush was in spring and generally starts during early September and finishes between mid-December and mid-January (Figure 9). The second flush in summer was from early to mid-January to the early March/end of March period (Figure 9). In 2005, only, there was a short period of shoot flush from mid-December to the end of January. In the years 2004 to 2006 the amount of shoot growth in spring and summer was similar. In the years 2007 and 2008 the spring shoot flush was greater than the summer shoot flush.

Over the five years the average start of the spring flush was the 30th of September and the average finish the 5th of December. The start of the spring

Table 7. Dates when the phenological events of spring flush and flowering occurred each year 2004-2008.

Spring flush	Earliest shoots	Growth ceased	Duration of flush (days)	Range of growing days
Year				
2004	16/10/2004	12/12/2004	51.8	24-71
2005	16/09/2005	8/12/2005	83.2	38-108
2006	18/09/2006	23/11/2006	65.7	35-107
2007	4/10/2007	4/12/2007	61.3	29-98
2008	6/10/2008	5/12/2008	59.3	42-92
Flowering	**First flower bud break**	**Average time of first open flowers**	**Flowering complete**	**Peak fruit number**
Year				
2004	6/10/2004	5/11/2004	16/12/2004	8/12/2004
2005	4/10/2005	21/10/2005	28/11/2005	21/11/2005
2006	7/9/2006	16/10/2006	8/12/2006	17/11/2006
2007	12/9/2007	20/10/2007	21/11/2007	28/11/2007
2008	17/9/2008	19/10/2008	26/11/2008	24/11/2007

flush was early or late by about two weeks from the average each year. The start and stop of the spring flush did not follow the same pattern as the 'on' or 'off' flowering cycle. In the years 2005 and 2006 the earliest shoots started within the same week and were about two weeks early compared to the average (Table 7). The years 2007 and 2008, the earliest shoots occurred within the same week but were four to six days later than the average. Although the start of the spring flush was within the same relative week in 2005 and 2006 the flush stopped about two weeks earlier in 2006 than in 2005 (Table 7).

In 2005 the total amount of shoot flush was greater than in the other years of the study (Figures 9 and 11b). The amount of flush 2004 was similar to the amount of flush in 2005 and 2006. After 2006 the amount of shoot flush decreased with the amount of flush in 2007 and 2008 less than in previous years with a weaker summer flush than spring flush (Figure 11b). The spring flush grew for an average of 51.8 to 83.2 days each year (Table 7) with the length of time individual spring flush shoots grew being variable ranging from 29 days up to 108 days. The duration of spring shoot growth changed each year but there was no pattern with the 'on' or 'off' cycle.

Root Growth

Feeder roots were present all year around with most feeder roots in winter, June and July, and in the 'off' flowering years (Figures 9 and 11c). Feeder root flushes occurred throughout the year, including winter. There was a pattern of a general increase of feeder roots with extra root flushes in 2005 and 2007 flushes preceding the 'on' flowering years 2006 and 2008 (Figure 11c). The number and timing of root flushes each year varied with four distinct root flushes in 2004 and five root flushes in the years 2005 to 2008 (Figure 9). In general, there was a root flush in spring either before the spring shoot flush, as in 2006 and 2007, or during the spring shoot flush, as in 2005, 2007 and 2008. Each year there were also root flushes in the period between the end of the spring flush, mid to late December in 2005 and 2006, mid-January in 2007 and 2008. In winter, July and August, there were root flushes in 2005, 2006 and 2007 but not in 2008 (Figure 9). The greatest amount of feeder roots

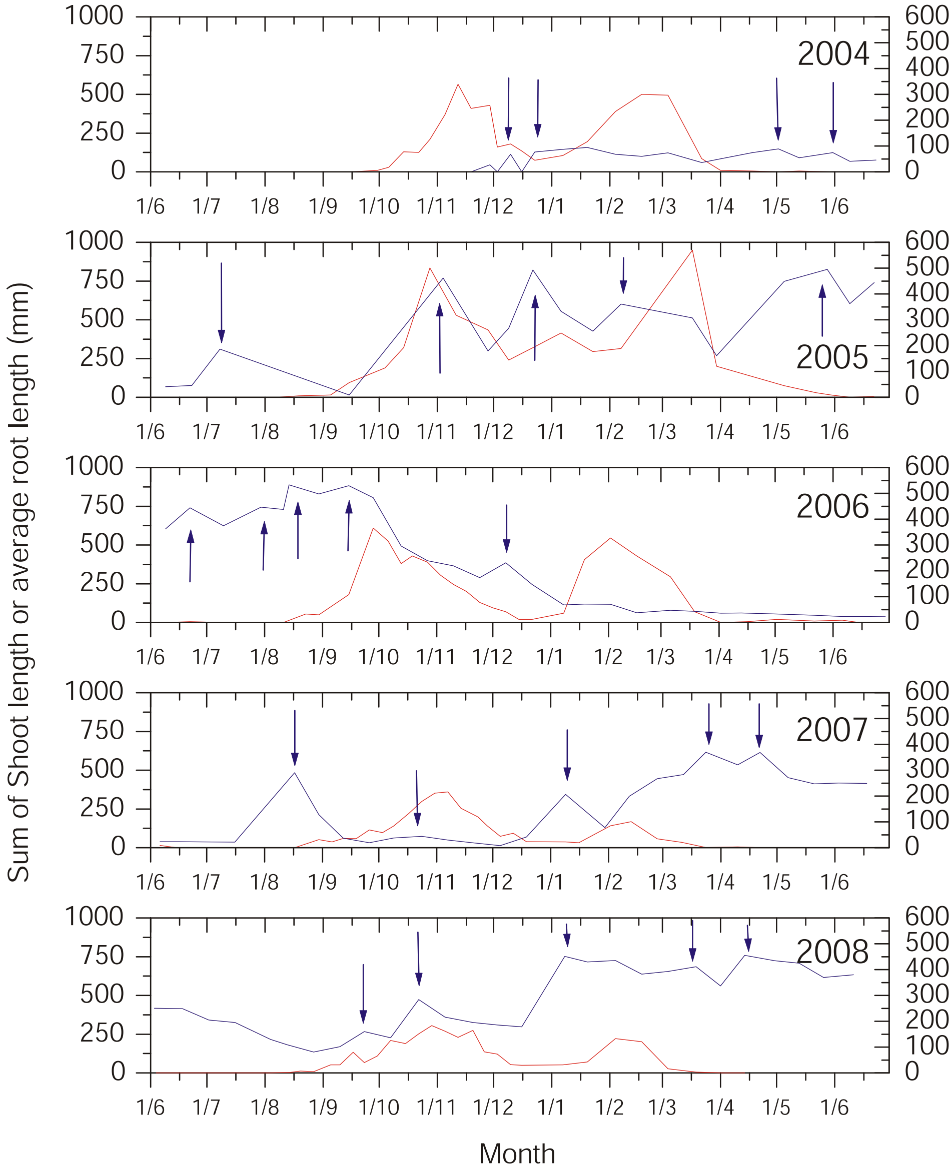

Figure 9. Total shoot and root length of five 'Hass' avocado trees from Orchard 2 for each year 2004 to 2008. The red lines represent the length of new shoots while the blue lines represent the root length of feeder roots at the soil mulch interface. Blue arrows indicate periods of root flush.

were produced in 2005 and the winter and spring of 2006. There were very low amounts of feeder roots in the 2006 summer and most of winter when there was very low rainfall and low soil moisture matrix potential (Figure 14).

Flowering

During the five years 2004 to 2008 there was an obvious alternate bearing pattern on the trees monitored in this study (Table 6). Fruit set in 2004 and 2006 was heavy and fruit set in 2005, 2007 and 2008 was moderate (Figure 10 and Table 6). Flower bud break varied across the years with bud break in 2004 and 2005 in early October and was up to one month earlier in September in 2006, 2007 and 2008 (Table 7). The time from flower bud break to the first open flower varied each year and was as few as 17 days in 2005, an 'off' flowering year, and as long as 39 days in 2006, an 'on' flowering year (Table 8). There was no clear pattern in the time taken to the first open flower between the 'on' flowering and 'off' flowering years. In the 'off' flowering year 2007 days from flower bud break to the first open flower were almost the same as in the 'on' flowering year 2006. Flowering was complete later in the 'on' flowering years, 2004 and 2006 in mid-December than in the 'off' flowering years 2005 and 2007 in mid to late November (Table 7). In 2008 flowering was complete at a similar time to the 'off' flowering years. The initial fruit set peak fruit number was reached within the same two week period, the third and fourth week of November, each year for 2005 to 2008 (Table 7). In 2004 the peak fruit number was reached about mid-December following the late flowering for that year. The greatest difference in the number of days from flower bud break to the completion of flowering was 37 days between the years 2006 (92 days) and 2005 (55 days).

The time from flower bud break to the earliest spring shoots was variable each year, ranging from 9 to 22 days, and in 2005 shoot growth began before flower bud break (Table 8). In the years 2007 and 2008 the time from flower bud break to the earliest spring shoots increased by four to seven days over the time in 2004. The time from the earliest spring shoots to the first open flower was similar in the years 2004, 2007 and 2008 ranging from 13 to 16 days (Table 8). In 2005 the time between the appearance of the earliest shoots was about twice as long as in 2004, 2007 and 2008. In 2006, the time between the earliest shoots and the first open flowers was 12 days greater than the 2004, 2007 and 2008 years. In the 'on' flowering years 2004 and 2006, flower opening continued after shoot growth stopped (Table 8). In

Table 8. Calculated time in days from flower bud break to earliest spring shoots, flower bud break to first open flower, earliest spring shoots to flower opening and completion of flowering to cessation of spring shoot growth each year 2004 to 2008.

Year	Flower bud break to earliest spring shoots	Flower bud break to first open flower	Period of flower opening	Flower bud break to end of flowering	Earliest shoots to first open flower	End of flowering to cessation of shoot growth
2004	15	29	41	70	16	(4)*
2005	(18)**	17	38	55	35	10
2006	9	39	53	92	28	(15)
2007	22	38	32	70	16	13
2008	19	32	38	70	13	9

*Flowering continued after shoot growth had ceased, **Shoot growth started before flower bud break.

Table 9. Average number of flowers, maximum percentage initial fruit set and fruit number of two determinate and two indeterminate flowering shoots each year 2004 to 2008.

	Number of flowers		Maximum % fruit set		Maximum fruit number	
Year	D[1]	I[2]	D	I	D	I
2004	260	242	17.4	17.7	45	39
2005	250	313	3.4	1.1	11	4
2006	1071	446	7.9	9.5	85	41
2007	271	227	8.2	8.3	21	19
2008	855	538	8.9	5.6	79	28

[1]Determinate flowering shoot, [2]Indeterminate flowering shoot

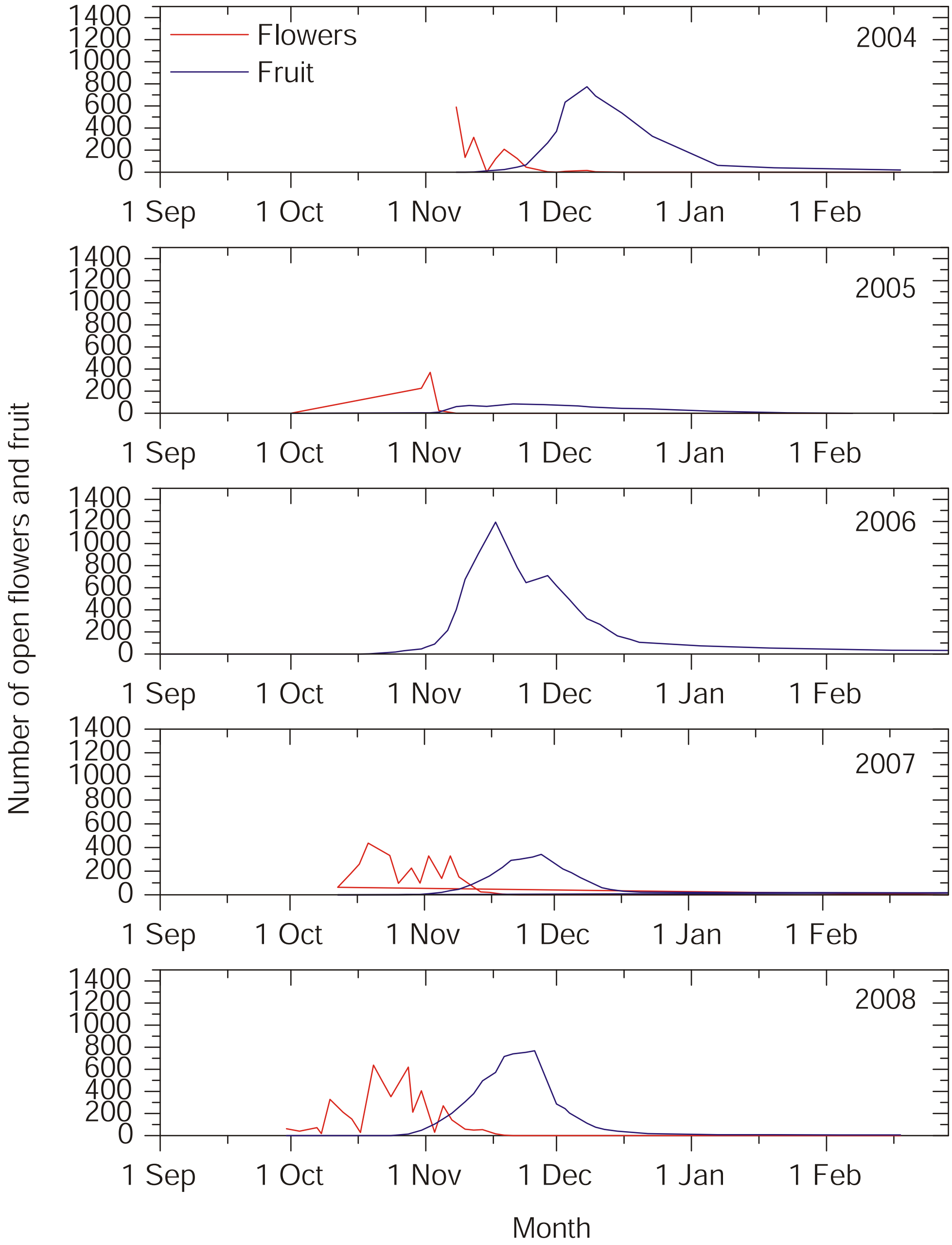

Figure 10. Total number of open flowers and fruit recorded on up to 40 flowering shoots over 5 'Hass' avocado trees from Orchard 2, 2004 to 2009.

the 'off' flowering years 2005 and 2007 shoot growth stopped up to two weeks after flower opening stopped. Although the flowering was heavy as in an 'on' flowering year, in 2008 flowering stopped 9 days before shoot growth stopped as if the trees were in an 'off' flowering year (Table 8).

The average number of flowers on determinate flowering shoots in the 'on' flowering years, 2006 and 2008 was generally greater than average flower numbers in the 'off' flowering years 2005 and 2007 (Table 9). The percentage of flowers that initially set a fruit was variable each year ranging from 9.5 % to 1.1%. Flower numbers were equally low in 2005 and 2007 but the percentage fruit set was lower in 2005 than in 2007. In 2004, the first year of the study and a year when a heavy crop was set, the flower numbers were as low as in an 'off'

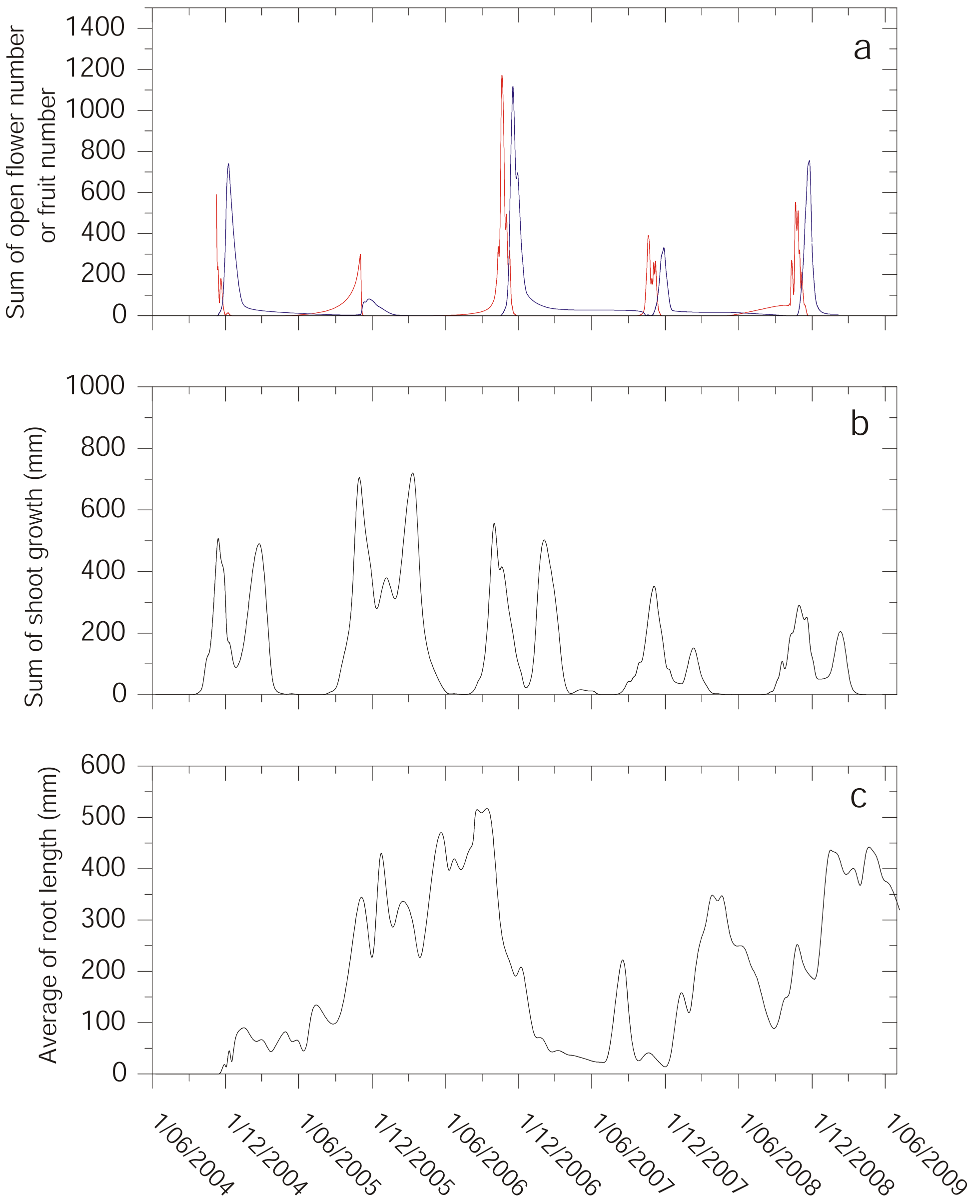

Figure 11. The sum of (a) open flower number and fruit numbers, (b) shoot length and (c) average feeder root length in 0.25m^2 for the years 2004 to 2008.

flowering year. The low flower numbers were because the counting of flowers started late in the flower opening period and is most likely to be inaccurate. For this reason the percentage fruit set in 2004 is also likely to be inaccurate and the 2004 flower numbers and percentage fruit set are not included in the analysis of flowering but have been reported for completeness. The maximum fruit number from 2004 is included in the analysis as fruit counts were started before flower opening was complete. The maximum fruit number for initial fruit set was lowest in 2005 and 2007 the 'off' flowering years compared to 2004, 2006 and 2008 the 'on' flowering years (Table 9). Percentage fruit set was similar between indeterminate and determinate flowering branches. The maximum fruit number of the initial fruit set was lower in the indeterminate flowering branches in each year of this study (Table 9).

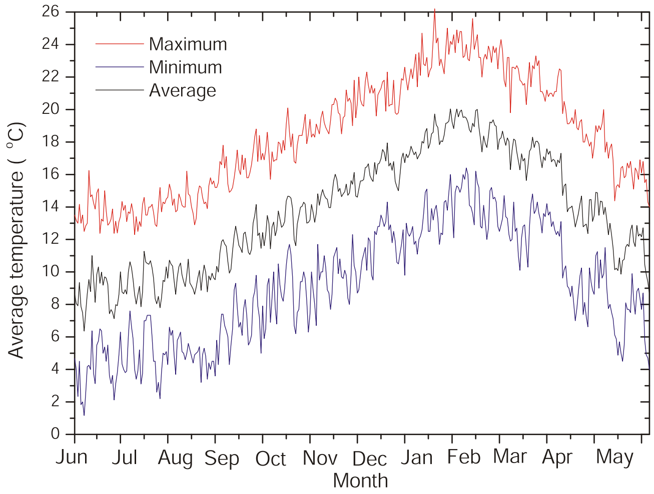

Figure 12. Average daily shade air temperature, average daily maximum and minimum daily shade air temperature for 'Hass' avocado tree in Orchard 2, 2004-2008.

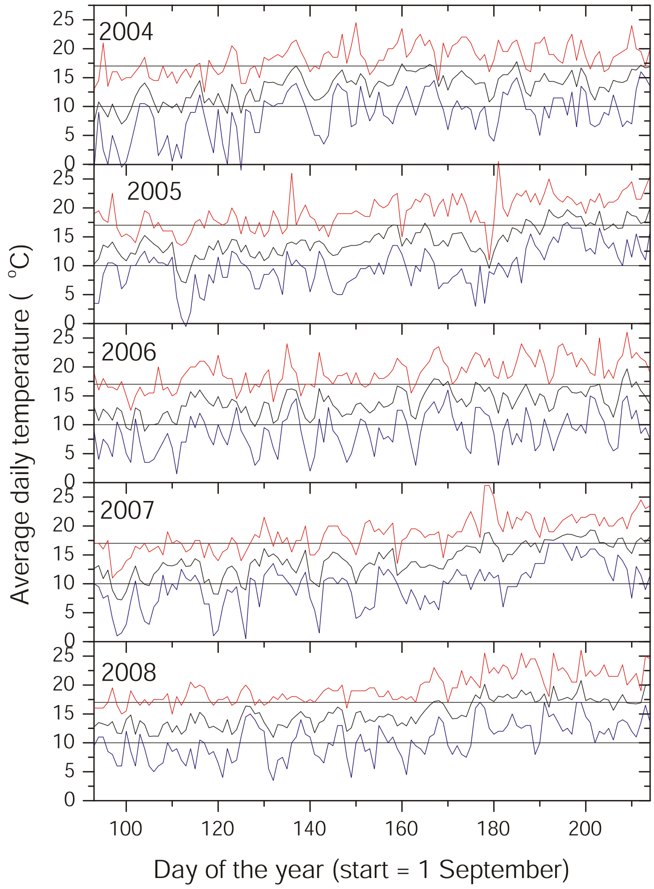

Figure 13. Daily average, maximum and minimum shade air temperatures for the period 1 September to 31 December for the years 2004 to 2008. The lower horizontal line on each graph represents 10°C and the upper horizontal line represents 17°C.

Weather

Air Temperature

The general temperature profile each year was similar with the coldest months from June and July and the warmest month February (Figure 12). The diurnal fluctuation in temperature was about 6°C to 8°C. The months June to January had a rising average temperature trend while the maximum temperature in June and July was relatively constant. The months March to June had a decreasing temperature trend. In June and July the average temperature ranged from 7°C to 11°C with the maximum between 12°C to 15°C and the minimum between 2°C to 7°C with some risk of frost. In February the daily average temperature was around 17°C to 20°C with the maximum between 26°C and 22°C and the minimum between 12°C and 16°C. The daily average temperatures each year were very variable (Figure 12). During the period of flower bud break, flower opening and fruit set, September to the end of December, there were many periods when the temperature was below 10°C (Figure 13). There was no clear pattern of the number of days where the minimum was below 10°C or the maximum was greater than 17°C with the 'on' and 'off' flowering years. In the 'on' flowering years, 2004, 2006 and 2008, the number of days the minimum was below 10°C was 72, 77 and 52, respectively. In the 'off' flowering years, 2005 and 2007, the number of days the minimum was below 10°C was 56 and 53, respectively. In the 'on' flowering years, 2004, 2006 and 2008, the number of days the maximum was above 17°C was 79, 87 and 100, respectively. In the 'off' flowering years, 2005 and 2007, the number of days the maximum was above 17°C was 93 and 83, respectively. During the flower opening period the number of days when the minimum was below 10°C was in the 'on' flowering years 2004, 2006 and 2008, 18, 30 and 20. In the 'off' flowering years, 2005 and 2007, the number of days when the minimum was below 10°C was 26 and 15.

Table 10. Average temperature (°C) during specific growth events during flowering and spring shoot flush each year 2004 to 2008.

	Growth events			
Year	**Start to finish of spring flush**	**Flower bud break to first open flower**	**Period of flower opening**	**Flower bud break to the completion of flowering**
2004	14.5	13.8	14.9	14.5
2005	13.6	13.0	14.1	13.7
2006	13.7	12.6	14.3	13.6
2007	14.1	12.4	13.7	13.0
2008	14.5	12.8	14.3	13.6

The average daily temperatures over the period of selected phenological events for each year are presented in Table 10. For the period of the start to finish of spring flush there was no clear pattern across the years 2004 to 2008 of warm temperatures being associated with the 'on' and 'off' flowering pattern. There was trend for the higher the average temperature to be the shorter the duration of the spring flush.

There was a general trend for the shortest times from flower bud break to first open flower to be associated with the warmer temperatures. There was trend for the warmer the average temperature during flower opening the longer the flower opening period. There appeared to be no relationship between the average temperature during flower bud break to completion of flowering and the number of days to complete flowering.

Rainfall and soil moisture matrix potential

Rainfall was very variable from month to month and day to day but tended to be reasonably evenly distributed through the seasons each year. Generally, there was less rain in spring and summer (September to February) than in autumn and winter (March to August) (Figure 14). The wettest season was autumn and overall 2006 was the driest year and 2005 the wettest (Table 6).

The average soil moisture matrix potential each month was relatively constant in the winter of 2004 and began to decrease through the spring and summer of 2005 to a low amount (Figure 14). This would indicate the trees came under water stress in the summer of 2005. During the autumn, winter and spring of 2005 the soil moisture matrix potential was relatively constant at above -25 kPa. In the years 2006 and 2007 and the summer of 2008 the soil moisture matrix potential was generally low indicating the trees were under water stress over that time period. The low rainfall in 2006 appears to have a long term effect in keeping the soil moisture matrix potential very low despite the good rainfall in July and August of 2007 and 2008 (Figure 14). There was typically a strong soil moisture deficit in the summer each year.

The soil moisture matrix potential tended to be lower at 60cm than 30cm depth indicating that the deeper soil layers were often drier than the top soil layer.

Soil Temperature

When averaged across the five years of the project, the lowest soil temperatures were in June, July and August where the soil temperature could fall below 9°C but could be as high as 11°C (Figure 15). From August the soil temperature rose steadily until mid-February when it reached about 19°C before declining. The general pattern of change in soil temperatures each month was similar each year (Figure 16). The coldest winter soil temperatures were in June, July and August in 2004 to 2006 (Figure 16). The winter soil temperatures were low for the longest in the years 2004 and 2005. The years 2006 and 2007 had the longest period of warm summer soil temperatures. The summer soil temperatures were similar each year.

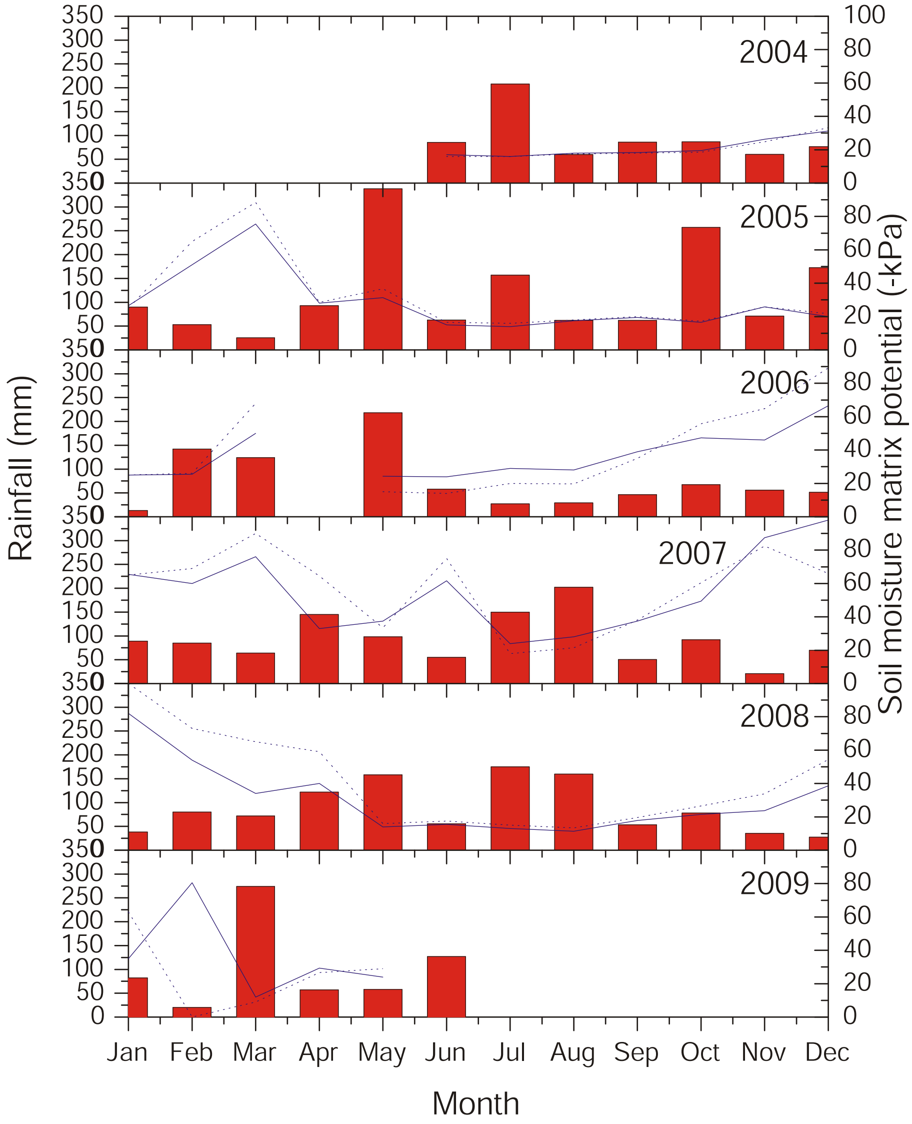

Figure 14. Average monthly soil moisture matrix potential at 30cm (blue line) and 60cm (dotted blue line) and total monthly rainfall (red columns) for Orchard 1 in 2004-2009. The trees were never irrigated during the project.

DISCUSSION

The avocado tree has an easy to recognise growth cycle where there is no period when the tree is completely dormant. The trees go through a number of visible changes during the year. The least amount of visible growth is in the winter period around June or July. For this reason a general description of the phenological cycle for Hass avocado trees grown in the Western Bay of Plenty in New Zealand has as its starting point 1 July. The description is based on the phenological events observed that go from the start of the growth of

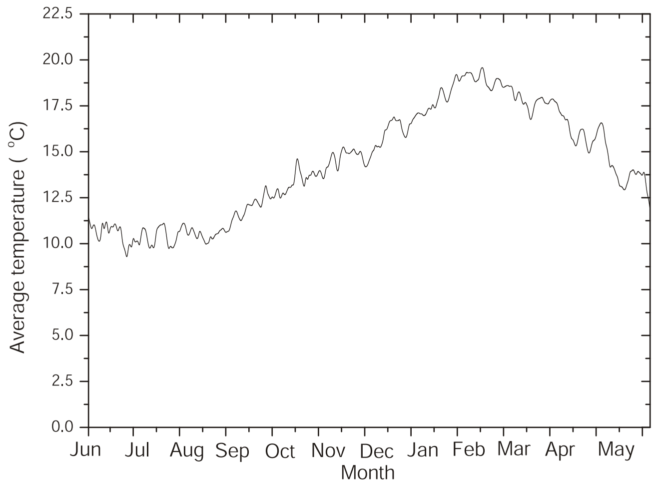

Figure 15. Average daily soil temperature (100mm depth) for 'Hass' avocado trees in Orchard 2, 2004-2009.

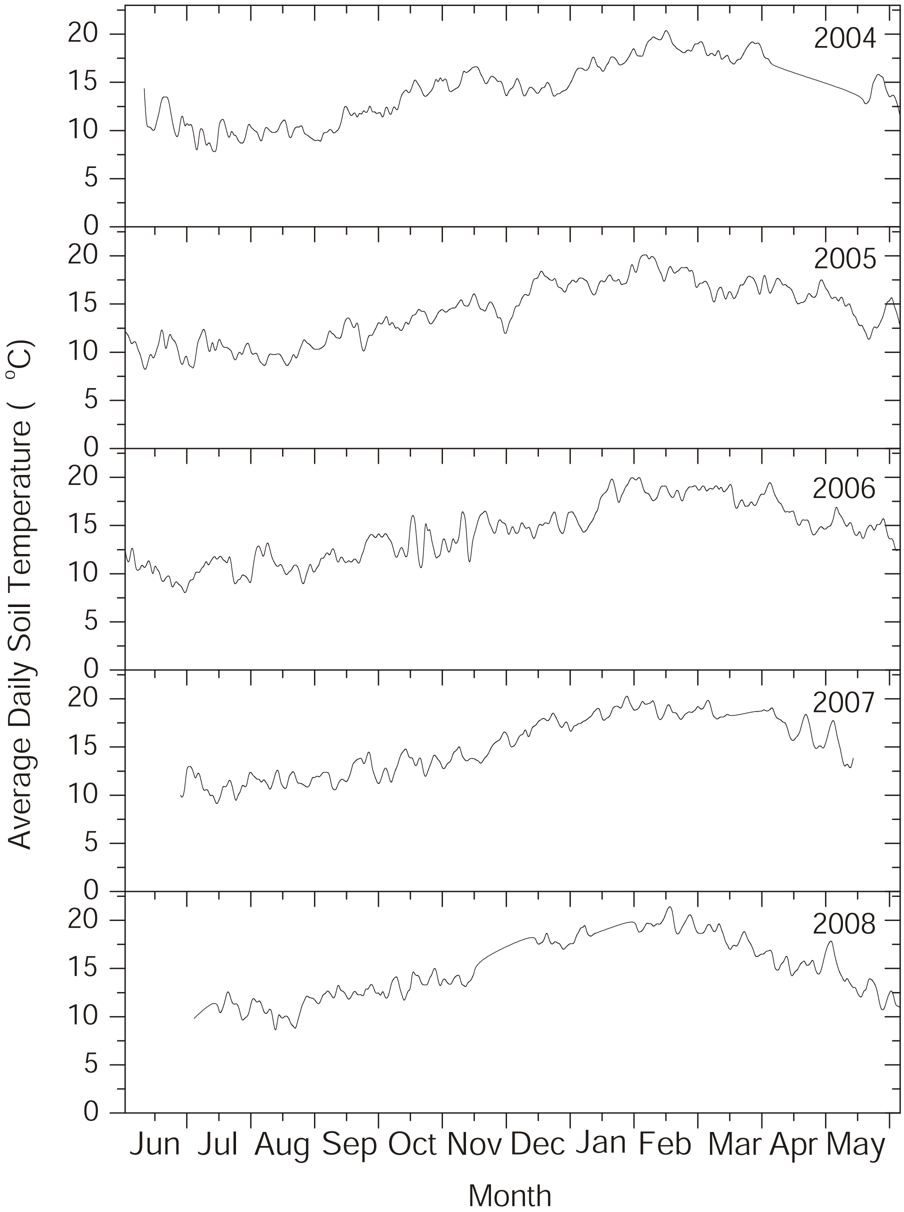

Figure 16. Average daily soil temperature at 100mm depth for 'Hass' avocado trees each year from 2004 to 2008.

fruiting wood to the harvest of mature fruit. The whole cycle takes up to two years and spans three calendar years. This phenological cycle is based on a fruit producing cycle and an individual tree will have three of these fruit producing cycles occurring at any one point in time each calendar year. The following is a general description of the Hass phenology based on a summary of the observations reported above of changes in the physical appearance of avocado trees and starts with the trees coming into an 'on' flowering year.

In the 'on' flowering year

In July there is no shoot growth but a low level of activity in root growth coinciding with the coldest soil temperatures and weather. At mid September flower bud break occurs and a root flush begins. By early October vegetative buds break for the new spring flush and by mid October the first to open flowers appear. Flower numbers are high. At the end of November the spring shoot flush is complete and by the beginning of December flower opening is complete. The amount of newly set fruit is high. The drop of the initial fruit set begins at the end of

November. Another root flush begins as the spring shoot flush finishes. A summer shoot flush begins in early January about the same time that the fruit drop has finished. The summer shoot flush is weaker than the spring shoot flush and finishes in early March at which time a root flush starts. Over the winter there is a general decline in feeder roots.

In the 'off' flowering year

In July there are root flushes despite the low soil temperatures and cold weather. At the beginning of September flower bud break starts but there is no root flush. By late September or early October the spring flush shoot starts to grow and by late October the first open flowers appear with flowering complete by mid November. Flower numbers are low. In early November there is a root flush. The initial fruit set is low and the drop of the initial fruit set begins late November. In early December the spring shoot flush is finished and the summer shoot flush begins early January finishing mid March. Summer shoot flush can be as strong as the spring shoot flush. Root growth and root flushes occur from January through to July.

The above description is a more detailed account of the tree growth cycle than in the current New Zealand Avocado Growers' Manual. The general feature of the growth cycle in the Growers' Manual is that the peak of flower opening and shoot growth are at similar times and that the spring root flush has an earlier peak. In summer there is a strong root flush and shoot flush peaking about early March. This study describes the phenology in more detail and shows that the tree growth cycle is different within each year of the alternate bearing cycle.

There are clear differences in the timing of growth patterns each year depending whether the trees are in the 'on' or 'off' flowering years of the alternate bearing cycle. The most notable differences are in the timing and amount of flowers along with the duration of the spring shoot flush and the number of feeder root flushes that can occur in winter. Based on the observations reported here a good indication of an 'on' flowering tree is where the shoot flush finishes before the flower opening is finished. This has important implications in that flowering and fruit set appear to be inhibiting shoot growth in the 'on' flowering year and when flowering is weak in the 'off' flowering year shoot growth is stronger. An adequate amount of shoot growth is needed each year to ensure that there will be sufficient flowers produced for a good fruit set. The shoot growth was weak in the two 'on' flowering years 2004 and 2006. In 2008 although the flower numbers and initial fruit set was high the flower opening did not go longer than the spring shoot growth. The crop harvested from the fruit set in 2008 although greater than an 'off' flowering crop was lower than expected. Analysing a combination of the shoot growth, flowering and fruit set growth patterns could be used as a method to predict the likely yield outcome each year. 'On' flowering trees have greater amounts of flowers that develop earlier and a longer period of flower opening than 'off' flowering trees. However, the percentage of flowers setting fruit can be similar in 'on' and 'off' flowering years. Therefore, it is the fewer flower numbers in the 'off' flowering year that may be the most important factor leading to low yields following the 'off' flowering. The amount of feeder roots coming into the 'on' flowering years was greater than the 'off' flowering years where the total amount of feeder roots died back. This pattern of overall feeder root accumulation and reduction across a two year cycle would suggest that roots may have an important role in supporting big fruit sets. The feeder roots accumulating in the time before an 'on' flowering may be an indication of other, as yet unknown, tree factors that are associated with a heavy fruit set. There were some aspects of the spring flush that were not affected by the alternate bearing cycle. They were: the time when spring shoots started to grow, the duration of the spring shoot growth and the duration of the spring shoot flush once flowering had finished. These may be influenced most by the current nutrient status of the tree and weather conditions rather than phenological events of the tree.

The visible indicators the trees setting up for a poor crop were observed to be the following:

- Plenty of shoot growth with about the same amount of shoot flush in the spring and summer.
- A feeder root flush once shoot growth was well underway instead of at the beginning of the spring shoot flush.
- Low flower numbers on flowering shoots. In the 'on' flowering year flower numbers were from two to four times greater than in the 'off' flowering year.
- Low initial fruit set before the fruit drop. For a good crop the average number of fruitlets is around 40 to 60 per flowering branch while for a poor crop average fruitlet number is about 0 to 20 per flowering branch.
- Flower opening finishes before the spring shoot flush is finished. In an 'off' flowering year the duration of flower opening is relatively short at two to four weeks compared to six to eight weeks in the 'on' flowering year.

During the past five years the general patterns of shoot and root growth was similar in that the trees always flowered and grew vegetative shoots and roots. However, there were differences of a few weeks from one year to the next when shoot and root flushes began, their duration and amount of growth between the two orchards and the 'on' flowering and 'off' flowering pattern. Such differences were large enough to be meaningful in the timing of tree management decisions. As an example, the start of the spring shoot flush varied by one to three weeks each year but was generally of similar duration on both orchards. The reason for the spring flush to be earlier or later each year is not known but could be related to the weather and crop load on the tree over winter. The spring shoot flush growing for a similar duration each year indicates that the finish of the spring flush could be predicted once the spring flush has begun. An early flush predicts that the spring flush will finish in late December while a late flush indicates a mid January finish. As the timing of shoot growth differs each year application of fertilizer could be changed according to when the shoot flush begins. This could be beneficial in then correctly using fertiliser to grow sufficient spring flush to obtain ideal fruiting wood each year. A practical example would be in some years fertiliser is applied when the trees are already flushing resulting in additional unwanted shoot growth rather than before the trees have started their growth flush. For best practice management of avocado trees taking into account the timing and strength of flowering and shoot flushes is required. For example when an avocado tree that appears to have flowered well as if in an 'on' flowering then also has a shoot flush that is stronger than would be expected the yield is likely to be lower than in an 'on' flowering year. Knowledge of how phenological events are related to one another and when they occur will allow an avocado grower to better interpret the yield potential of their tree and fine tune their orchard management.

Based on the observations on shoot growth and flowering of this study for avocado trees to crop consistently it is possible to suggest the necessary changes needed in the growth pattern for 'off' or 'on' flowering years. A simple working hypothesis is that for consistent crops the tree needs to produce similar numbers of flowers each year. The amount of flowers each year depends on the amount of shoot growth in the previous year. To have the right amount of flowers each year the trees have to grow the right amount. Alternate bearing is then due to not enough shoot growth in the 'on' flowering year and too much shoot growth in the 'off' flowering year. To get the correct amount of shoot growth in the 'on' flowering year the amount of flowers need to be reduced and extra shoot growth to be promoted. In the 'off' flowering year the amount of shoot growth needs to be reduced so that there will be less flowering in the following year.

Practical treatments that New Zealand avocado growers can use to have their trees producing similar amounts of flowers each year already exist. In the 'on' flowering year the trees can be flower pruned where a proportion of the flowering branches can be removed reducing flower numbers as well as stimulating extra shoot growth. In the 'off' flowering year the best treatments may be to use plant growth regulators to inhibit shoot growth or it may be possible to change the fertiliser mixture to avoid too much shoot growth. Applying these treatments at the right time would appear to have potential for managing alternate bearing.

The orchard management practices commonly used on New Zealand avocado orchards are based on a generalised timing of the phenology. That the timing of some important phenological events can vary from year to year and from orchard to orchard indicates that there would be an advantage for avocado growers or orchard managers to be able to more closely follow the growth cycles on their trees. The differences between orchards in when phenological events happen could also explain why orchards side by side can appear to need management inputs at different times. This study has started the process for developing a detailed picture of the avocado tree growth cycle but considerable gaps in our knowledge still exist. For example, the observations made in this study do not answer the question: What is the ideal fruiting wood? Defining the ideal fruiting wood in terms of shoot length, thickness, number of flowering buds, time of year when produced, number of leaves, branching pattern and its growth history would greatly help avocado growers to set a target for the best growth to achieve on the tree for greatest productivity. The study reported here has given a good basic foundation of information from which to develop a robust model of tree growth for productivity.

CONCLUSIONS

The general pattern of shoot and root growth was similar each year but there were differences in the timing and amount of growth between trees in different orchards and the 'on' and 'off' flowering years. The greatest differences in phenology were between trees in 'on' and 'off' flowering years of the alternate bearing cycle. The greatest effect was on shoot growth and flowering where in the 'off' flowering year there were few flowers and too much shoot growth while in the 'on' flowering year too many flowers and not enough shoot growth. Practical treatments to get good flowering each year include flower pruning or inhibiting excessive shoot growth depending on the alternate bearing cycle.

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