'HASS' AVOCADO TREE PHENOLOGY 2004-2008 IN THE WESTERN BAY OF PLENTY

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ABSTRACT

Important growth events of avocado trees can vary in their timing each year. Different timings of phenological events indicate that orchard management practices should be applied relative to the phenology of the tree for best results. Trees on 2 orchards in the Western Bay of Plenty were monitored for 4 years to establish the variation in phenology. Patterns of shoot and root growth were similar each year but the timing and amount of growth between trees in different orchards and the 'on' and 'off' flowering years differs. Orchard differences were in the number of shoot flushes, 3 for orchard 1 and 2 for orchard 2, possibly due to the use of irrigation on orchard 1. Spring shoot flush started at different times but was about the same duration on both orchards. Spring shoot flush generally ceased growing after 65 to 70 days in mid December to late January. The other major influence on the timing of phenological events was whether the trees were in an 'on' or 'off' flowering year. The aspects of the spring flush that were not affected by the alternate bearing cycle were: the start of spring flush, the duration of spring flush and the duration of spring flush after flowering. The trees in an 'on' flowering year had reduced growth in shoots and roots compared to trees in the 'off' flowering year. Trees in the 'off' flowering year had fewer flowers, longer time from flower bud break to the first open flower and flowering was over a slightly shorter time than trees in the 'on' flowering years. There is sufficient difference in the timing of phenological events from year to year, that for best tree management avocado growers could time management activities more closely to the trees growth cycle.

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

INTRODUCTION

The growth cycles of shoots, roots and flowers of avocados can indicate the best time for orchard management activities. Application of fertiliser is best done when the tree is going to enter a growth phase. 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. Important phenological events such as flowering and spring shoot growth can vary in their timing each year. An appreciation of when the tree is entering a growth phase allows orchard management practice to be fine tuned for best results. Monitoring of the phenology of trees over a number of years allows the degree of variation in tree growth events to be determined and to capture the differences between 'on' and 'off' flowering years. To evaluate how the differences in avocado phenology affect regular cropping, detailed and accurate descriptions of the phenology each year is required. Trees on 2 orchards in the Western Bay of Plenty have been monitored over 4 years to establish the difference in timing of phenological events each year and to also allow correlation of these events with each other and orchard factors. This report describes the first 4 years of 'Hass' avocado phenology measurements.

MATERIALS AND METHODS

The details of the orchards used in this study and the methods to measure shoot and root growth, flowering and fruit set as well as the temperature and soil moisture are as described previously (Dixon *et al.*, 2005).

RESULTS

Orchard 1

Phenology

Shoot Growth

There can be 3 shoot flush periods each year corresponding to spring, summer and autumn that occur about the same time each year (Figure 1). The first flush was in spring and usually starts during September/October and finishes mid December/January, the second flush is in summer from January to April and there may be a short period of shoot growth in autumn from April to May (Figure 1). The greatest amount of shoot growth is in spring then summer with a weak flush in autumn. The amount of shoot flush was greater in 2005, when there was no fruit set, than in 2004 and 2006 when there were heavy crops set. In 2007 the spring flush was about the same as in 2004 and 2006 with a weak summer flush. On average, the earliest spring flush shoots started growing from early to mid October and grew for about 60 to 70 days (Table 1). The length of time individual spring flush shoots grew was variable and generally ranged from 35 days up to 105 days. The duration of spring shoot growth tended to decrease from 2004 to 2006 and was similar in 2007 to 2006 with the average duration of the spring flush shorter by about 12 days in 2006 and 2007 compared to 2004.

Root Growth

There were at least 3 periods of root growth each year generally at times when shoot growth was weakest (Figure 1). The timing of root flushes varied each year depending on the timing when the shoot flush was low. Like shoot flushes the flush of roots could be divided into seasons, the first is spring where there could be one or more weak flushes of roots. The second was late summer/early autumn the strongest flush and a third winter root flush that could be strong generally in June or July. The number of root flushes and amount of roots was greatest in the spring of 2006 following a year when there was no fruit on the trees.

Flowering

Over the past 4 years there has been an obvious alternate bearing pattern on the trees monitored in this study. Fruit set in 2004 and 2006 was very heavy and fruit set in 2005 was absent with a poor fruit set in 2007 (Figure 2). Flower bud break varied from year to year with bud break in 2005, 2006 and 2007 in early to mid September but in early October in 2004 (Table 2). The time from bud break to the first open flower was about 1 month in 2004, 7 weeks in 2005 and 2007 and about one month in 2006. The time taken to the first open flower was about 3 weeks longer in the 'off' flowering year compared to the 'on' flowering year. Flowering was

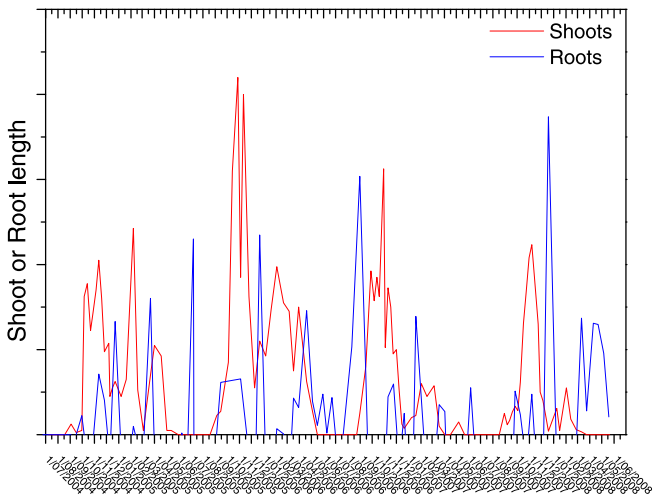

Figure 1. Total shoot and root length of five 'Hass' avocado trees from Orchard 1, 2004 to 2008.

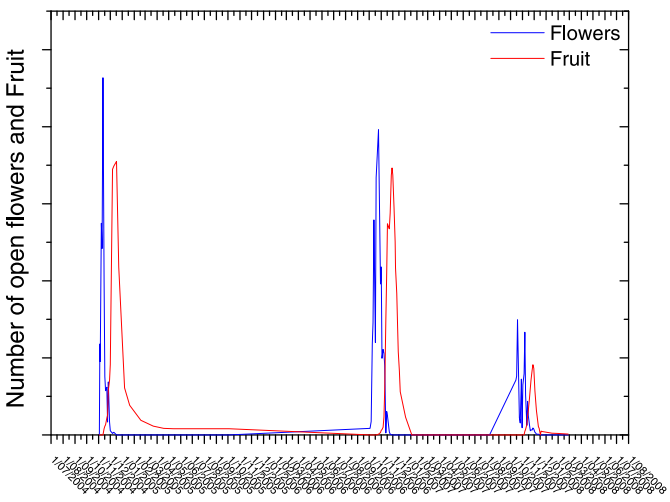

Figure 2. Total number of open flowers and fruit on 10 flowering shoots of 5 'Hass' avocado trees from Orchard 1 2004 to 2008.

complete in about 2 months in 2004 and about 3 weeks in 2005, took nearly 3 months in 2006 and two and a half months in 2007 (Table 1). Initial fruit set numbers peaked about 1 month after the peak of open flowers each year at about the same time as flowering was completed each year (Table 1). In 2004 the earliest vegetative shoots started to grow at a similar time as the flower bud break. In 2005, 2006 and 2007 flower bud break was about 1 month before vegetative growth was observed. Total numbers of flowers in the 'on' flowering years (2004 and 2006) were of similar numbers and greater flower numbers in the 'off' flowering years (2005 and 2007). The percentage of flowers that initially set a fruit was similar at 5 to 9% each year when flowers were present. The maximum fruit number was lower in 2007 than 2004 and 2006 (Table 2). Determinate and indeterminate shoot types had similar flower numbers and percentage fruit set.

Weather

Air Temperature

The general temperature profile each year was similar with the coldest months from mid-May to August and the warmest months from January to March (Figure 3). The winter weekly average temperature was about 8 to 10°C and in summer

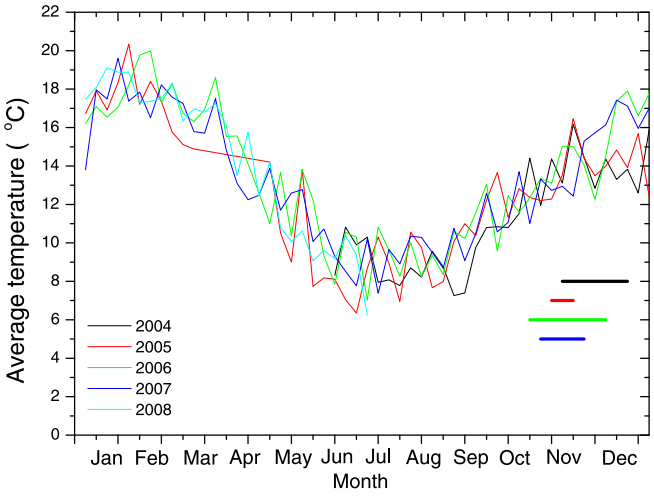

Figure 3. Average weekly shade air temperature for 'Hass' avocado trees in Orchard 1, 2004-2008. The bars represent the main bloom period each year.

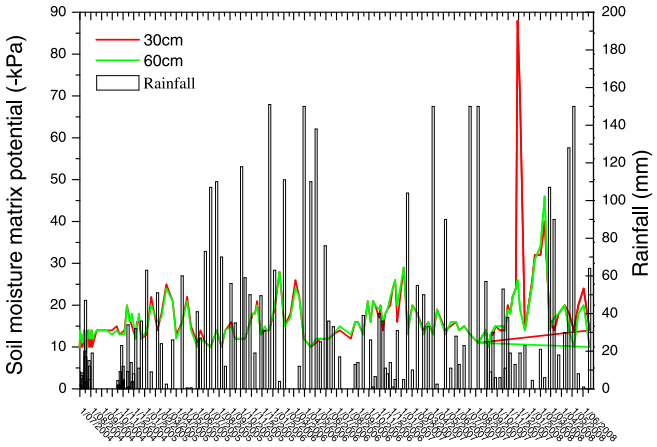

Figure 4. Soil moisture matrix potential at 30 and 60cm and rainfall for Orchard 1 2004-2008. During spring and summer the trees were irrigated with 9.5mm of water per m^2 every 3 to 4 days until the spring of 2007.

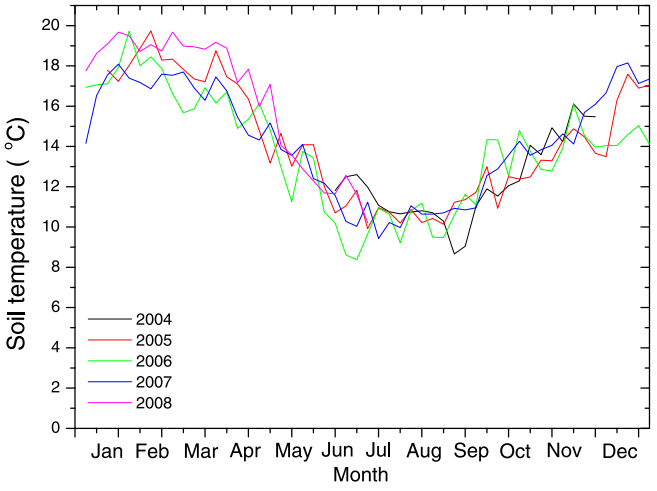

Figure 5. Average weekly soil temperature (100mm depth) for 'Hass' avocado trees in Orchard 1, 2004-2008.

the weekly average temperature was around 18 to 20°C. Frosts were possible from June to September and occasionally in October 2004. Frosts were fewer in 2005 but were present from June to September 2005. In 2006 frosts were possible in June only. Frost was possible in June to August in 2007. The years 2006 and 2007 had milder winters than the years 2004 and 2005. During the flowering period the temperatures were

similar each year but the period of main bloom varied from year to year (horizontal bars Figure 3). The main bloom period was short in 2005 at 3 weeks compared to 6 weeks in 2004 and 2006 and four weeks in 2007 (Table 1). The first week coincided with cooler temperatures after which the temperature rapidly warmed up each year.

Soil moisture matrix potential and rainfall

The soil moisture matrix potential tended to be lowest in summer generally reaching about -30kPa in February or March in 2004 to 2006 (Figure 4). In 2007 the irrigation was not applied as much as in the previous years and there were greater soil moisture deficits in spring and summer than previous years. There was little difference in soil moisture matrix potential at 30 or 60cm depth except in spring 2007. As these trees were regularly irrigated at 9.5mm per m^2 in 2004 to 2006, the trees were unlikely to have been under water stress. Rain occurred at reasonably regular intervals each year with the longest period where rain was absent of about 6 weeks at different times of the year (Figure 4). There was more rain in July 2005 to June 2006 than in the other years. The total rainfall from July 2004 to June 2005 was 780mm, from July 2005 to June 2006 was 1557mm and July 2006 to June 2007 was 837mm, July 2007 to June 2008 was 1237mm.

Soil Temperature

The lowest soil temperatures were in June and July where the soil was on average 9°C but was often between 10 to 11°C (Figure 5). From August the soil temperature rose steadily until February when it reached 18 to 20°C. The general pattern of soil temperatures was similar each year.

Orchard 2

Phenology

Shoot Growth

There were 2 distinct shoot flush periods each year corresponding to spring and summer (Figure 6). The first flush was in spring during September/October to mid December, the second in summer during January to March (Figure 6). The amount of shoot growth in spring and summer was similar. In 2005 the total amount of shoot flush was greater than in 2004 and 2006 with some additional shoot flush in December when there was no shoot growth. In 2007 the spring flush was less than in previous years with a weak summer flush. On average, the earliest spring flush shoots started growing from mid October in 2004, 2005 and 2006 (Table 1). In 2007 shoot flush started in early October. There has been a general trend for the spring flush to be earlier each year. In general, the spring shoot flush took about 70 days in 2004 and 2006, both 'on' flowering years. In the 'off' flowering years 2005 and 2007 the spring shoot flush duration was slightly less at about 65 days. The length of time individual spring flush shoots grew was variable and generally ranged from 30 days up to 100 days.

Root Growth

The number of feeder roots at the soil mulch interface was low in 2004 and 2006, the 'on' flowering years, and greatest in 2005, an 'off' flowering year with very little fruit set (Figure 6). In 2007, an 'off' flowering year, there were more feeder roots than 2005. There were two main periods of root growth each year 2004 and 2006, generally at times when shoot growth was weakest in December and June/July (Figure 6). In 2005 there were several periods of root flush throughout the year. In 2007 the main period of root growth was in summer then in autumn. The timing of root flushes varied each year depending on the timing of the shoot flush. Root growth in 2007 was generally when the shoot growth was weakest. The number of root flushes and amount of roots was greatest in the spring of 2005.

Flowering

Over the past 4 years there has been an obvious alternate bearing pattern on the trees monitored in this study. Fruit set in 2004 and 2006 was heavy and fruit set in 2005 and 2007 was low (Figure 8). Flower bud break was at about the same time in 2004 and 2005 in early October but was about 20 to 25 days earlier in 2006 and 2007 in early to mid September (Table 2). The time from bud break to the first open flower was about 1 month each year.

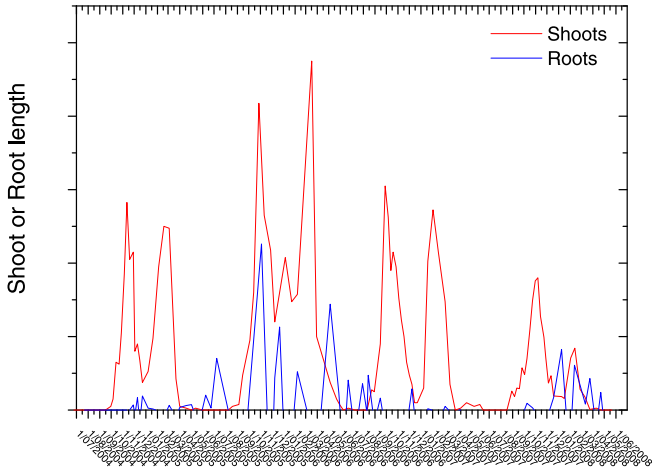

Figure 6. Total shoot and root length of 5 'Hass' avocado trees from Orchard 2 2004 to 2008.

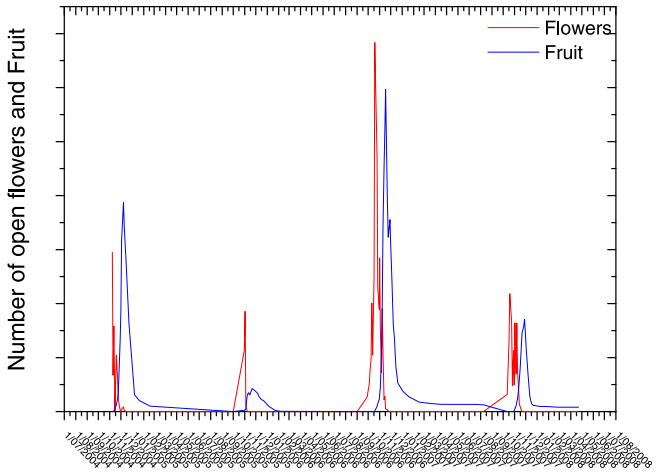

Figure 7. Total number of open flowers and fruit of 5 'Hass' avocado trees from Orchard 2, 2004 to 2008.

Flowering was complete in about 6 weeks in 2004, about 4 weeks in 2005, 7 weeks in 2006 and about 4 weeks in 2007 (Table 1). Initial fruit set numbers peaked around the time flowering was complete (Table 1). This time is about 1 month after the peak of open flowers each year (Figure 8). In 2004 and 2005 the earliest vegetative shoots started to grow about 10 days after flower bud break. In 2006 and 2007 flower bud break was about 1 month before vegetative growth was observed (Table 1). Total numbers of flowers was similar each year in indeterminate and determinate flowering shoots but was greater in 2006 on determinate flowering shoots (Table 2). The initial percentage fruit set in 2004 was very high at about 17% compared to 8 to10% in 2006 and 2007. In 2005 initial fruit set was low at between 1 to 3% (Table 2). Determinate and indeterminate shoot types did not have statistically significant different flower numbers or percentage fruit set.

Weather

Air Temperature

The general temperature profile each year was similar with the coldest months from mid-May to August and the warmest months from January to March (Figure 8). The winter weekly average temperature was about 7 to 11°C and in summer the weekly average temperature was around 17 to 20°C. Frosts were possible in 2004 from June to September and occasionally in October. Frosts were fewer in 2005 but were present from June to September 2005. In 2006 frosts were only recorded from June to August. In 2007 frosts were possible in July and August. During the flowering period the temperatures were similar each year but the period of main bloom varied from year to year (bars on Figure 8). The main bloom period in 2005 and 2007 was about 4 weeks compared to about 5-6 weeks in 2004 and 2006 (Table 1). The first weeks of flowering coincided with cooler temperatures after which the temperature rapidly warmed up.

Soil moisture matrix potential and rainfall

The soil moisture matrix potential was lowest in summer and often exceeded -70kPa from February to March (Figure 9). The spring of 2006 and summer to autumn of 2007 was very dry with the soil moisture matrix potential less than -50kPa most of the time (Figure 9). The dry period extended through the spring of 2007 and summer of 2008. The trees used in this study were not irrigated indicating the trees were likely to have been under water stress when the soil moisture matrix potential was very low. The soil moisture matrix potential at 60cm generally followed the 30cm soil moisture matrix potential in 2004 and 2005. In 2006 the soil at 60cm depth generally had a lower soil moisture matrix potential than at 30cm. Rain was relatively evenly spread throughout each

year with the longest period where rain was absent of about 6 weeks at different times of the year (Figure 9). There was less rain in July 2006 to June 2007 than in the other years. The total rainfall from July 2004 to June 2005 was 1325mm, from July 2005 to June 2006 was 1400mm, from July 2006 to June 2007 was 871mm and from July 2007 to June 2008 was 1166mm.

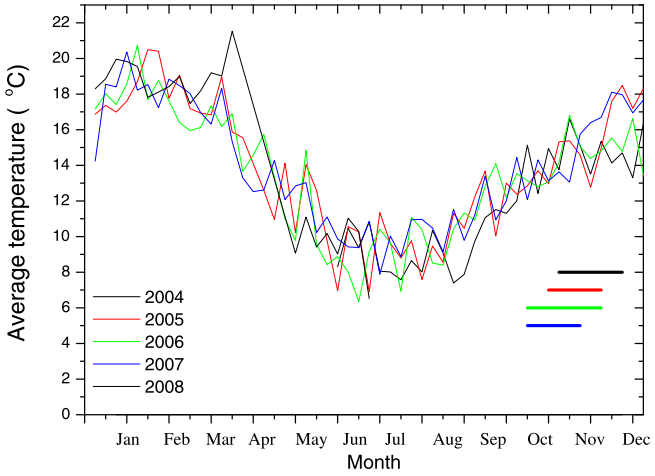

Figure 8. Average weekly shade air temperature for 'Hass' avocado trees in Orchard 2, 2004-2008. The bars represent the time of open flowers in the main bloom period each year.

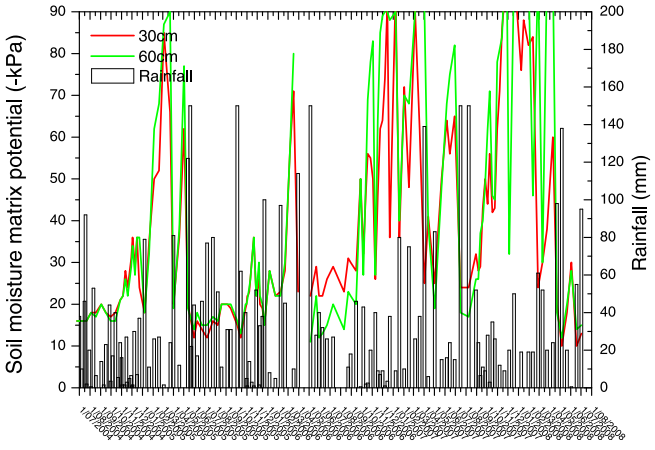

Figure 9. Soil moisture matrix potential at 30 and 60cm and rainfall for Orchard 2 2004-2008. The trees used in this study from this orchard were not irrigated.

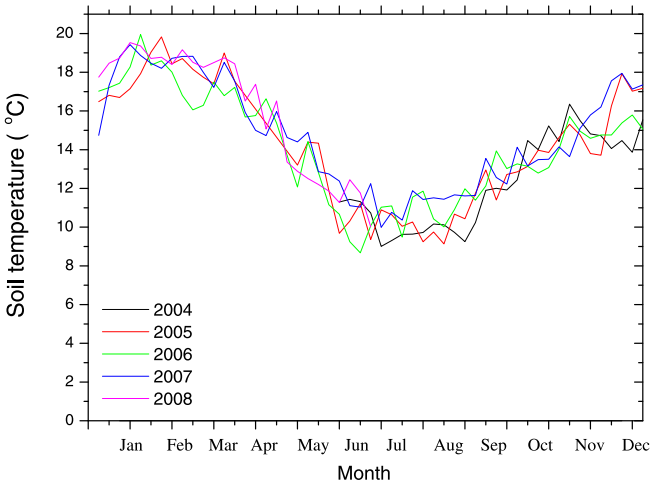

Figure 10. Average weekly soil temperature (100mm depth) for 'Hass' avocado trees in Orchard 2, 2004-2008.

Soil Temperature

The lowest soil temperatures were in June and July where the soil was on average 9°C but was often between 10 to 11°C (Figure 10). From August the soil temperature rose steadily until February when it reached 18 to 20°C. The general pattern of soil temperatures was similar each year.

DISCUSSION

During the past four years the patterns of shoot and root growth was similar. There were differences when shoot and root flushes began and the duration of growth of trees in different orchards and between the 'on' flowering and 'off' flowering years. A notable orchard difference was that there were 3 shoot flushes in orchard 1 and 2 shoot flushes in orchard 2. The increased number of flushes may have been due to the use of irrigation as in 2007 trees in orchard 1 had only 2 flushes once the amount of irrigation was reduced. The trees in orchard 1 in 2004 to 2006 did not have a period of time in the year when the soil moisture matrix potential was less than -30kPa. In 2007 the soil moisture matrix potential was less than -30kPa. The trees in orchard 1 were then experiencing soil conditions similar to orchard 2 where there were dry soil conditions, less than -50kPa soil moisture matrix potential, over January

Table 1. Dates when the phenological events of spring flush and flowering occurred each year.

Orchard 1				
Spring flush	**Earliest shoots**	**Growth ceased**	**Duration of flush (days)**	**Range of growing days**
Year				
2004	5/10/2004	25/1/2005	73.5	47-100
2005	14/10/2005	23/12/2005	69.4	48-91
2006	11/10/2006	11/12/2006	61.6	44-79
2007	9/10/2007	19/12/2007	62.0	35-105
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	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
Orchard 2				
Spring flush	**Earliest shoots**	**Growth ceased**	**Duration of flush (days)**	**Range of growing days**
Year				
2004	16/10/2004	22/1/2005	70.7	50-92
2005	13/10/2005	22/1/2006	66.6	43-89
2006	10/10/2006	30/1/2007	73.5	44-103
2007	6/10/2007	12/12/2007	63.0	30-99
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	28/10/2005	28/11/2005	21/11/2005
2006	15/9/2006	16/10/2006	8/12/2006	17/11/2006
2007	9/9/2007	19/10/2007	21/11/2007	28/11/2007

and February, conditions that could limit shoot and root growth (Lahav and Whiley, 2002). There were more roots at the soil mulch interface every year for orchard 1 than for orchard 2. The greater amount of roots along with good soil moisture levels could result in more growth due to the trees in orchard 1 having a greater ability to take up nutrients than trees in orchard 2. This could partly explain why in orchard 1 there was a third shoot flush in autumn.

The start of the spring shoot flush varied each year but was of similar duration on both orchards. In spring soil moisture availability in the non-irrigated orchard may not be limiting growth. The reason for

Table 2. Average number of flowers, maximum percentage fruit set and fruit number of two determinate and two indeterminate flowering shoots each year 2004 to 2006.

Orchard 1						
	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
Orchard 2						
	Number of flowers		Maximum % fruit set		Maximum fruit number	
Year	D	I	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

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

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 has been of similar duration each year indicating that when the spring flush begins determines when the spring flush stops. An early flush predicts that the spring flush will finish in late December while a late flush indicates a mid January finish. That the duration of shoot growth can differ each year implies that the timing of fertiliser applications needs to be adjusted to avoid excessive shoot flush. For example, applying fertiliser when the trees are still actively flushing when the intention is to apply the fertiliser at a time when the trees are not flushing may induce additional shoot growth that is not wanted. A good spring flush with an adequate amount of growth is considered to be required for good flowering wood in the next spring. The timing of fertiliser may be important to obtain ideal fruiting wood each year.

A major influence on the timing of some phenological events is whether the trees were in an 'on' or 'off' flowering year of an alternate bearing cycle. The growth of shoots and roots on the trees in 2005 and 2007 are examples of 'off' flowering years. The 'on' flowering years were 2004 and 2006. 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 are likely to be influenced most by the current nutrient status of the tree and weather conditions during spring rather than the previous phenology of the tree. The trees in an 'on' flowering year had reduced growth in shoots and roots compared to trees in the 'off' flowering year. Most notably trees in the 'off' flowering year tended to have fewer flowers and lower numbers of fruit in the initial fruit set, the time from flower bud break to the first open flower tended to be longer and the duration of flowering tended to be shorter than trees in the 'on' flowering years. The percentage of flowers setting fruit can be similar in 'on' and 'off' flowering years. The

reduction in shoot growth when there is a heavy crop, the 'on' flowering year, can be expected to lead to fewer flowers. This study has also identified that more than just the number of flowers and amount of shoot growth is affected. Not only are there fewer flowers open for a shorter time but there is a weak trend for fewer flowers set fruit in the 'off' flowering year compared to the 'on' flowering year. The reasons for this are not well understood but suggest that the inherent ability of the flowers to set a fruit may be different in 'on' and 'off' flowering years.

The orchard management practices commonly used are based on a generalised timing of certain phenological events, like the onset of flowering and end of flowering. That the timing of phenological events 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.

CONCLUSIONS

The patterns of shoot and root growth were 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. Irrigated trees appeared to have three shoot flushes a year compared to two shoot flushes for non-irrigated trees. 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 fewer flowers and a tendency for there to be a lower inherent capacity to set fruit.

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