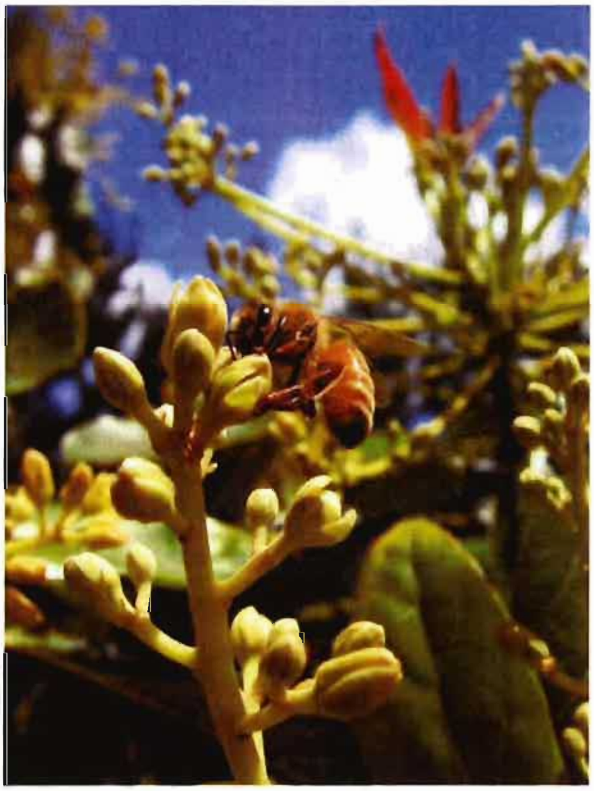
BORON AND ITS USE IN AVOCADOS: A guide for New Zealand growers



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Introduction

Productivity and maximizing yields are issues that avocados growers in New Zealand are constantly facing and trying to improve. Avocado yields can be variable from year to year and the trees can fall into a cycle of biennial bearing. Growers do their best to avoid this situation and aim to produce consistent crops from year to year.

Nutrition is a key aspect to having a healthy orchard that produces fruit from year to year. However, it is still an area that is relatively poorly understood by a lot of growers. Recommendations on what to apply and when varies between consultants and these can sometimes be very significant. Up to 11 fold differences in recommendations for certain nutrients for the same orchard have been seen in the past (J. Wilkinson, personal communication.). It is not surprising then that some growers are confused as to what is the best practice in regards to fertiliser practices.

The area of fertiliser management is a complex one which involves the use of a range of products and nutrients. Boron is only one of the nutrients in the 'package' that growers require. As boron is a micronutrient, it is not required at the same level as the major nutrients nitrogen, phosphorous, potassium, calcium and magnesium. However, because it is know to have an effect on flowering and fruit set, it is a nutrient that is of interest to growers in the quest to maximize yields.

This paper aims to review the research that has been carried out on boron over the years and present it in a way that is understandable and useful to avocado growers.

As the majority of commercially grown avocados in New Zealand are the 'Hass' variety, unless stated otherwise, all research and following discussion relates to 'Hass' avocados.

The role of Boron in plants

Boron is one of seven micronutrients required for plant growth in a range of plants. Its role and function in plant growth and reproduction is still unknown for a lot of plant species. Boron is known to have a key role in the structure and integrity of cell walls (Mengel and Krikby, 1978) but is also known to have a role in cell division, and fruit and seed development in some plants. In cell walls, it is involved closely with calcium and is involved in the movement of calcium into the plant. Boron has an important role in cell division and is essential in the areas of active growth such as root tips, new leaves and buds.

Boron can be a difficult nutrient to manage as the range between sufficient and toxic concentrations in plants is relatively narrow i.e. in some plants the difference between toxicity and deficiency can be as small as a few parts per million. Deficiency symptoms in plants often appear in the actively growing tissue where many plants show yellowing, stunting or rosetting symptoms. Toxicity symptoms often appear as a burn on the tip or margins of leaves.

The role of Boron in avocados

A number of studies have been carried out on boron around the world to determine its role in avocado production. In avocados, it is widely accepted that it is a key component of flowering and fruit set. Studies in South Africa have shown that boron deficiency in avocado reduces pollen viability, pollen tube growth and the potential for fertilization (Whiley et al. 1996). Australian studies have shown that correcting boron deficiency can increase fruit size and the quality of the fruit in storage (Smith et al., 1997).

Boron deficiency in avocados expresses itself in numerous ways. Like many plants, the growing tips of avocados are affected and growth can appear stunted. However, the most common visual symptom is shot hole of leaves, especially in the spring flush leaves that appear after flowering (Whiley et al., 1996). Other symptoms include swelling of shoot nodules, leaf yellowing, and fruit distortion. In New Zealand, it is uncommon to see widespread boron deficiency symptoms.

Boron toxicity is easy to induce as the range between optimum values and toxicity in avocados is very small. Symptoms of boron toxicity are a burn along the leaf margin which can spread across the whole leaf and induce premature leaf drop.

Key messages

- Boron is important component of flowering and fruit set in avocados
- Boron deficiency in avocados in New Zealand is rare
- Boron toxicity in avocados can be easily induced

Movement of Boron in plants

Studies from the 1970s on boron movement in plants showed that the uptake of boron from the soil was largely passive, with the nutrient primarily being transported through xylem tissues of most plants. However, some plants are known to transport boron in the phloem where it forms complexes with certain sugar molecules (Mengel and Kirkby, 1978). There is still some debate on how much of the plants boron requirement is fulfilled by the translocation through the phloem and it is still widely believed that uptake through the xylem is the main method of movement. It is generally accepted that regardless of how boron moves within different plant species, it is generally immobile compared to other plant nutrients.

Movement of Boron in avocados

In New Zealand, Plant and Food Research recently reported the findings of a study looking at boron and carbohydrate availability, movement and utilization in avocados (Thorp et al., 2009). Examining boron movement in avocados, they first looked to see whether boron levels increased or decreased with leaf age. They found that levels decreased with leaf age, suggesting that boron is being exported from leaves rather than accumulating.

To examine this boron movement out of leaves in more detail, Thorp et al. (2009) applied a boron isotope to leaves before flowering then examined leaves and floral tissue at mid bloom.

The studies confirmed the movement of boron from the leaf to the flower via the phloem. This study is supported by similar studies overseas which show that boron is remobilized from mature avocado leaves to inflorescences once boron levels in leaf cells are adequate for leaf function (Coetzer et al., 1993). The leaf boron level at which remobilization occurs is debatable. Whiley et al. (1996) reported that Australian research shows remobilization occurs in leaves with boron levels of 40 mg/kg, while South African studies show that it does not occur until levels are greater than 70 mg/kg.

Another aspect influencing the movement of boron in avocado trees is rootstock. Rootstocks vary in their ability to provide boron to the grafted scion. Rootstocks from Guatamalean decent (e.g. Reed, Velvick) appear to be more efficient than those of Mexican decent (e.g. Duke 7, Zutano) and can therefore be more prone to boron toxicity. Regardless of the influence on rootstock, it appears that uptake of boron from the soil and subsequent movement in the plant is limited. Robbertse et al. (1992, as cited in Coetzer et al., 1993, p. 2) found that boron applied to the soil took almost a month to reach to reach leaves near inflorescences and only increased to a maximum of 28 mg/kg from 15 mg/kg.

Foliar uptake of nutrient applied to avocados has been debated for a number of years. It is generally believed that avocados are poor at up taking nutrients through their leaves due to their leaf structure (*Avocado leaf analysis*, 2010). Foliar applied nutrients are absorbed through leaf cuticles and stomata. Plants with thin cuticles and numerous stomata are more likely to take up nutrients more effectively. Avocados leaves are waxy on both their upper and lower surface and contain very few stomata, hence the poor nutrient uptake. In contrast, flower tissue contains stomata on the lower surface and no wax layer on either surface.

Key messages

- Boron is relatively immobile compared to other plant nutrients
- Boron moves out of older leaves to the floral tissue in avocados
- Rootstocks can play a role in how easily boron is taken up from the soil
- Uptake of boron through avocado leaves is limited

Boron in the soil

In soil, boron is available to plants in the form of boric acid. In this form it is very soluble and is therefore prone to leaching, especially on sandy soils. Boron can bind onto soil organic matter and clay particles and from there can be released back into the soil solution. Boron is released from organic matter as the organic matter breaks down. This process can be accelerated by adding lime to the soil which stimulates microbial activity and in turn speeds up organic matter breakdown. Conditions which slow down microbial activity, such as dry weather, have the opposite effect and limits the amount of boron available to plants.

The availability of boron to plants is affected by soil pH. At a pH below 5 it forms complexes with iron and aluminum and is therefore unavailable for plant use. At a pH above 7 it also becomes unavailable.

Key messages

- Boron is bound to organic matter in the soil
- Once in the soluble form as boric acid, boron can be easily leached from soil
- Boron availability to plants from soil is best between pH5 and pH7

Boron and yield

As yield is one of the key factors that growers are looking to constantly improve, and boron is known to be a critical component of pollination and fertilization, many studies have been carried out to see whether manipulating boron levels can have an effect on yield. The increase in yield is thought to come from an increase in the number of pollen tubes reaching the ovule, resulting in a higher number of flowers being fertilised. Nitrogen is believed to have a similar effect as boron on the flowering process so a number of studies have looked at the foliar application of boron and/or nitrogen over the flowering period as a way of increasing yield.

In California, Jaganath and Lovatt (1996) found that a foliar application of either borax or low biuret urea at the cauliflower stage on trees with adequate leaf boron levels increased cumulative average yield across 3 years by 23-35%. Interestingly, combining the boron and urea as a single treatment resulted in a reduction in yield in every year of the experiment, due an increase in the number of flowers with double styles or stigmas. Lovatt and Ohr (1993) found that a single application of either boron or nitrogen gave the best results in terms of fruit set and yield compared to 2 or more applications and that foliar application of boron gave the best yield responses. Lovatt (1999) found that applying additional boron to tree which had a high leaf boron level (>180ppm) had a negative effect on yield with significant decreases in some years.

In Australia, Smith et al. (1997) found that applying borax to the soil on trees that were deficient in boron increased average fruit size but did not increase yield.

Coetzer et al. (1993) carried out a number of experiments in South Africa looking at the effect of boron on pollen germination, pollen tube growth, fruit set and fruit production and found a positive relationship between these factors and boron concentration. In all of their studies they found an improvement in fruit production of trees treated with boron over the control trees, but in some cases this was only marginal.

Robbertse and Coetzer (1991) reported that there may be some relationship between the nitrogen levels in the soil and leaves and the boron concentration in the leaves. They and other researchers have found that when nitrogen levels are high, boron levels tend to be low. The relationship between different nutrients and their uptake in plants is a complex one and factors such as this should not be discounted when looking at single nutrients.

Studies in the United States have found that foliar boron sprays are more effective when the weather conditions over flowering are poor for pollination and bee activity i.e. cool, wet weather (Hanson 1991, as cited in Lovatt, 1999, p. 610).

Because of the mixed results of overseas studies on yield, Dixon et al. (2004) conducted an experiment in 2004 to determine whether applications of boron and/or nitrogen were beneficial to fruit set and yield in New Zealand. They found that applying either a foliar Solubor® or Low Buiret Urea spray at the cauliflower stage had an inconsistent effect on fruit set and results varied between orchards. However, they did determine that the optimum boron level in flowers for fruit production was between 50 and 65ppm. A single spray of Solubor® increased boron levels from 45ppm to 82ppm compared to the control on Orchard 1, and from 35ppm to 51ppm on Orchard 2.

Key messages

- Foliar applications of boron or nitrogen may increase yield
- Studies on the effect of boron or nitrogen sprays on yield are variable
- New Zealand studies have been inconclusive

Testing for Boron

In New Zealand, testing for boron levels is done on avocado soil samples and leaf samples, generally taken around April. Recommendations in other avocado growing countries seem to be similar. The Department of Primary Industries in NSW and Queensland recommend taking leaf samples when the summer flush has hardened off from mid-April through to May (Dirau, 2003). They also state than soil tests can be done at anytime but recommend taking soil samples at the same time as leaf samples so the results can be interpreted together (Rigden, 2010). In South Africa, the recommendation is to take leaf samples which are 6 to 8 months old during February to April (*Cultivation of avocados*, 2010). In California, the recommendation is to sample the most recently expanded, and matured, healthy, terminal leaves from the spring flush and from non-fruiting branches in mid- August or October (*Avocado leaf analysis*, 2010).

Soil testing

There are 3 main tests used around the world for testing boron levels in soil; Mehlich 1, Mehlich 3 and DTPA. In New Zealand, the Mehlich 3 test is the main test used for measuring boron levels. The Mehlich 3 test is a multi extraction test which can determine levels of several nutrients in one extraction, including boron. Results are expressed as mg/l soil. The target range for boron in avocados as listed by Hill Laboratories is 2.5 – 4.5 mg/l.

Leaf testing

The standard recommendation in New Zealand is to sample leaves around late April to May each year. The leaves to be sampled are those that are the first fully expanded mature leaf. A study carried out in California by Bingham (1961) showed that nutrient levels in avocado leaves varied during the season (by up to 20% for boron) but were most stable between August and December (February to June equivalent in the southern hemisphere). The median range for boron in avocados as listed by Hill Laboratories is 30 – 50 mg/kg.

Other tissue testing

Although leaf tests are the main methods used for determining the boron status of avocados, some studies have looked at using other plant tissue as a method of determining boron levels. Razeto et al. (2003) tested avocado peduncles (stalks), pulp and leaves after applications of borax to avocado trees. They found a stronger correlation between peduncle and pulp boron levels and borax application compared to leaves. Razeto et al. (2003) also compared floral tissue with the standard May leaf sample and found the floral tissue to be more accurate than the leaf tissue.

In New Zealand, Hill Laboratories offer a testing service for floral avocado tissue.

> ***Key messages***
>
> - Soil and leaf tests are the most common methods for determining boron levels in avocados
> - Soil and leaf tests should be taken in April – May and is similar to timings used in other countries
> - Floral tissue testing and other tissue testing may be more accurate but is not common practice yet

Target levels for Boron

Knowing what the target level of boron you are aiming for is important to know if growers are to apply the right amount of a certain product. Target levels will vary depending on whether the leaf, floral tissue or soil is being tested. The tables below give a summary of what the target levels are from different countries and sources and highlight the variations between them.

Leaf

Country	**Level**	**Range**	**Source**
New Zealand	50ppm	40-60ppm	Grower manual
		30-50mg/kg	Hill Laboratories
	>22ppm		Hardy et al. (2004)
USA	>25 mg/kg		Jaganath & Lovatt (1996)
Australia	>30ppm		Rigden (2010)
South Africa	70 mg/kg		Coetzer et al. (1993)
Israel		50-100ppm	Lahav & Kadman (1980)

Flowers

Country	**Level**	**Range**	**Source**
New Zealand	60ppm	60-100ppm	Grower manual
		50-65ppm	Hardy et al. (2004)
South Africa	50 mg/ka	50-75 mg/kg	Coetzer et al. (1993)

Soil

Country	Level	Range	Source
New Zealand	5ppm	2-6ppm	Grower manual
		2.5 – 4.5 mg/L	Hill Laboratories
Australia	>40 mg/kg		Dirau (1993)

Boron products

There are various forms of boron used around the world for applying boron to plants. The ones listed below are some of the more common forms used by New Zealand growers on avocado orchards.

Solubor

Solubor® is a registered product containing a mixture of boric acid, borax pentahydrate and sodium pentaborate. The boron content of Solubor® is typically between 17.2% and 17.8%. There are also a number of other 'soluble boron' products on the market that are referred to but are not actually Solubor®. Two common ones sold in New Zealand are Agribor® and Actibor™. Both of these products contain di sodium octaborate and have a typical boron analysis of 20% as B (67% as B_2O).

Solubor and similar products are commonly applied as foliar sprays onto the tree around flowering. They are also used by growers with fertigation systems as a source of boron in a mix of different fertilisers.

Boric acid

Boric acid is also known as trihydroxidoboron and is made by reacting borax with a weak acid such as hydrochloric acid. Boric acid has a boron content of 17.5%. It is highly soluble with a solubility of 57g/L. Boric acid is used in New Zealand in either fertigation mixes or as a dressing made to the soil underneath the trees. As this is the form of boron that is taken up by the trees from the soil, it is immediately available for plants to use.

Borax

Borax is also known as sodium tetraborate and is a naturally occurring mineral. It has a boron content of 11.3%. Borax is reasonably soluble with a solubility of 25.2g/L. Borax is most commonly used as a soil dressing.

Granular boron

Granular boron, or Granubor, is a prilled boron product used for application to the soil around the base of avocado trees. It typically contains around 15% boron.

Nitrabor

Nitrabor is a calcium nitrate product with added boron for use as a prilled product applied to the soil. It typically contains 15.5% nitrogen, 19.2% calcium and 0.3% boron. As boron and calcium have a close relationship in uptake in plants, it is thought that combing the two in one product may enhance the uptake of both boron and calcium.

Proprietary branded products

There are a number of different branded boron products on the market in New Zealand. These are mainly used as foliar sprays applied to the trees around flowering.

- Wuxal® Boron is a suspension product containing 110g/L nitrogen (11%), 59.8g/L phosphorous (4.4%), 95.9g/L boron (7%) along with other trace elements
- Trace it B™ is a liquid product containing 856g/L boric acid (150g/L boron)
- Bortrac™ is a liquid product containing 4% nitrogen and 10.5% boron

Application of Boron

Industry recommendations

In most countries, the application of boron is based on soil and leaf test results taken during the season. In New Zealand, the main recommendations for managing avocados have been in the Avocado Industry Council Grower Manual. In the manual, the recommendation is to apply sodium borate, boric acid or granubor to the soil at 4 – 8g/m^2 canopy area in spring and autumn if soil levels are below the target guideline of 5ppm. This is coupled with 3 foliar sprays of boron; one at 30% flowering, one at 70% flowering and one when the new flush is at the pink stage. The recommendation is to use Solubor® at 100g per 100L sprayed to run off in 3000 – 5000 litres per hectare.

More recently, the Avocado Industry Council along with various consultants, have produced grower guides on orchard management. In these grower guides, the recommendation is to apply a foliar boron spray if the leaf test show boron levels are below 22ppm. They also recommend applying boron to the soil in January – March if soil levels are low (Hardy et al., 2008), however the definition of low is not given.

In Australia, the recommendation is to apply boron to the soil once levels reach below 40 mg/kg. The Department of Primary Industries New South Wales suggest applying either Solubor® at 4g/m^2 of ground area canopy or borax at 8g/m^2 of ground area canopy in October and again in April. They also advise a foliar spray of Solubor® at 1g per litre at flowering. The Department of Primary Industries in Queensland recommends applying a foliar spray of boron before flowering, once leaf levels are below 30ppm.

The Department of Agriculture, Forestry and Fisheries in South Africa states that many orchards are low in boron and that avocado trees should be sprayed every year with 100g/100L of Borax or 75g/100L of Solubor® (*Cultivation of avocados*, 2010).

Key messages
• Any boron applications should be based on the results of soil and leaf tests • Both soil and foliar applied boron applications may be required • Recommendations are varied

Cost of application

The cost of applying a product like boron, especially as a foliar spray which tends to be an additional practice, is important to growers as they like to see a benefit from any additional inputs they may be making. Applying boron as a soil dressing, either as a solid fertiliser or through fertigation, is commonly done with other nutrients so is not considered a separate cost in itself. However, foliar applied boron at flowering is an additional practice carried out purely to try and increase the boron levels in the floral tissue so is seen as an additional cost. The table below shows some of the cost of products applied on a per hectare basis of some of the more common foliar boron products.

Product	Pack size	Use Rate per ha	Amount of B in product	Amount of B applied per ha	Retail price	Cost of product applied per ha
Actibor™	25kg	2.5kg (100g/100L)	200g/kg	500g	$110	$11
Wuxal ®Boron	10L	3L/ha	95.9 g/L	287.7g	$100	$30
Bortrac™	10L	3L/ha	150g/L	450g	$150	$45
Trace it B™	20L	3L/ha	150g/L	450g	$232	$35

Note: these figures are for product cost only and do not take into account the cost of applying the product.

Actibor™ is the cheapest product to apply when compared to the others, hence why it is a popular choice amongst growers. It is a powdered product, compared to the others which are all liquids, so there is a need for the user to weigh out the product and dissolve it before using. Wuxal® Boron, Bortrac™ and Trace it B™ are all liquid products so are already in suspension and are easy to measure out. These products may also contain other nutrients, along with spreaders and stickers, so this needs to be taken into account by the grower when comparing costs.

Summary

Boron is an important nutrient in avocado production due to its effect on flowering and fruit set. In avocados, it is also an important component of cell walls and is used by areas of active growth in the developing cells. It is taken up by the plant from the soil where there is limited movement up to the leaves. At flowering, boron moves from older leaves into the developing floral tissue. The boron levels in this floral tissue may be enhanced with the application of a foliar boron spray at the early flowering stage.

The influence of boron on yield is varied and will differ between orchards. Studies have shown that a single application of either boron or nitrogen at flowering may have a positive effect on yield, especially in years where the weather during pollination is poor. However, boron levels from leaf tests must be taken into consideration as applying additional boron to trees with already high levels may decrease fruit production.

A range of recommendations have been given below when considering boron applications to your orchard. Practices will be different for different orchards and it is important to take into account your trees, your soil and your test results when making a decision.

Recommendations

- Carry out soil and leaf tests annually at the same growth stage each year (late April – May).
- Compare soil and leaf tests from the previous season with fertiliser practices to see what effect the fertilisers are having nutrient levels, and consider this when planning applications for the current season.
- If soil test levels are below 5ppm, consider applying a boron based fertiliser to the soil.
- Take into account soil type and rootstock when applying a soil based product and adjust rates accordingly.
- If leaf test levels are below 22ppm, apply either a foliar boron or nitrogen spray but do not apply them together.
- Consider testing floral tissue to determine whether boron levels in the flowers are adequate.

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