SHOOT GROWTH OF 'HASS' AVOCADO TREES IN 'ON' AND 'OFF' FLOWERING YEARS IN THE WESTERN BAY OF PLENTY

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ABSTRACT

Shoot growth occurs at specific times of the year with less shoot growth in 'on' flowering years than 'off' flowering years. The difference in shoot growth is considered to be a driver of alternate bearing as the shoot growth in spring each year becomes the fruiting wood in the next spring. To have a better understanding of shoot growth in 'on' and 'off' flowering years the data from the phenology monitoring project for the past four years was analysed. Avocado shoots grow slowly at first then increase in length at a relatively steady rate in an approximately linear manner before growth slows and stops. The overall rate of shoot growth was similar between 'on' and 'off' flowering years. Shoots had no period of constant growth but growth was synchronised within the tree, starting and stopping at a similar time on all branches at each aspect. The average duration of shoot growth was between about 80 and 110 days each year with a trend for the duration of shoot growth to be longer in the 'off' flowering year. The flower panicle grew with the same sigmoidal pattern as the vegetative shoot but for less time. Panicles continued to grow when the vegetative shoot started to grow and stopped at the peak of flower opening. Once individual flowers started to open the growth of the vegetative shoot increased being greatest during flower opening. The vegetative shoot growth decreased when flower opening was almost finished. Fruit numbers increased when shoot growth had slowed and almost stopped. The fruit drop appeared to coincide with the stopping of shoot growth. Thus shoot growth appeared to follow a pre-determined growth pattern. Where there was adequate light all around the tree the length of shoots was similar at each aspect. That flower opening and shoot growth appeared to be linked suggests that shoot growth can inhibit fruit set. Shoot growth appeared to be predictable indicating that measuring the rate of shoot growth it would be possible to assess if growth was sufficient for good flowering in the following spring.

Keywords: *phenology, duration, aspect, panicle*

INTRODUCTION

Managing avocado trees for consistent crops requires the avocado grower to apply inputs like fertiliser to the tree at the best time for shoot growth. When planning the timing of orchard management activities it is useful to have a good understanding of how the tree is growing in order to achieve the best outcomes. Shoot growth is an obvious activity of the tree that occurs at specific times of the year. On 'Hass' avocado trees in the AIC phenology monitoring project there can be three shoot flush periods each year corresponding to spring, summer and autumn. Each flush occurs about the same time each year (Dixon *et al.*, 2006). The first flush in spring 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. Individual avocado trees can alternate bear where the crop being carried on the tree is greater or smaller from one year to the next. In addition to the amount of crop changing each year the amount of shoot growth also changes. The differences in shoot growth between 'on' and 'off' flowering years are considered to be one of the main drivers of alternate bearing as the new shoot growth in spring each year becomes the fruiting wood in the following spring (Cutting, 2003). By better understanding how the shoots grow with respect to the pattern of increase in length, the rate of shoot growth and the duration of shoot growth under different circumstances, orchard management activities can be timed for greater effectiveness. The data on shoot growth collected as part of the phenology monitoring project for the past 4 years has been analysed to describe some of the important aspects of 'Hass' avocado shoot growth in both 'on' and 'off' flowering years. This information can then be used to consider if changes in the timing of orchard management activities, such as fertiliser application, may be required.

MATERIALS AND METHODS

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

The growth rates of shoots were calculated from a linear regression of the point where the increase in shoot length became approximately linear to the point where the increase in shoot length began to slow. Shoot length and growth was analysed by a One-Way Analysis of Variance using MINITAB version 13.31.

RESULTS

Shoot Growth

In general, the greatest amount of shoot growth was in spring each year while in summer there was less shoot growth. The amount of shoot flush overall the trees 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 similar to 2005 with a weak summer flush (Data not shown).

Avocado shoots grow in a well defined pattern where the shoot starts to grow slowly, then the length of the shoot increases at a relatively steady rate in a linear manner before the growth eventually slows and stops (Figure 1). For shoots that grow in both the spring and summer the pattern of growth is the same but summer grown shoots are shorter and grow more slowly than spring shoots. The average amount of growth can vary according to the cardinal position on the tree of the branch and between trees in different orchards (Figure 1). For the orchard located in

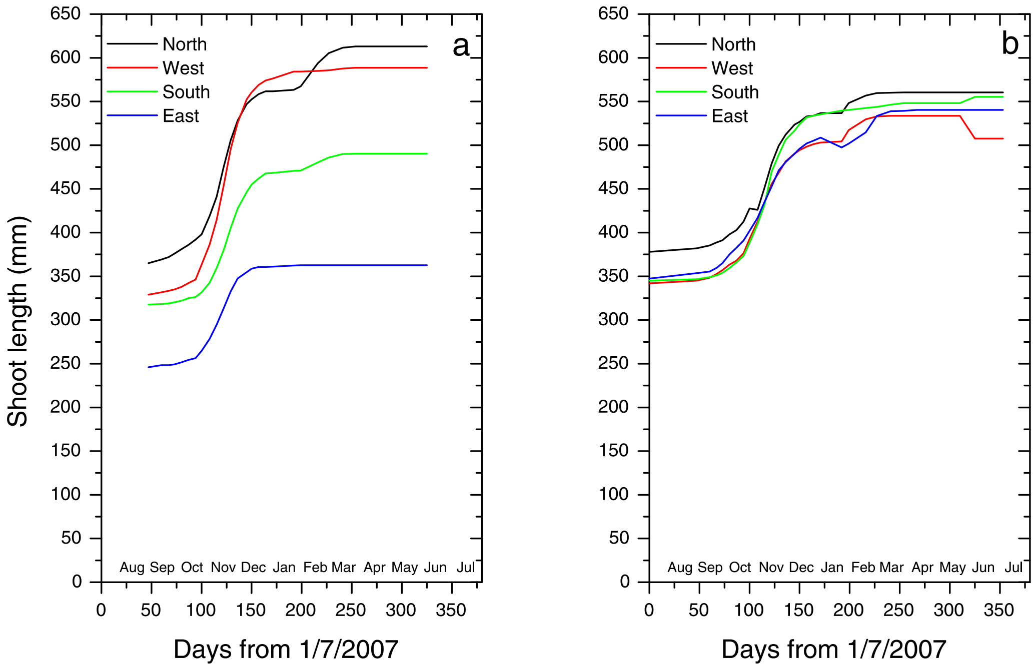

Figure 1. Average cumulative shoot length of indeterminate flowering shoots on each cardinal face of 'Hass' avocado trees in an orchard located in a) Te Puna or b) Tauranga in the spring and summer of 2007-2008. Each line is the average of 15 branches.

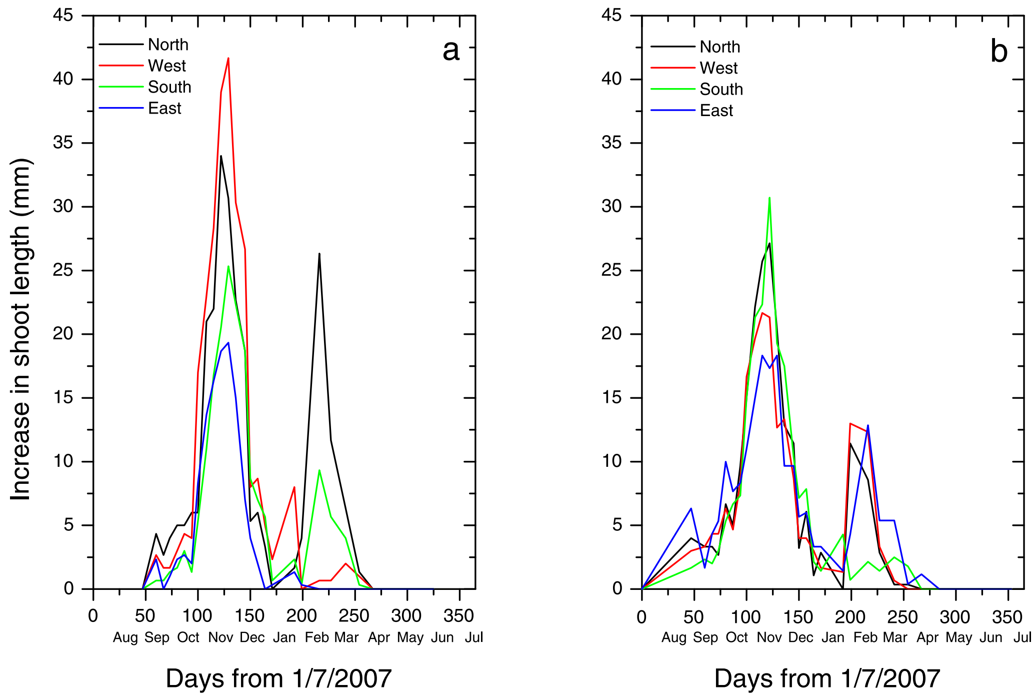

Figure 2. Average increase in shoot length of indeterminate flowering shoots every 14 days on each cardinal face of 'Hass' avocado trees in an orchard located in a) Te Puna or b) Tauranga in the spring and summer of 2007-2008. Each line is the average of fifteen branches.

Te Puna the north and west facing shoots grew more and faster than the shoots facing south and east (Figure 1a). By contrast, the shoots on the trees in an orchard located in Tauranga differed little in growth between the cardinal positions on the tree (Figure 1b).

The average increase in shoot length had a pattern of a small peak in growth at the beginning of flowering then a rapid increase in length reaching a peak in November before declining and stopping in January (Figure 2). The summer shoot flush has the same pattern of growth starting in January, peaking in February and stopping in March. The growth of the shoots in spring for the orchard at Te Puna was the greatest on the west facing shoots followed by north, south and east facing shoots (Figure 2a). The spring shoots in the orchard in Tauranga had the greatest increase on the south facing then the north, west and east (Figure 2b).

The growth of shoots in the summer did not follow the same pattern as in spring with the greatest increase in shoots that were north facing for the orchard in Te Puna. The increase in shoot length on trees in the orchard in Tauranga was similar for north, west and east facing shoots.

The total shoot growth in spring in 'on' or 'off' flowering years while not significantly different tended to be greater in both orchards in the 'off' flowering year when averaged across all aspects (Table 1). North facing shoots had consistently greater total shoot growth in the 'off' flowering year than the 'on' flowering year while the south facing shoots had almost the same total growth in 'on' or 'off' flowering years in both orchards (Table 1). The west and east facing shoots had a different pattern between 'on' and 'off' flowering years between the orchards.

Table 1. Average total shoot growth (mm) of indeterminate spring shoots in 'on' or 'off' flowering years on each cardinal face of 'Hass' avocado trees from 2004 to 2008.

Orchard	Te Puna			Tauranga		
Aspect	'On' year	'Off' year	Mean	'On' year	'Off' year	Mean
North	187.0	201.2ac[1]	196.4ac	159.0	176.5	170.7
West	171.5	233.8a	213.0a	179.5	148.3	158.7
South	153.0	152.3bc	152.7bc	169.5	169.8	169.7
East	161.5	133.5b	142.8b	171.5	189.3	183.3
Mean	168.3	180.2		169.9	170.9	

[1]Means followed by the same letter within a column are not different according to a One-Way Analysis of Variance using a Tukey's family error rate of 5%

The rate of shoot growth on the avocado trees used in this study was between 1.4 and 3.0mm per day. The overall average rate of shoot growth was similar between 'on' and 'off' flowering years for each orchard and tended to be slightly slower on the shoots for the orchard in Tauranga compared to the shoots on the Te Puna orchard (Table 2). The rate of shoot growth at the north and west facing in the Te Puna orchard and the west facing in the Tauranga orchard was different between years (Table 2). The rate of shoot growth was similar on the south and east facing shoots each year for the Te Puna orchard and the north, south and east facing shoots for the Tauranga orchard.

The average duration of shoot growth was between about 80 and 110 days each year (Table 3). There was a trend for the duration of shoot growth to be longer in the 'off' flowering year compared to the 'on' flowering year across both orchards (Table 3). The duration of shoot growth on each face of the tree differed between 'on' and 'off' flowering years (Table 3). Within each orchard there was a different pattern of the duration of shoot growth at each facing. On trees in the orchard located at Te Puna the shortest to longest duration of growth in the 'on' flowering year was on the north, west, south and east facings while in the 'off' flowering year the pattern was reversed (Table

Table 2. Average rate of shoot growth (mm/day) of indeterminate spring shoots in 'on' or 'off' flowering years on each cardinal face of 'Hass' avocado trees from 2004 to 2008.

Orchard	Te Puna			Tauranga		
Aspect	'On' year	'Off' year	Mean	'On' year	'Off' year	Mean
North	2.7[1]	1.9ab[2]	2.2ab	1.8	1.7	1.7
West	1.9	2.6a	2.4a	2.0	1.4	1.7
South	1.7	1.7b	1.7b	1.9	1.8	1.9
East	1.7	1.6b	1.6b	1.9	1.7	1.8
Mean	2.0	2.0		1.9	1.7	

[1]Grow rate for the most linear portion of the growth curve which was a part of the total duration of shoot growth; [2]Means followed by the same letter within a column are not different according to a One-Way Analysis of Variance using a Tukey's family error rate of 5%

Table 3. Average duration of shoot growth (days) of indeterminate spring shoots in 'on' or 'off' flowering years on each cardinal face of 'Hass' avocado trees from 2004 to 2008.

Orchard	**Te Puna**	**Tauranga**				
Aspect	**'On' year**	**'Off' year**	**Mean**	**'On' year**	**'Off' year**	**Mean**
North	79.9[1]	111.1	100.7	99.4	105.2	103.2
West	92.7	99.9	97.5	106.6	110.4	109.1
South	93.7	94.3	94.1	88.4	96.0	93.5
East	94.1	89.2	90.8	91.6	110.8	104.4
Mean	90.1	98.6		96.5	105.6	

[1]The start of shoot growth was considered to be at floral bud emergence of an indeterminate flowering shoot and the finish of shoot growth was when the apical bud ceased growing.

Table 4. Average total shoot length, duration of growth and rate of growth of indeterminate spring shoots each year and average growing degree days above 10°C (GDD10C), total rainfall and average soil moisture matrix potential during the period of spring shoot growth each year of 'Hass' avocado trees from 2004 to 2005.

Orchard	**Year**	**Length mm**	**Duration days**	**Rate of growth mm/day**	**GDD10C**	**Rainfall mm**	**Soil moisture -kPa**
Tauranga	2004	153.8	101.2	1.7	468.3	306.0	25.3
	2005	183.5	99.7	2.0	722.8	586.5	21.8
	2006	186.0	91.9	2.2	607.8	339.5	50.5
	2007	166.8	107.6	1.6	604.2	304.5	61.8
Te Puna	2004	156.0	97.0	1.8	753.4	367.5	15.3
	2005	179.9	101.2	1.9	751.7	746.5	16.2
	2006	180.5	83.3	2.2	432.4	237.5	19.4
	2007	180.3	97.8	2.0	571.3	313.5	23.9

3). In the orchard located at Tauranga there was no clear pattern between the years or which facing had the shortest or longest duration of growth.

The average shoot length, duration of growth and rate of shoot growth was weakly related to growing degree days above 10°C, total rainfall and average soil moisture matrix potential over the shoot growth period (Table 4).

Components of shoot growth

While avocado shoot growth followed a sigmoidal growth pattern the increase in shoot length for an indeterminate flowering shoot from a resting bud in winter was composed of the growth of both the flower panicle and the vegetative shoot (Figure 3). The flower panicle grew with the same sigmoidal pattern as the vegetative shoot but for a shorter duration. Panicle extension continued once the vegetative shoot started to grow and typically stopped at the peak of flower opening (Figure 3). Once the individual flowers started to open the growth rate of the vegetative shoot increased and was greatest during the period of flower opening. The vegetative shoot rate of growth decreased when the period of flower opening was almost complete (Figure 3). An increase in fruit numbers was observed when the shoot growth had slowed

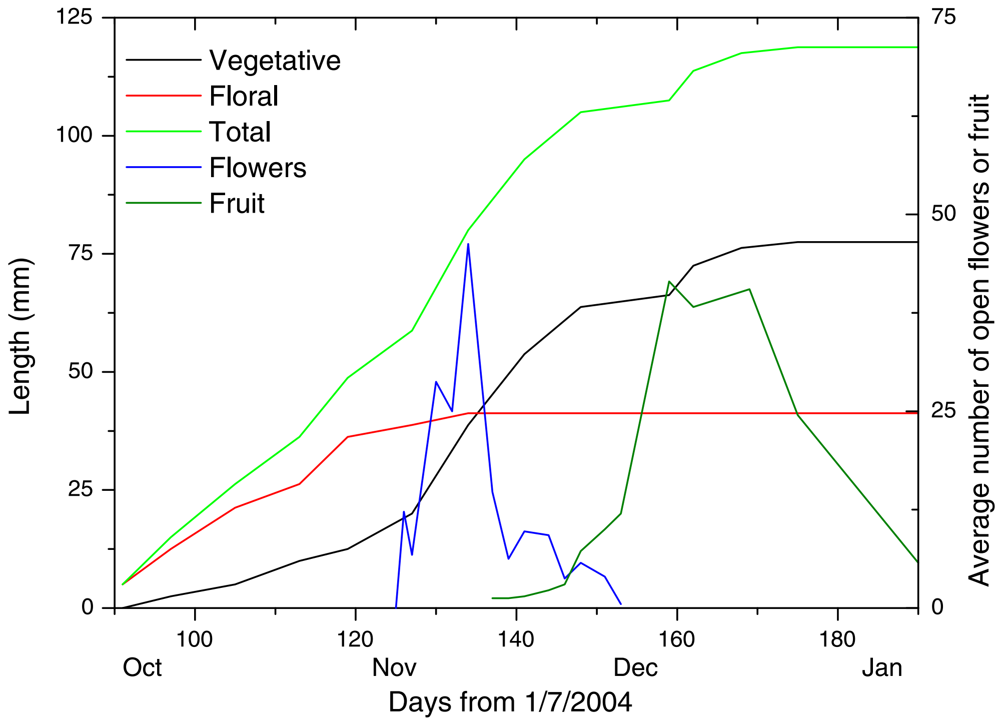

Figure 3. Average increase in length of the apical panicle and vegetative shoot with the average number of open flowers for an individual tree in the Te Puna orchard in 2004.

and almost stopped. A continual decrease in fruit numbers appeared to coincide with the cessation of shoot growth.

DISCUSSION

The sigmoidal pattern of cumulative shoot length is typical of the shoot growth pattern for many plants (Salisbury and Ross, 1992; Taiz and Zeiger, 1998). The cumulative increase in shoot length showed there was a period of increasing growth for a certain amount of time before declining and stopping. There was no period of constant growth but shoot growth was synchronised within the tree starting and stopping at a similar time on all branches at each aspect. The summer flush followed the same pattern but grew less than the spring flush. As this pattern was consistent each year and tree to tree it should be possible to predict when shoot growth will stop once the start or midpoint (maximum change in shoot length) is known. Thus shoot growth once started appears to follow a pre-determined growth pattern. The rate of shoot growth was similar on all branches but tended to be greatest where there was the most light and presumably greatest warmth, on the North and West sides of the trees. It would be possible to identify if there would be a need for canopy management following shoot growth by measuring how much shoot growth has occurred then projecting forward the lightly duration of shoot growth. If the shoot was going to become too long then the shoot could be reduced in length by pruning.

Shoots at different aspects on the trees grew to different average lengths in the orchard located at Te Puna where the trees were shading one another on the South and East sides. The length of shoots was similar at each aspect where there was adequate light all around the tree. The start and cessation of shoot growth was not affected by shading. This suggests the possibility that the timing and duration of shoot growth may be determined before spring. Should shoot growth be predetermined then the amount of shoot growth in spring could be predicted before it starts. An advanced notification of the amount of shoot growth would then allow the possibility of early intervention, for example additional fertiliser applied, if the potential new growth was judged to be inadequate. The summer shoot flush had the same growth characteristics as the spring shoot flush suggesting that shoot growth in summer could also be predetermined. At present we don't know what factors could set up shoot growth but they may include: the amount and timing of fertiliser application, water availability, crop load, flowering intensity and leaf emergence. The physical characteristics of shoots such as initial shoot length and thickness may also influence the amount, rate and duration of shoot growth. To gain a more detailed understanding of the factors that determine shoot growth further research is required.

The shoots were generally longer in an 'off' flowering year but there was also an influence of the aspect with the North and West facing shoots the longest. The additional length on the North and West facings may have been due to greater light levels and warmer temperatures. Such variable lengths in shoots at the different aspects may indicate there is competition at the different aspects of the tree for resources. Competition for resources between different parts of the tree appears to be unlikely as there was little difference in shoot length when there was no shading. It is possible that shoot growth is affected by the position on the tree where there are high light levels such as that found at the top of the tree. This study has not determined if shoot growth can be stimulated by addition of fertiliser and availability of water. The implications of the pattern of shoot growth are that once started shoot growth will follow a predetermined pattern that is not easily affected. If shoot growth is largely unaffected once started then the best time to apply fertiliser may be before shoot growth starts. The pattern of shoot development, proleptic or sylleptic, may affect fruit set potential as sylleptic shoots have greater numbers of flowers. Predicting the type of shoot that develops is likely to be important for predicting fruit set potential. Knowing the best shoot type for fruit set will help to define the kind of growth a grower should encourage on a tree for the most consistent cropping. Further study is required to determine if there are separate growth patterns for each shoot type. Such information could be used in determining the types of branches to be removed as part of a pruning programme.

Indeterminate avocado shoots are composed of both vegetative shoots and also flowering tissue. The growth of the panicle occurs before and with the same sigmoidal pattern as the vegetative shoot but the panicle starts and stops growing at different times to the vegetative shoot. The factors that induce a shoot to start growing and to stop growing are not well understood at present but when the shoots stop growing in summer the availability of water and nutrients are not likely to be limiting and there are high light levels and warm temperatures. That two types of tissue contribute to the development of a branch suggests two separate systems may be involved that control panicle expansion and shoot growth. Panicle expansion was linked to the opening of individual flowers as it stopped once flower opening ceased. Shoot growth was also affected by flowering as the rate of shoot growth increased once panicle expansion stopped. The linkage between flower opening and shoot growth may explain the competitive inhibition shoot growth may have on fruit set. There is a further suggestion that determinate shoots could have more resources than indeterminate shoots as the resources are not needed for shoot growth. It is also possible that shoot growth may be increased if the flowers were removed. Possible experiments where flowers are removed from indeterminate shoots to increase shoot growth could demonstrate the influence of shoots and flowers on promoting or inhibiting shoot growth.

There was no obvious relationship between climatic factors, such as temperature, rainfall and soil moisture potential, on shoot growth. This is not surprising as there were only two sites being measured in this study. This is insufficient replication to allow conclusions to be drawn on the relationship between climatic factors and shoot growth. There are other variables such as nutrient availability that may also have a strong influence on shoot growth. To determine the relationship on shoot growth and climate, replicated experiments are required where treatments can be imposed modifying shoot growth, rather than a survey as reported here. The information presented in this report indicates that shoot growth is not occurring in isolation and is likely to be co-ordinated with other phenological events. Future research will be focused on seeking a greater understanding of how shoot growth interacts with other phenological events through considering questions such as how much shoot growth is required to compete with fruit set depending in the 'on' or 'off' flowering year? Should shoot growth during spring occur in a pre-determined manner an important research direction may be on the factors that set up shoot growth on the tree.

CONCLUSIONS

Avocado shoot growth follows the same pattern at all aspects on the tree but is reduced on shaded parts of the tree. Shoot growth on individual branches was similar in the 'on' or 'off' flowering years. The start and finish of shoot growth occurs at about the same time suggesting that the amount of shoot growth may be pre-determined before spring or summer. Shoot growth appears to be predictable indicating that by measuring the rate of shoot growth an avocado grower would have a tool to assess if there is sufficient growth for good flowering in the following spring.

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