PATTERNS OF FRUIT GROWTH AND FRUIT DROP OF 'HASS' AVOCADO TREES IN THE WESTERN BAY OF PLENTY, NEW ZEALAND

J. Dixon, C.B. Lamond, D.B. Smith and T.A. Elmlsy
Avocado Industry Council Ltd., P.O. Box 13267, Tauranga 3110
Corresponding author: jonathandixon@nzavocado.co.nz

ABSTRACT

Good avocado orchard profitability in New Zealand depends on obtaining consistent high yields of large fruit. A good understanding of how the fruit grow and are retained is required to determine the best orchard management techniques to overcome alternate bearing. Little information exists for New Zealand 'Hass' avocado fruit on fruit growth and patterns of fruit drop. To determine the patterns of fruit set, fruit growth and interaction between fruit growth and fruit drop the growth of individual fruit were followed closely over one season. Large numbers of fruit are set initially but most of these fruit fall off by December in an apparently random pattern. The fruit that were retained were not in any single identifiable position within the panicle. The fruit increased in size in an S-shaped pattern as described by earlier researchers. There were two growth phases, an initial rapid growth phase that lasted from the end of flowering until at least March then a linear growth phase during winter until the fruit were harvested. The fruit were variable in the rate of growth within each phase. Fast growing fruit in the initial growth phase were not necessarily fast growing fruit in the linear growth phase. In general, the growth rate of fruit in the linear phase was about the same. As the growth rate of the fruit in the linear phase was similar it would be possible to predict the time when the fruit size profile reached a desirable size. This could then serve as a useful tool for avocado growers to plan their harvests for the most profitable fruit sizes.

Keywords: *cell division, growth rates*

INTRODUCTION

A key driver of avocado orchard profitability in New Zealand is obtaining consistent high yields. Therefore, large numbers of fruit need to be set and retained through to harvest. These fruit also need to grow to acceptable sizes that are desired by consumers of New Zealand avocados. A good understanding of how the fruit grow and are retained is required when determining the best orchard management activities to mitigate alternate bearing. Avocado fruit set follows effective pollination of avocado flowers (Dixon and Sher, 2002). The newly set fruit then grow rapidly and go through two main periods of fruit drop, one after flowering is completed and the other in February (Cutting and Dixon, 2004). As both fruit growth and fruit drop occur at the same time there is a possibility that differences in fruit growth between fruit are related to when the fruit falls off.

Botanically the avocado fruit is a single seeded berry with an unusual growth characteristic in that cell division continues as long as the fruit remains attached to the tree (Schroeder, 1953). Unlike many other fruit where fruit growth is by cell division followed by a period of cell expansion and then cell division and cell expansion avocado fruit have been observed to grow mainly by cell division. The growth of avocado fruit has been described as the following: in the first six weeks of development growth is by very rapid cell division, then cell enlargement which can stop at about 50% of its final size at maturity, after which the fruit size continues to increase by cell division (Cummings and Schroeder, 1942; Barmore, 1977). The growth curves of fruit from the avocado cultivars 'Fuerte' (Marsh, 1935; Schroeder, 1953; McOnie and Wolstenholme, 1982; Lee and Young, 1983), 'Hass' (Lahav and Kalmar, 1977, McOnie and Wolstenholme, 1982; van den Dool and Wolstenholme, 1983), and 'Lula' (Piper and

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Gardner, 1943) have been characterised. The fruit growth curve is S-shaped when mass or volume are plotted over time and usually is flat without marked periods of very rapid growth (Schroeder, 1953). The growth of fruit each day is influenced by the diurnal fluctuations in size where the fruit grows and shrinks with the water status of the tree (Schroeder and Wieland, 1956). The main increase in size happens during the night with the fruit slightly bigger at the beginning of each day (Schroeder, 1958). Differences in fruit size have been attributed to the timing of flowering with the oldest fruit on the tree attaining the largest size (Hatton and Reeder, 1969). The variation in fruit size has also been speculated to occur due to cultural practices, cross pollination, yield, water availability and climate (Barmore, 1977; McOnie and Wolstenholme, 1982; Gafni, 1984).

The developing seed within the fruit is thought to very strongly influence fruit growth by producing plant hormones that increase the sink strength of the fruit (Blumenfeld and Gazit, 1970a,b). The cause of fruit drop is thought to be related to changes or problems with the hormonal signals of the new fruit (Bower and Cutting, 1988). In particular the plant hormone ethylene is believed to be important for promoting the drop of the newly set fruit (Adato and Gazit, 1977). Most of the fruit that drop after the initial fruit set are either seedless or have a degenerated seed (Gazit and Degani, 2002). The fruit that drop later have developed problems with the seed coat. Other causes of fruit drop may be that the newly developing shoots compete with the newly set fruit and that cross pollinated fruit "out-compete" close pollinated fruit (Gazit and Degani, 2002). Little information exists on the patterns of fruit set within a panicle, *i.e.* do the first flowers to open set a fruit more frequently than flowers that open later? There is also little known about the pattern of fruit drop and the relationship between the fruit that drop and the growth rate of the fruit. And how does the final size of the fruit relate to the initial rates of growth? To determine the patterns of fruit set, fruit growth and any interaction between fruit growth and fruit drop the growth and time when individual fruit dropped was closely followed over the flowering and fruit growth in one season.

MATERIALS AND METHODS

All observations were conducted on one orchard in Te Puna located in the Western Bay of Plenty, New Zealand. One flowering branch was selected on each of 10 'Hass' grafted onto 'Zutano' seedling rootstock trees for marking the exact position of initial fruit set and for determining fruit abscission from December to February. Individual fruit diameter and length was measured to the nearest 1/10mm using 150mm digital callipers. Measurements of fruit size of attached fruit were taken at 10 to 13 day intervals as permitted by the weather. The width of all newly set fruit on 10 flowering shoots from one tree were measured from 5/12/2004 to 7/3/2005. The surviving fruit from the tree and the fruit on 10 shoots from a further nine trees were measured for width and length from 5/5/2005 to 27/9/2005. A total of eight fruit on the first tree survived from the initial fruit set to harvest. Fruit that had abscised between measurements were no longer counted. The mass of fruit was calculated using a formula based on the summing together the volume of a sphere: 4/3 x π x (width/2 x width/2 x length/2), and the volume of a cone: 1/3 x x (width/2 x length/2). To approximate the shape of an avocado fruit where the cone and sphere are co-joined the volume of a sphere was reduced by about one-third and the volume of a cone by about one-quarter. This formula calculated the mass of an individual avocado fruit very accurately when the calculated mass was compared to values obtained by volume displacement (Pak, 2002). Comparisons between measurements were analysed by One-Way ANOVA using MINITAB 13.31.

RESULTS

Patterns of fruit drop

The pattern of fruit drop was similar across the branches where the fruit size and numbers were monitored. The spring of 2004 was an "on" flowering and fruit set year with the trees used in

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the study setting and retaining a heavy crop of greater than 20 t/ha. The numbers of newly set fruit on each flowering shoot ranged from 30 to 200 immediately following flowering. Between 40 to 80% of the remaining fruit abscised every 10 to 14 days during December and January. The diagrams in Figure 1 illustrate the pattern of fruit drop and highlight that there were large numbers of fruit initially which dropped in a random pattern. There were no obvious positional effects on fruit retention with the fruit that survived the December and January drop distributed along the flowering branch.

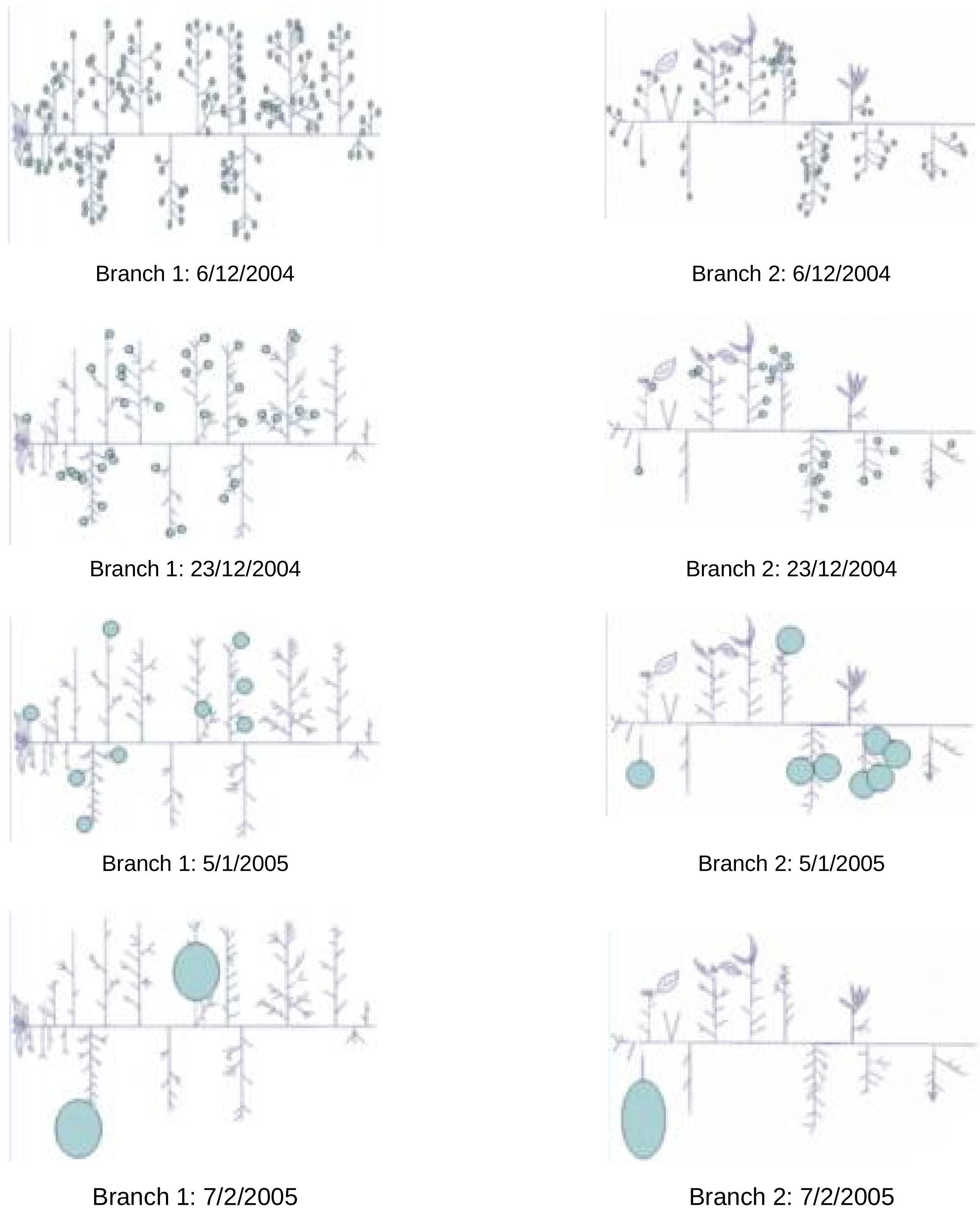

Figure 1. Position and number of fruit on two indeterminate flowering branches from 6/12/2004 until 7/2/2005.

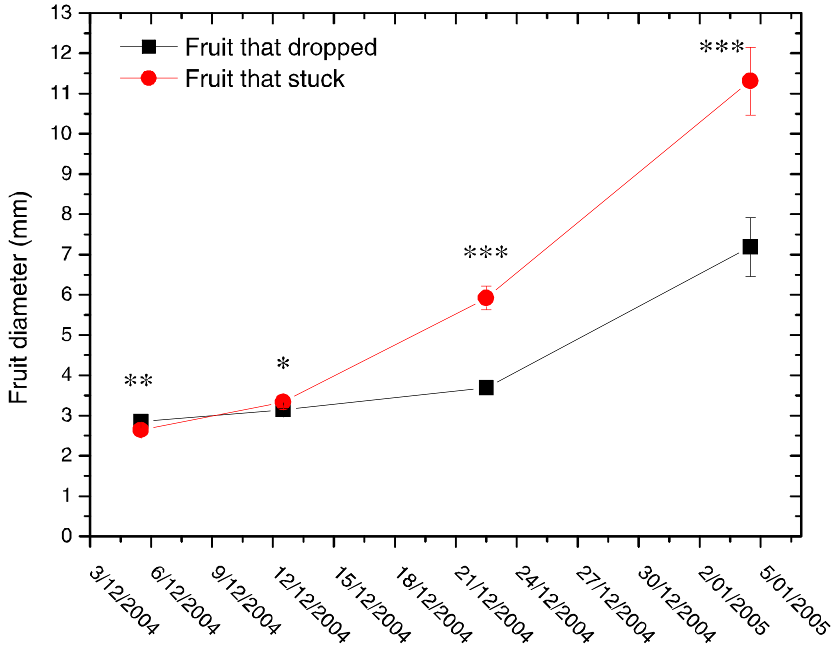

Figure 2. Diameter of newly set 'Hass' avocado fruit that either abscised or remained attached to the tree following measurement. Significance levels: * = $p < 0.05$, * * = $p < 0.01$, * * * = $p < 0.001$.

Fruit size and fruit drop

The fruit that dropped at the same assessment dates between 3/12/2004 and 7/1/2005 grew more slowly and were smaller than the fruit that were retained (Figure 2). Although statistically significant the sizes of fruit at each assessment date in early December (5/12/2004 and 13/12/2004) were very similar. From the latter half of December the fruit that dropped were smaller by up to half the size of fruit that did not drop.

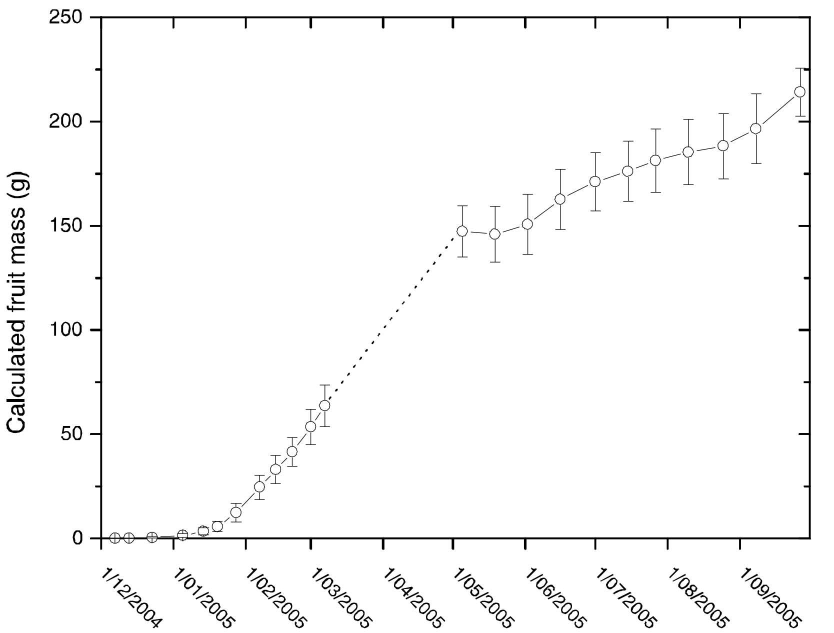

Figure 3. Change in size of fruit from fruit set, about mid November 2004, until harvest at the beginning of October 2005. Vertical bars represent the standard error of the mean for eight fruit from one tree.

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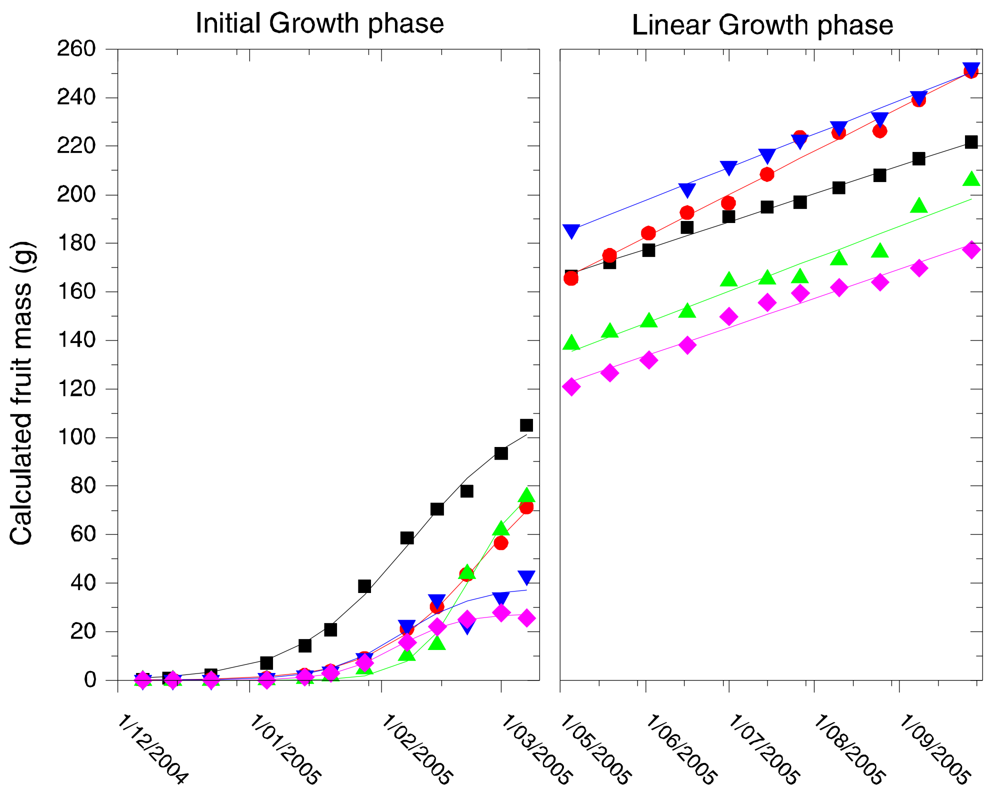

Figure 4. Change in size of individual fruit from one tree in the initial growth phase from fruit set until mid March and then the same fruit during the linear growth phase from May until harvest in the beginning of November.

Fruit growth

In general, fruit growth was in two phases. There was an initial rapid growth phase that could be described by a sigmoid function and a later linear growth phase (Figure 3). The growth of individual fruit was variable with some fruit growing up to four times the size of other fruit by March (Figure 4). The fruit that were the largest by March were not necessarily the biggest fruit at harvest. Growth rates of some fruit changed between initial growth phase period and the linear growth phase period. These fruit grew faster over the winter period (May to August) than other fruit that grew faster in the initial rapid growth phase.

DISCUSSION

Pattern of fruit set and drop appears to be random and may reflect more the variability in which flowers receive effective pollination and that many more fruit are set initially than the tree can carry. There is also no indication that there is more fruit set in particular positions on the panicle corresponding to the first to open flowers. The pattern of flower opening has been casually observed by the authors to follow no apparent pattern also. In other words, flowers at the base of the flowering stalk or at the tips of panicles do not necessarily open first. Such a lack of a pattern in flower opening is reflected in the pattern of initial fruit set appearing to be random as well. It is also not possible to predict which fruit will drop or be retained from the initial fruit set. The reason for the apparent random nature of the fruit drop is not known at present and requires further study.

There was a difference in the size of fruit that dropped in the first main period of fruit drop. The smaller fruit at any particular time, apart from just after flowering had concluded, were the most likely to abcise. The cause of the smallest fruit to drop off is not well understood but has been speculated to be due to a number of factors associated with the newly developing seed (Bower and Cutting, 1988).

The fruit that grow the least may have defective seeds (Gazit and Degani, 2002) or are "weaker" genetically and cannot provide a strong enough hormonal signal that prevents the fruit drop process from happening (Gazit and Degani, 2002). The observations reported here suggest that fruit growth and fruit drop are related in that the smallest fruit are the most likely to be shed from the tree. However, some small rapidly growing fruit are retained when other similar sized fruit are shed. There may also be a temporal factor where once the fruit reach a certain age or time from pollination they are either retained or shed. This would partly explain why some small fruit are retained when they were set later than other larger fruit (Figure 4).

The increase in the size of the fruit followed the same pattern as reported by Pak (2002). There was a two month period where the fruit growth was not recorded between the initial rapid growth phase and the linear growth phase. Based on the previous measurement by Pak (2002) of fruit on trees from the same orchard as in this study, we consider that the fruit size is most likely to have continued to increase rapidly until April and then entered the linear growth phase. This change in growth pattern in April agrees well with the morphological studies of fruit growth (Cummings and Schroeder, 1942) as the fruit in April were about half their final size at maturity. Based on previous research (Cummings and Schroeder, 1942) fruit growth from December until April was by both cell division (an increase in the number of cells) and by cell expansion. Once the winter period started cell expansion ceased and cell division was responsible for the fruit growth. The differences in the growth of individual fruit would indicate that growth due to cell division in winter may be influenced by different factors than in the initial rapid growth phase. Most of the fruit in the linear growth phase grew at the same rate (Figure 4) with the odd fruit as an exception. Climatic factors during winter may be the most important driver of fruit growth whereas competition for resources between fruit and factors to do with the seed may be more important in the initial growth phase.

The continued growth of the fruit by cell division from May onwards in a constant linear manner implies that it should be possible to predict when the fruit size will reach an arbitrary target. By measuring the change in fruit size several times during winter and calculating the rate of growth of the fruit it should be possible for to predict when the fruit will reach a certain size. This information could then be used to plan a harvesting schedule around a desired fruit size profile and could be used to predict the required interval between selective harvests so that small fruit in an early harvest can be harvested at a more desirable fruit size.

CONCLUSIONS

The patterns of fruit drop appear to be random and are therefore unpredictable. While the slowest growing fruit are in general the most likely to be shed by the tree the smallest fruit are not always shed. The fruit growth pattern was the same as reported overseas and in New Zealand with a rapid initial growth phase followed by a linear growth phase in winter. Fruit growth rates in winter could be used to predict fruit size profiles at harvest.

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