

FACTORS INFLUENCING FRUIT SET OF HASS AVOCADOS IN NEW ZEALAND.

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New Zealand has some of the southern most commercial avocado orchards in the world. The Bay of Plenty is the main growing region, at 37° to 38° South, with mean annual temperatures of 14.7 to 15.1°C that appears to suggest that the climate is marginal for successful avocado crops. However, a number of orchards consistently achieve yields in excess of 20 tonnes ha⁻¹, some reaching 30 tonnes ha⁻¹ in an 'on' year. Temperatures have been recorded during the main flowering and fruit set period over a number of years for more than 40 orchards throughout the major avocado growing regions of New Zealand and have been analysed with respect to the relationship of final yield to temperature. The analysis was to determine if the daily changes in temperature patterns over flowering and fruit set each year could explain the yearly fluctuations in yield from each orchard. The relationships between the patterns of daily temperatures, temperature accumulation and periods of "cold" events to yield and initial fruit set have been analysed. These relationships indicate that temperature alone is not limiting Hass avocado crops under the climatic conditions in New Zealand. Flowering and pollination appear to be sufficient for a large initial fruit set each year but the retention of the new fruit varies from year to year. Other possible limitations on Hass avocado fruit set such as water stress, nutrient availability and timing could influence alternate bearing and will be discussed along with the role of temperature on avocado flowering and fruit set.

Keywords: temperature, soil moisture, boron, flowering, yield, pollination events

FACTORES QUE INFLUENCIAN EL CUAJADO DE FRUTOS DE PALTA HASS EN NUEVA ZELANDA.

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Algunos de los huertos comerciales de palta más al sur del mundo están en Nueva Zelanda. Bay of Plenty, la principal zona de producción, se ubica entre los 37 y 38° de Latitud Sur con temperaturas medias de 14,7 a 15,1°C. Bajo este clima, aparentemente deficiente para el cultivo de paltos, se alcanzan de manera consistente producciones sobre las 20 Ton ha⁻¹ y en algunos huertos hasta 30 Ton ha⁻¹ en un año de alta carga de frutos. Durante varios años, se registraron temperaturas durante los períodos de floración y cuajado de frutos en más de 40

huertos de palta a lo largo del país y, además, se analizaron con respecto a la relación entre producción final y temperatura. El análisis se realizó para determinar si los cambios diarios en los patrones de temperatura durante la floración y cuajado de frutos, podrían explicar las fluctuaciones anuales en la producción de cada huerto. Dicho análisis incluyó la relación entre los patrones de temperatura diaria, la temperatura acumulada y los eventos de “frío”, así como el cuajado inicial de frutos. Estas relaciones indican que la temperatura por sí sola, no limita el cultivo de paltos bajo las condiciones climáticas en Nueva Zelanda. Al parecer, la floración y polinización ocurren en cantidad suficiente para producir un cuajado inicial grande de fruta, aunque la retención de éstas varía cada año. Otras posibles limitantes del cuajado de palta Hass, como el estrés hídrico y la disponibilidad de los nutrientes, que podrían provocar la alternancia de producciones, también serán discutidas conjuntamente con el papel de la temperatura sobre la floración y el cuajado de paltas.

2. INTRODUCTION

Defining the key factors that determine avocado yield is of importance to New Zealand avocado growers in order to achieve consistent high yields from their trees. Many trees in New Zealand orchards are observed to be strongly alternate bearing. The alternate bearing pattern of production within commercial New Zealand avocado orchards is widely attributed by New Zealand avocado growers and consultants to spring temperatures being marginal for successful avocado pollination and fruit set. Despite the trees experiencing relatively low temperatures over the main flowering and fruit set periods of October and November there are a number of orchards where yields in excess of 20 tonnes/ha are consistently achieved. There are also orchards that frequently exceed 30 tonnes/ha in an ‘on’ year of an alternate bearing cycle. Such yields would suggest that low temperatures during flowering may not be limiting fruit set. Orchard factors other than temperature therefore require investigation. The additional factors that have been reported to affect avocado fruit set are soil moisture matrix potential (Whiley and Lahav, 2002) and inflorescence boron content (Lahav and Whiley, 2002).

The Mexican and Guatemalan highlands are generally considered to be the area of origin that defines the ideal climate for the main commercially grown avocados in New Zealand, Hass fruiting scion on Zutano rootstocks. The climate of these areas has been described as having an average mean annual temperature of 15.9°C and rainfall of 860mm with the type of climate categorized as semi-tropical/subtropical highland (Wolstenholme, 2002). The mean annual temperature for the Western Bay of Plenty (36° to 37° South) that is the major growing region of Hass avocados in New Zealand over the last 14 years has been 15.0°C with a range of 14.3°C to 15.7°C. Rainfall averaged 1114mm and was relatively evenly distributed over the year with the late summer/autumn having the most rain on average. In New Zealand

avocado orchards the main flowering period is in spring (October/November) where night temperatures can often fall below 10°C and occasionally fall below 5°C. The lower mean annual temperature in the commercial avocado growing regions of New Zealand compared to the area of avocado origin is considered to be the cause of poor fruit set of Hass avocados (Dixon and Sher, 2002). The following reasons are used to justify this point of view:

- flower opening patterns are affected by cool temperatures with a truncation of the duration of the female flower opening on cool days reducing the time available to transfer pollen to the flowers within each day (Sedgley and Grant, 1983)
- honeybee activity for pollination is dependant on sufficiently warm temperatures that only occur for a short time each day (Robbertse et al, 1995)
- pollen grain germination and pollen tube growth are temperature dependant with an optimum growth rate at 25/20°C (day/night) (Sedgley, 1977); these temperatures are very rare in spring
- three or four days are required for fertilisation to occur at a constant 25/20°C (day/night) temperatures (Sedgley, 1977); long periods of warm temperatures are rare in spring.

For effective pollination to occur it has been postulated that 48 hours of stable weather conditions are required to achieve fruit set (Dixon and Sher, 2002). In New Zealand, two consecutive days where the daytime temperature exceeds 17°C and the night temperature exceeds 11°C have been proposed to define a pollination event (Hopping, 1981). Should either of these two temperature conditions be interrupted then fruit set failure is assumed to occur. Therefore, the fruit set in any one year could be predicted from the variation in daily temperatures and be used to explain fruit set failure. The yields of Hass avocado trees in New Zealand should correlate to the number of pollination events during the main flowering period. To test the validity of the pollination event concept as the overriding principle during flowering that defines fruit set. Each year shade air temperatures in a number of orchards were monitored every two hours during October and November. The number of pollination events was then related to final yield to define the relationship between temperatures in spring and subsequent yield.

Reduced availability of water to the avocado tree has been associated with decreased yield (Lahav and Whiley, 2002). The relationship between yield and water stress has been investigated mainly in relation to fruit growth and size. The critical phenological periods where water stress needs to be minimised are considered to be flowering and early fruit development and the rapid fruit growth phase in summer (Lahav and Whiley, 2002). During flowering Avocado trees are considered to have greatly increased water loss (Whiley et al, 1988) and it is for this reason that high soil moisture deficits over the flowering period may affect initial fruit set. Many avocado orchards in the Western Bay of Plenty in New Zealand are not irrigated and rely solely on rainfall. Tensiometer readings of -35 to -40 kPa in non-irrigated avocado

orchards are common October and November (Dixon et al, 2005) but readings exceeding -80 kPa have been recorded in some years (unpublished data). For New Zealand Hass avocados, water stress over flowering may have a negative effect on fruit set. To establish if there is a relationship between soil moisture deficit and fruit set the fruit set of irrigated and non-irrigated trees was compared.

Boron is widely regarded as an essential micro-nutrient of avocados that when at sub-optimal levels can limit fruit set and yield (Lahav and Whiley, 2002). The results of studies conducted in South Africa (Robbertse et al, 1989), California (Jaganath and Lovatt, 1998) and Australia (Smith et al, 1997) show that increased boron levels have a positive influence on pollen viability, fertilisation and fruit set. Similar claims have been made about applying foliar nitrogen as low biuret urea (Jaganath and Lovatt, 1998) over flowering. The improvement in fruit set was also more pronounced for Boron deficient trees and when climatic conditions over flowering were considered to be sub-optimal. In South Africa, the optimal Boron concentration for fruit set in the inflorescences has been reported to be around 50 mg.kg⁻¹ (Coetzer et al, 1993). In New Zealand, application of Solubor® up to three times over flowering is a common treatment believed to enhance fruit set. Given the claims that the application of Boron and/or Nitrogen to Hass avocado flowers is beneficial for fruit set under sub-optimal climatic conditions and the perception that the typical New Zealand spring temperatures are marginal, foliar Boron and/or Nitrogen sprays to flowers is believed to improve the fruit set of New Zealand Hass avocado trees. However, the application of Boron over flowering on New Zealand Hass avocados has not been evaluated for its effect on fruit set. A study was conducted to determine if applying Boron and/or Nitrogen during flowering is beneficial to fruit set of New Zealand Hass avocado trees. A general analysis of the results of the studies mentioned above are presented here to summarise our findings on the importance of spring temperature, soil moisture and foliar boron on the fruit set of New Zealand Hass avocado trees.

3. MATERIALS AND METHODS

3.1. Orchard Temperatures

Temperature Micro Loggers (iButton brand) were set to record shade air temperatures ($\pm 0.1^{\circ}\text{C}$) every two hours from early September until the end of January for the years 2002 to 2005. The loggers were placed within the canopy of trees at 1.5m height inside a screen with good air movement. There were 31 orchards monitored in 2002, 43 orchards in 2003, 65 orchards in 2004 and 75 orchards in 2005. The data recorded by each monitor was downloaded into Excel spreadsheets for analysis. The two hourly temperature records were used to calculate the total number of pollination events in October and November using the following criteria: the maximum temperature was greater than 17°C and the minimum temperature was greater than 11°C for two sequential days. Cumulative

growing degree days were calculated using a baseline temperature of 17°C, the temperature reported for good honeybee activity, and 15°C, reflecting the mean annual temperature. Yield was calculated as tonnes/ha from packer reports and normalised to the orchard area reported by each avocado grower in the year following the temperature recording. Hass avocados in New Zealand flower and set fruit in October and November but are harvested from September to February the following year, i.e. fruit set in 2002 will be harvested in 2003.

3.2. Soil moisture

In two avocado orchards located in the Western Bay of Plenty, New Zealand, soil moisture matrix potential at 30cm and 60cm (measured using Irrimeter® tensiometers) was recorded for a group of ten trees that were either irrigated or non-irrigated along with counts of new season fruit in December of 2005 and 2006 for two orchards.

3.3. Foliar Boron and Nitrogen

Over three seasons, commencing in 2004, Hass avocado flowers on two orchards were treated with foliar applications of 1% low biuret urea and boron (as Solubor®) at a rate of 100g per 100 L as individual chemicals or in combination. The sprays were applied at flower bud break, about 15% flower bud expansion, and about 50% open flower. The mineral content of treated and untreated flowers and leaves were analysed using a commercial testing service (Hill Laboratories, Hamilton, New Zealand). Counts of newly set fruit were made on four individual branches per treatment per tree before and after the December drop of the initial fruit set.

4. RESULTS AND DISCUSSION

4.1. Orchard temperature

Despite there being significant differences in yield between on and off cropping years (Table 1) there was only a weak relationship between yield and pollination events (Figure 1a), average monthly temperature over flowering and fruit set (Figure 1b), and growing degree days using a threshold of 15 or 17 degrees (Figure 2). This implies that temperatures over the flowering and fruit set during spring are not the main determinate of yield and that some other factors have a greater influence on fruit set.

Table 1. Hass avocado trees in the 'on' or 'off' cropping years average yields, mean temperature during October and November, pollination events (PE) and growing degree days (GDD).

Tabla 1: Producción promedio de árboles de palto Hass durante años 'on' y 'off'; temperaturas durante media Octubre y Noviembre; eventos de polinización (PE) y grados día (GDD).

Alternate Bearing	Yield (tonnes/ha)	Temperature (°C)	PE ¹	GDD15 ²	GDD17 ³
On	15.1a ⁴	14.35	11.8	79.5	37.7
Off	4.5b	14.50	11.0	81.0	37.2

¹Pollination events; ²Growing Degree Days > 15°C; ³Growing Degree Days > 17°C; ⁴Values within a column with the same letter are not different according to a One-way analysis of variance using Tukey's family error rate of 5%.

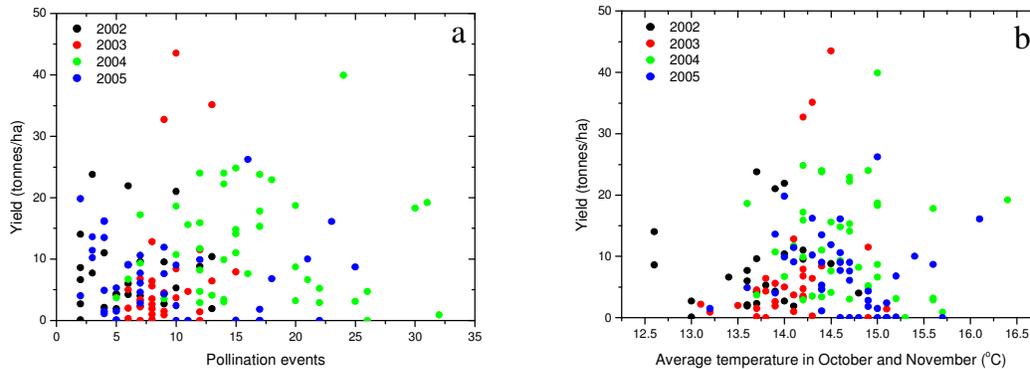


Figure 1. Relationship between a) pollination events and yield and b) average temperature during October and November and yield for avocado orchards throughout the growing regions of New Zealand.

Figura 1: Relaciones entre a) los eventos de polinización y la producción y b) la temperatura durante Octubre y Noviembre y la producción a lo largo de las zonas de cultivo de palta en Nueva Zelanda.

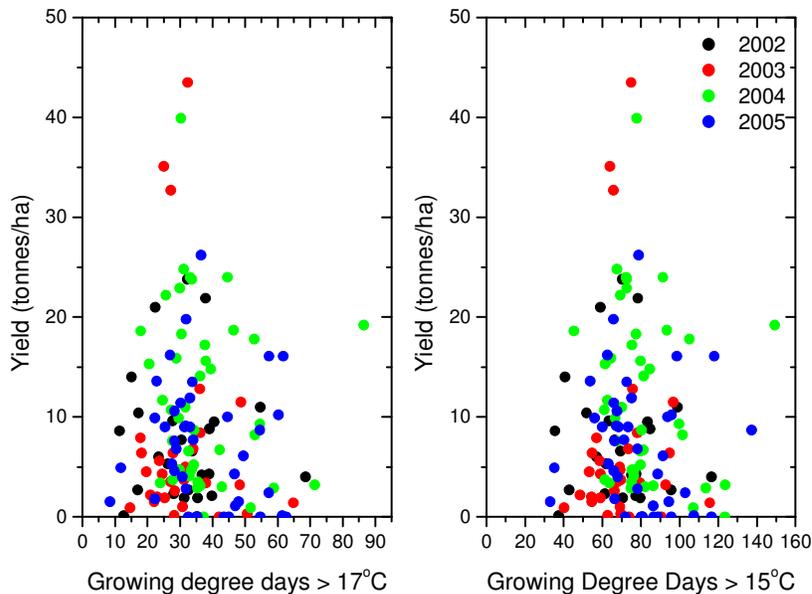


Figure 2. Relationship between growing degree days and yield for avocado orchards throughout New Zealand.

Figura 2: Relación entre los grados día y la producción de palta a lo largo de las zonas de cultivo de palta en Nueva Zelanda.

4.2. Soil Moisture

Irrigated trees tended to have wetter soils than non-irrigated trees during the months of October and November through a greater soil moisture matrix potential (Table 2). Low soil moisture matrix potential was weakly related to initial fruit set of non-irrigated trees in Orchard A having greater initial fruit set in 2006 than 2005 although the soil moisture matrix potential was less for non-irrigated trees in 2006 than trees in 2005 (Table 2, Figure 3). In contrast, the trees in Orchard B had similar soil moisture matrix potential each year (Table 2) but initial fruit set differed by about 10 fruit on average (Figure 3). Irrigated trees in Orchard A had similar initial fruit set (Figure 3) in 2005 and 2006 along with similar soil moisture matrix potentials (Table 2). The irrigated trees of Orchard B despite similar soil moisture matrix potential (Table 2) had greater initial fruit set in 2006 than 2005 (Figure 3).

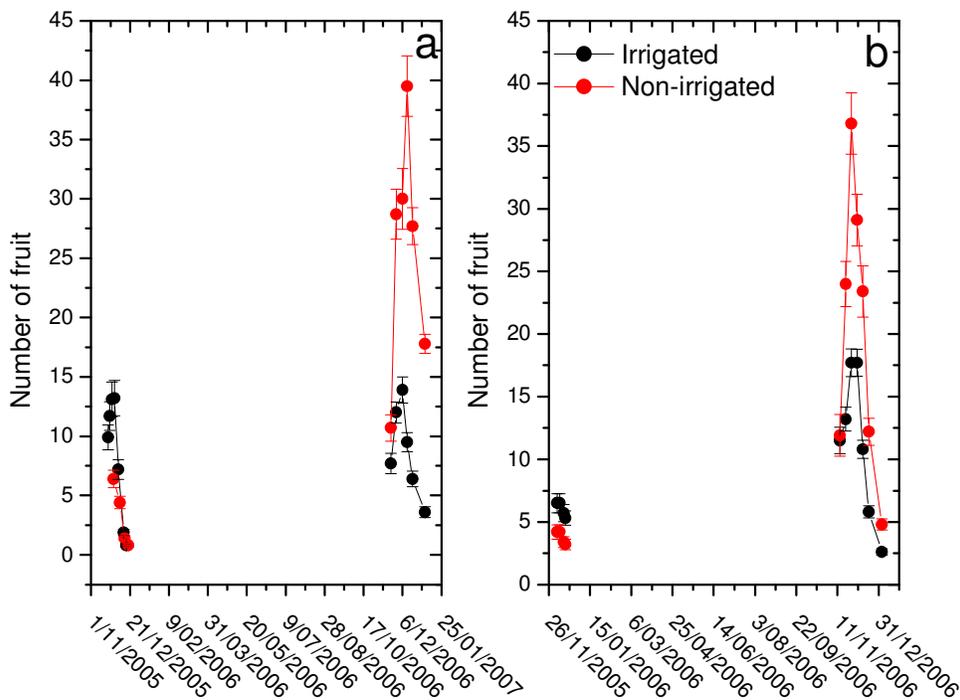


Figure 3. Initial fruit set and drop of irrigated and non-irrigated trees on two orchards a) and b) in 2005 and 2006.

Figura 3: Cuajado inicial y caída de fruto en árboles con y sin riego en dos huertos a) y b) en los años 2005 y 2006.

Table 2. Average soil moisture matrix potential (-kPa) of irrigated or non-irrigated trees during the period of initial fruit set and drop in 2005 and 2006.

Tabla 2: Humedad promedio de la matriz potencial de suelo en árboles con y sin riego durante los períodos de cuajado inicial y caída de frutos en los años 2005 y 2006.

Orchard	Irrigated		Non-Irrigated	
	2005	2006	2005	2006
A	19.3	17.2	14.3	33.5
B	13.5	13.6	25.8	23.0

4.3. Boron and Nitrogen

There was no relationship between leaf or panicle nitrogen concentration of the foliar applied nitrogen treatments and numbers of fruit initially set (data not shown). The

concentration of boron in flower panicles was poorly related to initial fruit set (Figure 4). This was despite Boron levels in treated flowers being increased by more than 70ppm above control flower levels. Such results may imply that once flower Boron levels are sufficient for fruit set, at about 30 to 40ppm, additional Boron has little influence on the levels of initial fruit set. Under New Zealand conditions addition of foliar Boron over flowering appear to have a minor influence on fruit set.

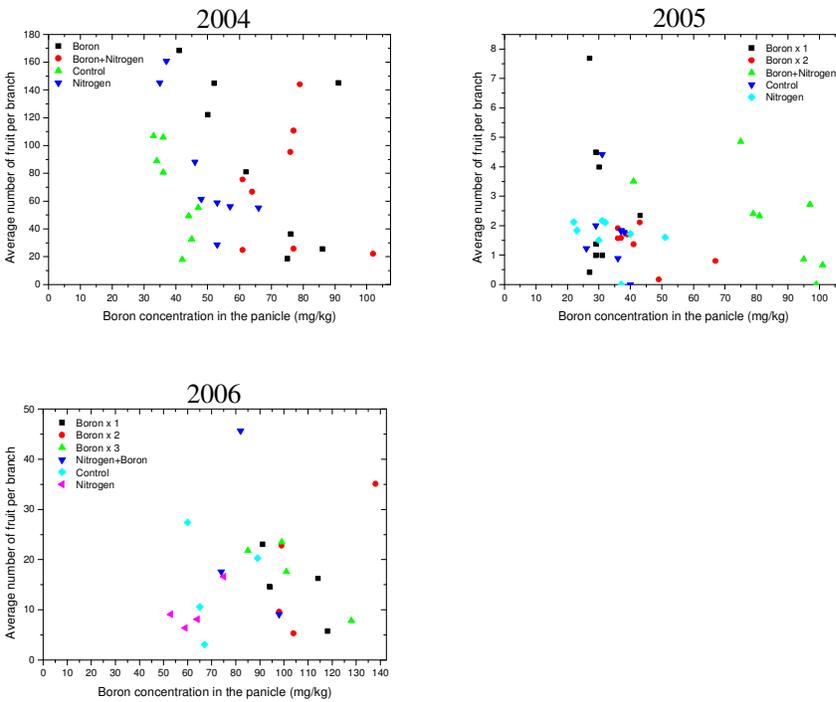


Figure 4. Relationship between boron concentration in the panicle and initial fruit set following application of foliar Boron (Solubor 100g in 100L) and Nitrogen (1% low biuret urea).

Figura 4: Relación entre la concentración de Boro en la panícula y el cuajado inicial de frutos luego de la aplicación foliar de Boro y Nitrógeno.

5. CONCLUSIONS

Fruit set in October and November in New Zealand Hass avocado orchards does not appear to be determined primarily by temperature, soil moisture or flower boron content. The implication is that as long as the basic essentials of good horticultural practice for avocados are followed then fruit set potential is pre-determined. The horticultural practices include: ensuring adequate numbers of insect pollinators, the trees are well sheltered to reduce wind movement and promote bee activity, the trees are free from water stress, and nutrient levels are not deficient. These results are surprising as it is counter intuitive that the weather and orchard management during the main period of flowering in spring does not have a direct influence on fruit set and yield.

The results of these studies highlight the fact that our understanding of what defines the level of fruit set each year is poor. We speculate that there must be factors influencing the tree outside of the main flowering period that have a major influence on fruit set that have not been clearly identified. This may explain why elucidating the causes of alternate bearing has been slow to occur. Furthermore, it would appear that a simple deterministic model of fruit set using temperature is inadequate to explain the levels of fruit set each year. To identify the important factors in fruit set we have looked to model the climatic conditions at different phenological events that occur before the fruit is harvested against yields. We suggest investigating the factors that affect possible key phenological events such as: vegetative shoot initiation in spring, flower bud initiation early autumn, leaf drop in mid winter and the drop of the initial fruit set at the time of the previous season's harvest. These factors could be used to identify yield potential from year to year and could consequently lead to new management practices that ensure consistent cropping for year to year.

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