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**Effects of soil &
foliar nutrient application strategies for improving
fruit quality for 'Zesy002' kiwifruit**

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Abstract

Nutrient management research work has been conducted in established kiwifruit varieties such as 'Hayward' and 'Hort16A'. But less is known about such research on the newly commercialised 'Zesy002' kiwifruit cultivar. A goal is to optimise sustainable production of quality fruits with high fruit dry matter percentage (FDM, a quality predictor at-harvest), without driving excessive vine vigour. The project is aimed to (i) increase calcium (Ca) nutrition and to (ii) optimise potassium (K) fertilisation to produce high quality 'Zesy002' kiwifruit at-harvest. The fundamental knowledge of the role of Ca and K nutrients and their interactions was used to increase the photosynthetic performance and improve at-harvest fruit quality. The study was based on the hypothesis that the competitive effect of high K supply on the uptake of Ca may be reduced at soil level by using (i) spatial and (ii) temporal separation of soil-applied Ca and K fertilisers, and (iii) foliar Ca applications after fruit set through to fruit maturity during the growing season. The study also tested the hypothesis that K application at different rates and growth stages through (i) soil-applied and (ii) foliar-applied fertilisation may better meet the nutrient demand of kiwifruit vines and developing fruit and therefore, may improve the potential of the fruit to compete for dry matter import. The results showed that both spatial and temporal separation of soil-applied Ca and K fertilisers reduced the competitive effect of high K input on the availability and uptake of Ca and therefore significantly increased leaf and fruit Ca concentration in 'Zesy002' vines compared to true control, not spatial and not temporal strategies and grower practice in each orchard. Likewise, foliar Ca significantly increased Ca concentration in leaf and fruit tissues in 'Zesy002' vines and significantly improved photosynthetic performance, nutrient uptake (vine physiology) and at-harvest fruit quality (fruit size and firmness). Both soil and foliar-applied nutrient strategies, which were used mainly to increase Ca nutrition, showed promising improvements in fruit quality; larger and firmer fruit with high soluble solids (SSC) and fruit dry matter concentration (FDM) at-harvest and after thirty-day storage. The results also showed that three split applications of soil K fertilisers (each 100 Kg K ha⁻¹) from bud-break (BB) through to 90 days after full bloom (DAFB) compared to one application either at BB, FB or 90 DAFB, improved at-harvest fruit quality in commercial orchards at Bay of Plenty and Hawke's Bay, New Zealand. Foliar application of K fertilisers from fruit set through

to harvest also improved vine physiology and at-harvest fruit quality. The optimisation of K by using both soil and foliar fertilisation strategies improved fruit growth rate during the growing season, at-harvest fruit weight, SSC and FDM compared to true control. The soil and foliar-applied nutrient (Ca and K) fertilisation strategies employed here were specifically targeted using 'the right time', 'right amount' and 'right plant organ' principles and successfully, delivered larger fruit with higher SSC and FDM at-harvest. For growers, this translates to a lower fruit count per tray (size class) and a higher taste Zespri grade, triggering increased premium payments and orchard gate returns. The fertiliser input used in foliar strategies was 3-8 Kg. ha⁻¹ and only a fraction of soil-applied fertilisation 50-300 Kg. ha⁻¹. Therefore, the foliar nutrient fertiliser application strategies employed in this study were inherently more sustainable approach compared to the soil-applied fertilisation. These research findings have significant implications in horticultural fruit crops to increase leaf chlorophyll, net photosynthesis and stomatal conductance, and increase leaf and fruit Ca and K concentration to deliver high quality fruit at-harvest. The research strategies used in this study can be very easily adapted to the existing fertilisation programs and applied in the commercial orchards. For example, fertiliser spreaders can be modified to side dress K to the weed-strip or broadcast K to alternate rows and broadcast Ca over the whole orchard floor to implement spatial separation of Ca and K fertilisers. Temporal separation of Ca and K can be very easily implemented by applying soil Ca fertiliser at BB and by delaying application of soil K fertiliser until closer to FB. Foliar Ca and K applications can also be easily included in the early season spray programs. For future research, there is a true potential to further maximise fruit quality gains by supplementing soil-applied fertilisation strategies with specific timely foliar applications.

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List of abbreviations

BB	bud-break
BD	bulk density
BOP	Bay of Plenty
Ca	calcium
CaCl ₂	calcium chloride
CAN	calcium ammonium nitrate
CDPKs	calcium dependent protein kinases
CEC	cation exchange capacity
CHO	carbohydrates
DAFB	days after full bloom
DW	dry weight
FC	foliar control
FDM	fruit dry matter percentage
FLRC	Farmed Landscapes Research Centre
FW	fresh weight
GP	grower practice
HU	Horticultural Unit
K	potassium
Ltd	Limited
Mg	magnesium
N	nitrogen
NR	nitrate reductase
NSS	not-spatially separated
NTS	not-temporally separated
NZDST	New Zealand daylight saving time
P	phosphorus

PGU	Plant Growth Unit
PN	net photosynthesis
ROS	reactive oxygen species
S	sulphur
SOA	sulphate of ammonia
SOP	sulphate of potash
SS	spatially separated
SSC	soluble solids concentration
TC	true control
TS	temporally separated
TZG	taste Zespri grade

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1 Introduction and literature review

1.1 General introduction

The release of a new gold kiwifruit cultivar (*Actinidia chinensis* var. *chinensis*), 'Zesy002' in 2012, and marketed as Zespri SunGold®, was launched after a bacterial disease (*Pseudomonas syringae* pv. *Actinidiae*, Psa) decimated a well-established gold kiwifruit cultivar 'Hort16A' in 2010 (Dwiartama, 2017; Everett et al., 2011). 'Zesy002' cultivar has helped the kiwifruit industry of New Zealand to successfully resume rapid growth. The latest estimates from Zespri International Limited (Ltd) showing that the industry is on track to supply over 80 M trays of 'Zesy002' in 2020, which is up from around 74 M trays of 'Zesy002' in 2019 and the supply forecast is 115 M trays in 2024/25 (Zespri, 2020a). The 2019 'Zesy002' licence release generated gross revenue of NZ\$211.9 M and currently, the industry has a total operating revenue at a value of NZ\$3.36 B in 2020 (Zespri, 2020b).

Because of its novel taste (sweet and juicy) 'Zesy002' fruit is gaining a strong reputation in (new) international markets (Singletary, 2012). Kiwifruit quality at "eating stage" is the prime factor that determines success in these international markets (Wright, 2005). The "fruit quality" predictor for kiwifruit at the "eating stage" is determined by the fruit dry matter concentration (FDM), along fruit firmness at-harvest that determines the storage potential and shelf life of the fruit (Richardson, 1997). Zespri International Ltd as the sole marketer, pays incentives to growers based on FDM to ensure that growers are maximising their financial returns based on improved fruit quality with yield (Yuan et al., 2020; Zespri, 2020a). Kiwifruit growers use many practices to achieve top quality fruit such as use of mineral nutrient fertilisers, canopy management, leaf and fruit thinning, and often root pruning in kiwifruit orchards (Boyd & Barnett, 2011; Costa, 1999; Currie et al., 2017; Zhang et al., 2020). These crop management practices are used principally to manipulate source-sink relationships. The biomass production and partitioning to fruits (sinks) controls the yield of the horticultural crops. The biomass production is dependent on the photosynthetic activity of leaves (source activity) and leaf area (source size).

Several studies have indicated that the nutrient concentration of the fruit determines its quality at-harvest and throughout the storage (Ferguson et al., 2003;

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Hopkirk et al., 1990). Mineral nutrients play an important role in many physiological processes and affect dry matter accumulation and water uptake. The relative quantities and timing of nutrient supplementation affect the distribution of dry matter between vegetative growth and the developing fruit (Marschner, 2012). It is well-established that nitrogen (N), potassium (K) and calcium (Ca) are important nutrients, which are accumulated in large amounts (approx. 110, 174 and 190 Kg ha⁻¹ per annum, respectively) by the kiwifruit vine (Montanaro et al., 2014). To maximise profitability of horticultural fruit crops in a sustainable fashion, fertiliser inputs should by definition match the plant requirement considering the production goals, in addition to the availability of nutrients in the soil. This pertains to the concept of applying the right fertiliser at the right amount, right time, right place and the right formulation, known as 'The 4Rs of Nutrient Stewardship' (Bryla, 2020).

Previously, much nutrient management research has been conducted for green kiwifruit (*Actinidia deliciosa* (A. Chev.) C. F. Liang et A. R. Ferguson var. *deliciosa* 'Hayward') and gold kiwifruit (*Actinidia chinensis* Planch. var. *chinensis* 'Hort16A') (Mills et al., 2008; 2009; Morton & Woolley, 2010; Smith et al., 1987c). So far, no nutrient management studies specific for 'Zesy002' have been conducted to date according to our knowledge in New Zealand. Currently, many commercial 'Zesy002' growers design their nutrient management plans either based on the green cultivar 'Hayward' or gold cultivar 'Hort16A' kiwifruit and/or depending as they learn each season (Table 1.1). However, both cultivars are physiologically quite different, with 'Zesy002' and 'Hort16A' breaking winter dormancy earlier than 'Hayward' which is late-flowering and late-maturing. Also, 'Zesy002' tends to set a higher crop load with bigger fruit compared to 'Hayward' and 'Hort16A' (Burdon et al., 2016). Furthermore, according to the nutrient management plans designed for 'Hayward', nutrient (N and K) fertilisers are applied in relatively large amounts (200-250 Kg N ha⁻¹, 150-250 Kg K ha⁻¹ and sometimes 500 Kg K ha⁻¹) in kiwifruit orchards per annum (Mills et al., 2008). However, applying such high rates of N and K fertilisers at a particular time without considering soil physical and chemical properties has potential complications for Ca nutrition and may negatively affect the availability and uptake of Ca by plant roots at soil level (Montanaro et al., 2014). Limited Ca nutrition in kiwifruit vines may have implications for the fruit quality both pre- and post-harvest such as low yield, possibly high incidence of physiological disorders,

disease and pest infestation and fruit softening (Ferguson et al., 2003; Prasad & Spiers, 1991; Thorp et al., 2003). In addition, high N and K fertiliser input might contribute to the environmental pollution and add to the orchard management costs (extra pruning due to excessive vegetative growth) (Patterson & Currie, 2010; Weinbaum et al., 2001; Weinbaum et al., 1992). Considering these physiological differences and nutrient implications this research project was conducted to bridge the knowledge gap to design a specific nutrient management plan for 'Zesy002'. This project was aimed to achieve sustainable production of high-quality fruit (high FDM at-harvest), without driving excessive vine vigour which increases pruning and labour costs as a negative effect. This PhD project assessed the rate, formulation, and time of application of mineral nutrient fertilisers. In addition, different strategies were designed to increase the uptake and accumulation of macronutrients in the leaf and fruit with the main emphasis to produce top quality fruit whilst minimising vegetative growth and N losses to the soil.

Table 1.1 The amount (Kg. ha⁻¹) and application time (in parenthesis) of nutrient fertiliser application recommended for mature 'Hayward and 'Hort16A' vines, and currently applied practices for 'Zesy002' in kiwifruit orchards across New Zealand.

Nutrients	*Recommendations for 'Hayward' Kg. ha ⁻¹ (application time)	** Previously applied for 'Hort16A'	***Currently applied for 'Zesy002'
N	170 (Sept and Nov)	100-250 (August)	30-126 (July-November)
K	100-150 (August or Sept)	250-350 (August or Sept)	100-328 (July-November)
Ca		80-130 (July/August)	50-284 (July-November)

*-Obtained from Warrington & Weston, (1990).

**-Reported by Mills et al., (2008)

***-Based on the nutrient management practices observed in this study from 2016-2019 selected for research in three commercial orchards across New Zealand.

1.2 Kiwifruit

Kiwifruit is a deciduous, vigorously growing, dioecious perennial woody fruiting vine from China (Honghua et al., 2017; Varkonyi-Gasic et al., 2011; Voogd et al., 2017). It belongs to the family Actinidiaceae, genus *Actinidia* and its species are characterised by being perennial, with its canes vigorously growing with climbing and strangling characteristics (Cangi & Atalay, 2006). The genus *Actinidia* has about 66 species around the globe and three species are of commercial interest: *A. chinensis* (golden kiwifruit), *A. deliciosa* (green or fuzzy kiwifruit) and *A. arguta* (baby kiwifruit or kiwi berry) (Peticila et al., 2012). The two most cultivated species

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in the market are *A. chinensis* and *A. deliciosa*. These species are largely cultivated because of their high economic return and large fruit size (Honghua et al., 2017). The cultivation of kiwifruit cultivars around the world has advanced fast, New Zealand, Italy and Japan and some other countries have cultivated new cultivars, but China is still by far the biggest (domestic) producer (Ferguson, 2014). Among them New Zealand is the most successful country in kiwifruit production for export, comprising 51.3 % of total kiwifruit exports, 545,800 tonnes of kiwifruit in 2019 worth NZ\$2.24 B (Freshfacts, 2019; Workman, 2020).

In 1904, kiwifruit seeds were first brought by Isabel Fraser (a teacher from Whanganui) from China into New Zealand (Boland & Moughan, 2013). Kiwifruit was then known by its Chinese name 'Yang Tao' and English names 'Chinese Gooseberry' and 'Monkey Peach'. In 1927, Hayward Wright bred a green cultivar of kiwifruit known as 'Hayward'. This is now the standard cultivar of exported kiwifruit around the globe and makes up 90 % of the world production of kiwifruit (Richardson et al., 2018). The gold-fleshed kiwifruit 'Hort16A' *A. chinensis* and its successor 'Zesy002', has received increasing popularity in the international market due to its novel skin, colour, sweet taste and flavour (Honghua et al., 2017). Zespri has recently launched red-fleshed kiwifruit cultivar 'Red19', which is like 'Zesy002' also bred by Plant and Food Research in New Zealand (Cheng et al., 2006; Shangyi, 2011), and is commercially marketed as Zespri® Red and 150 ha were released to growers in 2020 (Timewell, 2019). Zespri is also planning to license a further 1,500 ha from 2020 to 2023 (Zespri, 2020a).

Like other cultivars such as 'Hayward' and 'Hort16A' the 'Zesy002' can be grown on the same rootstocks. The rootstock is selected for desirable characteristics such as tolerance to their roots to wet conditions for long periods known as 'wet feet' and for reducing the vigour of the scion (Kiwifruitgrowers, 2019). There are a number of rootstocks available and the most common one is 'Bruno' due to its high Psa tolerance in NZ. Less common rootstocks are: 'Hayward', 'Kaimai', 'Hort16A', and 'Bounty' (Anon, 2012). Bounty is a rootstock with Psa tolerance and less vigorous than 'Bruno' but requires heavier soils and higher planting densities to quickly establish full canopy. Bounty is referred as a clonal rootstock, which means every individual plant is genetically identical (Anon, 2012). Therefore, every 'Bounty' rootstock in the orchard would deliver same attributes to the scion (Friend et al.,

2012). On the other hand, 'Bruno' rootstocks were grown from seedlings which means every 'Bruno' rootstock can be genetically different and has the potential to create variation in the vine growth and fruit quality (Cruz-Castillo et al., 1991; Wang et al., 1994). In this study, rootstocks 'Bruno' and 'Bounty' were tested for their impact on nutrient uptake in the pot grown 'Zesy002' vines. However, rootstock 'Bounty' was not tested for their impact on nutrient uptake in the orchard grown kiwifruit vines (Chapters 3 and 4).

All Zespri kiwifruit were produced from a total of 12,747 ha in the 2018/2019 season and 80 % of the planted hectares (10,228) were across six sub-regions of the Bay of Plenty (BOP) (Freshfacts, 2019). The climate of the BOP region is characterised by warm and temperate conditions with well-distributed rainfall (ca. 1000-1800 mm per annum) throughout the year with an average temperature of 14.6 °C per annum. Soils of the BOP region are well-structured; free draining, allophanic, sandy loam, support deep rooting crops, however, they are acidic and deficient in nutrients in their native state (Fatichi et al., 2014; Molloy et al., 1998; White et al., 2016).

The land coverage of kiwifruit in Hawke's Bay was 205 ha in the 2018/2019 season (Kiwifruitgrowers, 2019). Soils of the Hawke's Bay are rich, alluvial loams and river gravels, and the climate is warm and with more hours of sunshine (Molloy et al., 1998).

1.2.1 Fruit growth and development

Kiwifruit vines lay dormant in winter months from June to August and growers remove last season's fruiting canes, select and train new canes for the formation of new growth (Warrington & Weston, 1990). To overcome lack of chilling requirement and to stimulate and synchronise uniform bud-break (BB), growers spray 'Hydrogen cyanamide' (known as Hicane) a month before the onset of BB on dormant kiwifruit vines, from the last week of July to the end of August (Costa et al., 2010; MCpherson et al., 2001). During springtime from September to November kiwifruit vines begin to grow and new shoots along with flower buds appear on the canes (Warrington & Weston, 1990). In early or mid- September BB occurs in kiwifruit vines as shown in Figure 1.1 based on observations during this study. The flowering starts in late October, and the total duration of this flowering period is approximately 14 days. Mostly dormant 'winter' buds burst in spring and produce

flowers (full bloom, FB). If pollinated and fertilised successfully, all flowers are capable to form into fruit (Warrington & Weston, 1990).

As the fruit develops many of the functional, structural and chemical fruit characteristics change (Montanaro et al., 2014). The development of a kiwifruit berry follows a typical double-sigmoidal pattern for fruit weight and has been arbitrarily divided into three distinct stages (Hopping, 1976; Montanaro et al., 2014) as shown in Figure 1.1 based on a sub-set of estimated fruit size data obtained during this study in 'Zesy002' vines. Stage 1 (defined from full bloom (FB) till ca. 70 days after full bloom, DAFB) when the fruit growth begins, and fruit grows rapidly attaining more than half of its final fruit size. The rapid initial fruit growth is characterised firstly to cell division and then later by both cell division and cell expansion in the pericarp (Hopping, 1976). The peak period of cell division is from FB to 30 DAFB. Stage 2 (defined from ca. 70–100 DAFB) is characterised by slow growth and shorter duration than Stage 1 and concurs typically with the main starch accumulation (not quantified in this study) phase and therefore, influences fruit dry matter concentration at-harvest (Hopping, 1976; Richardson & Currie, 2007). Stage 3 (defined from ca. 100–180 DAFB) is characterised by an increasing accumulation of soluble sugars due to continuous sucrose import and net conversion of starch to soluble sugars. This stage is also characterised by rapid fruit growth which is where the typical sigmoidal growth pattern is established until the fruit fully matures (Hopping, 1976; Richardson & Currie, 2007). Fruit growth rate is a measure of both fresh weight and dry matter accumulation. Fresh weight reflects water accumulation and it depends on vine water status, fruit transpiration, xylem functionality and fruit osmotic potential. In contrast, fruit dry weight accumulation through xylem and/or phloem is typically unidirectional into the fruit and minerals and assimilates are not mobilised to the vine or through fruit transpiration (Hall et al., 2013; Morandi et al., 2010). A development model of kiwifruit berry suggests that growth stimulation in fresh and dry weight is due to the function of influx of xylem and phloem, and cell wall extensibility (Hall et al., 2013). Model sensitivity analyses highlighted that the growth is particularly sensitive to parameters that control water inputs and demand, especially early in the fruit development when xylem influx of water is higher. During the early phase of the fruit development (Stage 1) most of the Ca accumulates (Montanaro et al., 2014; Montanaro et al., 2006;

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Xiloyannis et al., 2000). The factors that affect xylem water influx, growth in fresh weight and accumulation of fruit Ca are closely connected. Regarding carbon (C) accumulation, leaves and shoots continue to grow throughout the fruit developmental period and suggests that the competition between these organs for assimilates and minerals takes place until the end of Stage 2 (Montanaro et al., 2014; Montanaro et al., 2006; Xiloyannis et al., 2000).

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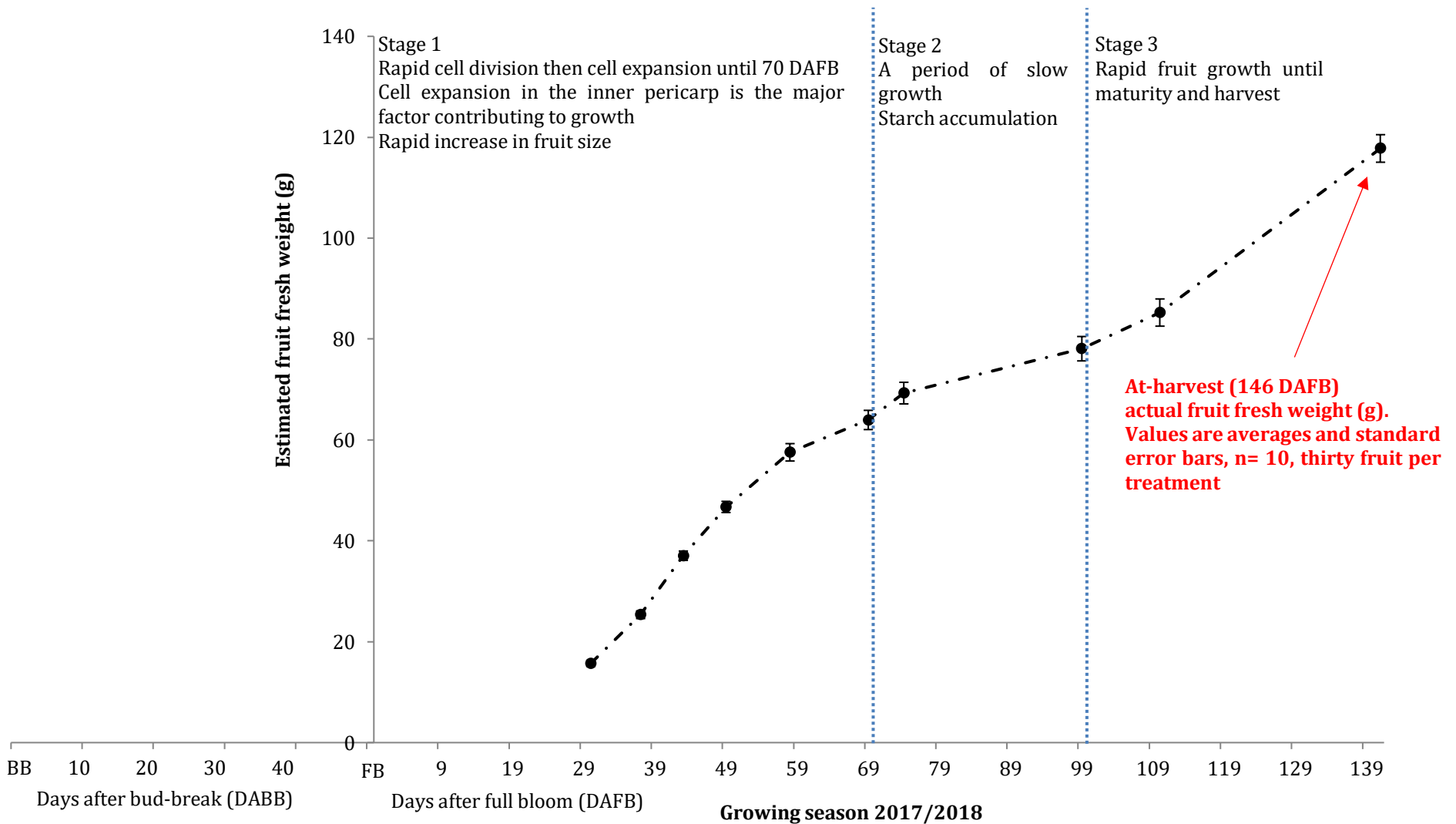


Figure 1.1 Seasonal pattern of estimated fruit fresh weight (g) of 'Zesy002' vines grown in the 2017/2018 season at the Paengaroa orchard, Bay of Plenty. Values are averages and standard error bars, n=10, four fruit per treatment. Bud-break was on 11-09-2017, full bloom was at 51 DABB on 01-11-2017 and the commercial harvest was at 146 DAFB on 27-03-2018. At-harvest actual fruit weight (g), values are averages and standard error bars, n = 10, thirty fruit per treatment.

1.2.2 Fruit quality from production to consumption

Fruit quality is a combination of many properties that gives the fruit its value (Kader, 1997). The relative importance of each fruit quality component varies with the particular fruit developmental stage such as pre- and at-harvest regarded as production, post-harvest as storage and handling stage and consumption. At production stage, fruit quality pertains to high yield, good appearance and long storage life to withstand distant shipping to overseas markets. This is judged by standards set for certain quality attributes and parameter values varies among fruit type and cultivars. These maturity indices are key to decide when to harvest to ensure satisfactory eating quality. Maturation is the stage of development which is most important for the completion of physiological or horticultural maturity (the stage of development when a plant or plant organ has attained prerequisites for utilisation by consumers). Fruit maturity at-harvest is the most important factor including other parameters that determine fruit is best to export or to store longer, a key decision that sustains exports year-round. The fruit of kiwifruit is climacteric and produces autocatalytic ethylene during ripening, therefore, it can be harvested at a physiologically mature stage but unripe and inedible (Chiaramonti & Barboni, 2010; Li et al., 2016; Schroder & Atkinson, 2006). Fruit ripening may occur slowly during the storage (i) at low temperatures or (ii) may be accelerated by ethylene exposure at higher temperatures (Ritenour et al., 1999).

The assessment of maturity indices helps to ensure sensory, nutritional and storage quality of the fruit in the horticultural fruit crops (Babu et al., 2017). Appearance, firmness and shelf life are important for wholesale retailers. Consumers judge quality at the time of purchase on the basis of appearance (freshness, colour and firmness). Subsequently, repeat purchase is dependent on the consumer's satisfaction in terms of eating quality. Consumers are also considerate of nutritional quality of fresh fruits: good source of energy, minerals, vitamins, dietary fibres and bioactive compounds in addition to colour and flavour (Kader, 1997). The nutritional and chemical composition of kiwifruit is important to well-informed consumers seeking health benefits (Drummond, 2013). Kiwifruit are nutrient rich, and regular consumption is reported to improve digestion, immunity and metabolic health (Boeing et al., 2012). The 'Zesy002' fruit is reported as a rich source of vitamin

C (161 mg 100g⁻¹ edible flesh) three times higher than oranges, good source of dietary fibre, potassium, vitamin E, and folate (Sivakumaran et al., 2018).

1.2.3 Kiwifruit industry and standard fruit quality criteria

The industry of New Zealand is primarily focused on fruit quality because it is a key element in deciding long term sustainable success of the kiwifruit industry in an increasingly competitive international market (Wright, 2005). The industry has set detailed maturity and at-harvest fruit quality standards for fruit size, firmness, SSC, FDM and fruit flesh green colour (Table 1.2) to allow clearance of the crop for harvest to ensure that the fruit is able to ripen during storage (at 1 °C) and to reduce the risk of a poor taste experience for consumers. Accredited laboratories test fruit maturity based on a ninety-fruit sample from an orchard block, which is taken for clearance assessment and upon meeting the standards, the orchard would be given official clearance to pick. Kiwifruit in general can be picked at a range of maturities to meet the specific market windows (Burdon, 2018). However, harvesting early when the fruit is still growing may affect the yield and returns for the grower. Therefore, kiwifruit industry in New Zealand has designed a payment model to encourage early harvests of certain quality parameters to provide quality fruit for early season's supply (Currie et al., 1999) and known as 'Kiwistart', 'Modified Kiwistart'.

Fruit size, firmness, SSC and FDM (Table 1.2) are indicators of the fruit quality at harvest (Richardson, 1997). Fruit size is used to assess the minimum supply standard for 'Zesy002'. Minimum size for standard supply per tray is 39 (count/tray; ≥84g/fruit) and the maximum size class is 16 (count/tray; ≥210-<240/fruit) (Table 1.3). Fruit firmness is measured in kilogram force (KgF) and is the primary quality index to indicate the eating ripeness of the fruit and determines the suitability of fruit for storage and best timing for export (Hopkirk et al., 1990). Fruit firmness at-harvest may range from 6 to 11 KgF. SSC in the fruit is measured in Brix° (one degree Brix is 1 gram of sucrose in 100 grams of solution at 20 °C), and is the commonly used index for harvesting mature fruit and indicates the ability of the fruit to ripen. Fruit green flesh colour is used as the maturity indicator and measured in hue angle (°Hue). The immature fruits are green with higher hue angle values (McGhie & Ainge, 2002). Fruit dry matter percentage (FDM) is a general measure of complex partitioning and transport of nutrients, water and carbohydrates (CHO) and acids into the fruit (Harker et al., 2009; Jaeger et al., 2011). Kiwifruit is categorised into

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'taste bands' known as 'Taste Zespri Grade (TZG)', which forms the basis to determine premium payments for the growers. Based on FDM grade value there are ten grade categories, the minimum acceptable grade is 1 with FDM<15.5%. Fruit dry matter acts as main incentive to growers to grow quality fruit (Table 1.4). However, in the 2019/2020 season the assessment of FDM was suspended due to the global pandemic.

Table 1.2 Standard maturity clearance criteria for kiwifruit 'Zesy002' cultivar based on dry firmness, SSC, dry matter and colour.

Clearance protocol	Units	Kiwistart	Modified Kiwistart	Mainpack	
Firmness	KgF		<4		
Mean SSC	°Brix			≥8.0°	
Dry matter	%	Sizes 16-36	≥16.9	≥16.4	≥16.1
		Sizes 39-42		≥16.6	≥16.6
Green flesh colour	°Hue values	≤112.9°	≤112.9°	≤109.3°	

Sourced from Zespri, (2019).

Table 1.3 Kiwifruit 'Zesy002' class1 sizes and their respective weight bands (grams) at packing.

Size	Weight band (g)
16	≥210 - <240
18	≥180 - <210
22	≥151 - <180
25	≥138 - <151
27	≥128 - <138
30	≥118 - <128
33	≥108 - <118
36	≥95 - <108
39	≥84 - <95
42 (Non-standard supply)	≥74 - <84

Sourced from Zespri, (2019).

Table 1.4 Taste Zespri Grade (TZG) and their respective dry matter percentage and grade value.

Grade	% Dry matter	Grade value (%)
1	<15.5	0
2	15.5-16.0	10
3	16.0-16.5	25
4	16.5-17.0	45
5	17.0-17.5	65
6	17.5-18.0	85
7	18.0-18.5	90
8	18.5-19.0	95
9	19.0-19.5	97
10	>19.5	100

Sourced from Zespri, (2019).

Kiwifruit growers are optimising the fruit size and dry matter concentration by using orchard management practices such as girdling, shoot pruning, enhanced pollination (Ainalidou et al., 2015), leaf and fruit thinning (removal of lateral fruit and the king fruit is kept as it is always larger and has higher dry matter than the lateral fruit) (Boyd & Barnett, 2011; Minchin. et al., 2010), cane and trunk girdling during spring and summer of the same season (Currie et al., 2017), adjusting crop load (Woolley & Cruz-Castillo, 2005) and fertiliser nutrient management (Mills et al., 2008; 2009; Morton & Woolley, 2010; Smith et al., 1987c). These practices are principally associated with fruit growth (specific cell division and expansion phases) (Hopping, 1976) and may manipulate the source-sink relationships.

1.3 The significance of nutrients in improving fruit quality

Mineral nutrients are required for leaf growth and are integral constituents of the photosynthetic apparatus and indirectly control photosynthesis through hydraulic and hormonal signals, and sugar signalling. Mineral nutrients play an important role in the formation of sink organs and the growth rate of sink organs can be limited either by the supply of photosynthates from source organs or the relative ability of sink organs to unload assimilates from the phloem and utilise them for growth and storage (Marschner, 2012). The external application of mineral nutrient fertilisers in addition to soil available mineralisation and nutrients from plant residues can regulate source strength (a function of source activity and source size).

1.3.1 Nitrogen

Nitrogen (N) is an essential macronutrient required in large amounts by plants and typically constitutes 1-5 % of the plant dry matter and N is highly mobile in plants (Marschner, 2012). Nitrogen is an integral constituent of chlorophyll, proteins, co-enzymes, phytohormones, nucleic acids and secondary metabolites. Nitrogen plays a central role in plant metabolism, protein synthesis, and carbon metabolism (Marschner, 2012). The external application of N is an essential orchard management practice to replenish the available N to the plant to maintain production and fruit quality (Burdon et al., 2004; Richardson et al., 1997).

In kiwifruit, N is required early in the growing season to quickly establish the canopy (photosynthetic apparatus). The application of soil N fertilisers is often used to increase fruit size and yield (Costa et al., 1997; Ferguson & Eiseman, 1983; Prasad & Spiers, 1985; Vizzotto et al., 1999). Even a minor deficiency of N can be detrimental for fruit growth in kiwifruit and can reduce vegetative growth, photosynthetic rates thus reducing carbon acquisition and dry matter accumulation (Buwalda et al., 1991). Kiwifruit vines take up 55-100 Kg N ha⁻¹ per annum with N fertilisers applied at a rate of 100-200 Kg N ha⁻¹ hence, increasing risk of N leaching. The plant residues and soil organic matter mineralisation also supplies N for plants. In kiwifruit orchards, relatively high rates of N fertilisers are applied with up to 250 Kg N ha⁻¹ reported by (Kader, 1997); Mills et al., (2008). However, excessive N application rates potentially increase vegetative growth, vine succulence, increases incidence of disease and pests and may increase orchard management cost (Elfving, 1988; Woodward & Patterson, 2009), adversely affects fruit quality as more water uptake and less dry matter accumulation thereby, high rate of fruit softening and increased incidence of physiological disorders (Prasad & Spiers, 1992; Sher & Yates, 1992). It also negatively impacts environment through nitrate leaching (Anon, 2013; Mills et al., 2005). The risk of nitrate leaching would be higher if N fertilisers are applied during winter months because of high drainage.

1.3.2 Potassium

Potassium (K) is an essential macronutrient required in large amounts by plants after N and typically constitutes 2-10 % of the plant dry matter (Marschner, 2012). Potassium is the most abundant nutrient in fleshy fruits and is highly mobile in plants, moves in both xylem and phloem, and is easily transported and redistributed

among various plant organs. Potassium is involved in many plant physiological processes such as osmotic regulation, stomatal conductance, photosynthesis, enzyme activation, hormonal signalling, gene expression, regulating reactive oxygen species (ROS), protein synthesis, phloem transport, translocation of photo-assimilates, cell expansion and sugar/acid metabolism (Basile et al., 2003; Epstein & Bloom, 2005; Guo et al., 2003; Huang, 1983; Maathuis & Diatloff, 2013; Marschner, 2012; Patrick et al., 2001; Rossiter et al., 2000; Wang et al., 2018b). The main role of K in plants is to maintain the electrical neutrality of solutions transporting photosynthates from shoots to roots and nutrient anions (NO_3^- and SO_4^{2-}) up the xylem vessels. A deficiency of K might negatively affect gas exchange through the reduction of stomatal opening and carbon dioxide (CO_2) diffusion thus affecting photosynthesis and plant productivity.

K has long been recognised as a 'quality nutrient' in plants (Dreyer, 2014; Li, 1952; Liang, 1984; Wang & Wu, 2013) as often K fertilisation is used to improve at-harvest quality of fruits and vegetables (Asaduzzaman & Asao, 2019; Datson Pm, 2011; Fernandes et al., 2018; Woldemariam et al., 2018). Potassium is known to increase berry growth and volume during cell expansion in grape vines (Mpelasoka et al. 2003). Optimum K nutrition is related to increase fruit size and production, SSC and improve taste and colour. In kiwifruit, K fertilisation improved fruit quality at eating stage (Wang et al., 2006). Smith et al., (1987c) associated reductions of the fruit yield with K deficiency in a commercial kiwifruit orchard. Kiwifruit vines have a high K demand as evident from annual K uptake rate of 100-200 Kg K ha⁻¹ per annum. The common K fertiliser application rates in New Zealand kiwifruit orchards are typically around 250-350 Kg K ha⁻¹ per annum and some orchardists apply rates as high as 500 Kg K ha⁻¹ per annum (Mills et al., 2008). Although many soils used for kiwifruit in New Zealand can have a low K content, such high application rates of K fertilisation may limit availability of other nutrients in the soil as discussed in section 1.4.

1.3.3 Calcium

Calcium (Ca) is an essential macronutrient required in large amounts after N and K and constitutes typically 0.2-1.0 % of the plant biomass (Marschner, 2012). Calcium has a dual role in both structural and functional activities in plants and is recognised as both a nutrient and an intracellular messenger (Fao, 2012). Calcium is involved

in several biochemical and physiological processes (Hepler, 2005). Calcium is an important structural component of cell walls and essential for cell wall strengthening. Calcium pectate plays a role in membrane stability and reduces the production of ethylene in the fruit (Buchanan et al., 2015; Faust, 1989; Hirschi, 2004; Kou et al., 2015; Naradisorn et al., 2004; Poovaiah, 1986). Calcium is also involved in cell division and expansion, growth differentiation, membrane stabilisation, ion homeostasis, osmoregulation, water relations, stomatal conductance enzyme activation and hormone signalling (Epstein & Bloom, 2005; Hocking et al., 2016; Marschner, 2012; Thor, 2019; White & Broadley, 2003). In plant tissues, Ca is present in large amount in vacuoles, endoplasmic reticulum, mitochondria and Golgi apparatus and in low concentration in the cytosol. Any transient change in cytosolic free Ca ions (Ca^{2+}) generates unique Ca signalling that carries specific information known as Ca signatures and is stimuli specific (Feijo & Wudick, 2018; Marschner, 2012; Pei & Gilroy, 2018).

In fruit production, the structural involvement of apoplastic Ca is of particular importance and influences the shelf-life of fruits including kiwifruit. In kiwifruit, Ca plays a significant role to maintain fruit quality (Sale & Clark, 2002). Fruit Ca content and fruit quality has been positively associated in kiwifruit (Ciccarese et al., 2013; Montanaro et al., 2006; Xie et al., 2002). Fruit Ca deficiency may even develop in fruit crops grown in orchard soils with sufficient Ca status but unavailable for plant uptake (Saure, 2005). Low fruit Ca content has generally been associated with physiological disorders in kiwifruit. Increased fruit Ca concentration from 0.32 to 0.42 mg g⁻¹ dry weight has been shown to improve fruit quality in kiwifruit cultivar Tsechelidis at-harvest (Koutinas et al., 2010) and post-harvest (Antunes et al., 2004; Basiouny & Basiouny, 2000; Cicco et al., 2007; Ferguson et al., 2003; Gerasopoulos & Drogoudi, 2005; Thorp et al., 2003). According to Sale & Clark, (2002) a mature kiwifruit vine requires at least 320 Kg Ca ha⁻¹ per annum to produce standard fruit yield. However, common application rates in both organic and conventional kiwifruit orchards in New Zealand are typically 80-130 Kg Ca ha⁻¹ (Mills et al., 2008).

1.3.4 Magnesium

Magnesium (Mg) plays an important role in the enzyme activation, as a constituent of many enzymes. It holds a central position in the chlorophyll molecule, and is involved in many processes, like electron transport, photosynthesis, carboxylase

reaction of photosynthesis, regulation of pH, cation-anion balance, turgor adjustment, synthesis of protein, starch and sugar, starch translocation, and phloem loading and unloading (Bose et al., 2011; Bybordi & Shabanov, 2010; Marschner, 2012; Tatagiba et al., 2016; Verbruggen & Hermans, 2013). Like other mobile nutrients, within the plant Mg is mobile and in deficient situations Mg is translocated from older to younger tissues (Marschner, 2012) and results in reduced chlorophyll content of the deficient leaves which ultimately reduces photosynthetic efficiency and C fixation (Mehne-Jakobs, 1995) and reduced sugar production. Magnesium is an important mineral nutrient to maintain the quality of the horticultural fruit crops during the growing season. Dimassi-Theriou & Bosabalidis, (1997) reported that increasing the Mg concentration enhanced the photosynthetic capacity of leaves in 'Hayward' kiwifruit. Clark & Smith, (1987) associated Mg deficiency with large yield reductions primarily due to the reduction in fruit number in the 'Hayward' cultivar due to fruit drop.

1.4 Nutrient availability and uptake at soil-root-fruit interface in kiwifruit vines

An efficient nutrient management plan must consider nutrient uptake limitations due to several factors such as soil and climatic characteristics, nutrient fertiliser input, orchard management practices and plant intrinsic features, operating at soil-root-fruit interfaces and pathways in horticultural fruit crops.

1.4.1 Soil level

Soil characteristics such as acidic pH, low organic matter, low cation exchange capacity (CEC) and base saturation, and high draining profile together with high rainfall events may potentially affect plant Ca availability (MCloughlin & Wimmer, 1999). Competition of K and Mg ions (K^+ and Mg^{2+}) with Ca^{2+} for binding sites at the soil interface is another factor limiting Ca uptake. High amount of K fertiliser may also limit Ca availability at soil level and is reported by many (Fageria, 2001; Jakobsen, 1993a; Jakobsen, 1993b; Johansen et al., 1968a; Pathak & Kalra, 1971; Rietra et al., 2017; Robson & Pitman, 1983; Taylor et al., 2004; Wiersum, 1979) due to monopoly of monovalent ions (K^+) over divalent ions (Ca^{2+} and Mg^{2+}) (Figure 1.2). In addition, K fertilisers (mainly sulphate of potash) are highly soluble compared to Ca fertilisers (gypsum and dolomite).

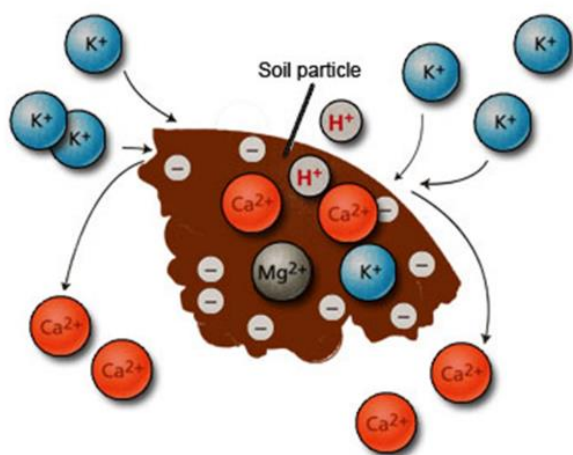


Figure 1.2 Monopoly of monovalent ions for exchange sites on soil colloids over divalent ions.

1.4.2 Root level

Calcium uptake is through the young root tips (where differentiated endodermal cells have not been formed yet) thus Ca uptake is restricted to the un-suberised fine root tips with cells with no casparian strips, which would compel a symplastic pathway (White, 2001). Therefore, the xylem movement of Ca is unidirectional and passive thus Ca cannot be re-supplied to fine roots from basipetal tissues making them particularly susceptible to low Ca supply from the soil (Bangerth, 1979; Harrison-Murray & Clarkson, 1973; White, 2001). Thus, any cultural practices in kiwifruit orchards causing reduction in root density in the upper soil layer (Montanaro et al., 2007) where available Ca is high (Jobbágy & Jackson, 2001) such as tillage or root pruning will negatively affect root Ca uptake (Testolin & Ferguson, 2009; Wiersum, 1979). Thus, it is recommended to avoid soil disturbance in order to increase root Ca uptake especially when fruit Ca demand is high (Montanaro et al., 2014).

1.4.3 Fruit level

Kiwifruit vines have an intrinsic vigorous growth habit that also negatively impacts import of Ca into the fruit. Ca is phloem immobile thus only transported through xylem vessels via transpiration stream. Therefore, highly transpiring organs such as leaves accumulate large concentrations of Ca compared to low transpiring organs such as fruits (Gilliham et al., 2011; Montanaro et al., 2015). In addition, fruit Ca import is also affected due to limited xylem functionality in fruits (xylem vessels rupture as fruit grows) during the fruit developmental stages (Montanaro et al.,

2014). Therefore, in comparison to leaves, the fruits are relatively poor sinks for Ca (Poovaiah et al., 1988).

1.4.4 Implications of low fruit Ca concentration

Calcium influences fruit development, fruit quality and disease susceptibility through developmental and stress signalling response, membrane stabilisation, water relations and cell wall modifications through cross-linking of de-esterified pectins (Hocking et al., 2016). To comply with both structural and functional roles, Ca needs to be available for the plant in sufficient amounts (Thor, 2019). A low fruit Ca concentration is directly linked to possible physiological fruit disorders (Prasad & Spiers, 1991; Taghavi et al., 2019). In kiwifruit vines, increased pre-harvest Ca nutrition improved fruit firmness and soluble solids at-harvest and exhibited lower fruit softening during storage and increased profitability (Gerasopoulos et al., 1996; Gerasopoulos & Drogoudi, 2005). Therefore, adequate pre-harvest Ca nutrition is required to improve the fruit quality. The external application of Ca has been reported to be beneficial in other fruit crops. Increasing fruit Ca concentration reduced the incidence of pre-harvest and post-harvest physiological disorders in apple (Ferguson & Watkins, 1989), avocado (Cutting & Bower, 1989; Witney et al., 1990), tomato (Ho & White, 2005), grape (Ciccarese et al., 2013) and kiwifruit (Ferguson et al., 2003; Thorp et al., 2003). These physiological disorders are characterised by cell membrane deterioration, turgor loss and leakage of cell fluids and caused by Ca deficiency in the affected fruit tissues.

1.5 Foliar nutrient fertiliser application

Many disorders in fruit crops mostly appear due to limited nutrient availability and limited transport from root to fruit. In kiwifruit, low fruit Ca, K and Mg uptake is reported to cause many physiological, pathological and physical fruit disorders during storage (Prasad & Spiers, 1991). Foliar nutrient application is a well-known strategy (Brown & Suwanarit, 1999; Mia, 2015; Smolen, 2012). Several benefits such as high nutrient recovery, reduction in the amount applied since it avoids the losses at soil level hence, less environmental damage (Bindraban et al., 2015; Fageria et al., 2009; Kannan & Charnel, 1986; Mia, 2015; Morton et al., 2019). For example, the average uptake of N from foliar application is 40 % higher than soil applied N application (Weinbaum et al., 1992). It has been shown by Morton, (2013) that

runoff by foliar applied urea was 2 % of the volume applied, which was equivalent to a combined total of 1.8 Kg N ha⁻¹ and considered not significant.

The foliar application is a target specific strategy which facilitates fast nutrient absorption and assimilation (Peuke et al., 1998), which in turn reduces the competition between vegetative and reproductive sinks. The foliar nutrient fertilisers can be applied at the time of demand in a growing season in a timely fashion and can remediate (minor) deficiencies in relative short time compared to soil applied nutrient fertilisation. The foliar nutrient application is an effective alternative in situations where soil nutrient fertilisation may trigger antagonistic nutrient interactions (Mia, 2015).

1.5.1 Limitations

Foliar nutrient fertiliser application may cause foliar damage (burn) if the concentration of the nutrient fertiliser spray is too high (Burkhardt, 2010). It often requires surfactants to increase absorption efficacy, however, surfactants might cause disruption and breakdown of cell membrane and might induce ethylene production (Fernandez et al., 2017; Fernandez & Eichert, 2009; Knoche et al., 1992; Lownds & Bukovac, 1989). It is usually effective for leaves with a large surface area. The foliar application efficiency is also dependent on climatic conditions like temperature, humidity, wind velocity and rainfall etc. Also, the cost of multiple applications can be prohibitive (Fageria et al., 2009; Oosterhuis, 2009; Stock & Davies, 1994).

1.5.2 Route of absorption

In general, the nutrient uptake by leaf cells follows the similar patterns after absorption as obtained with the roots (Baligar & Duncan, 1990). The absorption of nutrients is dependent on concentration, metabolic inhibitors, and enhanced by light (Marschner, 2012). After the application of foliar sprays, nutrients enter the leaf surface via: (i) stomata on both abaxial and adaxial surface of the leaf (Eichert et al., 1999; Eichert & Goldbach, 2008; Fernandez et al., 2017; Fernandez & Brown, 2013), (ii) aqueous or hydrophilic pores within the leaf cuticle (Tyree et al., 1990) and (iii) trichome (Haynes & Goh, 1977) as shown in the Figure 1.3. After passing through these entry points, foliar nutrients reach the cell wall and then cell membrane followed by a passage through spongy and palisade mesophyll cells as shown in Figure 1.3 (Malhotra et al., 2019). The nutrients within the leaf follow two

routes: apoplastic and symplastic to reach the vascular tissues (xylem and phloem respectively) before translocation from leaf to other plant parts (Baligar & Duncan, 1990). In general, the nutrients absorbed by the leaves are quickly transported to other parts of the plant. However, the translocation rate is dependent on the nature of the nutrients and on the plant species.

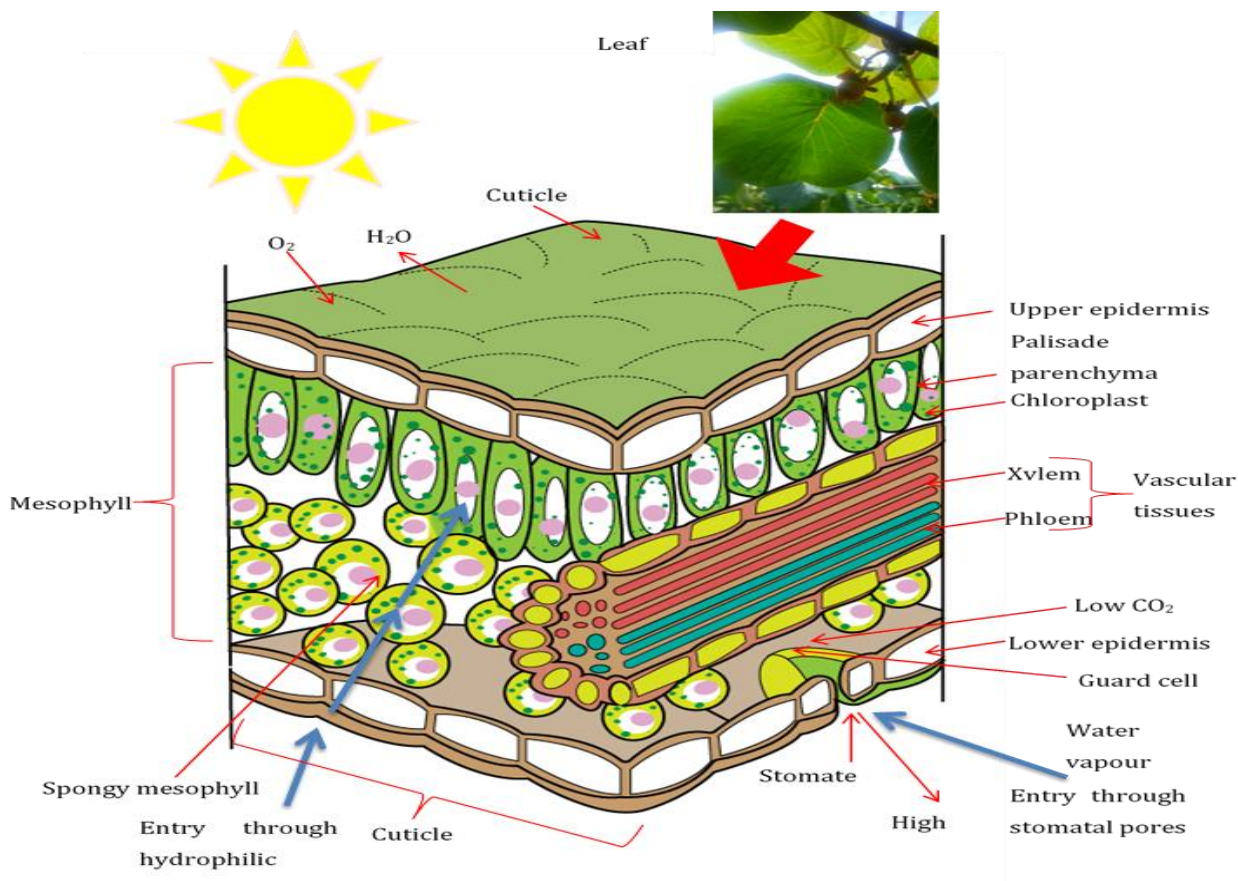


Figure 1.3 Foliar nutrient absorption routes in the leaf tissue.

1.5.3 Kiwifruit leaf and fruit anatomy, makes it a perfect fit for foliar application

The leaf of kiwifruit vine has many irregular shaped anomocytic stomata on the lower side (abaxial) of the leaf surface which facilitates uptake of foliar nutrients (Ferguson, 1990; Haynes & Goh, 1977). Such a dense covering of hairs on leaf and fruit possibly facilitates spray retention. On a pergola training system, the hanging fruit and the underside of the leaves are well exposed to foliar applications. Moreover, in kiwifruit, a thin fruit epidermal layer is present which has high rates of surface conductance compared to other fruit such as apple, a feature which ensures efficient foliar nutrient absorption particularly during early stages of fruit

development (Smith et al., 1995). Although, the abaxial surfaces of the leaf and young fruitlets of kiwifruit cultivars are challenging to wet and strongly repel spray droplets (Pathan & Gaskin, 2019), the use of surfactants which are able to reduce the surface tension of spray droplets may assist foliar nutrient uptake particularly during the early season (Pathan & Gaskin, 2019). However, numerous studies showed that without adding surfactants the foliar applied solutes were clearly taken up through stomata (Burkhardt et al., 2012; Eichert et al., 1998; Schonherr & Bukovac, 1978). Therefore, surfactants were not used to avoid interference and to investigate only the effect of foliar applied mineral nutrients with pH adjustment.

1.6 Problem statement

It is a general practice in kiwifruit orchards to apply excessive rates of K fertilisers due to high demand of K and the association of soil K fertilisation with improved fruit quality indices such as fruit size, colour and dry matter percentage. However, high soil K fertilisation and the characteristic features of Bay of Plenty's coarse textured soils, which are acidic soils in nature, with a high draining profile, and possible high rainfall events, combined with orchard management practices such as high input of soil N fertilisers and root pruning, and vigorous vegetative growth of kiwifruit vines could severely impact availability and uptake of Ca at soil-root-fruit interface in kiwifruit vines. Thus, low fruit Ca concentration may potentially increase fruit softening in 'Zesy002' during storage. Currently, growers are following combined nutrient management plan designed for 'Hayward' and 'Hort16A' (Table 1.1) and no nutrient management studies specific for 'Zesy002' have been conducted to date in New Zealand according to our knowledge. There remains a need for a cultivar specific nutrient management plan as identified by 'On-Orchard' steering group of Zespri International Ltd.

1.7 Objectives

This study was designed with main objectives:

- i- increase leaf and fruit Ca concentration at-harvest by specifically targeting to avoid the antagonistic effect of soil-applied K fertiliser on Ca uptake without reducing K input and

- ii- increase leaf and fruit K uptake to improve photosynthetic performance, fruit growth rate and at-harvest fruit quality indices such as fruit size, firmness, SSC and FDM in a sustainable fashion.
- iii- reduce excessive soil fertiliser nutrient input.

1.8 Main research questions

- 1- How to reduce the competitive effect of soil K fertilisation on the uptake of Ca without reducing the rate of K fertilisation in kiwifruit vines at soil level in commercial orchards at BOP?
- 2- How to increase Ca and K uptake in leaf and fruit tissues without increasing soil fertiliser input?
- 3- What is the optimum time of soil K fertilisation in 'Zesy002'?

1.9 Hypotheses

- 1- Spatial and temporal separation of soil-applied Ca and K fertilisers may reduce the antagonistic effect of K on the uptake of Ca in kiwifruit vines.
 - 2- Three applications of soil-applied K (100 Kg K ha⁻¹ each) at BB, FB and 70 DAFB may increase K uptake, fruit size, SSC and FDM at-harvest.
 - 3- Foliar applications of Ca and K fertilisers from fruit set through to fruit developmental stages may increase the uptake of nutrients in leaf and fruit tissues. Publications
- 1- Hashmatt, M., Kerckhoffs, L. H. J., Morton, A. R., Heyes, J. A. (2017). Current challenges in 'Zesy002' kiwifruit nutrient management research. The poster presented at the Plant Science Central Conference held in July 2017. (Appendix 1)
 - 2- Hashmatt, M., Morton, A. R., Heyes, J. A., Armour, D., Lowe, T., Black, M., & Kerckhoffs, L. H. J. (2018). Best nutrient management practices for the kiwifruit cultivar 'Sungold'. The oral presentation at the School of Agriculture and Environment Symposium held in November 2018. (Appendix 2)
 - 3- Hashmatt, M., Morton, A. R., Heyes, J. A., Armour, D., Lowe, T., Black, M., & Kerckhoffs, L. H. J. (2018). Effect of pre-harvest foliar calcium application on fruit quality in Zesy002 kiwifruit. In *Acta Horticultural Congress IHC2018: International Symposium on Water and Nutrient Relations and Management of 1253* (pp. 327-334). (Part of Chapter 5)

Introduction and literature review

- 4- Hashmatt, M., Morton, A. R., Heyes, J. A., Lowe, T., Black, M., & Kerckhoffs, L. H. J. (2019). Which foliar potassium fertiliser improves fruit growth and quality of 'Zesy002' kiwifruit at-harvest?' Oral presentation at the Plant Science Central Conference held in July 2019. (Appendix 3)
- 5- Hashmatt, M., Kerckhoffs L. H. J., & Lowe, T. (2019). Foliar boost for Zesy002. New Zealand Kiwifruit Journal, October/November 2019. (Appendix 4)

2 General materials and methods

2.1 Introduction

General methods reported in this chapter were conducted from 2016 to 2019. Specific experimental methods are given in the Materials and Methods section of that chapter.

In this study *Actinidia chinensis* var. *chinensis* 'Zesy002', marketed as Zespri® SunGold, kiwifruit vines were grafted on to green kiwifruit (*Actinidia deliciosa* (A.Chev.) C.F. Liang et A.R. Ferguson var. Bruno) rootstocks and open pollinated were used in different kiwifruit growing regions across New Zealand. Experimental sites were selected in main commercial kiwifruit growing regions across New Zealand. Two commercial orchards with different management practices were selected in Bay of Plenty. One commercial orchard was also selected in the Haumoana, Hawke's Bay. In addition, two-year-old, 'Zesy002' vines grafted onto green kiwifruit 'Bruno' rootstocks were grown in pots at the Horticultural Unit, formerly known as Plant Growth Unit, Massey University, Palmerston North to allow close measurements of detailed interventions of controlled systems. Experiments reported in this manuscript are:

- 1- Spatial separation of soil-applied Ca and K nutrient fertiliser experiment was conducted in the 2017/2018 season using mature 'Zesy002' vines in a commercial orchard in the Te Puke region of Bay of Plenty (Chapter 3).
- 2- Temporal separation of soil-applied Ca and K nutrient fertiliser experiment was conducted in the 2017/2018 season using mature 'Zesy002' vines in a commercial orchard in the Paengaroa region of Bay of Plenty (Chapter 4).
- 3- Spatial and temporal separation of soil-applied Ca and K nutrient fertiliser experiments were conducted in the 2017/2018 season using young pot-grown 'Zesy002' vines grafted onto 'Bruno' and 'Bounty' rootstocks in the orchard at the Horticultural Unit, Massey University, Palmerston North (Chapters 3 and 4).
- 4- Foliar-applied Ca fertiliser experiments were conducted in the 2017/2018 season to investigate vine physiology and at-harvest fruit quality using mature 'Zesy002' vines in Te Puke and Paengaroa orchard (Chapter 5), and Haumoana orchard (not presented).

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- 5- Foliar-applied Ca fertilisation experiment was conducted in the 2016/2017 season to investigate short-term fruit storage quality using mature 'Zesy002' vines in the Paengaroa orchard (Chapter 5). Published in *Acta Hort.*1253. ISHS 2019. DOI 10.17660/ActaHortic.2019.1253.43 XXX IHC – Proc. Int. Symp. on Water and Nutrient Relations and Mgt. of Hort. Crops Eds.: A. Bengal et al.
- 6- Soil-applied K fertilisation experiments were conducted from 2016 to 2019 using mature 'Zesy002' vines in commercial orchards at Te Puke and Paengaroa (BOP), and Haumoana (Hawke's Bay) (Chapter 6).
- 7- Foliar-applied K fertilisation experiments were conducted from 2016 to 2019 using mature 'Zesy002' vines in commercial orchards at Te Puke and Paengaroa (BOP), and Haumoana (Hawke's Bay) (Chapters 7 and 8).

The relevant information about the experimental sites is presented in (Table 2.1). In each commercial orchard, suitable blocks for research experiments were selected. Trial blocks were marked with "No Fertiliser" and "Caution" signs to avoid human error and fertiliser application by orchard workers. With nutrient management as exception, all other management practices were kept same as the rest of the orchard. These orchard practices were operated by the orchard management such as support structure, irrigation, pollination, copper sprays, training, summer and winter pruning, root pruning and trunk girdling. The root pruning was a common practice in the Paengaroa orchard, but practiced only once in the 2016/2017 season in the experimental block. No root pruning and girdling throughout the course of the study was carried in the Te Puke orchard. To avoid variability, healthy and uniform vines were selected in each orchard before treatment application. Where the foliar treatments were applied to individual canes per vine, care was taken to select one-year-old replacement canes of uniform size and length (usually full length). To avoid row variation due to soil spatial heterogeneity randomised block design was used and each row was used as a block in all experiments.

Table 2.1 Location co-ordinates and orchard characteristics of experimental sites.

Parameters	Units	Te Puke	Paengaroa	Haumoana	Horticultural Unit
Altitude	MSL	61	8	0	39
Row spacing	m	4.6	3.6	3.5	Not applicable
Bay length	m	4.6	6.0	7	Not applicable
Fruit load	fruits m ⁻²	50	50	*60	Not applicable
Irrigation		Zero	Sprinkler	Sprinkler	Drip/Trickle
Soil type		Te Puke loam	Paengaroa loam	Hastings silt loam	**Standard soil mix

*- The research block in the Haumoana orchard was kept un-thinned from 2016 to 2017.

** - Standard soil mixture was composed of one-part peat, one-part vermiculite, one-part sand and two-part Manawatu silt loam.

In every bay there were two female vines and every third bay a male vine along with female vines was present at Te Puke (2016-2018) and Paengaroa (2016/2017) orchard. In the 2017/2018 season at the Paengaroa orchard, every third row was stripped to male vines. The information about the growing season such as bud-break (BB), full bloom (FB), sampling and harvest date of each experimental site is presented in (Table 2.2).

Table 2.2 The seasonal information and calendar date of experimental sites at Te Puke and Paengaroa, Bay of Plenty and Horticultural Unit, Massey University, Palmerston North in the 2017/2018 season.

Key Events	Te Puke	Paengaroa	Haumoana	Horticultural Unit
*Bud break	25-09-2017	11-09-2017	15-09-2017	27-09-2017
**Full bloom	07-11-2017	01-11-2017	28-10-2017	09-11-2017
Clearance report	18-04-2018	Not provided	15-03-2018	Not applicable (NA)
Date of harvest	19-04-2018	27-03-2018	16-03-2018	25-04-2018
Days after full bloom (DAFB)	163 DAFB	141 DAFB	139 DAFB	161 DAFB
Fruit processing	24-04-2018	03-04-2018	16-03-2018	26-04-2018
Commercial harvest	29-04-2018	27-03-2018	17-03-2018	NA

*- Bud break is considered when 10 % of buds have green shoots at least 1 cm (2/5 inch) in length.

** - Full bloom is considered when 70 % flowering is completed.

Fruit samples were taken near commercial harvest, once the ninety-fruit sample passed the clearance and informed by orchard managers. In Bay of Plenty region generally, the climate is warm and temperate with significant rainfall well distributed throughout the year and considerably less wind speed due to the extensive sheltering (Chappell, 2014). Palmerston North climate is warm and temperate with significant rainfall. The management at the Paengaroa orchard was using commercially installed weather stations to monitor weather conditions. To

closely monitor daily weather conditions, orchard management permitted to access weather data online from (www.harvest.com) however, due to logging discrepancies data is not presented. For other experimental sites, weather data was accessed online from MetWatch HortPlus NZ Limited and provided by Zespri International Ltd, to monitor daily weather throughout the duration of this study.

2.2 Pot-grown 'Zesy002' vines

One-year-old green kiwifruit 'Bruno' and 'Bounty' rootstocks, and 'Zesy002' bud-woods (two buds per wood) were ordered from peach nursery in 2016 after obtaining license from Zespri International Ltd. Young vines were grown in the automatically ventilated unheated (24 °C) glass house and bud-wood was stored in the cold storage room (2 °C) at the Horticultural Unit, Massey University, Palmerston North. Vines were transferred to 45 litre (L) black planter bags (Easilift Superlift™) filled with the growing medium (coarse bark/compost/pumice mix/vermiculite/peat/sand/silt loam). The growing medium has a pH range of 6.0-6.4 measured according to saturation extract method reported by (Warncke, 1986) using a paste extract saturated with 25 mL water to 10 g media. Planter bags had a surface area of 0.1 m². Planter bags with vines (pot grown kiwifruit vines) were then transported to orchard block 3 covered with wind shelters and supported with wooden framework and a metal wire. Grafting was done in September, 2016 using whip and tongue method (detailed explanation in Kiwitech bulletin No. N53 'Grafting kiwifruit to a new variety and grafting videos available on www.zespricanopy.com). Thoroughly clean and sanitised grafting tools were used for grafting 'Zesy002' bud-woods onto 'Bruno' scion. Grafted bud-woods were wrapped around with grafting tape (Egmont self adhesive 20mm 100 mm grafting and budding tape) and tips were sealed with 'pruning paint' (Yates PruneTec pruning and grafting sealant 200 mL) to avoid any sap flow and dehydration (Figure 2.1).

General materials and methods

Pot grown 'Zesy002' vines were open pollinated and automated drip irrigated and received equally distributed 4 L of water per day. Pot grown vines were given modified Hoagland's nutrient solution (Hoagland & Arnon, 1950) to maintain normal plant growth (Paiva et al., 1998). Both calcium (Ca) and potassium (K) were not included in the Hoagland's nutrient solution for experimental purpose (Chapters 3 and 4).



Figure 2.1 Grafting 'Zesy002' bud-wood onto 'Bruno' scion in the orchard block 3 at the Horticultural Unit, Massey University, Palmerston North in September 2016.

2.3 Nutrient fertilisers and their formulations

Calcium formulation with nitrate and sulphate to soils had been reported to increase fruit Ca concentration (Greene & Smith, 1979; Perring, 1979; Van Lune, 1984). Therefore, we used gypsum, sulphate of potassium (SOP) and calcium ammonium nitrate (CAN) to supply Ca, K and N, respectively (Table 2.3). Gypsum has been reported to markedly increase crop production and the marketable yield in wide range of plant species (Davis & Persons, 2014; Ila'ava et al., 2000; Lee & Mudge, 2013; Sanderson et al., 1996a; Sanderson et al., 1996b; Sanderson & Eaton, 2004). The soil-applied fertilisers were provided by Ballance Agri-Nutrients Ltd.

Table 2.3 Nutrient composition percentage and product number of fertiliser formulations.

Nutrients (%)	Calcium sulphate (Gypsum)	Sulphate of potassium (SOP)	Sulphate of ammonium (SOA)	Calcium ammonium nitrate (CAN)
N	0	0	19.5	27
P	0	0	1	0
K	0	42	0	0
S	18	17	22	0
Mg	0	0	0	2
Ca	22	0	0	4
Ballance Product #	10661	10476	10098	10092

The amount of fertiliser required was calculated using the following formula:

$$\text{Required amount of fertiliser (g)} = \left[\frac{100 \times \text{required nutrient rate (Kg/ha)}}{\text{Available nutrient \% in fertiliser}} \right] \times [\text{Area (ha)} \times 1000(\text{g/Kg})] \quad (2.1)$$

2.4 Soil sampling

Soil testing of the experimental research block was conducted in July each year at experimental sites and soil test results of the entire block were also provided by orchard managers each year. To closely monitor soil nutrient status, soil sample of each treatment vine was taken before and after completing experiment. A soil core sample (composite of five sub-samples) from around the root zone of the vine was taken with the help of a soil corer at a depth of 0-15 cm and submitted for basic soil test and available N to the Farmed Landscapes Research Centre (FLRC) previously known as Fertiliser and Lime Research Centre at Massey University, Palmerston North and R J Hill Laboratories Limited.

2.5 Pre-harvest or on vine non-destructive measurements

Cane length and diameter was measured using length measuring tape, before and after completion of research experiments. Number of flowers, leaves and fruits were calculated using a digital hand-held counter per vine in soil experiments and per cane in the foliar experiments. The length and diameter of tagged leaves were measured from fruit set through to harvest with a measuring tape.

2.5.1 Fruit size measurements and fresh weight estimate

Length and diameter (mm) of tagged fruits from fruit set through to harvest were measured using electronic digital Vernier callipers (S_Cal EVo IP67, Model:

ISP091201D, Sylvac) with Bluetooth connectivity to android smart phones (Figure 2.2). Data was accessed using android supported application Sylvac BT Smart Demo was used to estimate fruit fresh weight. Fruit fresh weight was estimated using fruit length (L), and maximum and minimum diameters at the equatorial regions (Dmax and Dmin respectively) as described by Minchin et al., (2003) the slope of the regression line was used as the multiplier (0.54, $R^2 = 97.5\%$) and fruit fresh weight estimates were calculated using the following formula:

$$FW = ((L \times Dmax \times Dmin) \div 1000) \times 0.54 \quad (2.2)$$

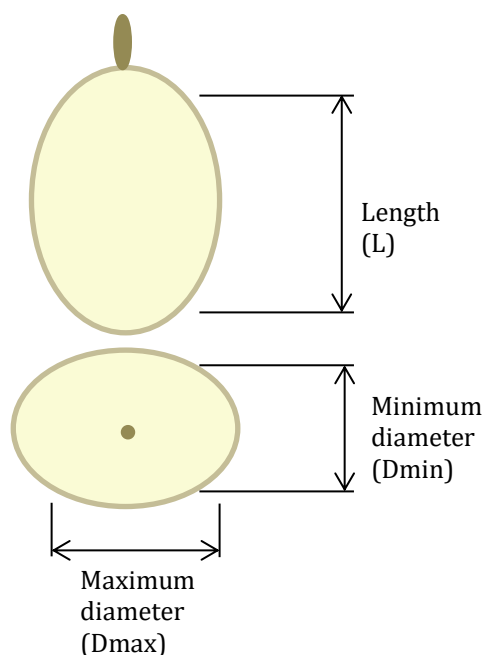


Figure 2.2 Illustration of fruit size measurements made on kiwifruits to estimate fruit weight.

2.5.2 Leaf chlorophyll measurements

The chlorophyll concentration of the mature fully expanded leaf was initially measured by a portable chlorophyll meter (Konica Minolta SPAD 502 Plus, Tokyo, Japan), and then determined by spectrophotometry according to the method of Lichtenthaler & Wellburn, (1983). One cm diameter was cut off a leaf with leaf punch and was immediately added to a labelled, aluminium foil covered falcon tube containing 5 mL methanol. Then homogenised with a smooth metal rod ensuring no solvent was lost. Followed by incubation for one hour and then the solution was filtered and read on BioChrom libra spectrophotometer at wavelengths 663.6, 646.6 and 750 nm. Chlorophyll $a+b$ was calculated using the following equation;

$$Chl\ a+b = 22.12 (A_{652.0} - A_{750}) + 2.71 \times (A_{665.2} - A_{750}) \quad (2.3)$$

2.5.3 Photosynthetic measurements

Stomatal conductance, net photosynthetic rate and leaf internal carbon dioxide (CO₂) concentration were calculated using a Licor portable photosynthesis system (LI-6400, LI-COR, Inc., Lincoln, Nebraska, USA) at a fixed light intensity (PAR) of 1,600 $\mu\text{mol m}^{-2} \text{s}^{-1}$. Measurements were taken between 10:00 am – 2:00 pm NZDST in sunny sky conditions on two to four fully expanded mature sun exposed leaves per treatment (not the full canopy) from the same canopy zone at the similar position on each shoot. Chamber CO₂ concentration was controlled at 400 $\mu\text{mol mol}^{-1}$. Measurements were based on the assumption that expanding leaves are representative of fixed carbon (Meinzer et al., 1993).

2.6 Destructive measurements

2.6.1 Leaf sampling

Leaf samples were collected for nutrient analysis from each vine before applying treatment in each experiment and then at-harvest (Figure 2.3). In soil experiments, each sample comprised of twenty youngest fully-expanded second leaves past the final fruit cluster on each fruiting lateral from each treatment vine (Smith et al., 1987c). In the foliar experiments, each sample comprised of six fully expanded youngest leaves selected from each treatment cane per vine. Leaves were weighed then acid washed and thoroughly rinsed with distilled water to avoid residual contamination due to nutrient deposition from the foliar spraying. Leaf samples were oven dried at 60 °C till a plateau was obtained then finely ground and 2.8 mg samples was taken into foil cups. A mass spectrometer at the Farmed Landscapes Research Centre (FLRC), Massey University, Palmerston North was used to measure mineral nutrient concentration.

2.6.2 Leaf xylem sap

Leaf samples were collected on 20, 40 and 60 DAFB between 10:00 am -12:00 pm NZDST. The xylem sap was extracted in the research laboratory at the Horticultural Unit, Massey University, Palmerston North following the method described by Romero et al., (2012) by applying a pneumatic pressure using a Scholander pressure chamber. The xylem sap was collected in Eppendorf tubes (1.5 mL) and stored at -20 °C until analysis. Both Ca and NO₃⁻ content were analysed by using atomic absorption spectrophotometer at the FLRC, Massey University, Palmerston North.

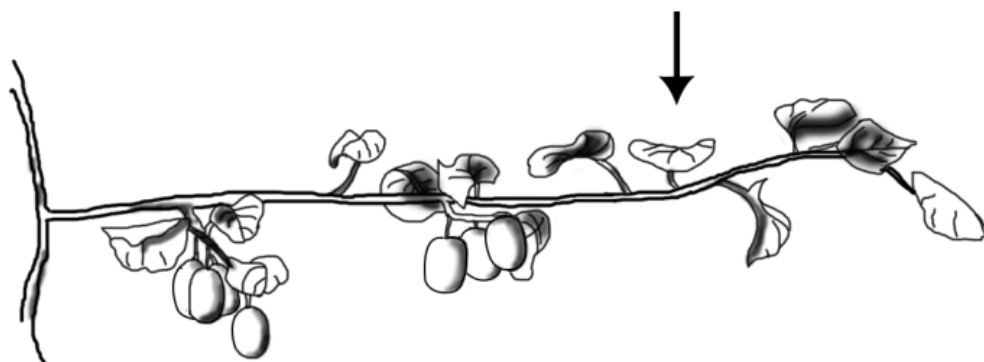


Figure 2.3 Leaf sampling of youngest fully expanded second leaf past final fruit cluster on fruiting laterals per treatment vine. Re-drawn from Crop Guide- Kiwifruit/Gold (Hort16A) from R J Hill Laboratories Ltd website [www. https://www.hill-laboratories.com/assets/Documents/Crop-Guides/Kiwifruit-Gold-Crop-Guide-KB6426-v4.pdf](https://www.hill-laboratories.com/assets/Documents/Crop-Guides/Kiwifruit-Gold-Crop-Guide-KB6426-v4.pdf).

2.6.3 Nutrient analysis

For cation analysis (Ca, Mg and K), finely ground 0.100g dried powder (leaf or fruit) was taken in marked digest tubes. At least one blank and two standards per block and some duplicate samples were taken in each run. In a fume-hood, 4 mL of concentrated nitric acid (HNO₃) was added to each tube and topped with a small glass funnel and left on heating block for reflux digestion overnight at 150 °C. Next day funnels were removed, and temperature was increased slowly to 250 °C to avoid spitting. Tubes were left in the block until completely evaporated to dryness (4-8 hours). The following day tubes were removed from the block and once cooled 5 mL of 2M HCl was added and left for one to two hours to dissolve residues. The final volume was made up to 25 mL mark with deionised water. Then analysed on atomic absorption spectrophotometer with standards in similar matrix. Anti-interference reagents caesium and strontium were added for ionic suppression.

For N analysis finely, ground dried powder (leaf or fruit) in the range of 0.1000-0.1010 g was taken in 100 mL Pyrex tube (MCKenzie & Wallace, 1954). Then 4 mL of the digest mixture (2.5 L H₂SO₄ and 250 g K₂SO₄ and 2.5 g selenium powder in a 5 L Pyrex beaker and was heated over a gas ring heater until it became clear.) was added and heated in an aluminium block at 350 °C for 4 hours. The tubes were cooled and diluted to 50 mL with deionised water and mixed thoroughly in a vortex mixture. Nitrogen was analysed using auto-analyser. At least one blank and two standards per block and some duplicate samples were taken in each run. The

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measured nutrient concentration by root, leaf and fruit tissues is referred as 'nutrient uptake'.

2.6.4 Fruit Sampling

To achieve unbiased sample and avoid fruit variation on a vine it is very important to devise an appropriate sampling strategy (Miles et al., 1996). In the 2016/2017 season a specific zone was assigned to pick fruit from each treatment vine. The sampling size was twenty-three fruit in the 2016/2017 season. In the 2017/2018 season fruit samples were taken randomly and sampling size was thirty fruits per treatment vine.

Fruits were wrapped in polythene sheets in Zespri provided trays and covered appropriately and transported (unconditioned) to cold storage facility, at the Horticultural Unit, Massey University, Palmerston North (Figure 2.4). Fruit samples were transported on the same day of the harvest and stored at 1-2 °C and 90-95 % relative humidity.



Figure 2.4 Fruit collected in Zespri trays with polythene liners.

2.7 Standard fruit maturity measurements

In the 2016/2017 season fruit samples were processed with the help of casual workers at the Horticultural Unit, Massey University, Palmerston North (Figure 2.5). Fruit samples per block were taken from cold storage room and equilibrated to room temperature before fruit measurements. Fruit samples were processed for fresh weight, firmness, SSC, FDM and nutrient analysis. In the 2017/2018 season

fruit samples were processed by AgFirst, Hawke's Bay to analyse standard fruit maturity quality for each fruit.

2.7.1 Fruit fresh weight

Fruit and leaf samples were weighed using electrical balance (calibrated) available at the Horticultural Unit, Massey University, Palmerston North. Both fresh weights and dry weights (g) measurements were made to two decimal points.

2.7.2 Firmness

Fruit firmness was measured based on the procedure reported by Pike et al., (1996). A thin layer of skin with the help of a sharp knife was removed from two equatorial sides at right angle of the fruit. Firmness was measured from two sides of the fruit (both values averaged) using a penetrometer Effegi Fruit Pressure Tester model FT 327 fitted with a 7.9 mm diameter tip. The penetrometer was then pushed into the surface removed sides of the fruit. The tip was cleaned for every treatment. After firmness measurement, two slices were cut from the centre of the fruit and weighed for dry matter and mineral nutrient analysis.

2.7.3 Soluble solids

Soluble solids concentration of the fruit was measured by following the procedure documented by Hopkirk et al., (1986). A pocket refractometer (Pocket PAL-1, ATAGO, Japan) was used to record °brix (grams of sucrose equivalent per 100 g of juice at 20 °C) of juice manually squeezed from each cut ends of the same fruit used for firmness. Two readings were averaged. A good care was taken to clean the refractometer with deionised water and dried with soft fabric for each treatment. The refractometer was re-calibrated regularly with standard sugar solutions and distilled water.

2.7.4 Fruit dry matter

Two slices from each fruit were kept in a snap-lock plastic bag to make a composite sample for each replicate. The bags were weighed before and after putting slices. Each bag was transferred to the freezer immediately after weighing and then later was transferred to freeze dryer and weighed until constant weight was achieved and then used for dry matter and mineral nutrient analysis.

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Fruit dry matter concentration was expressed in percentage and calculation using the following formula:

$$DM = (DW \div FW) \times 100 \quad (2.4)$$



Figure 2.5 Fruit processing at the Horticultural Unit, Massey University, Palmerston North in the 2016/2017 season showing fruit weight measurement, removing thin skin layer from two equatorial sides at right angle of the fruit and into the surface of the removed sides of the fruit for firmness measurement, manually squeezing juice from cut ends of the fruit and taking two slices from the centre of the fruit for dry matter and nutrient analysis.

2.8 Statistical analysis

Statistical analyses were carried out with the help of IBM SPSS Statistics 24 version. Treatment differences were tested at $P \leq 0.05$ using ANOVA. Pairwise Least Significant Difference (LSD) tests were used to compare treatments where significant differences were found.

3 Spatial separation of soil-applied calcium and potassium fertilisers improved nutrient uptake and at-harvest fruit quality in ‘Zesy002’ kiwifruit

3.1 Introduction

Kiwifruit is a vigorously growing perennial woody fruiting vine (Honghua et al., 2017; Varkonyi-Gasic et al., 2011; Voogd et al., 2017). Fruits are rich in nutrients, Ca, K, folate, vitamins (C, E, and K) and phytochemicals, carotenoids and fibre (Honghua et al., 2017; Vissers et al., 2013).

Fruit Ca deficiency may cause considerable economic losses in horticultural fruit crops. Although soil Ca deficiency is rare in nature, fruit Ca deficiency may develop even in orchard soils with sufficient Ca status (Saure, 2005). There are many factors affecting Ca nutrition in fruit crops in the soil-root-fruit pathway (discussed in detail in section 1.4) including ion antagonism where mono-valent ions such as K compete with and reduce the uptake of divalent ions such as Ca at the root surface (Fageria, 2001; Peticila et al., 2015); low soil pH; and high rates of N and K fertilisation leading to excessive vegetative vigour and reduced rates of fruit transpiration (a major driving force for fruit Ca accumulation) (Hocking et al., 2016; Kirkby, 1979; Kirkby & Pilbeam, 1984; MCloughlin & Wimmer, 1999b; Morandi et al., 2010; White, 2001; White & Broadley, 2003).

3.1.1 Problem statement

The characteristic features of Bay of Plenty soils (free-draining coarse textured soils that are naturally acidic and nutrient deficient) and abundant precipitation especially during winter, and current orchard management practices (such as root pruning and high rates of N and K fertilisation,) could reduce soil Ca availability and uptake. Furthermore, the vigorous growth habit of kiwifruit vines may limit fruit Ca intake. Low fruit Ca may be one of the reasons for the fruit softening in ‘Zesy002’ during storage.

3.1.2 Objectives

The main objective was to reduce the antagonistic effect of K fertilisation (without reducing K input) on Ca uptake at soil-root interface in order to increase Ca intake

in the leaf and fruit tissues during the growing season. In addition, to increase the photosynthetic performance and fruit growth rate during the fruit developmental stages and to improve at-harvest fruit size, firmness, soluble solids concentration (SSC), fruit dry matter (FDM) and fruit colour (green flesh).

3.1.3 Hypothesis

It was hypothesised that the spatial separation of soil-applied Ca and K fertilisers may avoid the antagonistic interaction between soil Ca and K and may increase Ca availability. The increased availability of Ca may increase the uptake and translocation of Ca in leaf and fruit tissues at-harvest. Therefore, cell wall linkages may strengthen, and at-harvest fruit firmness may improve. Both N and K together with Ca nutrition may improve the photosynthetic performance and may increase the at-harvest fruit quality in 'Zesy002' vines.

3.2 Materials and methods

In the 2017/2018 season two experiments were conducted: (i) at a commercial orchard in Te Puke, Bay of Plenty, and (ii) a controlled system pot experiment at the Horticultural Unit, Massey University, Palmerston North. In both pot and orchard experiments, the application time, rates and forms of nutrient fertilisers (N, Ca and K) were similar (Table 3.1). The fertiliser nutrient formulations; calcium ammonium nitrate, gypsum and sulphate of potassium, were used to supply N, Ca and K, respectively. A fraction of Mg was supplied through calcium ammonium nitrate fertilisation. All the nutrient fertilisers were applied at twenty-days after bud-break (DABB). The nutrient N and Ca fertilisers were applied in full single dose and K fertiliser was applied in two split doses at 20-25-day interval in both pot and orchard experiments. No foliar nutrient sprays were applied to the experimental vines in both pot and orchard experiments.

3.2.1 Pot experiment

The splitting of roots in pot grown 'Zesy002' vines

One-year-old pot grown 'Zesy002' (*Actinidia chinensis*) vines were grafted onto green kiwifruit rootstocks 'Bruno' and 'Bounty' in 45 L planting bags. These experiments were individual and were not designed as factorial rootstock experiments. The modified Hoagland's nutrient solution (Hoagland & Arnon, 1950) was supplied to the pot grown kiwifruit vines to maintain the normal plant growth.

Spatial separation of soil-applied calcium and potassium fertilisers

After growing for a year, the pot grown kiwifruit vines were taken out of the planting bags for root-splitting. Then, roots were washed and split into two equal parts, with each part planted in its own 25 L bag (Figure 3.1).



Figure 3.1 The split-root pot grown 'Zesy002' vines (a) splitting roots equally and (b) planting in to two separate bags (c) attached and then (d) supported with a wooden structure at the Horticultural Unit, Massey University, Palmerston North in the 2017/2018 season.

After transplanting, the pot grown kiwifruit vines were supported and trained. The split-root pot grown kiwifruit vines were supplied with the nutrient solution deficient in Ca and K and drip irrigated receiving 2 L to each side equally throughout the day and grown for thirty-days to recover. The split-root pot grown 'Zesy002' vines showed no symptoms of shock or stunted growth due to the root-splitting during recovery. After thirty-days of recovery period, treatments were applied to the split-root pot grown 'Zesy002' vines.

A true control (TC) receiving zero nutrient input was used in split-root pot plants (Table 3.1). Both Ca and K fertilisers along with N fertiliser were applied to each separate planting bag and the treatment was termed as not-spatially separated (NSS) treatment. In spatially separated (SS) treatment Ca fertiliser was applied to one of the attached planting bags and K fertiliser was applied to the other planting

bag both sides holding equally split-roots. Both split sides received N fertilisation. The experiment was randomised block design with ten replicates. At-harvest (161 DAFB), pot grown vines were transported from the orchard block to the research laboratory at the Horticultural Unit, Massey University, Palmerston North. Subsequently, harvesting of roots, leaves and fruits was completed for mineral nutrient analysis and fruit quality assessment.

Table 3.1 Nutrient fertiliser application rate (Kg. ha⁻¹), time of application in 2017 and fertiliser formulations used in true control (TC), non-spatially separated (NSS) and spatially separated (SS) treatments applied to the pot grown 'Zesy002' vines at the Horticultural Unit, Massey University, Palmerston North in the 2017/2018 season. Nitrogen and calcium fertilisers were applied in single full dose. Potassium fertiliser was split equally (150+150 = 300 Kg K ha⁻¹) and applied at specified dates.

Nutrients (Kg. ha ⁻¹)	TC	NSS	SS	Fertiliser formulations
N	0	50	50	Calcium ammonium nitrate
		29 th Sept (20 DABB)	29 th Sept (20 DABB)	
K	0	300	300	Sulphate of potassium
		29 th Sept & 22 nd Oct (20 & 45 DABB)	29 th Sept & 22 nd Oct (20 & 45 DABB)	
Ca	0	200	200	Gypsum
		29 th Sept (20 DABB)	29 th Sept (20 DABB)	
Mg		3.7	3.7	
	0	29 th Sept (20 DABB)	29 th Sept (20 DABB)	

3.2.2 Orchard experiment

The experiment was conducted two-days after bud-break (DABB) on a commercial orchard in the 2017/2018 season in Te Puke, Bay of Plenty. The 'Zesy002' cultivar was grafted onto green cultivar 'Bruno' vines. Rows were distributed 4.6 m apart, and vines were also planted 4.6 m apart in the row (Table 2.1). The orchard had zero irrigation, except the nutrient fertiliser application the vines were managed inclusively with the rest of the commercial orchard by the orchard management. Fruit samples were harvested near commercial harvest 163 days after full bloom (DAFB). A true control (TC) with zero nutrient input was used (Table 3.2). The nutrient fertilisers N, Ca and K were applied together around each vine and termed as not-spatially separated treatment (NSS). In spatially separated treatment (SS), Ca fertiliser was applied to one side of the vine and K fertiliser was applied to the other side of the same vine and N fertiliser was applied to both sides. The experiment was

randomised block design with eight replicates and rows were used as blocks to avoid soil spatial heterogeneity. Two buffer vines were used between treatment vines. To compare nutrient strategy of this experiment to the orchard practices, vines outside the experimental area were selected and termed as grower practice (GP).

Table 3.2 Nutrient fertiliser application rate (Kg. ha⁻¹) and time of application in 2017 in grower practice (GP), true control (TC), not-spatially separated (NSS) and spatially separated (SS) treatments applied to 'Zesy002' vines grown on the commercial orchard at Te Puke in the 2017/2018 season. Nitrogen and calcium fertilisers were applied in single full dose. Potassium fertiliser was split equally (150+150 = 300 Kg K ha⁻¹) and applied at specified dates.

Nutrients (Kg. ha ⁻¹)	*GP	TC	NSS	SS
N	112	0	50	50
	Aug		27 th Sep (20 DABB)	27 th Sep (20 DABB)
K	172	0	300	300
	Aug, Oct & Nov		27 th Sep & 20 th Oct (20 & 25 DABB)	27 th Sep & 20 th Oct (20 & 25 DABB)
Ca	72	0	200	200
	Aug		27 th Sep (20 DABB)	27 th Sep (20 DABB)
Mg	28		3.7	3.7
	Aug	0	27 th Sep (20 DABB)	27 th Sep (20 DABB)

*- Fertiliser formulations used by the grower were; Sulphate of potassium, diCal 8, gypsum, kieserite, brimstone sulphur, iron sulphate, zinc sulphate, ammonium sulphate nitrate and gromix.

3.2.3 Measurements

Soil samples were taken from each treatment vine (section 2.4). Root samples were only collected in the pot experiment at 161 DAFB, at-harvest. Root tissues were used for length and fresh weight measurements then oven dried at 60 °C to obtain a constant drying weight. After drying, root samples were finely ground to powdered form and subsequently used for nutrient analysis at FLRC, Massey University, Palmerston North (section 2.6.3). In the orchard experiment, leaf xylem sap was collected at 20, 40 and 60 DAFB by following the method described by Romero et al., (2012). Calcium and (NO₃) concentrations were analysed directly in the xylem sap and measured by atomic absorption spectrophotometer ($\lambda = 422.7$ nm; air-acetylene flame). Leaf chlorophyll concentration and photosynthetic response was measured at 82 DAFB in the orchard experiments. Fruit fresh weight (g) was estimated as described by Minchin et al., (2003). Fruits were tagged on each vine and length and diameters (maximum and minimum) were measured with digital

Vernier callipers (S_Cal EVo IP67, Model: ISP091201D, Sylvac) from fruit set through to harvest in 'Zesy002' vines in the orchard experiment. Leaf samples were collected at 20 DABB and 163 DAFB (at-harvest) from each treatment vine for nutrient analysis in both pot and orchard experiments. Fruit samples were collected at 161 and 163 DAFB from each treatment vine for standard fruit maturity analysis in the pot and orchard experiment, respectively. Unconditioned leaf and fruit samples from the orchard were transported same day of the harvest to the cold storage facility at Massey University, Palmerston North and stored at 1°C for ten days. Fruit samples were transported to AgFirst, Hawke's Bay for standard fruit maturity analyse. The standard fruit maturity test included fruit fresh weight, firmness, SSC and FDM. Two fruit slices each 2 mm thick were taken from each fruit and weighed for fresh weight (FW) then dried at 60 °C to a constant weight and re-weighed (DW). Dried fruit slices were then analysed for mineral nutrient analysis at the FLRC, Massey University, Palmerston North. Statistical analyses were carried out with the help of IBM SPSS Statistics 24 version. Treatment differences were tested at $P \leq 0.05$ using ANOVA. Pairwise Least Significant Difference (LSD) tests were used to compare treatments where significant differences were found.

3.3 Results and discussion

3.3.1 Pot experiment

Both 'Bruno' and 'Bounty' grafted pot grown vines showed similar nutrient uptake and at-harvest quality, therefore, in this chapter results from only 'Bruno' grafted vines are presented.

Standard soil testing showed ideal soil pH and adequate bulk density, cation exchange capacity, Olsen phosphorus, soil organic matter, and cation base saturation (Table 3.3). However, low exchangeable Ca, Mg, K and plant available N may be due to the low nutrient input in the modified Hoagland's nutrient solution (Hoagland & Arnon, 1950), which was used only to maintain the normal plant growth.

Table 3.3 Pre-treatment soil properties in the split-root pot experiment in July 2017 at the Horticultural Unit, Massey University, Palmerston North.

Parameters	Units	Values	Level	*Optimum range
pH	pH Units	6.5	Ideal	5.8-6.5
BD	g. mL ⁻¹	0.7	Adequate	0.6-1.00
CEC	me. 100g ⁻¹	15	Adequate	12-25
Olsen P	me. 100g ⁻¹	55	Adequate	30-60
Ca	me. 100g ⁻¹	3.5	Low	6.0-12.0
Mg	me. 100g ⁻¹	1.0	Low	1.00-3.00
K	me. 100g ⁻¹	0.62	Low	0.60-1.20
Na	me. 100g ⁻¹	0.03	Low	0.00-0.40
Plant available N	Kg. ha ⁻¹	105	Low	100-150
Organic matter	%	9	Adequate	7.0-17.0
Base saturation				
Ca	%	66	Adequate	55-67
Mg	%	11.0	Adequate	10-14
K	%	7.00	Adequate	5-7
Total	%	84		

One composite sample was made up of thirty sub samples.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

Leaf nutrient status (% DW) before the treatment application showed adequate levels of leaf N and Mg (Table 3.4). However, low levels of Ca and K may possibly because (i) pot grown vines were supplied with nutrient solution (Hoagland & Arnon, 1950) deficient in Ca and K and/or (ii) due to high demand of Ca and K by developing (1-5-year-old) vines (Buwalda & Smith, 1987).

Table 3.4 Pre-treatment leaf nutrient status (% DW) in the split-root pot grown 'Zesy002' vines at 20 DABB in the 2017/2018 season at the Horticultural Unit, Massey University Palmerston North.

Nutrients	% DW	Level	*Optimum range
N	2.30	Adequate	1.8-2.8
K	1.27	Low	1.8-3.1
Ca	1.16	Low	1.60-3.20
Mg	0.33	Adequate	0.25-0.50

One composite sample was made up of ten leaves each vine. Results presented below are average of thirty vines.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

Root nutrient status at-harvest showed that the spatial separation treatment (SS) significantly increased the uptake of Ca and Mg in root tissues compared to other

treatments in the pot grown 'Zesy002' vines (Table 3.5). This strongly suggests that the spatial separation of Ca and K fertilisers increased the absorption and uptake of Ca and Mg ions in root tissues potentially because the counteractive effect of K on the cation uptake was significantly avoided at soil level (Fageria, 2001; Jakobsen, 1993b). Thus, it can be expected that the increased availability of Ca and Mg at soil level would translate to the increased uptake of Ca and Mg in leaf and fruit tissues (De Freitas & Mitcham, 2012). The uptake of N and K in root tissues was not affected by the SS possibly because increasing Ca supply had no and/or less competing effect on the root absorption of N according to Lopez-Lefebvre et al., (2001). As reported by Davarpanah et al., (2018), increasing Ca had no effect on the uptake of N and K in leaf tissues, and according to Qiu et al., (1995) on the uptake of N and K in fruit tissues.

Table 3.5 Root nutrient status (% DW) at-harvest in the split-root pot grown 'Zesy002' vines at 161 DAFB by true control (TC), not-spatially separated (NSS) and spatially separated (SS) treatments in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Root (% DW)	TC	NSS	SS	Sig.
N	0.60±0.08b	0.83±0.06a	0.85±0.05a	0.036
K	1.02±0.08b	1.71±0.06a	1.69±0.05a	<0.000
Ca	0.56±0.03c	1.05±0.05b	1.67±0.04a	<0.000
Mg	0.21±0.04c	0.44±0.06b	0.65±0.05a	<0.000

Values are averages and standard errors, n = 5. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Leaf nutrient status at-harvest, as expected, showed that the SS significantly increased the uptake of Ca and Mg compared to NSS and TC (Table 3.6). This was probably due to the high root uptake of Ca and Mg, therefore, root to leaf translocation of Ca and Mg ions was increased (Shukla & Mukhi, 1979). The significantly increased leaf N uptake by the SS may be due to the synergistic effect of Ca and N in the presence of K (Minotti et al., 1968). This suggest that increasing the uptake of Ca due to the spatial separation of Ca and K fertilisers, significantly induced N uptake and translocation from root to leaf tissues in the pot grown 'Zesy002' vines.

Table 3.6 Leaf nutrient status (% DW) at-harvest in the split-root pot grown ‘Zesy002’ vines at 161 DAFB by true control (TC), not-spatially separated (NSS) and spatially separated (SS) treatments in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Leaf (% DW)	TC	NSS	SS	Sig.
N	1.15±0.04c	2.27±0.03b	2.49±0.04a	<0.000
K	1.22±0.03b	2.73±0.04a	2.68±0.06a	<0.000
Ca	1.04±0.04c	1.50±0.05b	2.17±0.06a	<0.000
Mg	0.23±0.03c	0.41±0.02b	0.53±0.05a	<0.000

Values are averages and standard errors, n = 5, (two replicates combined) one composite sample was made up of ten leaves from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Fruit nutrient status at-harvest showed that the SS in split-roots pot grown ‘Zesy002’ vines significantly increased Ca and Mg uptake than NSS and TC in ‘Zesy002’ vines (Table 3.7). This suggests that the competitive effect of K fertilisation on Ca and Mg absorption in root tissues was significantly avoided, therefore, the translocation of Ca and Mg from root to leaf tissues and then leaf to fruit tissues was increased by the SS (Ding et al., 2006; Domagała-Swiatkiewicz et al., 2019; Fageria, 2001; Garcia et al., 1999; Jakobsen, 1993b; Morton et al., 2008; Rhodes et al., 2018). In addition, increasing the uptake of Ca has induced synergistic effect on the uptake and translocation of N (Minotti et al., 1968) from root to leaf tissues and subsequently from leaf to fruit tissues in the pot grown ‘Zesy002’ vines at-harvest. The SS showed no effect on the uptake of K in leaf and fruit tissues at-harvest possibly due to the preferential uptake of K by plant roots and highly mobile nature of K ions in plant tissues (Marschner, 2012). TC showed low nutrient status in root, leaf and fruit tissues at-harvest compared to both SS and NSS in ‘Zesy002’ vines.

Table 3.7 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in the split-root pot grown 'Zesy002' vines at 161 DAFB by true control (TC), not-spatially separated (NSS) and spatially separated (SS) treatments in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Fruit (mg. 100g⁻¹ DW)	TC	NSS	SS	Sig.
N	145±3c	268±5b	297±6a	<0.000
K	203±5b	340±2a	331±7a	<0.000
Ca	17±1c	24±2b	38±3a	<0.000
Mg	11±1c	29±2b	35±2a	<0.000

Values are averages and standard errors, n = 5, (two replicates combined) one composite sample was made up of five fruit slices from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

At-harvest fruit quality testing (Table 3.8) showed that the SS significantly increased the fruit firmness, possibly due to increasing the fruit Ca uptake and probably Ca was interlocked in the middle lamella (Demarty et al., 1984; Hocking et al., 2016). Comparable fruit weight, SSC and FDM was observed in both SS and NSS probably due to the same N and K nutrition and suggests increasing the Ca nutrition due to the SS had no effect on the fruit size and dry matter accumulation.

Table 3.8 Standard fruit quality at-harvest in the split-root pot grown 'Zesy002' vines at 161 DAFB by true control (TC), not-spatially separated (NSS) and spatially separated (SS) treatments in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Parameters	Units	TC	NSS	SS	Sig.
Fresh weight	g	130.2±1.1b	145.5±2.0a	147.6±0.9a	<0.000
Size		27	25	25	NA
Firmness	KgF	6.56±0.10c	7.23±0.13b	7.65±0.14a	<0.000
SSC	°Brix	10.21±0.40a	10.51±0.26a	10.80±0.23a	0.414
FDM	%	17.83±0.08b	18.26±0.05a	18.34±0.03a	<0.000
Grade value (TZG)	%	85 (6)	90 (7)	90 (7)	NA

Values are averages and standard errors, n = 10, one composite sample was made up of five fruits from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

3.3.2 Orchard experiment

The orchard was located on a well-drained volcanic, Te Puke loam soil. The standard soil testing showed ideal soil physical and chemical properties (Table 3.9). High soil pH and exchangeable Ca and adequate bulk density, organic matter, Olsen P, exchangeable K and Mg base saturation were observed. Ideal CEC, exchangeable Mg and Ca base saturation were also observed. This indicated well-managed orchard

soils, however, low plant available N and K base saturation may possibly be due to high demand of kiwifruit vines for N and K (Buwalda & Smith, 1987; Mills et al., 2008).

Table 3.9 Pre-treatment soil properties in ‘Zesy002’ vines grown on the commercial orchard at Te Puke, Bay of Plenty.

Parameters	Units	Values	Level	*Optimum range
pH	pH Units	6.8	High	5.8-6.5
BD	g. mL ⁻¹	0.86	Adequate	0.6-1.00
CEC	me. 100g ⁻¹	21	Ideal	12-25
Olsen P	me. 100g ⁻¹	42	Adequate	30-60
Ca	me. 100g ⁻¹	15.0	High	6.0-12.0
Mg	me. 100g ⁻¹	2.19	Ideal	1.00-3.00
K	me. 100g ⁻¹	0.68	Adequate	0.60-1.20
Na	me. 100g ⁻¹	0.05	Ideal	0.00-0.40
Plant available N	Kg. ha ⁻¹	84	Low	100-150
Organic matter	%	10.0	Adequate	7.0-17.0
Base saturation				
Ca	%	72	Ideal	55-67
Mg	%	10.6	Adequate	10-14
K	%	3.3	Low	5-7
Total	%	85.9		

One composite sample was made up of twenty-four sub-samples.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

Pre-treatment leaf nutrient status showed low leaf Ca and K, and adequate N and Mg (Table 3.10). Possibly indicating high demand of Ca and K nutrients in orchard grown ‘Zesy002’ vines (Mills et al., 2008).

Table 3.10 Pre-treatment leaf nutrient status (% DW) at 20 DABB in the 2017/2018 season in ‘Zesy002’ vines grown on the commercial orchard at Te Puke, Bay of Plenty.

Nutrients	% DW	Level	*Optimum range
N	2.40	Adequate	1.8-2.8
K	1.50	Low	1.8-3.1
Ca	1.30	Low	1.60-3.20
Mg	0.29	Adequate	0.25-0.50

One composite sample was made up of twenty leaves collected from all the treatment vines. Results presented below are average of twenty-four vines.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

The SS significantly increased Ca accumulation in the leaf xylem sap compared to the NSS at 20, 40 and 60 DAFB (Figure 3.2).

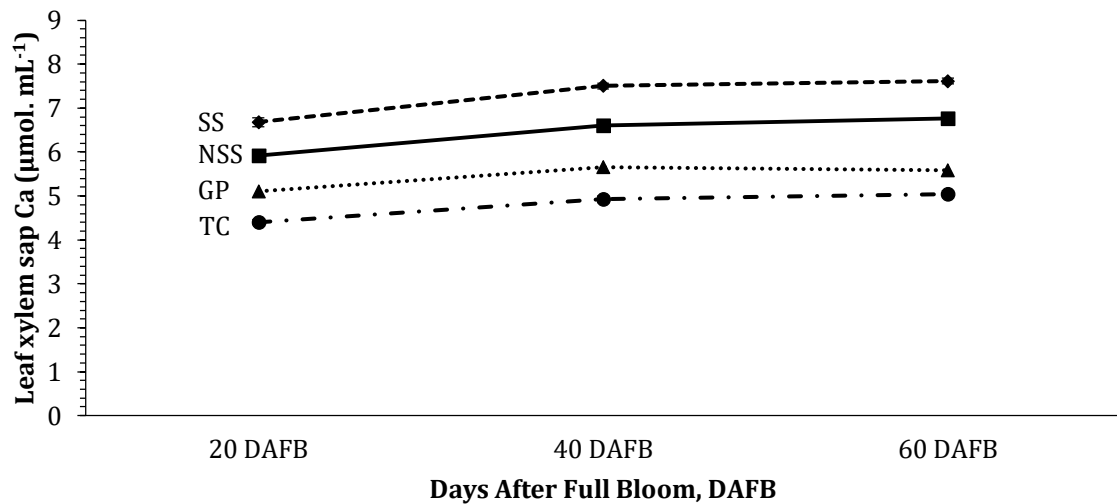


Figure 3.2 Leaf xylem sap calcium (Ca) concentration ($\mu\text{mol. mL}^{-1}$) taken at 20, 40 and 60 DAFB in the 2017/2018 season in 'Zesy002' vines by the true control (TC), not-spatially separated (NSS) and spatially separated (SS), and grower practice (GP) on the commercial orchard at Te Puke, Bay of Plenty. Values are averages with standard error bars. $n = 8$, one composite sample made up of ten leaves from treatment vines.

The SS significantly increased NO_3^- accumulation in the leaf xylem sap than the NSS at 20, 40 and 60 DAFB (Figure 3.3). A significantly strong positive correlation ($R^2 = 0.83, 0.89$ and 0.91) was found between Ca and NO_3^- concentration in the leaf xylem sap at 20, 40 and 60 DAFB, respectively at 95 % confidence interval (CI). This suggests increasing Ca induced N uptake in the presence of sufficient K on Te Puke loam soils (Minotti et al., 1968).

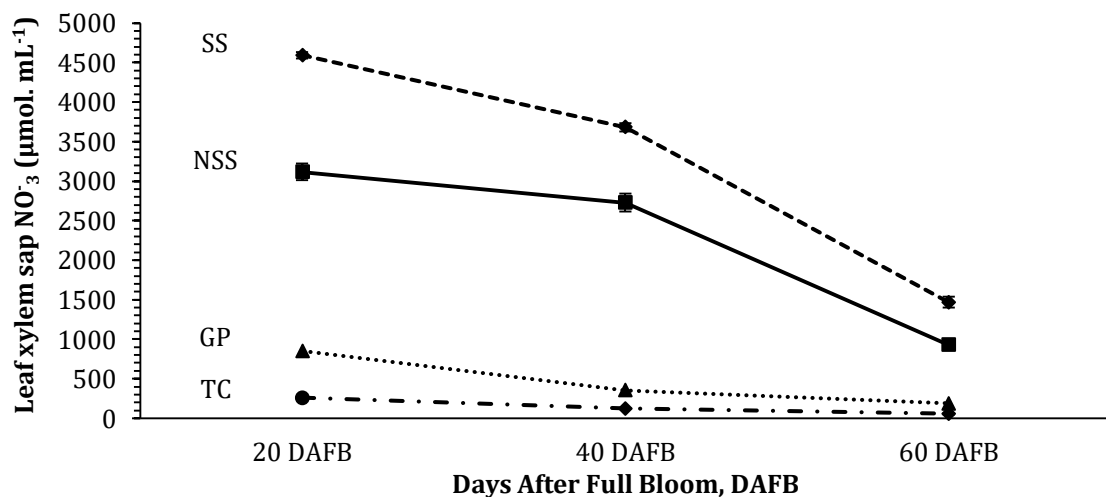


Figure 3.3 Leaf xylem sap nitrate (NO_3^-) concentration ($\mu\text{mol. mL}^{-1}$) taken at 20, 40 and 60 DAFB in the 2017/2018 season in 'Zesy002' vines by true control (TC), not-spatially separated (NSS) and spatially separated (SS), and grower practice (GP) on the commercial orchard at Te Puke, Bay of Plenty. Values are averages with standard error bars. $n = 8$, one composite sample made up of ten leaves from treatment vines.

Spatial separation of soil-applied calcium and potassium fertilisers

Both SS and NSS had comparable estimated fruit size from fruit set through to harvest in 'Zesy002' vines (Figure 3.4). Possibly due to the similar K nutrition as K is known to increase the berry growth and volume (Mpelasoka et al., 2003). The rapid increase in the fruit growth rate was observed at 38 DAFB in both SS and NSS and the increase was continued to 69 DAFB (Stage 1). Due to reasons out of the control of this study, measurements were not conducted beyond this point, but it could be predicted that from 70 DAFB the period of slow growth would occur through to 100 DAFB (Stage 2) then followed by the rapid increase in the growth rate till harvest during maturity period (Stage 3). It is suggested by Richardson & Currie, (2007) that the rapid increase in the fruit growth rate may be attributed to the rapid increase in the cell division and cell expansion and may continue until 70 DAFB.

Spatial separation of soil-applied calcium and potassium fertilisers

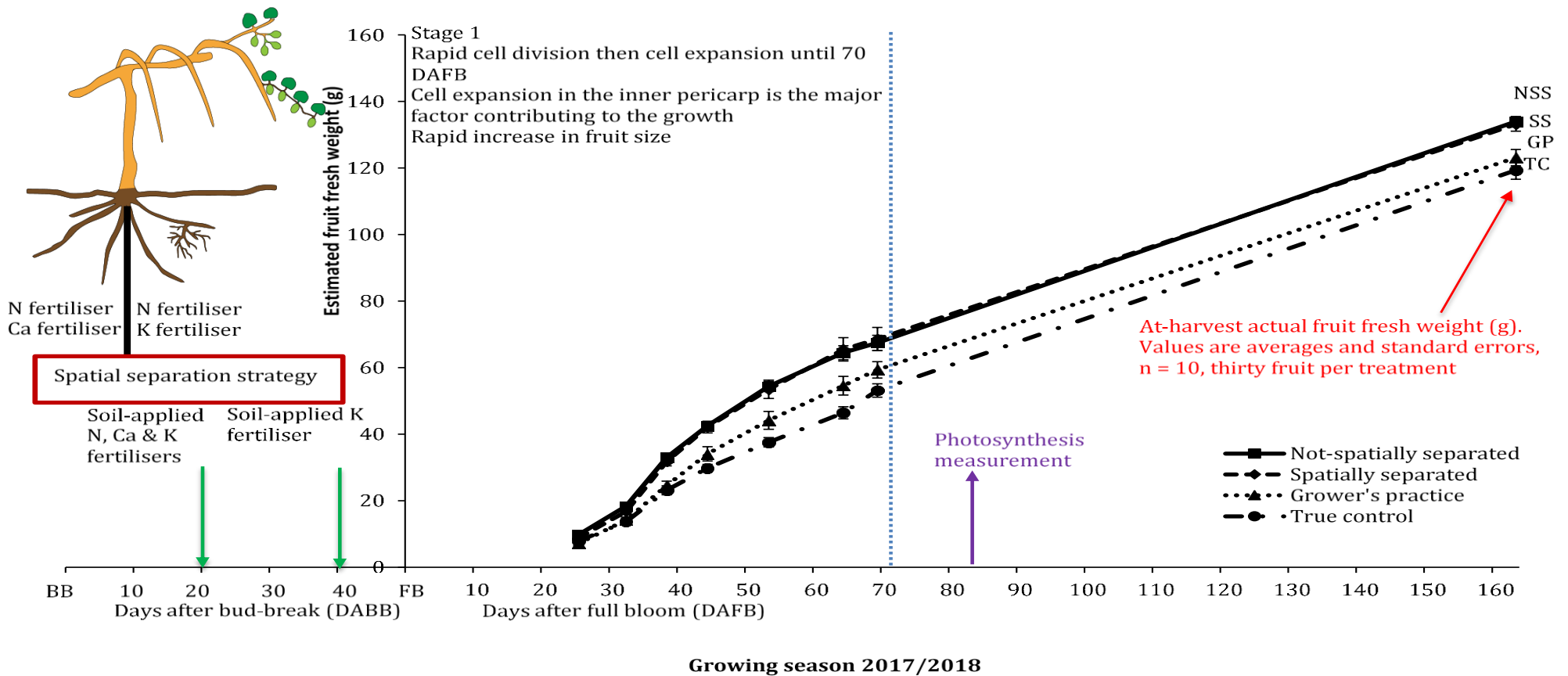


Figure 3.4 Effect of true control (TC), not-spatially separated (NSS) and spatially separated (SS), and grower practice (GP) on estimated fruit fresh weight (g) calculated using fruit length and diameter measurements from fruit set through to harvest in the 2017/2018 season in 'Zesy002' vines grown on the commercial orchard at Te Puke, Bay of Plenty. Values are averages and standard error bars, n = 8, four fruits per treatment vine were tagged, for at-harvest actual fruit fresh weight (g) measurement n = 8, thirty fruit per treatment.

The spatial separation of Ca and K fertilisers (SS) significantly increased leaf chlorophyll concentration ($17.3 \mu\text{g}\cdot\text{cm}^{-2}$) compared to the NSS and TC (15.8 and $7.0 \mu\text{g}\cdot\text{cm}^{-2}$ respectively) at 82 DAFB (Table 3.11). Likewise, the SS significantly increased net photosynthesis compared to the NSS and TC. There are likely two explanations for the improved photosynthetic performance by the spatial separation strategy in 'Zesy002' vines: (1) The improved photosynthetic performance may be associated with increasing Ca nutrition (Lechowski & Bialczyk, 1993) by the SS strategy as a significantly positive correlation at 95 % CI was found between leaf chlorophyll and Ca concentration in the leaf xylem sap ($R^2 = 0.60, 0.66$ and 0.62 at 20, 40 and 60 DAFB, respectively) and in the leaf tissues at-harvest ($R^2 = 0.89$) in 'Zesy002' vines. Likewise, significantly positive correlation was found between net photosynthesis and Ca concentration in the leaf xylem sap ($R^2 = 0.60, 0.64$ and 0.66 at 20, 40 and 60 DAFB, respectively) and in the leaf tissues at-harvest ($R^2 = 0.75$) at 95 % CI. This is consistent with Amor & Marcelis, (2003) reporting significant positive correlation ($R^2 = 0.86$) between net photosynthesis and leaf Ca concentration in tomato. It has been reported that exogenous Ca application affect protein and chlorophyll content (Bohner & Bangerth, 1988; Poovaiah et al., 1988). Thus, higher Ca nutrition by the SS may be contributing to the increased photosynthetic performance than NSS. The possible suggestion may be the role of Ca as a secondary messenger in chloroplast, stroma and thylakoids through acidification and redox status, photosynthetic electron flow and light-dependent metabolism as reviewed by Hochmal et al., (2015). Calcium also facilitates cytokinin activity and it is well-known that this hormone regulates photosynthetic rate and source-sink relationships (Saunders & Hepler, 1982). Calcium also facilitates calcium dependent protein kinases 'CDPKs' (Woodward et al., 2007) which have been reported to increase the photosynthetic CO_2 assimilation and chlorophyll content in plants (Chikov et al., 2007).

(2) The other likely explanation for the improved leaf chlorophyll by the SS may be the increased NO_3^- nutrition (Bassi et al., 2018; Hikosaka & Terashima, 1995). N is the integral constituent of chloroplast (Marschner, 2012) and a considerable fraction of leaf N is apportioned to the photosynthetic apparatus and used in chlorophyll (Griffin & Seemann, 1996; Sage, 2013; Zhang et al., 2008). A significantly positive correlation was observed between leaf chlorophyll and NO_3^- concentration

Spatial separation of soil-applied calcium and potassium fertilisers

in the leaf xylem sap ($R^2 = 0.56, 0.52$ and 0.51 at 20, 40 and 50 DAFB, respectively) at 95 % CI. Similarly, a significantly positive correlation was found between net photosynthesis and NO_3 concentration in the leaf xylem sap ($R^2 = 0.70, 0.72$ and 0.68 at 20, 40 and 60 DAFB, respectively) at 95 % CI. This is in confirmation with Cartelat et al., (2005), Samborski et al., (2009) and Schepers et al., (1996) reported strong correlation between leaf N and the leaf chlorophyll content. Similar results were reported in sugarcane and showed that N application increased the activity of carboxylases, chlorophyll content, sugar content, total protein and photosynthesis related metabolites thus increasing the rate of photosynthesis (Bassi et al., 2018). Stomatal conductance and leaf transpiration rates were comparable in both SS and NSS strategies and possibly attributed to the similar K application rate and comparable K concentration in leaf and fruit tissues in 'Zesy002' vines probably involved in the osmoregulation (Clark & Smith, 1988; Kim et al., 2010). Leaf internal carbon dioxide (CO_2) and leaf temperature were similar in all the treatments possibly indicating the uniform microclimate in the orchard due to wind shelters (Chappell, 2014).

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Table 3.11 Effect of true control (TC), not-spatially separated (NSS) and spatially separated (SS), and grower practice (GP) on leaf chlorophyll concentration, net photosynthesis, stomatal conductance, leaf internal carbon dioxide (CO₂), transpiration rate, and leaf temperature in ‘Zesy002’ vines grown at 82 DAFB in the 2017/2018 season on the commercial orchard at Te Puke, Bay of Plenty.

Parameters	Units	TC	NSS	SS	Sig.	GP
Leaf chlorophyll	µg. cm ⁻²	7.0±0.4c	15.8±0.5b	17.3±0.4a	<0.000	14.9±0.5
Net photosynthesis	µmol CO ₂ . m ² s ⁻¹	10.04±0.19c	12.68±0.73b	14.17±0.22a	<0.000	10.09±0.28
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.17±0.01b	0.25±0.02a	0.30±0.03a	<0.000	0.17±0.01
Internal CO ₂	µmol CO ₂ . mol ⁻¹ air	271.2±9.7a	270.9±6.9a	271.1±8.5a	1.000	270.6±8.8
Transpiration	mmol	3.47±0.23b	4.58±0.20a	5.10±0.35a	<0.000	3.29±0.24
Leaf temperature	°C	27.0±0.6a	27.3±0.2a	27.7±0.1a	0.631	27.5±0.3

Values are averages and standard errors, n=8. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

The SS significantly increased the uptake of Ca in leaf tissues at-harvest than NSS and TC (Table 3.12). This proposes that the spatial separation of Ca and K fertilisers significantly avoided the counteractive effect of K on the uptake of Ca ions in root tissues and therefore, the translocation from root to leaf tissues was increased (De Freitas & Mitcham, 2012; Fageria, 2001; Montanaro et al., 2014). Regarding other macronutrients the SS had no significant effect on the uptake of N and K in leaf tissues possibly due to high mobilisation of N and K (Marschner, 2012).

Table 3.12 Leaf nutrient status (% DW) at-harvest in ‘Zesy002’ vines at 163 DAFB by true control (TC), not-spatially separated (NSS) and spatially separated (SS), and grower practice (GP) in the 2017/2018 season on the commercial orchard at Te Puke, Bay of Plenty.

Nutrient (% DW)	TC	NSS	SS	Sig.	GP
N	1.55±0.05 b	3.07±0.13 a	3.27±0.09 a	<0.000	3.83±0.11
K	1.41±0.13 b	2.90±0.10 a	2.96±0.21 a	<0.000	2.70±0.04
Ca	1.27±0.12 c	2.36±0.09 b	2.88±0.13 a	<0.000	2.05±0.05
Mg	0.31±0.05 c	0.40±0.01 ab	0.48±0.03 a	0.004	0.52±0.02

Values are averages and standard errors, n = 4, (two replicates were combined) one composite sample was made up of twenty leaves from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

The SS significantly increased the uptake of Ca and Mg ions in fruit tissues at-harvest compared to the NSS (Table 3.13). This suggests that the antagonistic effect of high K supply on the availability and uptake of Ca and Mg ions was avoided at soil level (Fageria, 2001; Grunes et al., 1992; Jakobsen, 1993b; Johansen et al., 1968b). The uptake of K in root, leaf and fruit tissues was not affected by the SS in ‘Zesy002’ vines. This is consistent with Qiu et al., (1995) reporting that increasing Ca concentration has not limited the uptake of K in fruit tissues in papaya. This suggests spatial separation of Ca and K fertilisers as an effective strategy in increasing Ca nutrition of horticultural crops particularly without reducing K supply as kiwifruit vines have high K demand during the growing season (Crisosto, 1992; Mills et al., 2008). Few studies attempted to increase fruit Ca concentration by reducing K input and reported that antagonistic effect of K was avoided when K application rate was reduced to 50 % and fruit Ca concentration increased significantly in tomato, consequently, fruit storage quality was improved (Taylor et al., 2004). However, this strategy may have implications for horticultural fruit crops with high K demand. The SS significantly increased the uptake of N in fruit tissues at-harvest compared to the NSS and TC in ‘Zesy002’ vines. This suggests increasing Ca has a significantly

synergistic effect on N uptake and consistent with Wright, (2005) reporting external Ca supply significantly increased NO₃ content in the root and leaf tissues in *Brassica juncea* seedlings compared to control plants. This author suggested external Ca supply regulated N metabolism and increased activity of nitrate assimilating enzyme (nitrate reductase) in root and leaf tissues and therefore, increased the amount of proteins and carbohydrates. The increase in N intake may possibly be due to the signalling of Ca binding proteins such as CDPKs reported to participate in the nitrate transport in pear (Burdon et al., 2004).

Table 3.13 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in ‘Zesy002’ vines at 163 DAFB by true control (TC), not-spatially separated (NSS) and spatially separated (SS), and grower practice (GP) in the 2017/2018 season on the commercial orchard at Te Puke, Bay of Plenty.

Nutrients (mg. 100g ⁻¹ DW)	TC	NSS	SS	Sig.	GP
N	504±9c	542±11b	591±7a	<0.000	698±9
K	1224±14b	1469±21a	1452±9a	<0.000	1357±35
Ca	39±2c	62±2b	90±1a	<0.000	46±1
Mg	34±2c	41±2b	57±2a	<0.000	74±2

Values are averages and standard errors, n= 4, (two replicates were combined) one composite sample was made up of thirty fruit slices per treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

The spatial separation of Ca and K fertilisers did not result in uneven translocation or distribution in the canopy (Table 3.14). This suggests that regardless of which side of the canopy the nutrients are taken up by the roots, and their subsequent translocation is integrated evenly throughout the vine (Marschner, 2012).

Table 3.14 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in each side of the spatial separation treatment in ‘Zesy002’ vines at 163 DAFB in the 2017/2018 season on the commercial orchard at Te Puke, Bay of Plenty.

Nutrients (mg. 100g ⁻¹ DW)	Calcium fertiliser side	Potassium fertiliser side	Sig.
N	590±11a	593±23a	0.884
K	1449±22a	1456±6a	0.419
Ca	91±2a	88±1a	0.796
Mg	56±2a	57±4a	0.884

Values are averages and standard errors, n= 4, (two replicates were combined) one composite sample was made up of thirty fruit slices per treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

The SS significantly increased fruit firmness at-harvest than other treatments (Table 3.15). Fruit firmness was significantly co-related at 95 % CI with fruit Ca ($R^2 = 0.90$) and leaf Ca concentration ($R^2 = 0.70$) at-harvest. It could be suggested that

increasing Ca nutrition may increase the cell wall integrity and improve fruit firmness (Ranjbar et al., 2018). Other studies have also reported that increasing Ca nutrition enhanced fruit firmness in kiwifruit (Gerasopoulos et al., 1996; Morton et al., 2018), peach (Gayed et al., 2017), strawberry (Wojcik & Lewandowski, 2003) and apple (Wojcik et al., 2019). The SS strategy showed no effect on fruit fresh weight, SSC, FDM, green flesh colour and fruit count compared to NSS. This may be attributed to the similar rates of N and K fertilisation. A significantly positive correlation at 95 % CI was observed between FDM and fruit K concentration ($R^2 = 0.74$) at-harvest. This suggests the involvement of K in regulating photo-assimilate accumulation into the fruit (Trankner et al., 2018; Wang et al., 2018a).

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Table 3.15 Standard fruit quality at-harvest in 'Zesy002' vines at 163 DAFB on 19-04-2018 by true control (TC), not-spatially separated (NSS) and spatially separated (SS), and grower practice (GP) in the 2017/2018 season on the commercial orchard at Te Puke, Bay of Plenty.

Parameters	Units	TC	NSS	SS	Sig.	GP	*Clearance report
Fresh weight	g	119.3±2.7 b	133.9±1.5 a	133.1±2.0 a	0.008	123.1±2.5	124.9
Size class	-	30	27	27	NA	30	30
Firmness	KgF	6.26±0.05 c	6.66±0.12 b	7.24±0.08 a	<0.000	6.23±0.05	6.20
SSC	°Brix	9.39±0.18 a	9.92±0.24 a	10.21±0.12 a	0.122	8.38±0.22	8.50
FDM	%	17.08±0.08 b	17.56±0.12 a	17.61±0.06 a	0.031	17.30±0.05	17.40
Grade value (TZG)	%	65 (5)	85 (6)	85 (6)	NA	65 (5)	65 (5)
Green flesh colour	°H	103.3±0.1 a	102.5±0.2 b	102.4±0.2 b	0.001	103.6±0.1 a	107.8
Fruit count	Per vine	1456±108 a	1434±169 a	1461±93 a	0.675	1505±156	Ninety fruit

Values are averages and standard errors, n = 8, one composite sample was made up of thirty fruits from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences for each parameter.

*- The clearance report (18-04-2018) was provided by the orchard manager. The clearance sample was comprised of 90 fruits randomly selected from the orchard block 2 covering an area of 0.43 ha and total 10 rows of 'Zesy002' vines.

3.3.3 Comparison to grower practice

In this section, the comparison between experimental treatments and grower practice is made to understand the response of the spatial fertiliser strategy and nutrient application rates. Although, grower practice was outside the experimental block and statistically not comparable with experimental treatments. Both SS and NSS showed higher Ca accumulation in the leaf xylem sap from 20 through to 60 DAFB (Figure 3.2) and high Ca uptake in leaf and fruit tissues at-harvest compared to the GP (Table 3.12 and Table 3.13). This suggests that the GP experienced limitations regarding Ca availability and uptake possibly due to: (i) the competitive effect of K fertilisation (ii) comparatively low Ca fertiliser application rate (Table 3.2) (iii) Ca-displacement from the exchange sites due to high N fertilisation (Table 3.2) subsequently, Ca was lost due to leaching by high rainfall events and draining profile of sandy loam orchard soils. Consequently, reduction in Ca uptake at-harvest was observed by the GP in leaf and fruit tissues in 'Zesy002' vines. The photosynthetic performance (net photosynthesis, stomatal conductance and leaf transpiration rate) at 82 DAFB was low by the GP compared to both SS and NSS (Table 3.11). The leaf chlorophyll concentration was $14.9 \mu\text{g}\cdot\text{cm}^{-2}$ by the GP and increased to $17.3 \mu\text{g}\cdot\text{cm}^{-2}$ by the SS. These results suggest that Ca is involved in chlorophyll synthesis rather than N because the GP has higher N fertiliser rate and leaf N % DW but not higher leaf chlorophyll concentration. Although, linear chlorophyll to leaf N relationship is common, it is unclear why the GP showed lower leaf chlorophyll than SS and NSS. Possibly, above a certain level of leaf N, the concentration of chlorophyll is not increased, and excess N is stored as NO_3^- or Rubisco (Millard, 1988; Tegeder & Masclaux-Daubresse, 2018).

The significantly rapid increase in the fruit growth rate (Figure 3.4) was observed at 38 DAFB by both SS and NSS. Although, the rapid increase in the fruit growth rate was commenced at 44 DAFB by the GP. Both SS and NSS received high input of Ca and K compared to the GP. It could be suggested that the rapid increase in the fruit size (cell division and cell expansion) was possibly due to: (i) increased Ca uptake as Ca is a well-known secondary messenger in regulating the growth hormone 'auxin' (Dela Fuente & Leopold, 1973; Li et al., 2019). In kiwifruit a strong positive correlation ($R^2 = 0.92$) was reported by Sorce et al., (2011) between fruit Ca and auxin concentration. (ii) The role of K in increasing the fruit size as K is known to

increase berry growth and volume during cell expansion (Mpelasoka et al., 2003). The improvement in source-sink relationships by both SS and NSS compared to the GP may be attributed to the high input of Ca and K fertilisation. Although, the accumulation of NO_3^- (Figure 3.3) in the leaf xylem sap was low in the GP than both SS and NSS from 20 through to 60 DAFB, the uptake of N in leaf and fruit tissues at-harvest was higher (Table 3.12 and Table 3.13) by the GP than other treatments. This suggests possibly in the research block N fertilisation was not applied in August 2017 instead was applied later in January 2018. High uptake of Mg in fruit tissues at-harvest (Table 3.13) was observed by the GP than other treatments possibly due to high Mg input (Table 3.2). Regarding at-harvest fruit quality, both SS and NSS showed high fruit weight, firmness and SSC while green flesh colour was low (possibly due to low fruit N, Table 3.13) than the GP (Table 3.15). At-harvest, fruit fresh weight showed positive correlation with fruit Ca concentration ($R^2 = 0.68$) and fruit K concentration ($R^2 = 0.89$) at 95% CI. Therefore, increased fruit fresh weight at-harvest could be attributed to high input of Ca and K by both SS and NSS than TC and GP.

3.4 Conclusion

The spatial separation of Ca and Mg fertilisers resulted in a marked increase in vine and fruit Ca uptake and fruit firmness. This finding offers a simple technique that can easily be adopted by the kiwifruit industry to improve fruit post-harvest quality.

4 Temporal separation of soil-applied calcium and potassium nutrient fertilisers improved nutrient uptake and at-harvest fruit quality in ‘Zesy002’ vines

4.1 Introduction

Kiwifruit is a deciduous, perennial woody fruiting vine (Honghua et al., 2017; Varkonyi-Gasic et al., 2011; Voogd et al., 2017) and belongs to family Actinidiaceae. The spp. *deliciosa* (‘Hayward’) and *chinensis* (‘Zesy002’) within this family are globally cultivated because of their high economic return and large fruit size (Honghua et al., 2017).

Potassium is highly mobile and the most abundant cation in plant tissues, and easily taken up by the plant roots because the plant membranes are highly permeable for K (Marschner, 2012). Potassium is essential for the kiwifruit vine growth, yield and improves fruit quality at-harvest (Wang et al., 2006). Kiwifruit vines uptake K in larger amounts, therefore, high application rate of K fertilisers (250-350 Kg K ha⁻¹) is often recommended (Mills et al., 2008). However, excess K supply in kiwifruit orchards may have a negative impact on the uptake of other cations such as Ca and Mg (Barker & Pilbeam, 2015; Fageria, 2016; Marschner, 2011).

Fruit Ca and fruit quality are correlated in kiwifruit (Ciccarese et al., 2013; Montanaro et al., 2006; Xie et al., 2002). It has been reported that increasing the fruit Ca status improved the fruit quality both at- and post-harvest (Antunes et al., 2004; Basiouny & Basiouny, 2000; Cicco et al., 2007; Ferguson et al., 2003; Gerasopoulos & Drogoudi, 2005; Koutinas et al., 2010; Thorp et al., 2003). Increasing the pre-harvest Ca nutrition in kiwifruit vines has been observed to significantly improve the fruit firmness and SSC at-harvest and reduced the fruit softening during storage (Gerasopoulos et al., 1996; Gerasopoulos & Drogoudi, 2005). Therefore, adequate pre-harvest Ca nutrition is required to improve the fruit quality in kiwifruit vines. However, many factors affect Ca uptake by plant roots at soil level such as cation antagonism, certain soil and climatic characteristics and cultural practices. It is well-accepted that cations of similar size and characteristics, undergo competition for

uptake known as 'cation-cation antagonism' (Barker & Pilbeam, 2015; Fageria, 2001; Jakobsen, 1993b). For example, the antagonistic interaction between $K \times Ca$ and $K \times Mg$ limits the uptake of Ca and Mg by plants, respectively.

4.1.1 Problem Statement

The use of high K input in the kiwifruit orchards potentially increases the antagonistic effect of K on the absorption and uptake of Ca and Mg ions at soil level in kiwifruit vines (Nazarideljou et al., 2019). In addition, the characteristic features of BOP soils such as sandy, free draining and acidic in nature and high rainfall events may potentially limit the availability of Ca for the uptake in root tissues at soil level. Consequently, reducing the uptake and translocation of Ca into fruit tissues and potentially affect at-harvest fruit quality of 'Zesy002' vines.

4.1.2 Objectives

The main objective was to reduce the competitive effect of soil-applied K fertilisation on the uptake of Ca and Mg in 'Zesy002' vines without reducing K supply during the growing season. Sub-objectives were to: (i) increase the absorption and uptake of Ca and Mg in root, leaf and fruit tissues (ii) increase the photosynthetic performance and fruit growth rate (iii) therefore, improve the at-harvest fruit quality (size, SSC and FDM).

4.1.3 Hypothesis

The application of soil-applied nutrient fertilisers containing N, Ca and Mg at bud-break and application of K fertiliser 23-days after bud-break (temporal separation strategy) may avoid cation antagonistic interaction ($K \times Ca$ and $K \times Mg$) at soil level and may increase Ca and Mg availability for uptake in 'Zesy002' vines. The potential increase in fruit Ca concentration may strengthen the cell wall structure thus potentially improving fruit firmness at-harvest. Likewise, the potential increase in Mg uptake may increase fruit SSC at-harvest. Temporal separation of soil-applied nutrient fertilisers may not affect the absorption and uptake of N and K in 'Zesy002' vines. High K input (300 Kg K ha^{-1} in two split doses) may increase the photosynthetic performance in 'Zesy002' vines during the growing season. Thus, potentially improving the fruit quality at-harvest.

4.2 Materials and methodology

The temporal separation experiments were conducted using the pot and orchard grown 'Zesy002' vines in the 2017/2018 season. Both pot and orchard experiments received same application rate and nutrient formulations of soil-applied fertilisers. Both N and Ca nutrient fertilisers were applied in single full dose while K fertiliser was applied in two split doses at an interval of 20-25 days in the pot and orchard experiments. No foliar nutrient sprays were applied in both pot and orchard experiments.

4.2.1 Pot experiment

A controlled system pot experiment was conducted at the Horticultural Unit, Massey University, Palmerston North in the 2017/2018 season. The yellow-fleshed 'Zesy002' was grafted onto one-year-old green rootstock 'Bruno' and 'Bounty' grown in 45 L planting bags. In this chapter, only 'Bruno' grafted gold-fleshed vine results are presented. Each pot plant was irrigated with drip irrigation system and fertilised using modified Hoagland's nutrient solution (Hoagland & Arnon, 1950) to maintain normal plant growth. In this experiment the application of Ca and K fertilisers was separated in a temporally fashion, and soil nutrient fertilisers were applied to the surface of the pot grown 'Zesy002' vines. The temporal separation treatment (TS) received Ca fertiliser at 20 DABB and K fertiliser at 40 and 60 DABB (Table 4.1). The treatment receiving both Ca and K fertilisers at the same time at 20 DABB was termed as not-temporally separated treatment (NTS). Both TS and NTS received N fertiliser at 20 DABB. The treatment receiving zero nutrient input was termed as true control (TC) in the pot grown 'Zesy002' vines.

Table 4.1 Nutrient fertiliser application rate (Kg. ha⁻¹), time of application in 2017 and fertiliser formulations used in true control (TC), not-temporally separated (NTS) and temporally separated (TS) treatments applied to the pot grown ‘Zesy002’ vines at the Horticultural Unit, Massey University, Palmerston North in the 2017/2018 season. Nitrogen and calcium fertilisers were applied in single full dose. Potassium fertiliser was split equally (150+150 = 300 Kg K ha⁻¹) and applied at specified dates.

Nutrients (Kg. ha ⁻¹)	TC	NTS	TS	Fertiliser formulations
N	0	50 17 th Oct (20 DABB)	50 17 th Oct (20 DABB)	Calcium ammonium nitrate
K	0	300 17 th Oct & 6 th Nov (20 & 40 DABB)	300 6 th & 26 th Nov (40 & 60 DABB)	Sulphate of potassium
Ca	0	200 17 th Oct (20 DABB)	200 17 th Oct (20 DABB)	Gypsum
Mg	0	3.7 17 th Oct (20 DABB)	3.7 17 th Oct (20 DABB)	

4.2.2 Orchard experiment

The experiment was conducted using the ‘Zesy002’ (*Actinidia chinensis*) grafted onto green ‘Bruno’ (*Actinidia deliciosa*) vines on the commercial orchard in the 2017/2018 season at Paengaroa, Bay of Plenty. Rows were 3.6 m apart, and vines were 6 m apart in the row. Each row was sprinkle irrigated. Except the nutrient fertiliser application, the vines were managed inclusively with the rest of the commercial orchard by the management. The experimental vines received canopy management and copper sprays in place in this orchard. TC with zero nutrient input was used (Table 4.2). Both Ca and K fertilisers were applied on two-days after bud break (DABB) and termed as NTS. In TS, Ca fertiliser was applied at 20 DABB and K fertiliser was applied at 43 DABB. Both TS and NTS received N fertiliser at 20 DABB. In order to compare the nutrient strategy used in this experiment to the current orchard nutrient practices, few vines outside the experimental area were selected and termed as (GP). The experiment was randomised block design with ten replicates and rows were used as blocks to avoid the soil spatial heterogeneity. Two buffer vines were used between treatment vines.

Table 4.2 Nutrient fertiliser application rate (Kg. ha⁻¹) and time of application in 2017 in grower practice (GP), true control (TC), not-temporally separated (NTS) and temporally separated (TS) treatments applied to ‘Zesy002’ vines grown on the commercial orchard at Paengaroa, Bay of Plenty, in the 2017/2018 season. Nitrogen and calcium fertilisers were applied in single full dose. Potassium fertiliser was split equally (150+150 = 300 Kg K ha⁻¹) and applied at specified dates.

Nutrients (Kg. ha⁻¹)	*GP	TC	NTS	TS
N	27	0	50	50
	Sept (BB)		13 th Sept (20 DABB)	13 th Sept (20 DABB)
K	118	0	300	300
	Sept (BB)		13 th Sept & 1 st Oct (20 & 40 DABB)	1 st & 21 st Oct (40 & 60 DABB)
Ca	7.2	0	200	200
	Sept (BB)		13 th Sept (20 DABB)	13 th Sept (20 DABB)
Mg	3.1	0	3.7	3.7
	Sept (BB)		13 th Sept (20 DABB)	13 th Sept (20 DABB)

*- The fertiliser formulations used by the grower were; Sulphate of potassium, Calcium ammonium nitrate, organibor and Elemental sulphur.

4.2.3 Measurements

Soil samples were taken from around the root zone of each treatment vine (see section 2.4). Root samples were only collected from the pot experiment at 161 DAFB (at-harvest). Root tissues were used for length and fresh weight measurements then oven dried at 60 °C to attain constant dry weight. After drying, root samples were ground to fine powder and subsequently used for the nutrient analysis at FLRC, Massey University, Palmerston North (see section 2.6.3). Leaf xylem sap was collected at 20, 40 and 60 DAFB by following the method described by Romero et al., (2012) with the help of the pressure chamber (see section 2.6.2). Calcium and nitrate concentrations were analysed by atomic absorption spectrophotometer ($\lambda = 422.7$ nm; air-acetylene flame). Leaf chlorophyll concentration and photosynthetic performance (see sections 2.5.2 and 2.5.3) of ‘Zesy002’ vines was measured prior to harvest at 85 DAFB. Leaf samples were collected at 20 DABB and at-harvest from each treatment vine (see section 2.6.1) for the nutrient analysis (see section 2.6.3). Fruit samples were collected at-harvest from each treatment vine for the standard fruit maturity analysis (see section 2.7). Both leaf and fruit samples (unconditioned) were transported same day of the harvest to the storage facility at the Horticultural Unit, Massey University, Palmerston North and stored at 1°C for

seven-days. Fruit samples were then processed by AgFirst, Hawke's Bay to analyse the standard fruit maturity parameters for each fruit (see section 2.7). The standard fruit maturity test included fruit fresh weight, firmness, total soluble solid concentration (SSC), fruit dry matter (FDM) and fruit colour. Dried fruit slices were analysed for mineral nutrients at FLRC, Massey University, Palmerston North. Statistical analyses were carried out with the help of IBM SPSS Statistics 24 version. Treatment differences were tested at $P \leq 0.05$ using ANOVA. Pairwise Least Significant Difference (LSD) tests were used to compare treatments where significant differences were found.

4.3 Results and discussion

4.3.1 Pot experiment

In this chapter, only 'Bruno' grafted vines results are presented because both 'Bruno' and 'Bounty' vines showed similar nutrient uptake and at-harvest quality.

Pot soils exhibited ideal soil pH and adequate bulk density, cation exchange capacity (CEC), Olsen phosphorus and base saturation (Table 4.3). However, low exchangeable Ca, Mg, K and plant available N may possibly be due to the low nutrient input (Ca and K deficient) for the past six months in the modified Hoagland's nutrient solution (Hoagland & Arnon, 1950), in the pot grown 'Zesy002' vines.

Table 4.3 Pre-treatment soil properties in the pot grown 'Zesy002' vines in July 2017 at the Horticultural Unit, Massey University, Palmerston North.

Parameters	Units	Values	Level	*Optimum range
pH	pH Units	6.5	Ideal	5.8-6.5
BD	g. mL ⁻¹	0.8	Adequate	0.6-1.00
CEC	me. 100g ⁻¹	18	Adequate	12-25
Olsen P	me. 100g ⁻¹	50	Adequate	30-60
Ca	me. 100g ⁻¹	3.2	Low	6.0-12.0
Mg	me. 100g ⁻¹	1.0	Low	1.00-3.00
K	me. 100g ⁻¹	0.51	Low	0.60-1.20
Na	me. 100g ⁻¹	0.01	Low	0.00-0.40
Plant available N	Kg. ha ⁻¹	100	Low	100-150
Organic matter	%	8.0	Low	7.0-17.0
Base saturation				
Ca	%	67	Adequate	55-67
Mg	%	12.5	Adequate	10-14
K	%	6.00	Adequate	5-7
Total	%	85.5		

One composite sample was made up of thirty sub samples.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

Leaf nutrient analysis before applying treatments showed low Ca and K in the pot grown 'Zesy002' vines (Table 4.4). Possibly this reflects the demand of Ca and K nutrients in the pot grown 'Zesy002' vines as the nutrient solution applied to the pot plants was deficient in Ca and K. The adequate N found in leaf samples may possibly be due to N mobilisation as N is not stored in the root (Warrington & Weston, 1990). Likewise, leaf Mg was adequate possibly due to the nutrient input in the modified Hoagland's solution (Hoagland & Arnon, 1950).

Table 4.4 Pre-treatment leaf nutrient status (% DW) in the pot grown 'Zesy002' vines at 20 DABB on 30th October 2017 in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Nutrients	% DW	Level	*Optimum range
N	2.42	Adequate	1.8-2.8
K	1.24	Low	1.8-3.1
Ca	1.12	Low	1.60-3.20
Mg	0.37	Adequate	0.25-0.50

One composite sample was made up of ten leaves from treatment vines. Results presented below are average of thirty vines.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

Root nutrient status showed that the TS significantly increased uptake of Ca by three-folds and Mg by two-folds compared to the NTS at 161 DAFB in the pot grown ‘Zesy002’ vines (Table 4.5). These results suggest that K supply (300 Kg K ha⁻¹) together with Ca and Mg fertilisation all-at-once significantly reduced root Ca and Mg uptake. It is well-established that the absorption of Ca, Mg and K behave competitively (Daliparthi et al., 1994; Ding et al., 2006; Domagała-Swiatkiewicz et al., 2019; Fageria, 2001; Garcia et al., 1999; Jakobsen, 1993b; Morton et al., 2008; Rhodes et al., 2018). Shukla & Mukhi, (1979) reported the antagonistic interactions between K × Ca and K × Mg. These interactions are physiological in nature and takes place during the process of root nutrient absorption and further during translocation from the root to shoot. It is reported that increasing K supply suppressed Ca uptake (Bar-Tal & Pressman, 1996; Malvi, 2011; Pathak & Kalra, 1971). The TS significantly increased Ca and Mg absorption by roots probably because absorption was not counteracted by K⁺ due to the absence of K fertilisation for about 23 days. These results are consistent with other reports that increasing K supply can reduce Ca uptake in grapes (Garcia et al., 1999), strawberries (Nazarideljou et al., 2019), and Mg in Lucerne (Omar & El Kobbia, 1966) and cherry (Trojanos et al., 2000). Root N, K, Ca and Mg uptake in root tissues at-harvest was significantly lower in TC because this treatment-was not fertilised (see Table 4.1).

Table 4.5 Root nutrient status (% DW) at-harvest in the pot grown ‘Zesy002’ vines at 161 DAFB by true control (TC), not-temporally separated (NTS) and temporally separated (TS) treatments in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Nutrients (% DW)	TC	NTS	TS	Sig.
N	0.65±0.03 b	0.88±0.04 a	0.82±0.05 a	0.009
K	1.06±0.06 b	1.68±0.05 a	1.70±0.03 a	<0.000
Ca	0.52±0.06 c	1.04±0.05 b	1.56±0.09 a	<0.000
Mg	0.24±0.02 c	0.42±0.05 b	0.57±0.07 a	0.002

Values are averages and standard errors, n = 5, one composite sample was made up of root tissues collected from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

The TS strategy significantly increased leaf Ca and Mg uptake by two-folds and three-folds, respectively, in the pot grown ‘Zesy002’ vines compared to NTS (Table 4.6). These results support our hypothesis that temporal separation of K from Ca and Mg fertiliser applications can increase the uptake of Ca and Mg by avoiding antagonistic or competitive effects of K on the uptake of other cations. Kirkby,

(1979) suggested that the uptake rate is dependent on the concentration of the individual cation in the nutrient solution and the uptake mechanism. They commented that K uptake is active or possibly enters the cell through facilitated diffusion (Ratner & Jacoby, 1976) and K⁺ ions often compete strongly for uptake with other cations, consequently, K uptake is favoured in comparison to other cations (Kirkby, 1979). Zamaniyan et al., (2012) reported that the excessive K input in the nutrient solution reduced Ca uptake in root and leaf tissues in chicory. They also confirmed that decreasing Ca levels increased the incidence of leaf tipburn and the hole pith of chicons. Hannaway et al., (1982) reported that Mg absorption by roots in Kenhy tall fescue plants was not affected by K supply in the solution culture, however, shoot Mg accumulation was reduced with increasing K input in the solution culture. They suggested limited root to shoot translocation of Mg is due to the antagonistic effect of K. Likewise, Ohno & Grunes, (1985) reported that Mg translocation from root to shoot was depressed due to increasing K concentration in roots possibly due to the competition for metabolically produced binding compounds (Omar & El Kobbia, 1966). They commented that the mechanism of the antagonistic interaction between Mg and K mainly exist in in the translocation step. At-harvest N uptake in root and leaf tissues was comparable in both TS and NTS suggesting that N absorption by roots was not affected by the temporal separation of nutrient fertilisers.

Table 4.6 Leaf nutrient status (% DW) at-harvest in the pot grown ‘Zesy002’ vines at 161 DAFB by true control (TC), not-temporally separated (NTS) and temporally separated (TS) treatments in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Nutrients (% DW)	TC	NTS	TS	Sig.
N	1.17±0.07 b	2.35±0.12 a	2.19±0.05 a	<0.000
K	1.18±0.08 b	2.70±0.12 a	2.69±0.09 a	<0.000
Ca	1.02±0.08 c	1.57±0.10 b	1.91±0.009 a	<0.000
Mg	0.21±0.02 c	0.36±0.03 b	0.58±0.07 a	<0.000

Values are averages and standard errors, n = 5, one composite sample was made up of ten leaves from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Fruit nutrient status showed that the TS significantly increased Ca and Mg uptake by two-folds compared to the NTS at 161 DAFB in the pot grown ‘Zesy002’ vines (Table 4.7). This suggests that the antagonistic effect of K on the uptake of Ca and Mg was avoided at soil level, hence, increased the uptake of Ca and Mg in root, leaf

and fruit tissues. According to (De Freitas & Mitcham, 2012) the limited Ca availability at soil level may translate to reduced Ca nutrition and potentially induce Ca deficiency disorders in fruits. It is reported that fruit Ca uptake is compromised due to the competitive effect of K for uptake at soil-to-fruit pathway in kiwifruit (Montanaro et al., 2014), sweet cherry (Winkler & Knoche, 2019) and in tomato (Taylor et al., 2004). Fruit N uptake at-harvest was significantly higher by the NTS compared to the TS. Possibly indicating the synergistic interaction between N and K therefore, increasing the translocation of N to fruit tissues (Minotti et al., 1968; 1969). Similar K uptake in root, leaf and fruit tissues at-harvest was found in both TS and NTS. This suggests that K absorption was not affected by increasing Ca and Mg supply rate as reported by Omar & El Kobbia, (1966) in lucerne with increasing Mg fertiliser rate.

Table 4.7 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in the pot grown ‘Zesy002’ vines at 161 DAFB by true control (TC), not-temporally separated (NTS) and temporally separated (TS) treatments in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Nutrients (mg. 100g ⁻¹ DW)	TC	NTS	TS	Sig.
N	140±4c	273±6a	255±7b	<0.000
K	210±6b	336±4a	342±5a	<0.000
Ca	15±2c	28±3b	40±4a	0.001
Mg	14±2c	25±2b	36±5a	0.003

Values are averages and standard errors, n = 5, one composite sample was made up of five fruit slices from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Fruit fresh weight and FDM was similar in both TS and NTS at-harvest in the pot grown ‘Zesy002’ vines (Table 4.8). This suggests that increasing Ca and Mg uptake both in leaf and fruit tissues due to the temporal separation of nutrient fertilisers had no effect on fruit size. This is consistent with Raese & Drake, (1995) reported increasing fruit Ca had no effect on fruit weight at-harvest in apple. The other possible explanation may be the similar N and K fertilisation that probably translated to similar fruit size in both TS and NTS. The TS strategy significantly increased fruit firmness and soluble solids concentration (SSC) at-harvest compared to the NTS strategy. A significantly positive correlation ($R^2 = 0.80$ at 95 % CI) was found between fruit Ca and fruit firmness at-harvest. This is in confirmation with reports suggesting that pre-harvest Ca application improved fruit firmness in the horticultural fruit crops; papaya (Madani et al., 2016), sweet cherry (Wojcik et al.,

2013), apple (Siddiqui & Bangerth, 1995) and table grape (Bonomelli & Ruiz, 2010). Likewise, Qiu et al., (1995) reported positive correlation between fruit mesocarp Ca concentration and the fruit firmness. The temporal separation experiments suggest that increasing the fruit Ca concentration possibly increased the binding of Ca²⁺ ions to the pectins in the cell wall thus increased the cell wall rigidity and cell-to-cell cohesion (Demarty et al., 1984; Hocking et al., 2016) thus, potentially improved the fruit firmness at-harvest. Significantly improved SSC may be attributed to the increased fruit Mg concentration. Leaf and fruit Mg concentration was positively correlated ($R^2 = 0.88$ and 0.87 at 95 % CI) to SSC at-harvest. These results are consistent with Harty et al., (2002), Morton et al., (2008), and Sobrinho, (1992), reporting increasing leaf Mg concentration significantly increased SSC in citrus possibly due to the starch and/or sugar synthesis (Bybordi & Shabanov, 2010; Marschner, 2012). True control (TC) treatment showed significantly lower at-harvest fruit quality possibly due to the lower nutrient uptake and translocation during the growing season compared to both TS and NTS. This suggests the zero-nutrient input in TC had a significant effect on the at-harvest fruit quality in 'Zesy002' vines (see Table 4.1).

Table 4.8 Standard fruit quality at-harvest in the pot grown 'Zesy002' vines at 161 DAFB by true control (TC), not-temporally separated (NTS) and temporally separated (TS) treatments in the 2017/2018 season at the Horticultural Unit, Massey University, Palmerston North.

Parameters	Units	TC	NTS	TS	Sig.
Fresh weight	g	135.3±2.6 b	149.3±2.8 a	153.3±3.2 a	<0.000
Size class	-	27	25	22	NA
Firmness	KgF	6.37±0.08 c	7.02±0.24 b	7.69±0.10 a	<0.000
SSC	°Brix	10.05±0.09 c	10.60±0.22 b	11.1±0.18 a	0.001
FDM	%	17.96±0.08 b	18.38±0.07 a	18.41±0.06 a	<0.000
Grade value (TZG)	%	85 (6)	90 (7)	90 (7)	NA

Values are averages and standard errors, n = 10, one composite sample was made up of five fruit slices from each treatment vine. Differences are considered significant at $P < 0.05$. Different letters beside values within rows denote significant differences.

4.3.2 Orchard experiment

The Paengaroa orchard has well drained volcanic soils with zero soil-water deficit and drainage as a common winter occurrence. The orchard soil showed adequate soil exchangeable Ca and % Ca base saturation (Table 4.9). However, low CEC, soil organic matter and sandy loam soil type combined with a draining profile and high rainfall events may potentially limit Ca availability for the plant uptake at soil level

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(McClaren & Cameron, 1990). Both pH and bulk density of orchard soils was found in the adequate range and indicates well-managed soils. Olsen P was found in the adequate range, however, low soil exchangeable K and % K base saturation. Possibly indicating the characteristic features of BOP soils i.e. naturally retaining phosphates and deficient in K (Molloy et al., 1998). The other possible explanation for low soil K on exchangeable sites may be due to K loss and low soil replenishment of K in the sandy loam soils of the orchard. Bolton, (1968) stated that K fertiliser rapidly leach through the profile of an acid soil. It is well-known that in sandy soils or acid lateritic soils with low CEC the leaching rates of K are often high and may result in the significant K loss (Sitthaphanit et al., 2009; Wulff et al., 1998). Thus, rapid K depletion may occur over relatively short durations if the removal of K is not balanced by the regular K supply with mineral fertilisation or by the adequate recycling of crop remains and organic manures (Hoang et al., 2019; Ma et al., 2013). According to Sitthaphanit et al., (2009), the leaching losses of K on sandy soils may be reduced by the split application of K fertiliser. Therefore, split application of K fertilisers was used. The orchard soils exhibited low plant available N, possibly indicating N leaching due to the aforementioned characteristics of soils and climate of BOP. Likewise, low soil exchangeable Mg was observed in the orchard soils therefore, kiwifruit vines grown in this orchard may encounter limited Mg nutrition. Thus, it can be speculated that high input of K fertilisation (100-300 Kg K ha⁻¹) on this orchard may meet K demand of 'Zesy002' vines. However, the uptake of Ca and Mg may be limited adversely and leaf nutrient analysis at bud-break may show low Ca and Mg in 'Zesy002' vines grown in this orchard.

Table 4.9 Pre-treatment soil properties in ‘Zesy002’ vines in July 2017 in the commercial orchard at Paengaroa, Bay of Plenty.

Parameters	Units	Values	Level	*Optimum range
pH	pH Units	6.2	Adequate	5.8-6.5
BD	g. mL ⁻¹	0.82	Adequate	0.6-1.00
CEC	me. 100g ⁻¹	12.28	Low	12-25
Olsen P	me. 100g ⁻¹	39	Adequate	30-60
Ca	me. 100g ⁻¹	10.05	Adequate	6.0-12.0
Mg	me. 100g ⁻¹	1.10	Low	1.00-3.00
K	me. 100g ⁻¹	0.16	Low	0.60-1.20
Na	me. 100g ⁻¹	0.01	Low	0.00-0.40
Plant available N	Kg. ha ⁻¹	78	Low	100-150
Organic matter	%	5.0	Low	7.0-17.0
Base saturation				
Ca	%	65	Adequate	55-67
Mg	%	13.45	Adequate	10-14
K	%	3.93	Low	5-7
Total	%	85.4		

One composite sample was made up of thirty sub-samples.

*- The respective level for each parameter is based on the optimum range provided by an accredited laboratory, Hill Laboratories Limited 2017.

Leaf nutrient status before applying treatments showed low Ca (Table 4.10). Although, soil Ca was adequate, low leaf Ca may possibly be indicating: (i) soil Ca was unavailable for the plant uptake, (ii) low soil Ca replenishment due to the low soil organic matter and zero Ca fertilisation and (iii) leaching loss of Ca due to high rainfall events or all the above-mentioned factors. Therefore, adequate Ca fertilisation at-bud break together with a strategy to avoid the competitive effect of K on Ca uptake by roots may increase Ca nutrition of ‘Zesy002’ vines during the growing season. Low leaf N and K may possibly indicating high N and K demand in kiwifruit vines as suggested by Mills et al., (2008). Low leaf Mg may possibly be due to low soil exchangeable Mg although % Mg base saturation was adequate as mentioned in the Table 4.9.

Table 4.10 Pre-treatment leaf nutrient status (% DW) in ‘Zesy002’ vines at 20 DABB in the 2017/2018 season in the commercial orchard at Paengaroa, Bay of Plenty.

Nutrients	% DW	Level	*Optimum range
N	1.90	Low	1.8-2.8
K	1.60	Low	1.8-3.1
Ca	1.25	Low	1.60-3.20
Mg	0.21	Low	0.25-0.50

One composite sample was made up of twenty leaves collected from treatment vines. Results presented below are average of thirty vines.

* - The respective level for each parameter is based on the optimum range provided by an accredited laboratory, Hill Laboratories Limited 2017.

Leaf xylem sap analysis showed that the temporal separation (TS) strategy significantly increased Ca accumulation at 20, 40 and 60 DAFB compared to the NTS (Figure 4.1). This suggests that the TS treatment significantly increased Ca uptake in ‘Zesy002’ vines at soil level. These results also suggest that the differences between treatments were established earlier during the growing season (after the fertiliser application, 20-45 DABB).

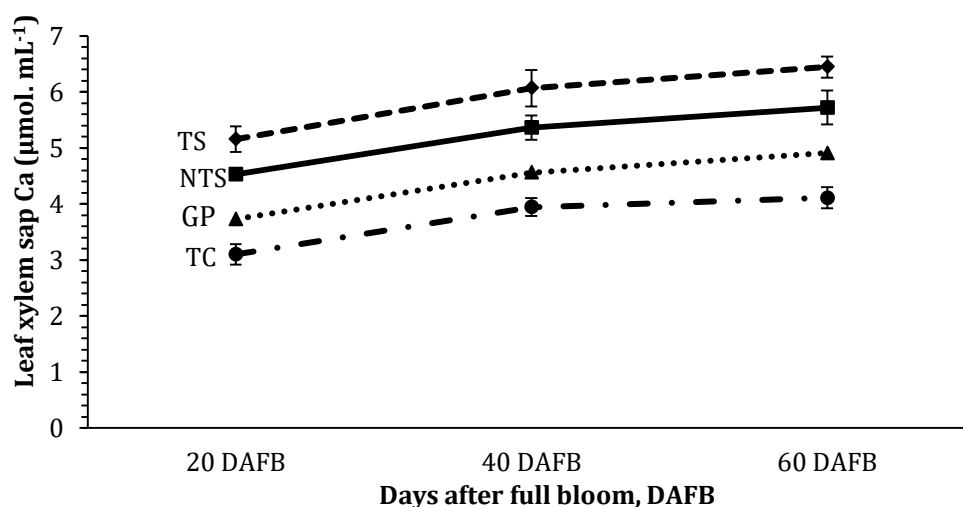


Figure 4.1 Leaf xylem sap calcium (Ca) concentration ($\mu\text{mol. mL}^{-1}$) taken at 20, 40 and 60 DAFB in the 2017/2018 season in ‘Zesy002’ vines grown in the commercial orchard at Paengaroa, Bay of Plenty by true control (TC), not-temporally separated (NTS) and temporally separated (TS), and grower practice (GP). Full bloom was on 6th November 2017. Values are averages with standard error bars, n = 10, one composite sample was made up of ten leaves from each treatment vine.

The TS significantly increased NO_3^- accumulation in the leaf xylem sap than the NTS at 20, 40 and 60 DAFB in ‘Zesy002’ vines (Figure 4.2). This suggests high NO_3^- mobilisation due to the temporal separation of Ca and K fertilisers.

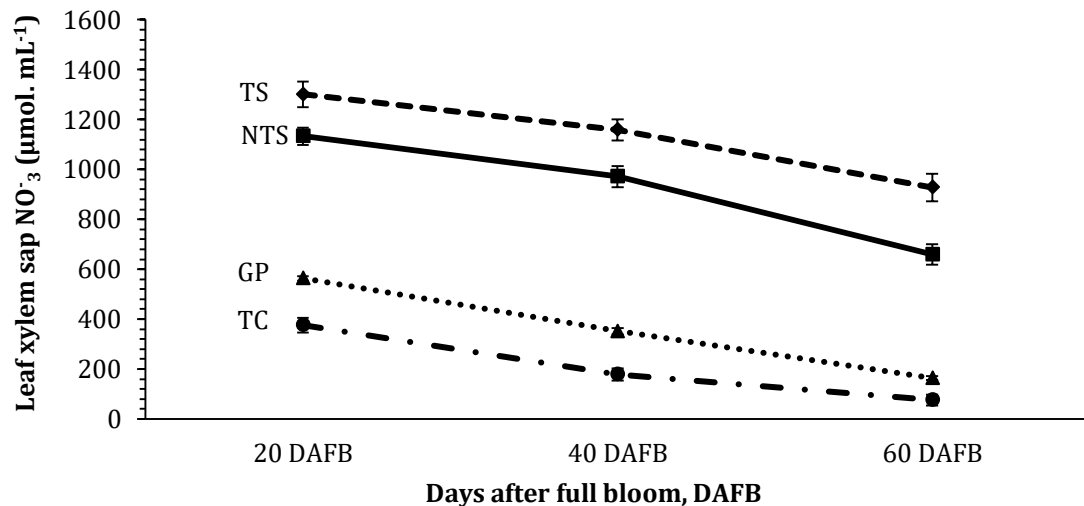


Figure 4.2 Leaf xylem sap nitrate (NO_3^-) concentration ($\mu\text{mol. mL}^{-1}$) taken at 20, 40 and 60 DAFB in the 2017/2018 season in 'Zesy002' vines grown in the commercial orchard at Paengaroa, Bay of Plenty by true control (TC), not-temporally separated (NTS) and temporally separated (TS), and grower practice (GP). Full bloom was on 6th November 2017. Values are averages with standard error bars, $n = 10$, one composite sample was made up of ten leaves from each treatment vine.

The TS treatment had no significant effect on the estimated fruit weigh (g) from fruit set through to harvest compared to the NTS in 'Zesy002' vines (Figure 4.3). Likewise, actual fruit fresh weight (g) at-harvest was comparable in both TS and NTS treatments. This may be attributed to the similar rate of N and K application. Probably indicating the regulatory effect of K^+ ions on the cell division and cell expansion through osmotic and turgor regulation (Nazarideljou et al., 2019). The first rapid increase in both TS and NTS treatments was observed at 38 DAFB during the growing season and maintained through to 69 DAFB (Stage 1). Subsequently, followed by a period of slow growth from 70 DAFB through to 98 DAFB (Stage 2). The fruit size was then rapidly increased from 99 DAFB through to harvest (Stage 3). The treatment differences regarding leaf xylem Ca concentration were already developed from 20 through to 60 DAFB as shown in the Figure 4.3. In green-fleshed kiwifruit Hopping, (1976) reported growing cycle to last from 10 to 58 DAFB (Stage 1), 60-70 DAFB (Stage 2) and 70 DAFB through to harvest (Stage 3).

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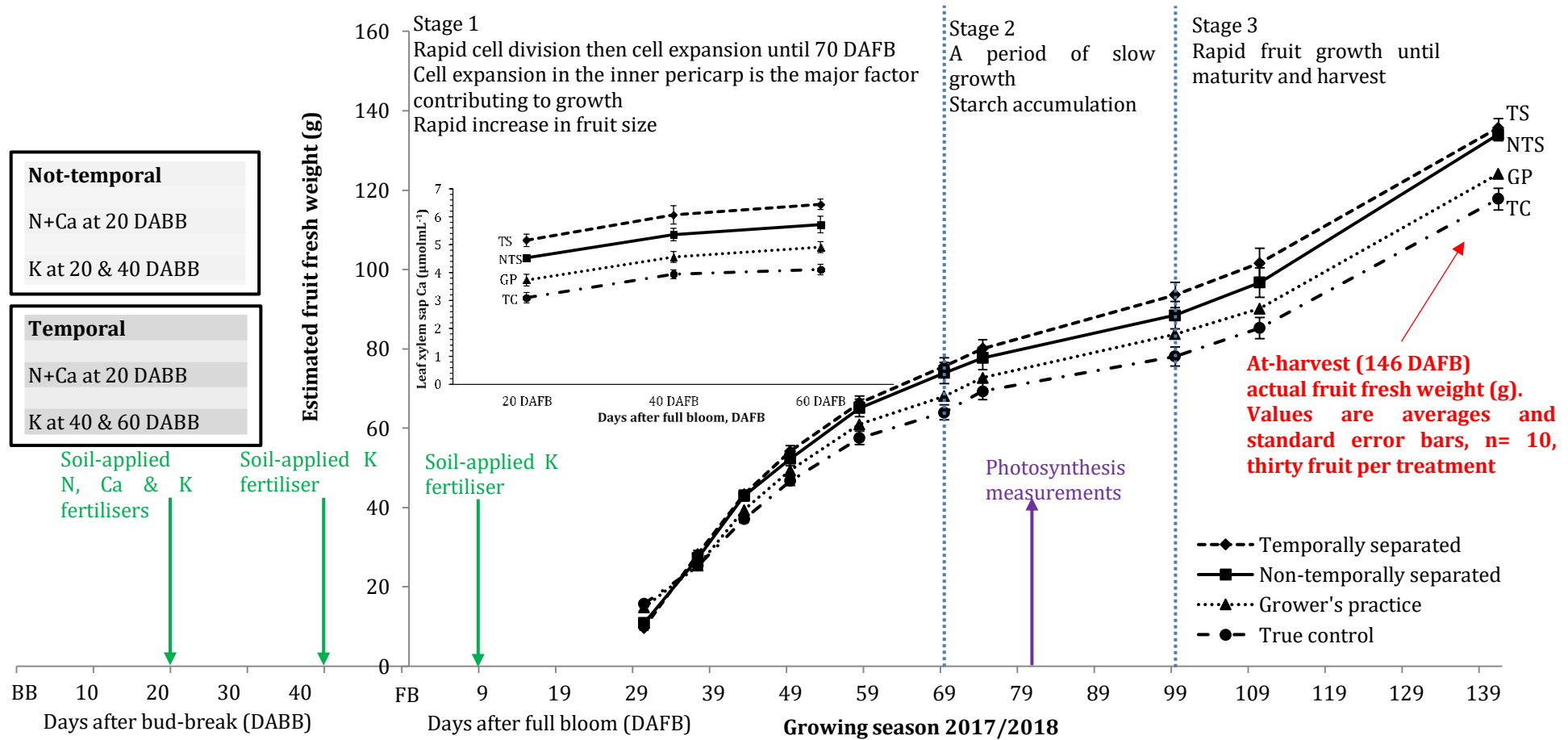


Figure 4.3 Effect of true control (TC), not-temporally separated (NTS) and temporally separated (TS), and grower practice (GP) on estimated fruit size (g) from fruit set through to harvest in 'Zesy002' vines grown in the commercial orchard at Paengaroa, Bay of Plenty in the 2017/2018 season. Values are averages and standard error bars, n=10, four fruit per treatment. Bud-break was on 11-09-2017, full bloom was at 51 DABB on 01-11-2017 and the commercial harvest was at 146 DAFB on 27-03-2018.

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No significant difference was observed for leaf chlorophyll concentration, net photosynthesis, stomatal conductance and leaf transpiration (photosynthetic performance) in both TS and NTS at 85 DAFB in 'Zesy002' vines (Table 4.11). It can be suggested that increasing Ca nutrition due to the temporal separation of Ca and K fertilisers had no effect on the photosynthetic performance in 'Zesy002' vines during the growing season. Similar photosynthetic performance in 'Zesy002' vines may be attributed to the similar N and K fertilisation (Table 4.2) in both TS and NTS. Possibly due to the interactive effect of N and K as suggested by Hu et al., (2019) reported optimal N and K application regulated the leaf photosynthetic capacity through the co-ordination of CO₂ diffusion and carboxylation. They reported an appropriate ratio of N and K was improving photosynthetic efficiency and crop yield in oilseed cultivar 'Huayouza 9'. The other possible explanation may be the K fertilisation. It is reported that increasing the ionic K⁺ concentration in the guard cells was improving cell turgor, water use efficiency and stomatal conductance (Ahmad & Maathuis, 2014; Jordan-Meille & Pellerin, 2008). According to Guo et al., (2019) increasing K supply increased net photosynthesis, stomatal conductance and leaf transpiration rate in wheat plants. Likewise, Sitko et al., (2019) observed reductions in the leaf chlorophyll of K deficient plants. It is reported that K deficiency caused reduction in the chlorophyll content and the degradation of the chloroplast structure (Zhao et al., 2001) under severe K depletion, net photosynthesis and stomatal conductance was usually downregulated (Battie-Laclau et al., 2014). Both TS and NTS showed significantly improved leaf chlorophyll, net photosynthesis, stomatal conductance and leaf transpiration rate than the TC during the growing season in 'Zesy002' vines. This suggests that the N, Ca and K fertilisation irrespective of the application time significantly improved the photosynthetic performance of 'Zesy002' vines during the growing season. Leaf internal CO₂ and leaf temperature were similar in all treatments possibly due to the uniform micro-climate in the orchard.

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Table 4.11 Effect of true control (TC), not-temporally separated (NTS) and temporally separated (TS), and grower practice (GP) on leaf chlorophyll concentration, net photosynthesis, stomatal conductance, leaf internal carbon dioxide (CO₂), transpiration rate, and leaf temperature in 'Zesy002' vines at 85 DAFB in the 2017/2018 season in the commercial orchard at Paengaroa, Bay of Plenty.

Parameters	Units	TC	NTS	TS	Sig.	GP
Leaf chlorophyll	µg. cm ⁻²	12.6±0.6 b	17.5±0.3 a	17.5±0.3 a	<0.000	15.5±0.3
Net photosynthesis	µmol CO ₂ . m ² s ⁻¹	12.23±0.44 b	15.61±0.52 a	16.15±0.37 a	<0.000	12.88±0.40
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.16±0.01 b	0.21±0.01 a	0.22±0.01 a	<0.000	0.17±0.01
Internal CO ₂	µmol CO ₂ . mol ⁻¹ air	243.8±2.1 a	243.7±2.9 a	243.7±2.8 a	1.000	243.4±5.4
Transpiration	mmol	2.50±0.03 b	2.97±0.06 a	2.95±0.09 a	<0.000	2.64±0.09
Leaf temperature	°C	22.0±0.4 a	21.5±0.4 a	21.4±0.4 a	0.835	21.9±0.7

Values are averages and standard errors, n=10. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Temporal separation of soil-applied calcium and potassium fertilisers

Leaf nutrient status showed that the TS significantly increased Ca uptake than NTS and TC at 141 DAFB in 'Zesy002' vines (Table 4.12). This suggests that the TS strategy avoided the antagonistic effect of K fertiliser on Ca uptake in 'Zesy002' vines at soil level. Possibly because for about 23 days K was not supplied, hence, there was less competition for uptake among cations. These results suggest that K supply at an application rate of 300 Kg K ha⁻¹ along with Ca and Mg fertilisation significantly reduced the uptake of Ca and Mg nutrients. Both TS and NTS showed comparable uptake of N, K and Mg in leaf tissues at-harvest.

Table 4.12 Leaf nutrient status (% DW) at-harvest in 'Zesy002' vines at 146 DAFB by true control (TC), not-temporally separated (NTS) and temporally separated (TS), and grower practice (GP) in the 2017/2018 season in the commercial orchard at Paengaroa, Bay of Plenty.

Nutrients (% DW)	TC	NTS	TS	Sig.	GP
N	1.48±0.12 b	3.24±0.06 a	3.15±0.05 a	<0.000	2.94±0.41
K	1.56±0.16 b	3.01±0.11 a	3.05±0.11 a	<0.000	2.21±0.04
Ca	1.20±0.08 c	2.61±0.11 b	3.13±0.18 a	<0.000	1.50±0.18
Mg	0.25±0.05 b	0.36±0.04 ab	0.44±0.04 a	0.047	0.34±0.03

Values are averages and standard errors, n = 5, one composite sample was made up of twenty leaves from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Fruit nutrient status showed that the TS significantly increased fruit Ca uptake to 74 mg. 100g⁻¹ DW from 52 and 30 mg. 100g⁻¹ DW by NTS and TC, respectively, at 141 DAFB in 'Zesy002' vines (Table 4.13). Likewise, the TS significantly increased fruit Mg uptake than the NTS and TC. This suggests temporal separation of Ca and K fertilisers significantly avoided the competition between cations for uptake by the fruit. This is in accordance with De Freitas & Mitcham, (2012) and Gaion et al., (2019) suggested increasing Ca availability for plant uptake at soil level in the nutrient medium would increase Ca uptake and accumulation and ultimately increasing fruit Ca concentration thus fruit Ca deficiency disorders may potentially be avoided. Morton et al., (2008) reported that high K either in soil exchangeable sites or through fertiliser input may significantly reduce Mg uptake in citrus in Gisborne soils of New Zealand beside other factors. It is well-accepted in literature that K⁺ ions are easily taken up by the plant roots and reduce the diffusion of the more hydrated Mg²⁺ ions and Ca²⁺ ions (Marschner, 2012) . The pot experiment results are in confirmation with this and showed that the temporal separation of Ca and K fertilisers significantly increased Ca and Mg uptake in roots, leaves and fruits

than non-temporal separation of these nutrients in 'Zesy002' vines. This suggests application of K fertiliser (300 Kg K ha⁻¹) may potentially reduce Ca and Mg uptake in 'Zesy002' vines. The competitive effect of K on Ca and Mg uptake is reported by Fageria, (2001), Montanaro et al., (2014) and Penalosa et al., (1995). Fruit K uptake was comparable in both TS and NTS treatments. This suggests increasing Ca nutrition due to the temporal separation of Ca and K fertilisers had no effect on the uptake of K by the fruit. This is in confirmation with Davarpanah et al., (2018) reported increasing Ca supply had no effect on K uptake. Interestingly, fruit N uptake was significantly high in the NTS than all other treatments. Possibly indicating more leaf to fruit N translocation in the NTS treatment. Potentially due to the synergistic effect of K on the uptake of N, since both N and K fertilisers were applied at the same time in the NTS. This suggests the K application together with N and Ca fertilisation all at once significantly increased the fruit N uptake at-harvest.

Table 4.13 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in 'Zesy002' vines at 146 DAFB by true control (TC), not-temporally separated (NTS) and temporally separated (TS), and grower practice (GP) in the 2017/2018 season in the commercial orchard at Paengaroa, Bay of Plenty.

Nutrients (mg. 100g⁻¹ DW)	TC	NTS	TS	Sig.	GP
N	496±10c	565±7a	533±6b	<0.000	511±10
K	1202±36b	1502±31a	1510±31a	<0.000	1245±35
Ca	30±7c	52±3b	74±5a	<0.000	35±7
Mg	23±3c	35±2b	46±3a	<0.000	31±3

Values are averages and standard errors, n = 5, (two replicates were combined) one composite sample was made up of thirty fruit slices per treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Standard fruit maturity testing showed that the TS significantly increased at-harvest fruit firmness to 7.98 KgF from 7.40 and 6.90 KgF by the NTS and TC, respectively, in 'Zesy002' vines (Table 4.14). This suggests the TS significantly increased Ca concentration and probably was eventually interlocked in the middle lamella (Hocking et al., 2016; White & Broadley, 2003), increasing the cell wall integrity (Ranjbar et al., 2018), hence, fruit firmness was improved. Increased fruit firmness due to Ca application has also been documented in kiwifruit (Gerasopoulos et al., 1996; Hopkirk et al., 1990), peach (Gayed et al., 2017), strawberry (Wojcik & Lewandowski, 2003), tomato (Xiuming & Papadopoulos, 2003) and apple (Wojcik et al., 2019). Comparable fruit weight, SSC and FDM was observed in both TS and NTS. This suggests increasing Ca nutrition due to the temporal separation of Ca and

Temporal separation of soil-applied calcium and potassium fertilisers

K fertilisers had no effect on fruit fresh weight, SSC and FDM at-harvest. This is in confirmation with Gerasopoulos & Drogoudi, (2005) reporting that increasing external Ca supply had improved fruit firmness and showed no effect on SSC.

Temporal separation of soil-applied calcium and potassium fertilisers

Table 4.14 Standard fruit quality at-harvest in ‘Zesy002’ vines at 146 DAFB by true control (TC), not-temporally separated (NTS) and temporally separated (TS), and grower practice (GP) in the 2017/2018 season in the commercial orchard at Paengaroa, Bay of Plenty.

Parameters	Units	TC	NTS	TS	Sig.	GP
Fresh weight	g	117.8±2.7 b	134.0±1.5 a	135.7±2.3 a	<0.000	124.1±0.9
Size class	-	33	27	27	NA	30
Firmness	KgF	6.90±0.07 c	7.40±0.13 b	7.98±0.15 a	<0.000	6.94±0.09
SSC	°Brix	7.18±0.06 b	7.89±0.06 a	8.12±0.09 a	<0.000	7.21±0.41
FDM	%	16.76±0.14 b	17.05±0.10 ab	17.36±0.10 a	0.023	16.87±0.39
Grade value (TZG)	%	45 (4)	65 (5)	65 (5)	NA	45 (4)
Green flesh colour	°H	104.2±0.3 a	104.5±0.2 a	104.4±0.3 a	0.815	104.9±0.9
Fruit count	Per vine	1330±129 a	1314±120 a	1297±131 a	0.977	1271±130

Values are averages and standard errors, n = 10, one composite sample was made up of thirty fruits from each treatment vine. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

4.3.3 Comparison to grower practice

Since grower practice (GP) was outside the research block therefore, comparisons were not made on statistical basis but only to understand the trends between research treatments and the GP. Both temporal (TS) and non-temporal separation (NTS) treatments increased Ca and NO₃ accumulation in the leaf xylem sap (Figure 4.1 and Figure 4.2), the photosynthetic performance (Table 4.11) and the fruit size (Figure 4.3) during the growing season compared to the GP. The increased nitrate accumulation in the leaf xylem sap may have been stored in leaf tissues (Colla et al., 2018; Temme et al., 2011) as a constituent in the chlorophyll and improved the photosynthetic performance (Song et al., 2019). The other possible explanation for the improved photosynthetic performance may be the high K input as suggested by Guo et al., (2019) and Sitko et al., (2019). This suggests that increasing the rate of soil-applied nutrient fertilisers (N, Ca and K) irrespective of their application time had significantly improved the leaf chlorophyll and the photosynthetic performance in 'Zesy002' vines than the GP. Consequently, large fruit size by both TS and NTS treatments compared to the GP during the growing season. This may be attributed to the high input of nutrient fertilisers (N, K and Ca) used in both TS and NTS treatments compared to the GP. Likewise, both TS and NTS treatments improved K nutrition in leaf and fruit tissues at-harvest compared to the GP (Table 4.12 and Table 4.13). This may be attributed to the higher K application rate in both TS and NTS treatments (300 Kg K ha⁻¹) than that of the GP (118 Kg K ha⁻¹) (Table 4.2). The NTS treatment showed high fruit N uptake at-harvest than the GP, whereas both TS and GP showed comparable fruit N uptake (Table 4.13). This suggests the application of K together with N and Ca was increasing the fruit N uptake at-harvest. Both NTS and GP showed comparable fruit Ca and Mg uptake at-harvest, whereas the TS treatment showed high fruit Ca and Mg than the GP (Table 4.13). This suggests the uptake of Ca and Mg was potentially limited due to the K application. It can be suggested that the temporal separation of Ca and K avoided the counteractive effect of K on the uptake of Ca and Mg therefore, significantly improving Ca and Mg nutrition in 'Zesy002' vines. At-harvest fruit quality was improved by both TS and NTS compared to the GP (Table 4.14). Both NTS and GP showed comparable FDM whereas the TS treatment showed high FDM than the GP. This suggests that increasing the Ca nutrition due to the temporal separation of Ca and Mg fertilisers

increased the sinks strength (fruit). Fruit green flesh colour and crop load was comparable in all treatments (Table 4.14).

4.4 Conclusion

The temporal separation of Ca and K fertilisation was an effective strategy to avoid the competitive effect of K on the uptake and translocation of Ca and Mg without affecting the uptake and translocation of N and K in 'Zesy002' vines. The application of Ca, N and K fertilisers all at once was limiting Ca and Mg uptake in 'Zesy002' vines grown on volcanic soils with low CEC, organic matter, and low soil N, K, Ca on exchange sites under the uniform crop load. The temporal separation strategy had no effect on the photosynthetic performance and fruit size during the growing season. At-harvest fruit quality was improved by the temporal separation strategy in 'Zesy002' vines. This provides a strong basis for the development of nutrient fertilisation strategies considering the different application times of Ca and K fertilisers for the improvement of at-harvest fruit quality in 'Zesy002' kiwifruit.

5 Foliar-applied calcium fertilisers improved nutrient uptake, photosynthetic performance and fruit quality at-harvest (2017/18) and after storage (2016/17) in ‘Zesy002’ vines¹

5.1 Introduction

A new gold kiwifruit cultivar (*Actinida chinensis*), marketed as Zespri SunGold®, launched after a bacterial disease (*Pseudomonas syringae* pv. *Actinidiae*, Psa) which completely phased out ‘Hort16A’, has helped the kiwifruit industry of New Zealand (NZ) to resume rapid growth in gold kiwifruit exports (Dwiartama, 2017). The fruit quality of kiwifruit is the primary concern for the industry (Wright, 2005) as it is the key factor that determines the long term and sustainable success of the industry in the increasingly competitive and consumer preferential international fresh food markets (Jaeger et al., 2003).

Calcium is an essential macro-element involved in several roles in plants such as stabilisation of cell membranes, structural functions in cell walls, maintenance of cell turgor pressure and acts as a counter-ion for organic and inorganic anions in vacuoles and also acts as a cytoplasmic secondary messenger (Jackman & Stanley, 1995; Picchioni et al., 1995; Rojas, 2000; Sugimura et al., 1999; White, 2001). Calcium is involved in regulating the activity of enzymes in photosynthesis (Mignani et al., 1995; Wang et al., 2019a). Also, Ca regulates many biochemical and physiological processes (Jones & Lunt, 1967) of the fruit including membrane integrity, cell wall structure and ripening (Khan & Ali, 2018). Fruit quality is mainly influenced by Ca via formation of Ca pectate which is associated to increase the strength of middle lamella and cell wall and maintains tissue mechanical strength therefore, determines the storage potential of the fruit in horticultural fruit crops (Buchanan et al., 2015; Faust, 1989; Hirschi, 2004; Kou et al., 2015; Naradisorn et al., 2004; Poovaiah, 1986).

¹Part of the chapter has been published: Hashmatt, M., Morton, A. R., Heyes, J. A., Armour, D., Lowe, T., Black, M., & Kerckhoffs, L. H. J. (2018). Effect of pre-harvest foliar calcium application on fruit quality in Zesy002 kiwifruit. In XXX International Horticultural Congress IHC2018: International Symposium on Water and Nutrient Relations and Management of 1253 (pp. 327-334).

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Calcium is acquired by plant roots from the soil solution and then translocated via xylem to the shoots. Since Ca is phloem immobile therefore, the growth of young leaves and fruits (developing tissues and organs) is dependent upon the concurrent uptake of Ca from the root, mainly facilitated by the transpiration stream (Kadir, 2005; Malakouti et al., 1999). Soil Ca deficiency rarely occur in soils however, fruit Ca deficiency may become an issue in horticultural fruit crops, with the risk of significant economic losses. There are many factors that limit the availability and uptake of Ca by horticultural fruit crops at soil-root-fruit pathway level discussed in detail in section 1.4 (De Freitas & Mitcham, 2012).

It is well documented in literature that the exogenous foliar Ca applications significantly increased the concentration of Ca in horticultural fruit crops and corrected fruit Ca deficiency and regulated fruit ripening and senescence (Ferguson & Boyd, 2002; Greene & Smith, 1979; Kadir, 2005; Khan & Ali, 2018). The foliar Ca application in correct quantity and proportion (without causing leaf damage) at appropriate time might increase the shelf life and nutritive status of fruit crops (Aghdam et al., 2012; Davarpanah et al., 2018; Link, 1974). The foliar nutrient application ensures direct absorption of nutrients to leaf and fruit through outer skin layers (Link, 1974). Nutrients supplied to the leaf first penetrate through the cuticular membrane, and then enter the epidermal cell walls followed by absorption through the guard cells. Further, Ca is distributed throughout the mesophyll of the whole leaf via the chloroplast in guard cells. After permeation, nutrients may move in either direction in leaf i.e. towards the tip or base. However, in roots nutrients are transported towards the tip of the leaf through xylem driven by the transpiration pull (Kannan & Charnel, 1986; Ringoet et al., 1971).

The foliar Ca is applied before and after harvest in the horticultural fruit crops mainly to prevent physiological disorders, delay fruit ripening and to improve the fruit quality (Cheour et al., 1990; Poovaiah, 1979; Poovaiah et al., 1988). In kiwifruit, the pre-harvest foliar Ca application is also effective to delay fruit maturity to improve fruit quality characteristics at-harvest and storability and shelf life (Koutinas et al., 2010; Xie et al., 2002). The foliar CaCl_2 is the most widely used pre-harvest foliar Ca application and reported effective to improve fruit Ca content and storage and shelf life (Antunes et al., 2004; Koutinas et al., 2010).

5.1.1 Problem statement

Long-distance transport of Ca from root to the fruit tissues faces many challenges including antagonistic effect of K on Ca availability at soil level and due to phloem immobility of Ca in 'Zesy002' vines.

5.1.2 Objectives

The main objective of the study was to increase Ca nutrition, photosynthetic performance and improve fruit quality at-harvest and after thirty-day storage at 1 °C in 'Zesy002' vines. This study was designed to investigate the effect of the foliar Ca applications on fruit Ca uptake and at-harvest fruit quality. In addition, a storage trial (thirty-days) was also conducted in the 2016/2017 season to evaluate the effect of foliar Ca on fruit quality after storage.

5.1.3 Hypothesis

The direct application of the pre-harvest foliar Ca fertilisers from fruit set through to harvest may increase Ca absorption and uptake by leaf and fruit tissues during the fruit developmental stages. The pre-harvest foliar Ca application at late fruit growth stage may address limited Ca uptake by root and translocation to fruit due to phloem immobility. Consequently, at-harvest fruit quality may improve as a result. The increased fruit Ca uptake may be linked to higher fruit firmness at-harvest and may improve long-term storage of the fruit. This approach involves direct penetration of Ca ions into the fruit that may increase Ca content in fruit tissues. Due to the direct involvement of Ca ions in the cell wall binding, the fruit firmness may improve at-harvest and this may retain during post-harvest storage.

5.2 Materials and methods

Two experiments were conducted to investigate:

- 1- Effect of the foliar Ca on nutrient uptake and fruit quality after thirty-day storage at 1°C in the 2016/2017 season (Paengaroa orchard, Bay of Plenty).
- 2- Effect of the foliar Ca on nutrient uptake and fruit quality at-harvest in the 2017/2018 season (Te Puke and Paengaroa orchards, Bay of Plenty). The foliar Ca experiments was also conducted in the Haumoana orchard in the 2017/2018 season to investigate the effect in Ca rich soils and vines with adequate Ca. The main focus of this chapter is foliar Ca application at Bay of Plenty orchards and discussed in detail.

5.2.1 Foliar Ca experiment in the 2016/2017 season

A foliar Ca trial in the 2016/2017 season was conducted in a commercial kiwifruit orchard (Paengaroa, Bay of Plenty, NZ). Different formulations of Ca such as CaCl_2 and a commercial product; Calbit C[®] Valagro (Ca complexed with ammonium woodensulfonate LSA) along with the foliar control treatment were used. The foliar Ca treatments were applied at the rate of 1% w/v. The treatments were sprayed on canes on ten different 'Zesy002' vines (spaced at 3.5 × 6 m) chosen randomly in a commercial kiwifruit orchard. To ensure optimum nutrient absorption pH of the foliar sprays was maintained at pH 5.5 by using buffer (Spray-aide[™] Miller Chemical and Fertiliser Corporation Hanover, Pennsylvania, 17331, USA) (Sheet, 2002). No surfactants were used in the preparation of the foliar sprays. The first foliar spray was applied on December 1, 2016 (30 DAFB) and the total of five foliar sprays was applied at 7-10-day intervals. The treatments were sprayed onto the leaves and developing fruit by using 5 Litre hand sprayers till runoff. A non-foliar spray buffer cane was allocated between the treated canes of each vine to avoid spray drift and cross contamination. The crop load was maintained 60 fruit m⁻² and standard orchard management practices were followed by the orchard management. The soil test results (07-06-2016) classified soil as loam with a pH 6.2, medium electrical conductivity 0.145 m S cm⁻¹ and organic matter 5.53 %. All the treatment vines including the foliar control were given soil applied N (50 Kg ha⁻¹ in the form of calcium ammonium nitrate) at BB and soil K (150 Kg ha⁻¹ in the form of sulphate of potash) at full bloom. Fruit samples (sample size of 15 fruit, see section 2.6.4) were collected at commercial harvest on 15th March 2017 and stored for thirty-day at 1°C at the Horticultural Unit, Massey University, Palmerston North. After thirty-day storage, standard fruit testing was conducted by following the procedure mentioned in detail in the section 2.7.

5.2.2 Foliar Ca experiment in the 2017/2018 season

The foliar experiments were carried out on the commercial orchards at Te Puke and Paengaroa, Bay of Plenty, New Zealand in the 2017/2018 season. The commercial orchards were located on the typical loam soils with the targeted crop load of 60 fruit m⁻². The foliar Ca was applied at the rate of 0.5 % Ca (w/v) and pH of the foliar solutions was adjusted to 5.5 by using a buffer. A buffer-only foliar control was also used. The foliar Ca formulations used in these experiments were:

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(i) Calbit C, (Valagro[®] SpA, Via Cagliari – Zona Industriale - Atessa (CH), Italy); a commercially available Ca product complexed with LSA (Ammonium Lignin Sulfonate and stable at pH between 3 and 6.5).

(ii) Calcium chloride (hydroponic grade: HortPet Ltd, Auckland, New Zealand).

The initial pH of the foliar solutions was very high; therefore, pH was adjusted to 5.5 to improve the effectiveness of the foliar applied solutions (Table 5.1). The buffer used to adjust the solution pH was an acidifying water-soluble and non-ionic spreader-activator (Spray-aide[™]; active ingredient: 780 g/L alkylaryl polyoxyethylene glycol phosphate ester; Miller Chemical and Fertiliser Corporation Hanover, Pennsylvania, 17331, USA.) was added to the foliar solutions. Distilled water was used to prepare the foliar solutions.

Table 5.1 The initial and adjusted pH and temperature (°C) in parenthesis, of the foliar treatments.

Treatments	Foliar control	Foliar Calbit	Foliar CaCl₂
Water only	7.2 (21.2°C)	7.3 (21.4°C)	7.3 (21.4°C)
Water+salt	NA	7.5 (21.8°C)	8.0 (21.9°C)
Water+salt+Spray-aide [™]	5.5 (21.5°C)	5.5 (21.6°C)	5.5 (21.6°C)
Amount of Spray-aide [™] used per10 Litre solution	3 mL	5 mL	8 mL

The foliar treatments were applied early morning (7.00 - 8.00 a.m. NZDST) and on days with no rainfall forecast. The foliar treatments were hand sprayed to leaves and fruits using approximately 500 mL spray solution until runoff to ensure maximum absorption. The foliar sprays were dried within 2-3 hour of application according to the visual observation. The foliar treatments were applied twenty to thirty-days after full bloom (DAFB) and repeated six times at an interval of seven to fourteen-days in each orchard. All the foliar treatments were applied to the selected canes on the same vine in a randomised block design with ten replicates at the Te Puke orchard. On the other hand, at the Paengaroa orchard, each foliar treatment was applied to the selected canes on a different vine in a randomised block design with five replicates. For comparison, leaf and fruit samples were taken from vines next to research block under the current grower's management and termed as the 'grower practice' (GP). The experimental vines including the GP in each orchard also received soil fertilisation (Table 5.2).

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At the Haumoana orchard, the treatment plan was similar as used for the Bay of Plenty orchards. All the foliar treatments were sprayed till run-off on the selected canes of the same vine with a randomised block design and ten replicates. Both soil N (sulphate of ammonia) and K (sulphate of potash) fertilisers were applied at 50 and 100 Kg ha⁻¹, respectively.

Table 5.2 The total input of mineral nutrient fertilisers (Kg. ha⁻¹) applied through soil and foliar methods and the application time used by grower practice and the foliar experiment in the 2017/2018 season in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty, New Zealand. Both soil N and K fertilisers were applied in full dose at 20 DABB on 15th October 2017 at Te Puke and on 1st October 2017 at Paengaroa orchard.

Nutrients (Kg. ha ⁻¹)	*Te Puke grower	**Paengaroa grower	***Soil-applied	Foliar-applied	Total input
N	112	27	50	0	50
	Aug	Sept	Oct		
K	172	118	100	0	100
	Aug	Sept	Oct		
Ca	72	7.2	0	5	5
	Aug	Sept		Nov-March	
Mg	28	3.1	0	0	0
	Aug	Sept			

*- The soil-applied fertiliser formulations used by the grower at the Te Puke orchard were; Sulphate of potassium, Gypsum, Dical8, Ammonium sulphate nitrate, Iron sulphate, Zinc sulphate, Brimstone sulphur, Kieserite.

** - The soil-applied fertiliser formulations used by the grower at the Paengaroa orchard were; Sulphate of potassium, Calcium ammonium nitrate, organibor and Elemental sulphur.

*** - The soil-applied fertiliser formulations used for the foliar Ca experiment were; Sulphate of ammonia and Sulphate of potassium. The foliar Ca fertiliser formulations were Calbit C, calcium complexed with LSA, Valagro® and Calcium chloride.

The standard soil testing was conducted in July 2017 in each orchard. Leaf samples were taken pre-treatment and at-harvest for mineral nutrient analysis. One composite leaf sample was made up of ten leaves from each treatment vines Results presented below are average of twenty-four vines. The chlorophyll concentration of the mature fully expanded leaf was initially measured by a portable chlorophyll meter, and then determined by spectrophotometry according to the method of Lichtenthaler & Wellburn, (1983). Stomatal conductance, net photosynthetic rate and leaf internal carbon dioxide (CO₂) concentration were calculated using a Licor portable photosynthesis system (see section 2.5). The fruit growth rate was estimated using fruit length (L), and maximum and minimum diameters at the equatorial regions (D_{max} and D_{min} respectively, see section 2.5.1) as described by Minchin et al., (2003). Length and diameter (mm) of tagged fruits from fruit set

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through to harvest were non-destructively measured using electronic digital Vernier callipers. The harvest procedure comprised of thirty fruit samples randomly taken from each replicate on the same day of the commercial harvest (141 DAFB) at the Paengaroa orchard, and near the commercial harvest (162 DAFB) at the Te Puke orchard. Fruit samples were wrapped in polythene liners stored in Zespri provided trays and then transported to the cool storage facilities at the Horticultural Unit, Massey University, Palmerston North. Fruit samples were stored for 2-3 days at 0°C and then transported to AgFirst Laboratory at Hawke's Bay for standard at-harvest fruit quality assessment. Statistical analysis (ANOVA) was carried out with the help of IBM SPSS Statistics 24 version. Treatment differences were tested at $P \leq 0.05$ using ANOVA. Pairwise Least Significant Difference (LSD) tests were used to compare treatments where significant differences were found. The fruit assessments for mean fruit fresh weight, firmness, soluble solids (SSC), dry matter percentage (FDM) and mineral nutrient analysis were performed as described earlier in section 2.7. Statistical analysis (ANOVA) and LSD was performed using General Linear Model procedure of SPSS. The Duncan's multiple range tests $P \leq 0.05$ was used to evaluate differences between means.

5.3 Results and discussion

5.3.1 Foliar Ca and at-harvest fruit quality

Pre-treatment standard soil testing at the Te Puke orchard showed ideal physical and chemical properties (Table 5.3). Soil pH, CEC, organic matter and the soil exchangeable Ca, Mg and K were adequate. On the other hand, the Paengaroa orchard soils showed low CEC, organic matter, and low exchangeable Mg and K. Although, the Paengaroa orchard soils showed adequate soil pH and Ca on exchange sites and Ca % base saturation, other soil (high draining profile and sandy loam soils) and climatic (high rainfall events) characteristics and orchard management practices (high K fertilisation) together with low soil CEC and organic matter (aforementioned) may have implications for Ca availability for the absorption and uptake by roots (McClaren & Cameron, 1990). Further limiting the uptake and translocation of Ca in to leaf and fruit tissues during the growing season. Both orchard soils showed low plant available nitrogen and K % base saturation.

Table 5.3 Pre-treatment soil properties in ‘Zesy002’ vines in July 2017 in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty.

Parameters	Units	Te Puke	Level	Paengaroa	Level	*Optimum range
pH	pH Units	6.8	High	6.2	Adequate	5.8-6.5
BD	g. mL ⁻¹	0.86	Adequate	0.82	Adequate	0.6-1.00
CEC	me. 100g ⁻¹	21	Ideal	12.28	Low	12-25
Olsen P	me. 100g ⁻¹	42	Adequate	39	Adequate	30-60
Ca	me. 100g ⁻¹	15.0	High	10.05	Adequate	6.0-12.0
Mg	me. 100g ⁻¹	2.19	Ideal	1.10	Low	1.00-3.00
K	me. 100g ⁻¹	0.68	Adequate	0.16	Low	0.60-1.20
Na	me. 100g ⁻¹	0.05	Ideal	0.01	Low	0.00-0.40
Plant available N	Kg. ha ⁻¹	84	Low	78	Low	100-150
Organic matter	%	10.0	Adequate	5.0	Low	7.0-17.0
Base saturation						
Ca	%	72	Ideal	65	Adequate	55-67
Mg	%	10.6	Adequate	13.45	Adequate	10-14
K	%	3.3	Low	3.93	Low	5-7
Total	%	85.9		85.4		

One composite sample was made up of twenty-four subsamples at Te Puke and thirty subsamples at the Paengaroa orchard.

Pre-treatment leaf nutrient analysis at 20 DABB showed below average Ca and K at both Te Puke and Paengaroa orchards in ‘Zesy002’ vines (Table 5.4). Regarding the Paengaroa orchard, as expected, low leaf Ca was found in ‘Zesy002’ vines. Leaf K was low in both Te Puke and Paengaroa orchards suggesting K demand in ‘Zesy002’ vines (Mills et al., 2008). Leaf N and Mg was adequate at the Te Puke orchard and low at the Paengaroa orchard.

Table 5.4 Pre-treatment leaf nutrient status (% DW) at 20 DABB in ‘Zesy002’ vines in the 2017/2018 season in commercial orchards at Te Puke and Paengaroa.

Nutrients (% DW)	Te Puke	Level	Paengaroa	Level	*Optimum range
N	2.10	Adequate	1.50	Low	1.8-2.8
K	1.20	Low	1.10	Low	1.8-3.1
Ca	1.10	Low	1.05	Low	1.60-3.20
Mg	0.32	Adequate	0.16	Low	0.25-0.50

One composite sample was made up of ten leaves from each treatment vine.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

Six foliar sprays were applied after fruit set through to fruit maturity during the 2017/18 growing season. After the first spray both foliar Ca treatments significantly increased estimated fruit size at 43 DAFB compared to the foliar control (FC) and maintained the progressive increase in fruit growth rate through to harvest in ‘Zesy002’ vines on the commercial orchards at Te Puke (Figure 5.1) and Paengaroa (Figure 5.2). This suggests the foliar Ca application had a significant effect on the

Foliar-applied calcium and at-harvest fruit quality

fruit growth rate during the growing season. The increased fruit growth rate may be due to the increased Ca absorption and uptake that possibly increased cell elongation and expansion (Ahmad et al., 2016; Hepler, 2005). The other possible explanation may be the strong correlation between fruit Ca and the growth hormone auxin in kiwifruit vines during the fruit development (Sorce et al., 2011).

In both orchards, after fruit set through to 70 DAFB fruit growth rate was increased rapidly (due to cell division then cell expansion together with rapid accumulation of organic acids) by all treatments (Stage 1, described in detail in section 1.2.1). A period of slow growth was observed from 70 to 100 DAFB by all treatments (Stage 2). The second rapid increase in fruit growth rate (entirely due to cell expansion and rapid accumulation of sugars) was observed from 100 DAFB and maintained through to harvest (Stage 3) by all treatments in each orchard.

At the onset of stage 3 (i.e. second rapid increase in fruit growth rate), the foliar CaCl_2 treatment showed increased fruit growth rate through to harvest compared to the foliar Calbit in both orchards. However, the Te Puke orchard showed that the actual fruit fresh weight at-harvest was decreased possibly due to some unusual activity in the orchard. Fruits from each tagged foliar CaCl_2 canes have been accidentally removed near harvest and therefore compromised the final fruit size measurements (Figure 5.1). The increased estimated fruit size by the foliar CaCl_2 may be also attributed to the accumulation of chloride ions well-known to increase cell hydration and turgor pressure which are essential for cell elongation (Maas, 1984; Smith et al., 1987b).

Foliar-applied calcium and at-harvest fruit quality

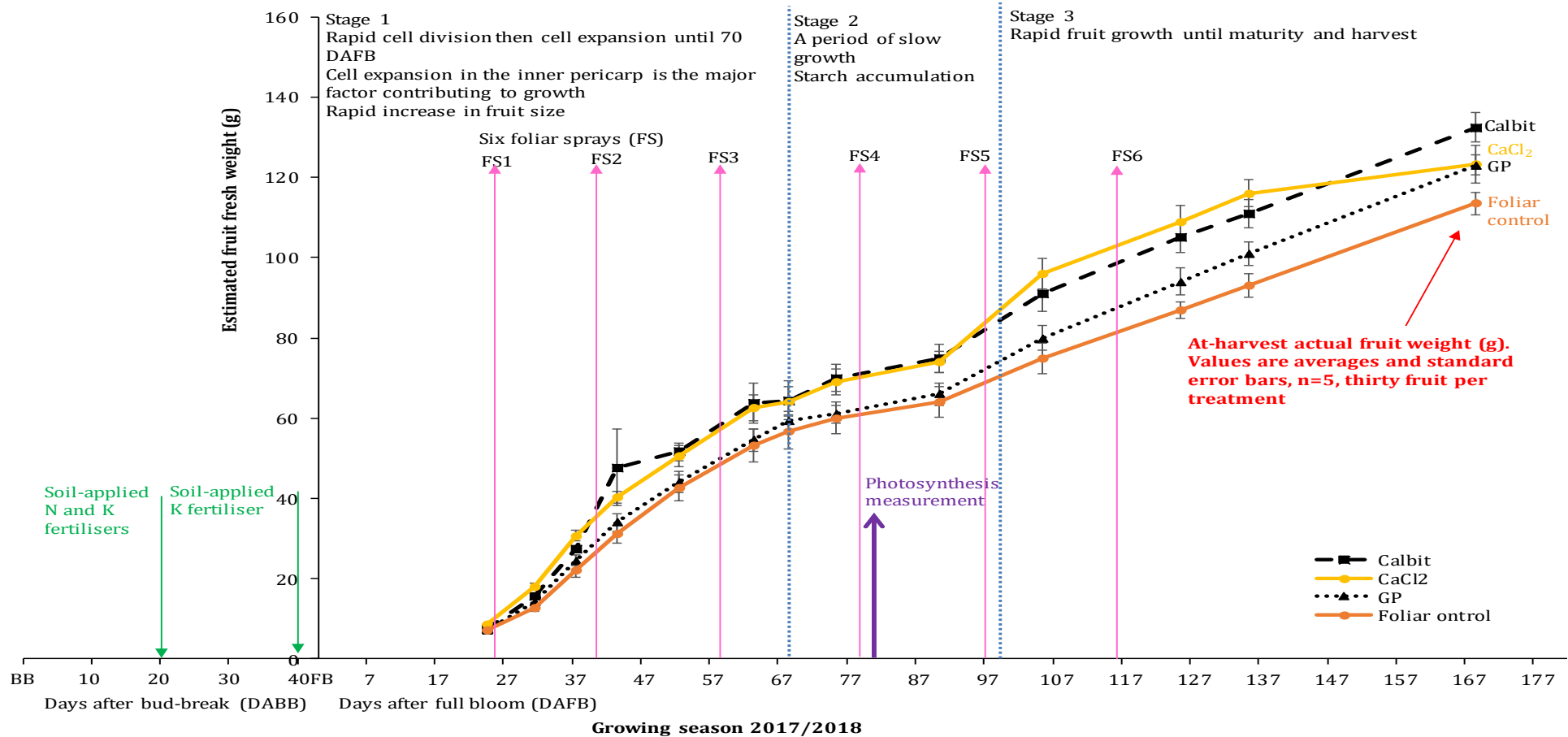


Figure 5.1 Effect of foliar control (FC), foliar Calbit and foliar CaCl₂, and grower practice (GP) on estimated fruit size (g) from fruit set through to harvest in 'Zesy002' vines grown in the commercial orchard at Te Puke, Bay of Plenty in in the 2017/2018 season. Values are averages and standard error bars, n=10, four fruit per treatment. Bud-break was on 25-09-2017, full bloom was at 43 DABB on 07-11-2017 and the commercial harvest was at 163 DAFB on 19-04-2018. At-harvest actual fruit weight (g), values are averages and standard error bars, n = 10, thirty fruit per treatment.

Foliar-applied calcium and at-harvest fruit quality

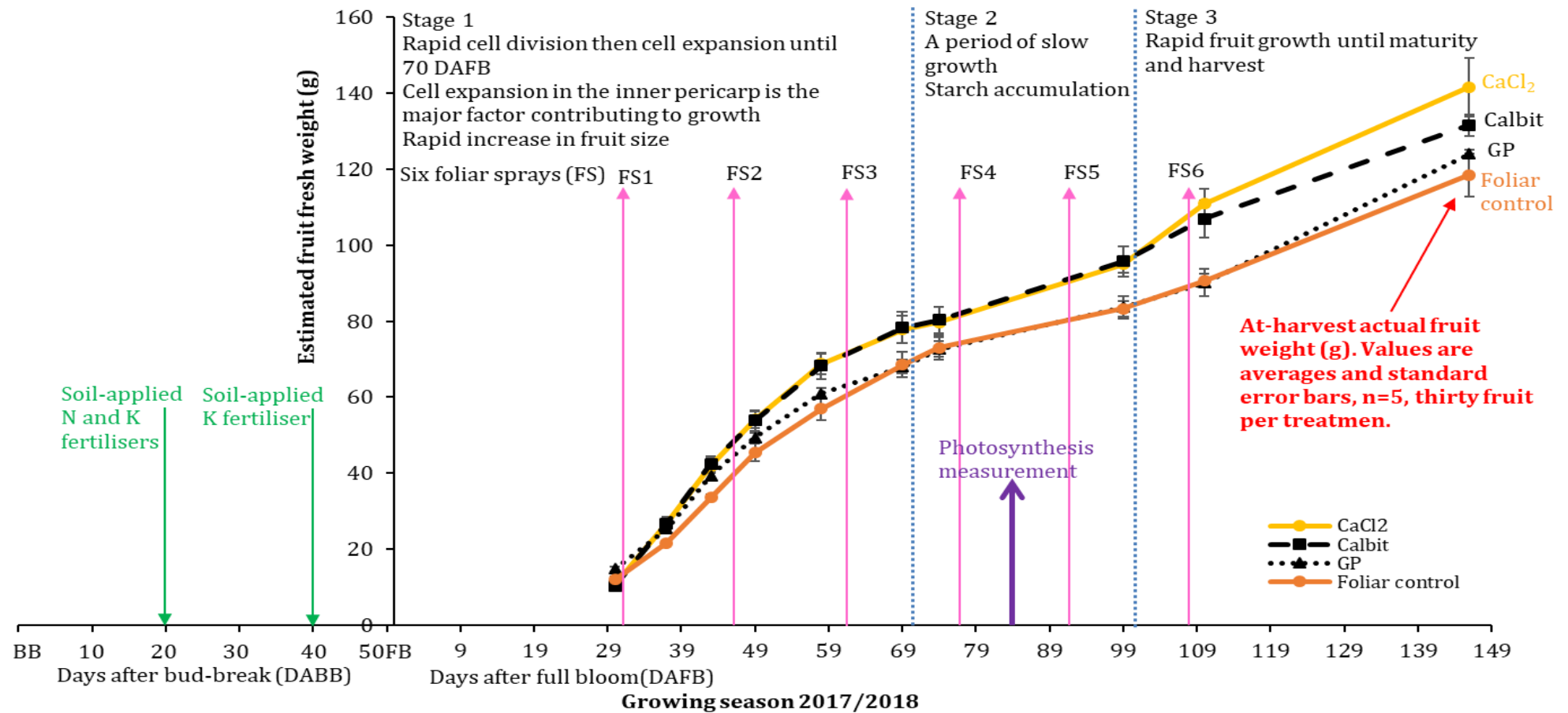


Figure 5.2 Effect of foliar control (FC), foliar Calbit and foliar CaCl₂, and grower practice (GP) on estimated fruit size (g) from fruit set through to harvest in 'Zesy002' vines grown in the commercial orchard at Paengaroa, Bay of Plenty in the 2017/2018 season. Values are averages and standard error bars, n=5, four fruit per treatment. Bud-break was on 11-09-2017, full bloom was at 51 DABB on 01-11-2017 and the commercial harvest was at 146 DAFB on 27-03-2018. At-harvest actual fruit weight (g), values are averages and standard error bars, n = 5, thirty fruit per treatment.

Foliar-applied calcium and at-harvest fruit quality

Both foliar Ca treatments significantly increased the photosynthetic performance in the orchard grown 'Zesy002' vines at Te Puke and Paengaroa, compared to the FC (Table 5.5 and 5.6). These results are in confirmation with Bakeer, (2016) reporting the foliar CaCl_2 significantly increased leaf total chlorophyll, leaf area compared to the control. The foliar Calbit showed significantly high photosynthetic CO_2 fixation than the foliar calcium chloride (CaCl_2) and FC in the 'Zesy002' vines at both orchards. A significantly positive correlation was observed between leaf Ca and net photosynthesis ($R^2= 0.88$ for Te Puke and 0.74 for Paengaroa). Both foliar Ca treatments showed similar leaf chlorophyll concentration, stomatal conductance and rate of leaf transpiration in 'Zesy002' vines grown on each commercial orchard. These results are in harmony with reports that the foliar Ca significantly increased leaf chlorophyll in pepper plants (Buczowska et al., 2016) and spring shrub forsythia cultivars (Marosz & Nogowska, 2018). It had been reported that the exogenous Ca application could affect protein and chlorophyll content in plants (Gao et al., 2019; Poovaiah et al., 1988). The increased leaf Ca concentration potentially improved chlorophyll. A significantly positive correlation was observed between leaf Ca and leaf chlorophyll ($R^2= 0.79$ Te Puke and 0.82 Paengaroa). These results are consistent with Ramalho et al., (1995) reporting strong positive correlation between leaf Ca and the total chlorophyll concentration ($R^2=0.90$) in coffee plants. Other researchers had also reported positive correlation between the leaf Ca and the leaf chlorophyll and observed improved yield in wine grapes (Wang et al., 2019b) possibly due to the enhanced photosynthesis (Hepler & Wayne, 1985). Another study had reported that increasing the exogenous Ca supply significantly increased the photosynthetic pigments (chlorophylls and carotenoids concentrations), nitrate reductase activity, higher stomatal conductance (14 %), transpiration (18 %) and net photosynthesis (21 %) than control plants in a medicinal legume (*Cassia sophera* L.) (Naeem et al., 2009). Leaf internal CO_2 and leaf temperature were similar in all the foliar treatments in each orchard possibly due to the uniform microclimate (windbreaks) in each orchard (Chappell, 2014). To date no information is available regarding the effect of the foliar Calbit on the photosynthetic performance in 'Zesy002' vines.

Foliar-applied calcium and at-harvest fruit quality

Table 5.5 Effect of foliar control (FC), foliar Calbit® and foliar calcium chloride (CaCl₂), and grower practice (GP) on leaf chlorophyll concentration, net photosynthesis, stomatal conductance, leaf internal carbon dioxide (CO₂), transpiration rate and leaf temperature in 'Zesy002' vines at 81 DAFB in the commercial orchard at Te Puke, Bay of Plenty.

Parameters	Units	FC	Calbit	CaCl ₂	Sig.	*GP
Leaf chlorophyll	µg. cm ⁻²	16.5±0.6 b	19.0±0.4 a	18.8±1.1 a	0.049	14.9±0.5
Net photosynthesis	µmol CO ₂ . m ² s ⁻¹	11.82±0.08 c	18.38±0.37 a	17.15±0.24 b	<0.000	10.09±0.28
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.26±0.01 b	0.48±0.03 a	0.42±0.02 a	0.000	0.17±0.01
Internal CO ₂	µmol CO ₂ . mol ⁻¹ air	298.9±3.1 a	300.0±3.0 a	298.7±3.8 a	0.960	270.64±8.76
Transpiration	mmol	2.19±0.06 b	3.28±0.13 a	3.05±0.11 a	<0.000	3.29±0.24
Leaf temperature	°C	20.3±0.1 a	20.4±0.1 a	20.3±0.1 a	0.937	27.5±0.3

Values are averages and standard errors, n=10. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 5.6 Effect of foliar control (FC), foliar Calbit® and foliar calcium chloride (CaCl₂), and grower practice (GP) on leaf chlorophyll concentration, net photosynthesis, stomatal conductance, leaf internal carbon dioxide (CO₂), transpiration rate and leaf temperature in 'Zesy002' vines at 84 DAFB in the commercial orchard at Paengaroa, Bay of Plenty.

Parameters	Units	FC	Calbit	CaCl ₂	Sig.	*GP
Leaf chlorophyll	µg. cm ⁻²	15.9±0.4 b	17.7±0.8 a	17.9±0.5 a	0.049	15.5±0.3
Net photosynthesis	µmol CO ₂ . m ² s ⁻¹	12.32±0.60 c	18.43±0.34 a	15.95±0.09 b	<0.000	12.88±0.40
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.31±0.03 b	0.51±0.02 a	0.44±0.04 a	0.003	0.17±0.01
Internal CO ₂	µmol CO ₂ . mol ⁻¹ air	305.2±4.4 a	302.9±2.3 a	303.5±5.4 a	0.924	243.4±5.4
Transpiration	mmol	3.01±0.21 b	4.00±0.03 a	3.65±0.20 a	0.004	2.64±0.09
Leaf temperature	°C	22.4±0.1 a	22.1±0.1 a	22.2±0.1 a	0.163	21.9±0.7

Values are averages and standard errors, n=5, two leaves per treatment. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- In each orchard the photosynthetic measurements were recorded on a different calendar day for the GP and the foliar Ca experiment, therefore, the GP was not analysed statistically.

Foliar-applied calcium and at-harvest fruit quality

At-harvest nutrient status showed the foliar control (FC) had significantly low Ca levels in leaf and fruit tissues and probably indicates severe Ca deficiency (Table 5.7). It could be expected that the effect of the foliar Ca sprays would likely be accentuated in these unusual conditions. Leaf Ca uptake at-harvest was significantly increased by both foliar Ca treatments compared to the FC at Te Puke and Paengaroa (Table 5.7). This suggests the foliar Ca application had significant effect on the absorption of Ca in leaf tissues. This is in confirmation with reports that the foliar Ca applications significantly increased leaf Ca in kiwifruit (Koutinas et al., 2010), grapevines (Haghi et al., 2019), pomegranate (Bakeer, 2016; Davarpanah et al., 2018), apple (Danner et al., 2015) and blueberry (Ochmian, 2012). Likewise, both foliar Ca treatments significantly increased fruit Ca uptake at-harvest compared to the FC at Te Puke and Paengaroa orchards (Table 5.8). This suggests the foliar Ca application affected on the uptake and translocation of Ca in the leaf and fruit tissues. These results are consistent with reports that the foliar Ca sprays significantly increased fruit Ca compared to the control in apple in the 2013 season (Cline, 2019). Another study reported the pre-harvest foliar Ca applications increased fruit Ca by 50 % compared to unsprayed fruits in the 2001 and 2002 seasons in peach (Elmer et al., 2007). Similarly, the pre-harvest foliar Ca applications increased fruit Ca in the range of 26-82 % than untreated plants in sweet cherry (Landi et al., 2016; Michailidis et al., 2017; Tsantili et al., 2007; Wojcik et al., 2013; Wojcik et al., 2002). Our results suggest that the pre-harvest foliar Ca applications from fruit set through to harvest increased fruit Ca uptake which is possibly limited due to low Ca uptake at soil level, phloem immobility, xylem dysfunctionality and xylem vessel rupturing in the rapidly growing fruit. Both foliar Ca treatments showed similar Ca uptake in the leaf and fruit tissues at-harvest this suggests these two foliar Ca formulations possibly had no significant effect on Ca uptake in leaf and fruit tissues. The uptake of N, K and Mg was similar in leaf and fruit tissues by all the foliar treatments. This suggests the foliar Ca application had no significant effect on the uptake and translocation of N, K and Mg in leaf and fruit tissues in the orchard grown 'Zesy002' vines at Te Puke and Paengaroa. This is consistent with studies reporting external Ca application had no significant effect on leaf N and Mg uptake in kiwifruit (Koutinas et al., 2010), leaf N and K uptake in pomegranate (Davarpanah et al., 2018) and leaf N, K and Mg in grape (Bonomelli & Ruiz, 2010).

Foliar-applied calcium and at-harvest fruit quality

Table 5.7 Leaf nutrient status (% DW) at-harvest in 'Zesy002' vines by foliar control (FC), foliar Calbit® and foliar calcium chloride (CaCl₂), and grower practice (GP) in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty.

Nutrients (% DW)	Te Puke (163 DAFB)					Paengaroa (146 DAFB)				
	FC	Calbit	CaCl ₂	Sig.	*GP	FC	Calbit	CaCl ₂	Sig.	*GP
N	3.64±0.12a	3.68±0.16a	3.72±0.15a	0.933	3.83±0.11	3.55±0.17a	3.46±0.20a	3.59±0.19a	0.883	2.94±0.41
K	2.85±0.34a	2.98±0.39a	2.92±0.31a	0.965	2.70±0.04	3.36±0.13a	3.42±0.12a	3.45±0.09a	0.854	2.21±0.04
Ca	1.25±0.21b	3.59±0.29a	3.51±0.19a	<0.000	2.05±0.05	1.22±0.11b	3.75±0.43a	3.69±0.21a	<0.000	1.50±0.18
Mg	0.34±0.07a	0.38±0.06a	0.35±0.08a	0.900	0.52±0.02	0.28±0.05a	0.31±0.07a	0.28±0.08a	0.943	0.34±0.03

Values are averages and standard errors, n = 5, one composite sample per treatment each made up of twenty leaves. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 5.8 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in 'Zesy002' kiwifruit by foliar control (FC), foliar Calbit® and foliar calcium chloride (CaCl₂), and grower practice (GP) in the commercial orchards at Te Puke and at Paengaroa, Bay of Plenty.

Nutrients (mg. 100g ⁻¹ DW)	Te Puke (163 DAFB)					Paengaroa (146 DAFB)				
	FC	Calbit	CaCl ₂	Sig.	*GP	FC	Calbit	CaCl ₂	Sig.	*GP
N	608±8.7a	586±14.8a	611±18.9a	0.438	698±9	605±4.2a	580±8.9a	598±14.81a	0.252	511±10
K	1438±17.1a	1445±30.7a	1431±47.3a	0.956	1357±35	1565±16.8a	1554±25.6a	1547±16.3a	0.814	1245±35
Ca	33±6.7b	115±13.2a	104±15.5a	0.001	46±1	28±4.5b	96±5.7a	103±11.1a	<0.000	35±7
Mg	45±6.1a	48±9.3a	50±4.4a	0.868	74±2	27±5.0a	30±4.9a	29±7.2a	0.897	31±3

Values are averages and standard errors, n = 5, one composite sample per treatment each made up of thirty dried fruit slices. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- The GP was not analysed statistically.

Foliar-applied calcium and at-harvest fruit quality

Both foliar Ca treatments significantly increased at-harvest fruit fresh weight compared to FC (Table 5.9). The foliar Calbit treatment significantly increased fruit fresh weight and firmness compared to the FC at the Te Puke orchard (Table 5.9). The foliar CaCl₂ treatment significantly increased at-harvest fruit fresh weight compared to the FC at the Paengaroa orchard (Table 5.10). This is in agreement with (Bakeer, 2016) reporting the foliar CaCl₂ significantly increased fruit fresh weight in pomegranate. A significantly positive correlation was observed between fruit Ca and fruit fresh weight ($R^2= 0.74$ for Te Puke and 0.64 for Paengaroa) and between fruit Ca and fruit firmness ($R^2= 0.45$ for Te Puke and 0.31 for Paengaroa). The increased fruit fresh weight due to the foliar Ca is consistent with reports that the pre-harvest foliar Ca sprays increased fruit size in peach (El-Alakmy, 2012) and pomegranate (Bakeer, 2016; Rouhi et al., 2015). The foliar Calbit treatment significantly increased at-harvest fruit firmness compared to FC in each orchard at Te Puke and Paengaroa. Likewise, the foliar Calbit treatment significantly increased fruit firmness compared to the foliar CaCl₂ treatment at the Paengaroa orchard. This may be due to Ca complexation with ammonium woodensulfonate (LSA) in the foliar Calbit treatment. However, more experimental work is recommended to investigate the exact nature of the effect of the foliar Calbit treatment on fruit firmness. A preliminary storage trial was conducted at Massey University, Palmerston North and tested tensile strength and storage quality of the foliar treatments from the Te Puke orchard. The results (unpublished) demonstrated that the foliar Calbit treatment improved firmness retention and maintained soluble solid conversion compared to the foliar CaCl₂ and FC treatments. The foliar Calbit treatment maintained the tensile strength during the storage and improved ripening quality compared to the foliar CaCl₂ and FC treatments. Researchers associated increased fruit Ca with firmer fruit in response to pre-harvest Ca sprays in horticultural fruit crops (Dris and Niskanen, 1999) and reported improved fruit firmness at-harvest and post-harvest (Zhang et al., 2019).

At-harvest, SSC, FDM, green flesh colour and fruit count were similar for all the foliar treatments. These results are consistent with reports that the foliar Ca sprays had no significant effects on SSC in kiwifruit (Koutinas et al., 2010), pomegranate (Bakeer, 2016; Davarpanah et al., 2018; Korkmaz et al., 2016), strawberry (Lanauskas et al., 2006), cherry (Erogul, 2014) and apple (Danner et al., 2015). Both

Foliar-applied calcium and at-harvest fruit quality

foliar Ca treatments showed higher size class and TZG than FC at the Te Puke orchard.

Foliar-applied calcium and at-harvest fruit quality

Table 5.9 Standard fruit quality at-harvest in ‘Zesy002’ vines at 163 DAFB by foliar control (FC), foliar Calbit® and foliar calcium chloride (CaCl₂), and grower practice in the 2017/2018 season in the commercial orchard at Te Puke, Bay of Plenty.

Parameters	Units	FC	Calbit	CaCl ₂	Sig.	*GP	*Clearance report
Fresh weight	g	114.2±2.1 b	132.5±3.6 a	123.3±4.6 ab	0.005	123.1±2.5	124.9
Size class	-	33	27	30	NA	30	30
Firmness	KgF	6.31±0.10 b	6.82±0.07 a	6.54±0.13 ab	0.040	6.23±0.05	6.20
SSC	°Brix	10.21±0.10 a	10.11±0.23 a	10.32±0.26 a	0.172	8.38±0.22	8.50
FDM	%	17.26±0.10 a	17.65±0.19 a	17.55±0.21 a	0.906	17.30±0.05	17.40
Grade value (TZG)	%	65 (5)	85 (6)	85 (6)	NA	65 (5)	65 (5)
Green flesh colour	°H	102.5±0.2 a	102.3±0.2 a	102.6±0.3 a	0.612	103.6±0.1	107.8
Fruit count	Per cane	58±3 a	58±5 a	52±2 a	0.393	1505±156	Ninety fruit

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of thirty fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 5.10 Standard fruit quality at -harvest in ‘Zesy002’ vines at 146 DAFB by foliar control (FC), foliar Calbit® and foliar calcium chloride (CaCl₂), and grower practice in the 2017/2018 season at the Paengaroa commercial orchard.

Parameters	Units	FC	Calbit	CaCl ₂	Sig.	*GP
Fresh weight	g	118.5±5.6 b	131.6±2.8 ab	141.6±7.8 a	0.045	124.1±0.9
Size class	-	33	27	27	NA	30
Firmness	KgF	7.17±0.14 c	8.29±0.26 a	7.75±0.04 b	0.003	6.94±0.09
SSC	°Brix	7.38±0.12 a	7.62±0.30 a	7.41±0.31 a	0.747	7.21±0.41
FDM	%	17.20±0.09 a	17.28±0.11 a	17.16±0.16 a	0.700	16.87±0.39
Grade value (TZG)	%	65 (5)	65 (5)	65 (5)	NA	45 (4)
Green flesh colour	°H	104.6±0.3 a	105.0±1.1 a	103.7±0.3 a	0.279	104.9±0.9
Fruit count	Per cane	69±3 a	73±3 a	70±6 a	0.799	1271±130

Values are averages and standard errors, n = 5, one composite sample per treatment each made up of thirty fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- Both GP and clearance report were not analysed statistically.

5.3.1.1 Comparison to grower practices

Both foliar Ca treatments increased fruit growth rate compared to the GP during the growing season in each orchard. Likewise, both foliar Ca treatments increased photosynthetic performance in 'Zesy002' vines compared to the GP in each orchard. Both foliar Ca treatments showed higher Ca uptake by leaf and fruit tissues at harvest compared to the GP in each orchard. Fruit Ca was significantly increased by both foliar Ca treatments than GP in each orchard.

The GP at the Te Puke orchard showed higher fruit N and Mg uptake possibly due to high fertiliser input compared to the foliar experiment (Table 5.2). The GP at the Paengaroa orchard showed lower N and K uptake, and similar Mg uptake by leaf and fruit tissues compared to both foliar Ca treatments. Comparatively high leaf nutrient status was observed by GP at the Te Puke than GP at the Paengaroa orchard possibly due to high nutrient input at the Te Puke orchard. At the Te Puke orchard, both foliar Ca treatments had higher fruit firmness, SSC, FDM and TZG, and lower green flesh fruit colour compared to the GP. Likewise, both foliar Ca treatments increased fruit fresh weight, size class, firmness, SSC, FDM and TZG compared to the GP at the Paengaroa orchard. This suggests the foliar Ca strategy has the potential to increase fruit quality gains.

5.3.2 Foliar Ca and fruit quality after storage

Fruit Ca content was highly significantly increased from 93 to 144 and 129 mg.100g⁻¹ DW by the foliar CaCl₂ and Calbit applications respectively, compared to the foliar control (Table 5.11). Gerasopoulos et al., (1996); Gerasopoulos & Drogoudi, (2005); Kadir, (2005); Link, (1974); Singh et al., (2007) Koutinas et al., (2010) documented increased fruit Ca content due to the pre-harvest foliar Ca applications compared to control in apple, kiwifruit and strawberry. The increased fruit Ca content in kiwifruit may be attributed to the direct exogenous foliar Ca application which may have allowed Ca to penetrate through outer skin layers (Gerasopoulos et al., 1996). The other reason may be the timely foliar Ca application, at late fruit developmental stage characterised by loose cell wall of the fruit that likely facilitated Ca penetration in the fruit (Hardenburg & Anderson, 1979). The foliar CaCl₂ application significantly increased fruit K and Mg compared to the foliar control (Table 5.11). Fruit Mg was significant increased to 64 mg.100g⁻¹ DW by the foliar Calbit application compared to the foliar control (54 mg.100g⁻¹ DW). Both foliar Ca

applications might have helped to restore sufficient levels of fruit K and Ca (Jaleel et al., 2007).

Table 5.11 Fruit nutrient status (mg. 100g⁻¹ DW) after thirty-day storage at 1 °C in the 2016/2017 season by the foliar control, foliar Calbit[®] and foliar calcium chloride (CaCl₂) in 'Zesy002' vines grown in the commercial orchard at Paengaroa, Bay of Plenty, New Zealand.

Nutrients (mg. 100g ⁻¹ DW)	FC	Calbit	CaCl ₂	Sig.
K	1318±2.87 b	1438±7.6 ab	1683±7.25 a	<0.000
Ca	93±0.26 b	129±0.60 a	144±0.37 a	<0.000
Mg	54±0.09 b	64±0.29 a	69±0.27 a	<0.000

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of fifteen dried fruit slices. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Both foliar Ca treatments increased the fruit fresh weight (8-19 g) compared to the foliar control (Table 5.12). The foliar CaCl₂ was significantly effective in increasing fresh weight by 19 and 12 g compared to foliar control and Calbit application, respectively. Kadir, (2005); Kazemi, (2013); Raese & Drake, (2000) reported increased fruit size due to Ca application. Similarly, Bakeer, (2016); Davarpanah et al., (2018); El-Alakmy, (2012); Rouhi et al., (2015) observed that the foliar Ca increased fruit size in pears and pomegranate. This increase in fruit size may be due to the regulatory role of Ca in plant metabolism (Franck et al., 2007) by following a myriad of pathways in which Ca stimulates plant physiological response by operating as an secondary messenger in plant cell growth and development (Hepler, 2005; Zhu et al., 2013).

Fruit firmness was significantly increased from 3.91 to 4.75 KgF by the foliar CaCl₂ application compared to the foliar control (Table 5.12). These results are consistent with other researchers observing that the foliar Ca treated kiwifruit (Gerasopoulos & Drogoudi, 2005) and strawberry (Singh et al., 2007) fruits were firmer after five day storage than control. The possible reason for increased fruit firmness due to the foliar Ca treatments could be the increased Ca penetration into the fruit tissues which may have bound to pectic molecules (Demarty et al., 1984) and formed cation cross bridges (Grant et al., 1973) in the middle lamella (Knee & Bartley, 1981) and inhibited dissolution of middle lamella and strengthened cell wall structure that may improve fruit firmness due to the cell wall modulation (Khan & Ali, 2018).

It is documented that in kiwifruit solubilisation of cell wall (galactose and galacturonic acid) (Redgwell et al., 1992) induces production of ethylene (Kim et al.,

1987), thus Ca binding in the cell wall may limit production of ethylene (Conway & Sams, 1987) and increase the storage life of the fruit (Cicco et al., 2007; Poovaiah et al., 1988). Both foliar Ca applications reduced SSC compared to the foliar control (Table 5.12). The foliar CaCl₂ significantly reduced SSC from 13.48 to 12.87 °Brix compared to the foliar control. Likewise, foliar Calbit reduced SSC to 13.04 °Brix compared to the foliar control. These results are in agreement with Singh et al., (2007) and the reduction in SSC could possibly be associated with delay in Ca-mediated regulation of fruit maturity process (Ferguson, 1984). An increasing fruit SSC content during storage is considered as an indicator of fruit ripening and is directly related to more available soluble sugars converted from starch (Kazemi et al., 2011). The foliar CaCl₂ and Calbit increased fruit dry matter concentration from 16.5 to 17.7 and 17.1 % compared to the foliar control, respectively (Table 5.12). The results are consistent with Coolong et al., (2014) documenting that the foliar Ca significantly increased 8 % fruit dry matter compared to control in tomato.

Table 5.12 Standard fruit quality after thirty-day storage at 1 °C in the 2016/2017 season by the foliar control, foliar Calbit[®] and foliar calcium chloride (CaCl₂) in 'Zesy002' vines grown in the commercial orchard at Paengaroa, Bay of Plenty, New Zealand.

Parameters	Units	FC	Calbit	CaCl ₂	Sig.
Fruit fresh weight	g	135.4±3.0 b	143.0±5.7 b	154.7±4.4 a	<0.000
Size class	-	27	25	22	NA
Firmness	KgF	3.91±0.18 b	4.22±0.24 b	4.75±0.25 a	<0.000
SSC	°Brix	13.48±0.16 a	13.04±0.30 ab	12.87±0.24 b	<0.000
FDM	%	16.5± 0.5 b	17.7±0.4 a	17.1±0.3 ab	<0.000
Grade value (TZG)	%	25 (3)	85 (6)	65 (5)	NA

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of fifteen dried fruit slices. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

5.3.3 Foliar Ca application in the Haumoana orchard

This experiment was conducted with the aim to investigate the effect of the foliar Ca in kiwifruit vines with adequate Ca grown on Ca rich soils. The orchard soils showed ideal soil physical and chemical properties such as adequate pH, bulk density (BD), plant available N and organic matter, and high cation exchange capacity (CEC) and soil exchangeable Ca (Table 5.13). Pre-treatment leaf nutrient testing showed adequate leaf Ca status (Table 5.13). At-harvest leaf and fruit Ca was significantly increased by the foliar Ca application compared to the unsprayed leaf and fruit.

Likewise, the foliar Ca significantly increased fruit size compared to the foliar control. The foliar Ca showed similar fruit firmness, soluble solids, fruit dry matter and fruit colour compared to the foliar control. This suggests the foliar Ca is an efficient strategy to increase Ca nutrition of the leaf and fruit in kiwifruit vines with adequate leaf Ca, grown on Ca rich soils.

Table 5.13 Pre-treatment soil and leaf nutrient status, and effect of the foliar Ca applications on at-harvest leaf and fruit Ca concentration and fruit quality in 'Zesy002' vines grown at the Haumoana orchard in the 2017/2018 season. The significantly higher desirable values are highlighted yellow.

Parameters	Units	2017	Level	*Optimum range
Pre-treatment standard soil test				
pH	pH Units	6.2	Adequate	5.8-6.5
BD	g. mL ⁻¹	0.81	Adequate	0.6-1.00
CEC	me. 100g ⁻¹	31	High	12-25
Olsen P	me. 100g ⁻¹	98	High	30-60
Ca	me. 100g ⁻¹	20.1	High	6.0-12.0
Mg	me. 100g ⁻¹	3.36	High	1.00-3.00
K	me. 100g ⁻¹	1.64	High	0.60-1.20
Na	me. 100g ⁻¹	0.17	Adequate	0.00-0.40
Plant available N	Kg. ha ⁻¹	125	Adequate	100-150
Organic matter	%	9.1	Adequate	7.0-17.0
Pre-treatment leaf nutrient status				
N		2.7	Adequate	1.8-2.8
K		2.4	Adequate	1.8-3.1
Ca	% DW	1.90	Adequate	1.60-3.20
Mg		0.31	Adequate	0.25-0.50
At-harvest nutrient status and fruit quality				
		Foliar control	Foliar Ca	
Leaf Ca	% DW	2.20±0.3 b	3.78±0.4 a	
Fruit Ca	mg. 100g ⁻¹ DW	70±7 b	112±8 a	
Fresh weight	g	117±14 b	129±3 a	
Size class	-	33	27	
Firmness	KgF	9.1±0.3 a	9.4±0.1 a	
SSC	°Brix	5.5±0.2 a	5.4±0.1 a	
FDM	%	17.2±0.4 a	17.1±0.1 a	
Grade value	%(TZG)	65 (5)	65 (5)	
Green flesh colour	°H	107.5±1 a	107.1±0.5 a	

5.4 Conclusion

Foliar Ca sprays increased Ca absorption and uptake in leaf tissues and improved the photosynthetic performance of 'Zesy002' vines grown on two commercial orchards at Bay of Plenty with different orchard management practices. The foliar Ca applications increased CO₂ fixation and cell expansion resulting in increased fruit size with similar FDM. The foliar Ca applications were effective to increase both absorption and uptake of Ca by fruit tissues during the growing season. The foliar Calbit treatment was significantly effective in improving net photosynthesis compared to both foliar CaCl₂ and foliar control treatments in both orchards.

The pre-harvest foliar Ca applications increased fruit Ca uptake and improved fruit firmness and reduced SSC and restored fruit dry matter. This suggests significant beneficial effects of the foliar Ca application at late fruit developmental stage of 'Zesy002' kiwifruit on nutritional and other fruit quality characteristics. The foliar CaCl₂ treatment improved fruit quality characteristics probably by delaying maturity and improving firmness after thirty-day storage. The foliar Ca applications may have compensated fruit Ca requirement in addition to soil Ca application. It is recommended as a best practice to supplement soil applied N and Ca with the foliar Ca at later fruit developmental stage to achieve high fruit quality in 'Zesy002' kiwifruit. The foliar Ca is an effective strategy in Ca deficient situations (soil and vine) and can be equally effective to increase leaf and fruit Ca concentration in kiwifruit vines with adequate Ca status. In addition, the fruit quality gains such as fruit size could potentially be maximised without reducing dry matter accumulation and therefore maintain fruit dry matter percentage.

6 Soil-applied potassium fertilisers in three split applications improved nutrient uptake and at-harvest fruit quality in 'Zesy002' vines

6.1 Introduction

Potassium (K) regulates several physiological and biophysical processes such as regulating osmotic pressure, cell expansion, stomatal opening, enzyme activation, anion neutralisation, charge balance, ATP synthesis, and nutrient and assimilates transport from leaves into fruits via phloem. Potassium regulates osmotic potential and loading of photosynthates mainly sucrose in the sieve tubes of phloem tissues and promotes their translocation (Philippar et al., 2003; Wang & Wu, 2013). As a result sink strength of the fruit increases because more soluble sugars are imported into the fruit (phloem unloading) (Kumar et al., 2006; Marschner, 2012; Teo et al., 2006). Consequently, K improves fruit size and colour, sugar content, dry matter and firmness and thus sometimes referred to as “quality nutrient” in fruit crops (Usherwood, 1985). The fruit taste and flavour in kiwifruit fruits is strongly correlated with high fruit dry matter concentration (FDM) The carbohydrate transport from leaves to fruit via phloem and transport of water and mineral nutrients from the root to the fruit via xylem affects the FDM. This vital transport process can be regulated by mineral nutrition especially K (Katrina, 2005). In horticultural fruit crops, fruit K % and dry matter accumulation is linearly correlated (Hansen, 1979; Rogers et al., 1953).

In New Zealand in the 1980s, K deficiency in green kiwifruit vines was identified as the main limiting factor affecting fruit production and quality (lower fruit number and a smaller fruit size) and the potential productivity of the vine (due to significant reduction in effective green leaf area) for the upcoming season (Smith et al., 1987c). In kiwifruit vines, K is required to establish a canopy with efficient photosynthetic performance during the growing season. Therefore, it is a common practice in kiwifruit orchards to apply K fertilisation at bud-break. With the progression of fruit growth, fruit K demand also increases (Niederholzer et al., 1991; Smith et al., 1987a). Limited K nutrition during fruit growth and developmental stages potentially reduces fruit growth rate and dry matter accumulation.

6.1.1 Problem statement

Much research work into kiwifruit nutrition was undertaken more than two decades ago (Sale, 1997). Since then both production system and goals has been changed with much emphasis on fruit quality indices such as size and fruit dry matter (Richardson, 1997). Also, no nutrient management study specific for 'Zesy002' cultivar has been conducted to date according to our knowledge. There was an urgent need to devise a cultivar specific nutrient management plan for 'Zesy002' to achieve sustainable production of fruits with high FDM as a key quality predictor at-harvest. The study was conducted to identify the best application time for K fertilisation during the growing season to meet K demand.

6.1.2 Objectives

Optimise the K nutrition to improve nutrient uptake and at-harvest fruit quality. Satisfy the K requirement during the growing season from early canopy development through to fruit developmental stages to increase fruit K uptake and possibly fruit growth rate. This will potentially improve at-harvest fruit quality in 'Zesy002' vines.

6.1.3 Hypothesis

The optimum application time of K fertilisation may improve nutrient uptake and at-harvest fruit quality. The application of K fertiliser applied in three split doses at 20 DABB, FB and 70 DAFB (split K) may meet K demand in 'Zesy002' vines from canopy development right through to fruit developmental stages. The full dose application of K fertiliser at bud-break and after full bloom may improve canopy development and photosynthetic performance. On the other hand, full dose K application at 70 DAFB may compensate fruit K demand as growing fruits become the strongest K sinks.

6.2 Materials and methods

The soil-applied K fertiliser experiments were conducted for three growing seasons from 2016 to 2019 within three commercial orchards at Te Puke and Paengaroa, Bay of Plenty, and Haumoana, Hawke's Bay, New Zealand. Treatments were applied to each vine in a randomised block design with four replicates in each orchard. For comparison, leaf and fruit samples were also taken from vines next to research block under the current grower's management and termed as 'grower practice' (GP) in

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2017/2018 and 2018/2019 seasons (Table 6.1). Soil K fertilisation was applied at BB, FB and 70 DAFB and termed as early, mid and late K, respectively (Table 6.2).

Soil K fertilisation was applied in two split applications at 20-day interval. The split K treatment received K from BB through to 90 DAFB during the growing season. All treatments received 300 Kg K ha⁻¹, 50 Kg N ha⁻¹ and 200 Kg Ca ha⁻¹ except true control receiving zero nutrient fertilisation.

At the Te Puke orchard soil-applied K treatments were applied for three seasons (2016-2019), at the Paengaroa only one season 2016/2017 as experimental vines were male stripped by the orchard management in 2017, and at the Haumoana for two seasons (2016-2018). In the 2016/2017 season fruits were transported to the storage facility (1 °C) and standard at-harvest fruit quality was analysed at the Horticultural Unit, Massey University, Palmerston North. Fruit samples only from the Paengaroa orchard were analysed after thirty-day storage at 1 °C. In seasons 2017-2019 fruit samples were wrapped in polythene liners and stored in Zespri provided trays and then transported to the cool storage facilities at the Horticultural Unit, Massey University, Palmerston North. Fruit samples were stored for 2-3 days at 1 °C and then transported to AgFirst Laboratory in Hawke's Bay for standard at-harvest fruit quality assessment. In the 2017/2018 season, fruit samples from the Haumoana orchard were transported directly to AgFirst Laboratory within an hour of harvest. Statistical analysis (ANOVA) was carried out with the help of IBM SPSS Statistics 24 version. Treatment differences were tested at $P \leq 0.05$ using ANOVA. Pairwise Least Significant Difference (LSD) tests were used to compare treatments where significant differences were found.

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Table 6.1 Soil-applied nutrient fertiliser application rate (Kg. ha⁻¹) and time of application used by the growers in each orchard and the soil experiment from 2016 to 2019 at Te Puke and Paengaroa, Bay of Plenty, and Haumoana, Hawke's Bay, New Zealand.

Nutrients (Kg. ha ⁻¹)	Te Puke grower			Paengaroa grower	Haumoana grower		True control	Split K	Early K	Mid K	Late K
	2016	2017	2018	2016	2016	2017	2016-2018				
N	126	112	126	30	37	35	0	50	50	50	50
	July, Oct & Nov	Aug	Aug & Nov	Sep	Oct	Oct			Sep-Oct (20DABB)		
K	328	172	186	250	103	150	0	300 (100+100+100)	300	300	300
	July, Oct & Nov	Aug	Aug & Nov	Sep	Sep	Sep & Nov			(Table 6.2)		
Ca	284	72	105	50	0	0	0	200	200	200	200
	July, Oct & Nov	Aug	Aug & Nov	Sep					Sep-Oct(20DABB)		
Mg	98	28	28	30	0	25	0	0	0	0	0
	July, Oct & Nov	Aug	Aug & Nov	Sep		Sep					

Table 6.2 Soil-applied K treatments and their application time and rate in seasons 2016-2019 at BOP and Hawke's Bay commercial orchards.

Treatments	K application time and rate Kg. ha ⁻¹			Total K
	20DABB	FB	70 DAFB	
True control (TC)	0	0	0	0
Split K	100	100	100	300
Early K	150+150 (20 & 40 DABB)			300
Mid K	150+150 (FB & 20 DAFB)			300
Late K	150+150 (70 & 90 DAFB)			300

At Te Puke and Paengaroa orchards, calcium ammonium nitrate, sulphate of potassium and gypsum were used to supply N, K and Ca, respectively. At the Haumoana orchard sulphate of ammonia, sulphate of potassium and gypsum were used. The treatments were applied each year from 2016 to 2019.

6.3 Results and discussion

Pre-treatment standard soil testing showed ideal soil physical and chemical characteristics at both Te Puke and Haumoana orchards, and low soil exchangeable K, plant available nitrogen and organic matter at the Paengaroa orchard (Table 6.3). In 2016/2017 and 2017/2018 seasons the Te Puke orchard soils showed identical soil physical and chemical properties. In the 2018/2019 season organic matter and Mg % base saturation were low, total base saturation was adequate, and the other soil properties were identical to the previous seasons at the Te Puke orchard. Likewise, the Haumoana orchard soils showed identical soil physical properties for 2016/2017 and 2017/2018 seasons. Pre-treatment leaf nutrient status was low at the Paengaroa (2016/2017) and adequate at the Haumoana orchard (2017/2018) (Table 6.4). Both leaf N and K status was low at the Haumoana orchard in the 2016/2017 season. At the Te Puke orchard the leaf K status was low in seasons 2017/2018 and 2018/2019.

The application of K in three split doses from BB through to 70 DAFB significantly increased estimated fruit size compared to mid and late K, and true control (TC) during the growing season in 'Zesy002' vines at the Te Puke orchard in the 2017/2018 season (Figure 6.1). The estimated fruit size at 70 DAFB was significantly higher by split, early and mid K treatments compared to both late K and TC at the Te Puke orchard. Late K application showed similar fruit growth rate until 50 DAFB compared to other treatments. Then fruit growth rate was reduced from 50 DAFB by late K application compared to split, early and mid K applications. After K fertiliser application at 70 and 90 DAFB, fruit growth rate was increased by late K application. Fruit growth rate was similar by all treatment from fruit set through to final harvest at the Haumoana orchard in the 2017/2018 season (Figure 6.2). The fruit growth curve was double sigmoidal and the first rapid increase in fruit growth rate was observed from fruit set through to 70 DAFB, followed by a period of slow growth from 70 DAFB through to 100 DAFB. The second rapid increase in fruit growth rate was observed from 100 DAFB through to harvest in 'Zesy002' vines grown at Te Puke and Haumoana orchards.

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Table 6.3 Pre-treatment soil physical properties in ‘Zesy002’ vines from 2016 to 2018 in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty and at Haumoana, Hawke’s Bay, New Zealand.

Parameters	Units	Te Puke						Paengaroa		Haumoana				*Optimum range	
		2016	Level	2017	Level	2018	Level	2016	Level	2016	Level	2017	Level	2016&2017	
pH	pH Units	6.6	High	6.8	High	6.7	High	6.4	Adeq	6.1	Adeq	6.2	Adeq	5.8-6.5	
BD	g. mL ⁻¹	0.85	**Adeq	0.86	Adeq	0.80	Adeq	0.84	Adeq	0.80	Adeq	0.81	Adeq	0.6-1.00	
CEC	me. 100g ⁻¹	23	Ideal	21	Ideal	21	Ideal	10.50	Low	30	High	31	High	12-25	
Olsen P	me. 100g ⁻¹	45	Adeq	42	Adeq	57	Adeq	27	Low	99	High	98	High	30-60	
Ca	me. 100g ⁻¹	14	High	15.0	High	14.6	High	7.8	Adeq	20.4	High	20.1	High	6.0-12.0	
Mg	me. 100g ⁻¹	2.30	Ideal	2.19	Ideal	2.09	Ideal	1.90	Adeq	3.35	High	3.36	High	1.00-3.00	
K	me. 100g ⁻¹	0.71	Adeq	0.68	Adeq	0.81	Adeq	0.30	Low	1.65	High	1.64	High	0.60-1.20	
Na	me. 100g ⁻¹	0.06	Ideal	0.05	Ideal	0.06	Ideal	0.04	Ideal	0.18	Adeq	0.17	Adeq	0.00-0.40	
Plant available N	Kg. ha ⁻¹	80	Low	84	Low	80	Low	81	Low	115	Adeq	125	Adeq	100-150	
Organic matter	%	9.0	Adeq	10.0	Adeq	7.5	Low	3.87	Low	9.0	Adeq	9.1	Adeq	7.0-17.0	
Base saturation															
Ca	%	71	Ideal	72	Ideal	70	Ideal	60	Adeq	65	Adeq	66	Adeq	55-67	
Mg	%	12	Adeq	10.6	Adeq	10.0	Low	11	Adeq	12	Adeq	10.5	Adeq	10-14	
K	%	4	Low	3.3	Low	3.9	Low	4	Low	6	Adeq	5.5	Adeq	5-7	
Total	%	87	High	85.9	High	83.9	Adeq	75	Adeq	83	Adeq	84	Adeq	60-85	

Table 6.4 Pre-treatment leaf nutrient status (% DW) in ‘Zesy002’ vines at 20 DABB from 2016 to 2018 on the commercial orchards at Te Puke and Paengaroa, Bay of Plenty and at Haumoana, Hawke’s Bay, New Zealand.

Nutrients (% DW)	Te Puke						Paengaroa		Haumoana				*Optimum range	
	2016	Level	2017	Level	2018	Level	2016	Level	2016	Level	2017	Level	2016	2017
N	3.2	High	2.10	Adequate	2.60	Adequate	1.80	Low	1.70	Low	2.7	Adequate	2.0-2.8	1.8-2.8
K	2.9	Ideal	1.20	Low	1.15	Low	1.30	Low	1.20	Low	2.4	Adequate	2.1-2.9	1.8-3.1
Ca	1.22	Low	1.10	Low	1.30	Low	1.17	Low	1.50	Adequate	1.90	Adequate	1.40-2.30	1.60-3.20
Mg	0.32	Adequate	0.32	Adequate	0.34	Adequate	0.18	Low	0.26	Adequate	0.31	Adequate	0.25-0.40	0.25-0.50

*- The respective level for each parameter is based on the normal range found in this crop as provided by an accredited laboratory, Hill Laboratories Limited 2016 and 2017.

**- Adequate

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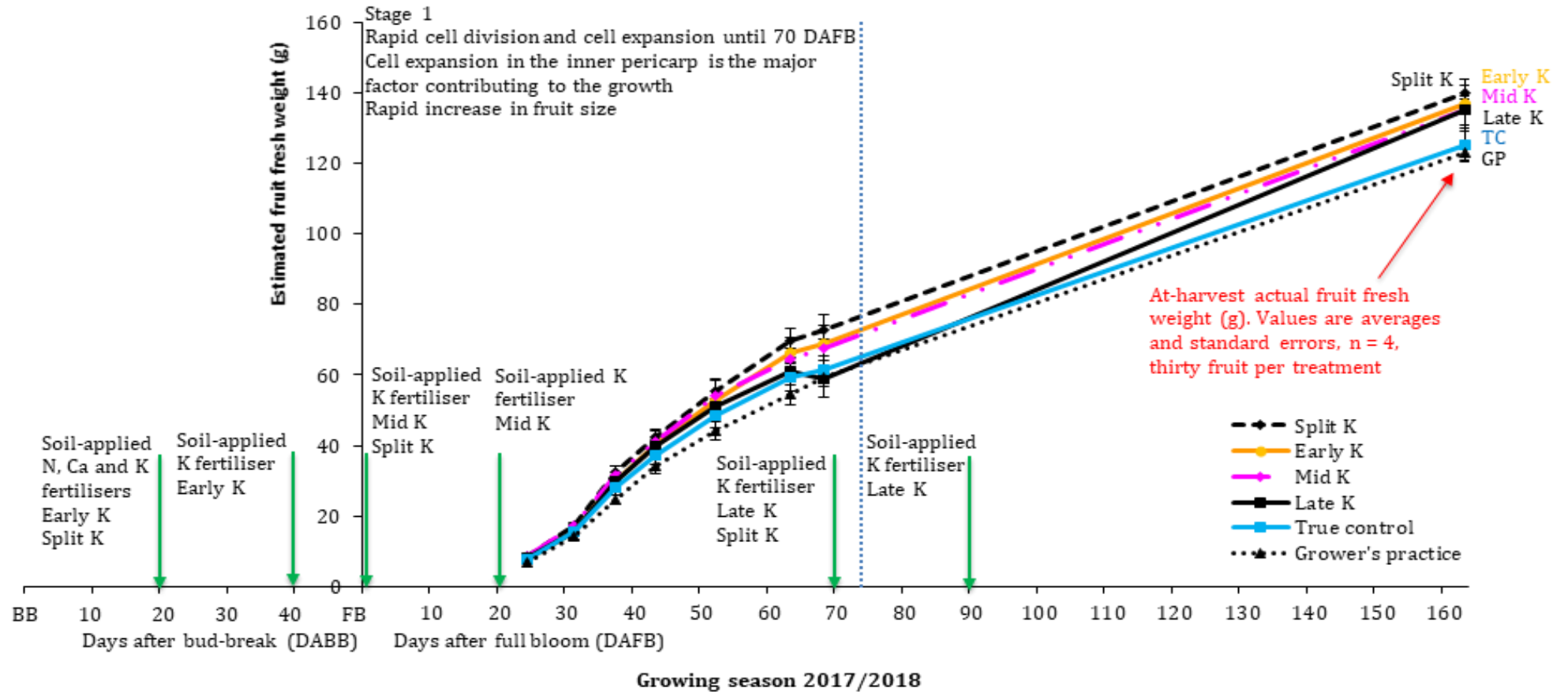


Figure 6.1 Effect of true control (TC), split K, early K, mid K and late K applications, and grower practice (GP) on estimated fruit size (g) from fruit set through to harvest in 'Zesy002' vines grown in the commercial orchard at Te Puke, Bay of Plenty in the 2017/2018 season. Values are averages and standard error bars, n=4, four fruit per treatment. Bud-break was on 25-09-2017, full bloom was at 43 DABB on 07-11-2017 and the commercial harvest was at 163 DAFB on 18-04-2018. At-harvest actual fruit weight (g), values are averages and standard error bars, n = 4, thirty fruit per treatment.

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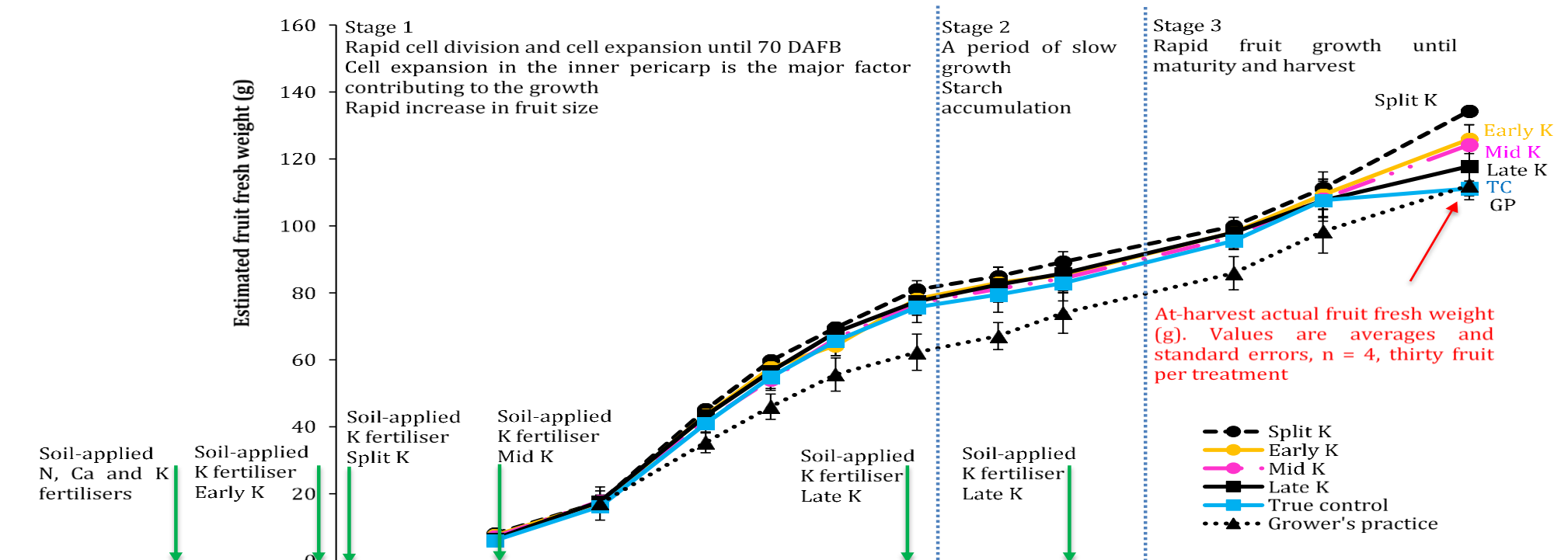


Figure 6.2 Effect of true control (TC), split K, early K, mid K and late K applications, and grower practice (GP) on estimated fruit size (g) from fruit set through to harvest in 'Zesy002' vines grown on the commercial orchard at Haumoana, Hawke's Bay in the 2017/2018 season. Values are averages and standard error bars, n=4, four fruit per treatment. Bud-break was on 15-09-2017, full bloom was at 43 DABB on 28-10-2017 and the commercial harvest was at 136 DAFB on 13-03-2018. At-harvest actual fruit weight (g), values are averages and standard error bars, n = 4, thirty fruit per treatment.

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Both mid and late application of K significantly increased fruit Ca and Mg uptake compared to split and early application of K and true control (TC) at the Te Puke orchard in the 2017/2018 season (Table 6.5). Likewise, significantly higher fruit Ca uptake was observed by mid and late K compared to split and early K and TC at the Haumoana orchard in the 2017/2018 season (Table 6.6). This suggests a possible competitive effect of K on the uptake of Ca because Ca and K fertilisers were applied at the same time by split and early K. On the other hand, mid and late K treatments suggest temporal separation effect because Ca and K fertilisers were applied at different times and the counteractive effect of K on the uptake of Ca was reduced. Therefore, the fruit Ca uptake was significantly increased by mid and late K applications compared to split and early K in 'Zesy002' vines.

Fruit N uptake was significantly higher by split and early K compared to mid and late K treatments in 'Zesy002' vines at Te Puke and Haumoana orchards in the 2017/2018 season. This suggests that the application of N, Ca and K together at once significantly increased uptake of N possibly due to the synergistic interaction between (N× K) and (N × Ca) (Fageria, 2001; Minotti et al., 1968). Similar fruit K uptake was observed by soil-applied K treatments at each orchard in 'Zesy002' vines. This suggests that the uptake of K by fruit tissues was irrespective of the time of K application possibly due to high (developing) fruit K demand in kiwifruit vines (Buwalda & Smith, 1987). True control (TC) showed significantly low fruit nutrient status compared to soil-applied K treatments due to no fertiliser input, in 'Zesy002' vines grown at Te Puke and Haumoana orchards in the 2017/2018 season.

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Table 6.5 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in 'Zesy002' vines by true control (TC) and soil-applied K treatments, and grower practice (GP) at the Te Puke orchard in the 2017/2018 season. The red outlined boxes are used to compare two groups; split and Early K vs Mid and Late K.

Nutrients (mg. 100g ⁻¹ DW)	Te Puke (163 DAFB)					Sig.	*GP
	True control	Split K	Early K	Mid K	Late K		
N	470±9c	611±9a	613±11a	566±14b	560±16b	<0.000	698±9
K	1196±15b	1521±23a	1530±26a	1541±23a	1533±25a	<0.000	1357±35
Ca	32±3c	60±4b	58±5b	93±3a	96±4a	<0.000	46±1
Mg	30±3c	46±4b	44±5b	60±5a	63±3a	<0.000	74±2

Table 6.6 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in 'Zesy002' vines by true control (TC) and soil-applied K treatments, and grower practice (GP) at the Haumoana orchard in the 2017/2018 season. The red outlined boxes are used to compare two groups; split and Early K vs Mid and Late K.

Nutrients (mg. 100g ⁻¹ DW)	Haumoana (136 DAFB)					Sig.	*GP
	True control	Split K	Early K	Mid K	Late K		
N	549±11c	635±6a	641±8a	601±8b	606±9b	<0.000	573±7
K	1249±19b	1603±12a	1610±9a	1613±12a	1615±9a	<0.000	1328±5
Ca	55±5c	74±4b	76±5b	94±4a	93±3a	<0.000	66±4
Mg	33±4a	39±2a	37±7a	35±7a	36±9a	0.976	42±3

Values are averages and standard errors, n = 4, one composite sample per treatment each made up of thirty dried fruit slices. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- The GP was not analysed statistically.

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In the 2016/2017 season all soil-applied K treatments showed no significant effect on at-harvest fruit quality in each orchard. This may be associated to the buffering capacity of the orchard soils and/or typical high nutrient fertiliser inputs (K rates 300-450 Kg ha⁻¹) in commercial kiwifruit orchards (Tables 6.7, 6.8 and 6.9). Higher fruit weight, SSC and FDM were observed by all soil-applied treatments compared to the TC in each orchard. Split K showed higher fruit weight, SSC and FDM compared to the other soil-applied K treatments in each orchard. The split K application significantly increased SSC at-harvest compared to the TC at the Haumoana orchard (Table 6.9). This suggests that the split K application effectively met K demand throughout the growing season and nutrient uptake after leaf emergence then compensated K demand by the growing fruit and improved at-harvest fruit quality (Buwalda, 1991; Buwalda & Smith, 1987; Smith et al., 1987c). Higher fruit firmness was observed by both mid and late K applications compared to split and early K in each orchard in 'Zesy002' kiwifruit vines. The increased fruit firmness may be associated with higher fruit Ca uptake because of temporal separation of Ca and K fertilisation in mid and late K treatments (Tables 6.5 and 6.6). In the 2017/2018 season soil-applied K treatments showed higher fruit weight, SSC, FDM and TZG, and lower size class and green flesh colour compared to TC in each orchard (Tables 6.10 and 6.11). Both mid and late K applications significantly increased fruit firmness at-harvest compared to split and early K applications at the Te Puke orchard (Table 6.10). This may be attributed to the increased fruit Ca status due to the temporal separation of Ca and K fertilisers. In addition, both mid and late K applications showed higher green flesh colour at-harvest compared to split and early K. It is unclear if mid and late K treatments were delaying maturity due to increased fruit Ca uptake and/or late K fertiliser application. The split K application showed higher fruit weight, SSC, FDM, TZG and lower fruit size class, firmness and green flesh colour compared to other treatments at the Te Puke orchard. This suggests that the split K treatment was advancing fruit maturity.

Soil-applied K treatments showed higher fruit weight, SSC, FDM, and TZG compared to TC at the Haumoana orchard in the 2017/2018 season in 'Zesy002' vines (Table 6.11). Both mid and late K significantly increased fruit firmness at-harvest compared to split and early K at the Haumoana orchard and may be linked to increased Ca uptake and suggests counteractive effect of K on the uptake of Ca was

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significantly reduced. Split K increased fruit weight, SSC, FDM, TZG and reduced fruit size class, firmness and green flesh colour compared to other treatments at the Haumoana orchard. Possibly split K application was advancing fruit maturity compared to other soil-applied K treatments. Soil-applied K treatments improved at-harvest fruit quality in the 2018/2019 season compared to TC at the Te Puke orchard (Table 6.12). Split K showed higher fruit weight, SSC, FDM and TZG, and lower fruit size class, firmness and green flesh colour compared to other treatments. These three-year results suggest that soil-applied K treatments significantly improved at-harvest fruit quality compared to true control in each orchard. Both split and early K showed similar improvements regarding at-harvest fruit quality. Treatments were advancing the fruit maturity in the ascending order as split and early>mid and late. The reverse order was observed regarding fruit Ca uptake; mid and late K>split and early K. This suggests increased Ca uptake was potentially delaying fruit maturity, however, this response needs further investigation. At each orchard crop load was maintained by the management. Fruit count was actively managed similar by all treatments in each orchard in 2017/2018 and 2018/2019 seasons.

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Table 6.7 Standard fruit quality at-harvest in 'Zesy002' vines at 167 DAFB on 22-04-2017 by soil-applied K treatments in the 2016/2017 season in the commercial orchard at Te Puke, Bay of Plenty. Clearance report on 23-04-2017 and commercial harvest on 24-04-2017. The red outlined boxes are used to compare two groups; split and Early K vs Mid and Late K.

Parameters	Units	True control	Split K	Early K	Mid K	Late K	Sig.	*Clearance report
Fresh weight	g	137.0±2.7a	149.4±8.0a	147.9±2.7a	148.9±3.6a	139.2±6.8a	0.324	147.1
Size class	-	27	25	25	25	25	NA	25
Firmness	KgF	7.37±0.31a	6.76±0.41a	6.92±0.44a	7.26±0.22a	7.44±0.22a	0.528	6.4
SSC	°Brix	9.34±0.46a	10.90±0.68a	10.51±0.87a	10.52±0.58a	10.14±0.63a	0.521	10.0
FDM	%	17.51±0.37a	18.33±0.37a	18.24±0.55a	17.87±0.50a	18.09±0.55a	0.753	17.9
Grade value (TZG)	%	65 (5)	90 (7)	90 (7)	85 (6)	90 (7)	NA	85 (6)

Values are averages and standard errors, n = 4, one composite sample per treatment each made up of twenty-three fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 6.8 Standard fruit quality after thirty-day storage at 1°C in 'Zesy002' vines harvested at 134 DAFB on 15-03-2017 by soil-applied K treatments in the 2016/2017 season in the commercial orchard at Paengaroa, Bay of Plenty. The red outlined boxes are used to compare two groups; split and Early K vs Mid and Late K.

Parameters	Units	True control	Split K	Early K	Mid K	Late K	Sig.
Fresh weight	g	132.3±5.1a	155.2±7.7a	151.2±12.1a	149.0±4.4a	144.0±1.6a	0.243
Size class	-	33	27	30	25	25	
Firmness	KgF	4.24±0.34a	3.54±0.36a	3.31±0.50a	4.16±0.41a	4.40±0.69a	0.442
SSC	°Brix	12.79±0.62a	14.21±0.28a	13.59±0.54a	13.33±0.27a	13.11±0.63a	0.354
FDM	%	16.64±0.53a	18.09±0.49a	17.20±0.52a	18.27±0.67a	16.83±0.56a	0.186
Grade value (TZG)	%	45 (4)	90 (7)	65 (5)	90 (7)	45 (4)	NA

Values are averages and standard errors, n = 4, one composite sample per treatment each made up of twenty-three fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- The clearance report was not analysed statistically.

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Table 6.9 Standard fruit quality at-harvest in 'Zesy002' vines at 133 DAFB on 19-03-2017 by soil-applied K treatments in the 2016/2017 season in the commercial orchard at Haumoana, Hawke's Bay. The red outlined boxes are used to compare two groups; split and Early K vs Mid and Late K.

Parameters	Units	True control	Split K	Early K	Mid K	Late K	Sig.
Fresh weight	g	121.7±2.1a	128.7±6.0a	126.2±3.7a	124.9±4.6a	121.4±6.1a	0.788
Size class	-	30	27	30	30	30	NA
Firmness	KgF	8.50±0.39a	7.90±0.31a	7.80±0.38a	8.09±0.38a	8.12±0.34a	0.667
SSC	°Brix	8.85±0.11b	9.42±0.17a	9.43±0.10a	9.35±0.15 a	9.14±0.08ab	0.025
FDM	%	16.84±0.33a	17.37±0.20a	17.28±0.19a	17.35±0.01a	17.29±0.18a	0.412
Grade value (TZG)	%	45 (4)	65 (5)	65 (5)	65 (5)	65 (5)	NA

Values are averages and standard errors, n = 4, one composite sample per treatment each made up of twenty-three fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 6.10 Standard fruit quality at-harvest in 'Zesy002' vines at 163 DAFB by soil-applied K treatments and grower practice (GP) in the 2017/2018 season in the commercial orchard at Te Puke, Bay of Plenty. Clearance report on 18-04-2018. The red outlined boxes are used to compare two groups; split and Early K vs Mid and Late K.

Parameters	Units	True control	Split K	Early K	Mid K	Late K	Sig.	*GP	*Clearance report
Fresh weight	g	124.6±4.2b	139.9±1.7a	137.5±6.1ab	139.5±3.7a	134.6±4.7ab	0.130	123.1±2.5	124.9
Size class	-	30	25	27	25	27	NA	30	30
Firmness	KgF	6.25±0.08bc	6.09±0.07c	6.03±0.10c	6.46±0.14a	6.52±0.16a	0.030	6.23±0.05	6.2
SSC	°Brix	9.39±0.26b	10.52±0.16a	9.84±0.16ab	9.90±0.22ab	9.43±0.27b	0.016	8.38±0.22	8.5
FDM	%	17.30±0.25b	18.31±0.23a	17.76±0.15ab	17.75±0.22ab	17.55±0.19b	0.047	17.30±0.05	17.4
Grade value (TZG)	%	65 (5)	90 (7)	85 (6)	85 (6)	85 (6)	NA	65 (5)	65 (5)
Green flesh colour	°H	102.9±0.4a	101.8±0.2b	102.3±0.2ab	102.5±0.2ab	102.7±0.2a	0.077	103.58±0.09	107.8
Fruit count	Per vine	1105±139a	1151±99a	1117±110a	1175±67a	1170±118a	0.987	1505±156	Ninety fruit

Values are averages and standard errors, n = 4, one composite sample per treatment each made up of thirty fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- Both GP and clearance report were not analysed statistically.

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Table 6.11 Standard fruit quality at-harvest in 'Zesy002' vines at 136 DAFB by soil-applied K treatments and grower practice (GP) in the 2017/2018 season in the commercial orchard at Haumoana, Hawke's Bay. Clearance report on 15-03-2018. The red outlined boxes are used to compare two groups; split and Early K vs Mid and Late K.

Parameters	Units	True control	Split K	Early K	Mid K	Late K	Sig.	*GP	*Clearance report
Fresh weight	g	111.2±2.2c	134.3±0.3a	125.9±4.3ab	124.2±6.0ab	117.8±0.8bc	0.003	112.1±4.3	118.0
Size class	-	30	27	30	30	33	NA	30	30
Firmness	KgF	9.18±0.20a	8.78±0.09c	8.74±0.05c	9.17±0.11a	9.43±0.09a	0.005	8.91±0.04	8.7
SSC	°Brix	5.55±0.04a	5.80±0.21a	5.62±0.12a	5.61±0.18 a	5.59±0.05a	0.739	5.33±0.09	5.2
FDM	%	16.82±0.20b	17.70±0.34a	17.57±0.15ab	17.36±0.35ab	17.28±0.10ab	0.167	17.44±0.32	18.2
Grade value (TZG)	%	45 (4)	85 (6)	85 (6)	65 (5)	65 (5)	NA	65 (5)	90 (7)
Green flesh colour	°H	108.0±0.5a	105.9±0.9b	105.8±0.4b	106.9±0.7ab	107.8±0.1a	0.049	108.8±0.6	110.9
Fruit count	Per vine	772±94a	805±110a	841±92a	938±117	847±62	0.796	818±60	Ninety fruit

Values are averages and standard errors, n = 4, one composite sample per treatment each made up of thirty fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 6.12 Standard fruit quality at-harvest in 'Zesy002' vines by soil-applied K treatments and grower practice (GP) in the 2018/2019 season in the commercial orchard at Te Puke, Bay of Plenty. The red outlined boxes are used to compare two groups; split and Early K vs Mid and Late K.

Parameters	Units	True control	Split K	Early K	Mid K	Late K	Sig.	*GP
Fresh weight	g	123.6±1.4b	131.7±1.3a	126.2±0.9ab	122.3±1.5b	122.7±0.18b	0.019	123.0±3.0
Size class	-	30	27	30	30	30	NA	30
Firmness	KgF	6.34±0.19b	6.59±0.05b	6.55±0.04b	6.97±0.08a	6.96±0.11a	0.014	6.27±0.29
SSC	°Brix	11.51±0.45ab	12.30±0.07a	11.55±0.18ab	11.32±0.30b	11.02±0.06b	0.037	11.43±0.17
FDM	%	18.43±0.13b	19.23±0.16a	18.71±0.15ab	18.74±0.25ab	18.39±0.20b	0.038	18.77±0.18
Grade value (TZG)	%	90 (7)	97 (9)	95 (8)	95 (8)	90 (7)	NA	95 (8)
Green flesh colour	°H	100.5±0.2ab	100.1±0.1c	100.3±0.1bc	100.7±0.1ab	100.8±0.1a	0.013	100.9±0.1
Fruit count	Per vine	1393±17a	1373±18a	1380±15a	1404±19a	1424±18a	0.299	1419±14

Values are averages and standard errors, n = 4, one composite sample per treatment each made up of thirty fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- Both GP and clearance report were not analysed statistically.

6.3.1 Comparison to grower practices

Soil-applied K treatments compared to grower practice at the Te Puke orchard showed higher firmness, SSC, FDM and TZG in the 2016/2017 season. Likewise, all soil-applied K treatments compared to grower practice (GP) and the clearance report showed bigger fruit, higher SSC, FDM and TZG and lower size class and green flesh colour at both Te Puke and Haumoana orchards in the 2017/2018 season. Soil-applied K treatments improved at-harvest fruit quality compared to the GP at the Te Puke orchard in the 2018/2018 season. Split K treatment showed improved at-harvest fruit quality in each orchard from 2016-2019.

6.4 Conclusion

Three split K applications (each 100 Kg K ha⁻¹) from bud-break through to 90 DAFB significantly increased fruit growth rate and improved at-harvest fruit quality in 'Zesy002' vines grown on commercial orchards at Bay of Plenty and Hawke's Bay region of New Zealand from 2016 to 2018. The split K application strategy was effective to meet the K nutrient demand of the growing fruit and increased dry matter accumulation during the growing season and advanced fruit maturity with gains in fruit quality (size, SSC and FDM).

7 Foliar-applied potassium salts improved nutrient uptake, photosynthetic performance, and at-harvest fruit quality in 'Zesy002' vines

7.1 Introduction

Potassium (K) increases the absorption and translocation of anions in the plants. This synergistic interaction of K with other nutrients such as nitrates, sulphates and phosphates is well established (Fageria, 2001). Potassium increases nitrate transport in the xylem by acting as counter ion. The availability of K in sufficient amount rapidly converts nitrates into proteins (direct role of K) which is then utilised by plants and transformed into biomass (Coskun et al., 2017; Hewitt & Osborne, 1962; Hewitt & Smith, 1974; Murray, 1960). Thus, yield and fruit quality improves significantly due to K fertilisation in horticultural fruit crops such as in kiwifruit (Wang et al., 2006), apple (Nava & Dechen, 2009), pear (Brunetto et al., 2015) and citrus (Quaggio et al., 2006).

In kiwifruit, fruit K uptake is correlated with at-harvest fruit quality (Katrina, 2005). As fruit growth progresses, fruits becoming strong sinks for K and compete with other sinks. Since K pool is labile in leaves, deficiency first appears in leaves adjacent to fruits. Late season K loss in leaves is concurrent with K accumulation in fruits (Niederholzer et al., 1991; Smith et al., 1987a). If soil K is limited during the fruit maturation stage in kiwifruit vines, then leaf K deficiency might develop and may limit and translocation and utilisation of nutrients and assimilates. Similarly, during early fruit developmental stages the young fruitlets require relatively high N for the synthesis of protein and enzymes to sustain the active metabolism associated with the rapid cell division (Cheng et al., 2007). Therefore, any limitation in N and K uptake during the growing season would negatively affect at-harvest fruit quality in kiwifruit vines. For the high production of quality fruits kiwifruit vines require high nutrient input (Buwalda & Smith, 1987; Mills et al., 2008) and to meet this demand excessive use of fertilisers is a common practice in kiwifruit orchards in New Zealand. For example, soil application of N fertilisers above 200 Kg N ha⁻¹ and K fertilisers 450 Kg K ha⁻¹ in a growing season has been recommended historically for kiwifruit orchards (Buwalda et al., 1990; Mills et al., 2008; Sale, 1997). However,

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application at such high rates drive excessive vegetative growth in kiwifruit vines and increases environmental risks (nitrification and leaching losses). The formulation of soil-applied K fertiliser such as K_2SO_4 and KCl previously had been reported to affect nutrient uptake, vine physiology and fruit yield in kiwifruit vines (Buwalda & Smith, 1991). Therefore, it is important to apply mineral nutrients to the right target (fruit) in right amount at the right time through right fertiliser formulation suitable for plant growth (Bryla, 2020).

The soil-applied fertilisation does not always guarantee efficient acquisition of mineral nutrients from roots to desirable plant parts (fruits). There are many obstacles at soil-root-fruit pathway such as nutrient deficiency and/or unavailability due to fixation in soil e.g. K fixation in New Zealand soils (McClaren & Cameron, 1990), negative interaction with other ions such as Ca and Mg affected by high K (Fageria, 2001; Kahn & Hanson, 1957), leaching and volatilisation losses (Fageria et al., 2009; Quin et al., 2017), difficulty reaching deep roots of kiwifruit vines, unfavourable soil conditions such as low pH and temperature, slow nutrient absorption by roots and poor translocation of nutrients from roots to fruits (Fageria et al., 2009).

The foliar nutrient application is a well-acclaimed strategy (Brown & Suwanarit, 1999; Mia, 2015; Smolen, 2012) to achieve several benefits such as high nutrient recovery, reduction in the amount applied since it avoids the losses at soil level therefore, less environmental damage, (Bindraban et al., 2015; Fageria et al., 2009; Kannan & Charnel, 1986; Mia, 2015). However, the foliar application of macronutrients (at high application rates) potentially damage leaf and also increases application cost compared to the soil-applied fertilisation method. The foliar application is a target specific strategy (at right time to the right organ but only small doses are delivered) which facilitates fast nutrient absorption and assimilation (Peuke et al., 1998). Consequently, the competition between vegetative and reproductive sinks reduces. The foliar nutrient fertilisers can be applied at the time of high demand in a growing season and effects will be visible in short time compared to soil-applied nutrient fertilisers. The foliar nutrient application from early growth stages can benefit canopy development and CO_2 fixation as it stimulates regrowth, source size and activity and maximises the yield potential. In order to gain high returns, the foliar nutrients must be applied in sufficient amount

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and appropriate formulation (water soluble) for optimum absorption. Many studies have reported beneficial effects of different formulations of the foliar K fertilisers in fruit crops. Foliar potassium sulphate (K_2SO_4) increased yield and fruit quality in fig (Gaaliche et al., 2019; Irget et al., 2008; Mimoun et al., 2017). Foliar potassium nitrate (KNO_3) increased soluble solids in litchi and increased fruit yield in mango (Sarker & Rahim, 2013). However, our knowledge of the foliar application of K and its effects on nutrient acquisition and fruit quality in 'Zesy002' is limited.

7.1.1 Problem statement

High inputs of soil-applied N and K fertilisers may induce excessive vegetative growth which negatively affects at-harvest fruit quality and also increases the risk of nitrate leaching and labour costs in kiwifruit orchards (Snelgar et al., 2012). Any limitation in N and K uptake during early canopy development potentially affect CO_2 fixation and consequently, the production of quality fruit in kiwifruit vines. The specific fertiliser formulation may affect nutrient uptake and growth in kiwifruit vines.

7.1.2 Objectives

This study was conducted to evaluate the effectiveness of two different formulations of the foliar K fertilisers before the onset of full bloom to increase K absorption, translocation and utilisation by kiwifruit vines to improve photosynthetic performance and at-harvest fruit quality in 'Zesy002' vines.

7.1.3 Hypothesis

The present study was conducted based on the hypothesis that the pre-harvest foliar KNO_3 applications may improve vine and fruit physiology. The increased photosynthetic CO_2 assimilation may increase biomass synthesis. Readily absorbed foliar K may improve plant water status as an osmoticum to increase the driving force for water uptake (Hsiao & Lauchli, 1986). This may result in increased water and nutrient transport. Through synergistic interaction of K with nitrate-nitrogen (NO_3^-), nutrient absorption and utilisation may be promoted. Consequently, at-harvest fruit quality may improve in 'Zesy002' vines. The foliar K_2SO_4 may improve K and sulphate nutrition of leaf and fruit. The foliar KNO_3 applications may supplement the soil supply and reduce the amount of fertiliser required therefore, reducing nitrate leaching losses.

7.2 Materials and methods

The experiment was conducted in a commercial orchard in the 2016/2017 season at Haumoana, Hawke's Bay (Table 7.1). Low application rate of soil N fertiliser 50 Kg N ha⁻¹ (as SOA) was used only to maintain vine health, in contrast to historical recommendations (100-200 Kg N ha⁻¹). The foliar KNO₃ and the foliar K₂SO₄ at an application rate of 1% K (w/v) along with a 'buffer control' were used. The water-soluble non-ionic spreader-activator buffer (containing glycols and glycol ethers as a soluble concentrate) was used to adjust the pH of the final foliar treatment solutions. The pH was adjusted to 5.5 to maximise the nutrient absorption and avoid phyto-toxicity. The foliar treatments were applied seven-days before full bloom and repeated five times at an interval of ten-days.

Table 7.1 The relevant information of key events and activities in the commercial orchard at Haumoana, Hawke's Bay in the 2016/2017 growing season.

Key Events	Date
Bud-break	15-09-2016
First leaf sampling (pre-treatment)	29-09-2016 (14 DABB)
First foliar application	29-10-2016 (44 DABB)
Last foliar application	12-12-2016 (88 DABB or 36 DAFB)
Full bloom	06-11-2016 (52 DABB)
Second leaf sampling	06-01-2017 (113 DABB or 61 DAFB)
At-harvest leaf and fruit sampling	19-03-2017 (133 DAFB)
Fruit processing	27-03-2017
Clearance report	07-04-2017
Commercial harvest	07-04-2017

The experimental vines received both soil and foliar applied mineral nutrient fertilisation (Table 7.2). The equivalent of soil-applied fertilisation through the foliar application is calculated and mentioned in Table 7.2. The grower used only soil-applied fertilisation and no foliar nutrient sprays to the best of our knowledge. In experimental vines no Ca and Mg fertilisation either through soil or foliar was applied. Also, no soil K fertilisation was used in this foliar experiment and only a fraction of K input (5 Kg ha⁻¹) was used compared to GP (103 Kg ha⁻¹).

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Table 7.2 The total input of mineral nutrient fertilisers (Kg. ha⁻¹) applied through soil and foliar methods and the application time used by grower practice and the foliar experiment in the 2016/2017 season in the commercial orchard at Haumoana, Hawke's Bay, New Zealand.

Nutrients	*Haumoana grower (Only soil-applied) Kg. ha ⁻¹	**Soil-applied	Foliar-applied	Total input
N	37 Oct	50 Sept	2 Oct-Dec	52
K	103 Sep	0	5 Oct-Dec	5
Ca	0	0	0	0
Mg	0	0	0	0

*- The soil-applied fertiliser formulations used by the grower at the Haumoana orchard were; Sulphate of potassium, sulphate of ammonia and sulphur G.

**-. The soil-applied fertiliser formulation used for the foliar K experiment was sulphate of ammonia.

The foliar treatments were applied to the selected canes on each vine in a randomised block design with ten replicates. The foliar treatments were applied early morning (7.00 a.m. NZDST) to ensure maximum absorption and less losses, and on days with no rainfall forecast. The foliar treatments were hand sprayed to leaves and fruits approximately using 500 mL spray solution for each cane till runoff to ensure maximum absorption. The foliar sprays were dried within 2-3 hour of application according to the visual observation. The nutrient composition and other properties of the foliar K fertilisers are presented in Table 7.3 and indicate the foliar KNO₃ has higher water solubility and pH compared to the foliar K₂SO₄.

Table 7.3 Nutrient composition and some important features of the foliar K fertilisers used in this study.

Parameters	Units	KNO ₃	K ₂ SO ₄
Total N	%	13.5	0
Nitrate N	%	13.5	0
K ₂ O (Soluble potash)	%	46	52
K	%	38.4	43.2
S	%	0	18
Solubility	g. L ⁻¹ of water	315	70
pH	1 % solution	8-9	6-7
Electrical conductivity (1g/L)	mS. cm ⁻¹ at 25 °C	1.3	1.54

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Twenty-three samples from each replicate were harvested nineteen-days before the commercial harvest of the orchard. Fruits were transported on the same day of the harvest to the storage room at Massey University, Palmerston North and stored for seven-days at 1°C. Fruit fresh weight (g), firmness (KgF) and soluble solids concentration (°Brix) were recorded for each fruit. Two equatorial cross-sectional slices were taken from the equatorial region of each fruit. A slice from each fruit was pooled together to make a composite sample. Composite samples were fresh weighed (FW) and freeze dried until constant weight was achieved. The dried slices were re-weighed (DW) and fruit dry matter percentage (FDM) was calculated as:

$$\text{FDM} = (\text{DW} / \text{FW}) \times 100$$

The soil testing was conducted with the help of soil core with 15-20 cores at a depth of 15-30 cm from around vines before commencing the experiment in August 2016. Leaf samples were collected before fruit set and 60 and 132 days after full bloom, DAFB. After collection, leaf samples were fresh weighed and washed thoroughly with distilled water to avoid any residual deposition due to the foliar sprays and/or leaching of nutrients from leaf surface (Marschner, 2012). Then dried and fine powdered to analyse nutrient concentration at the Farmed Landscapes Research Centre, Massey University, Palmerston North. Statistical analysis was carried out with the help of IBM SPSS Statistics 24 version. Treatment differences were tested at $P \leq 0.05$ using ANOVA. Pairwise Least Significant Difference (LSD) tests were used to compare treatments where significant differences were found.

7.3 Results and discussion

The orchard soils showed ideal soil physical and chemical properties before treatment applications (Table 7.4). The soil exchangeable K was high, and plant available N was adequate. However, pre-treatment leaf nutrient status at 14 DABB indicated low leaf N and K, and probably reflect cold soil conditions and no uptake because fertilisers were not applied yet and the leaf mineral nutrient concentration would be indicative of remobilised vine (Table 7.5). This is in confirmation with Smith et al., (1987c) reporting no apparent correlation between soil exchangeable K and K status in kiwifruit vines. On the other hand, leaf Ca and Mg adequate was adequate.

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Table 7.4 Pre-treatment soil properties in July, 2016 in 'Zesy002' vines grown in the commercial orchard at Haumoana, Hawke's Bay.

Parameters	Units	Haumoana	Level	*Optimum range
pH	pH Units	6.1	Adequate	5.8-6.5
BD	g. mL ⁻¹	0.80	Adequate	0.6-1.00
CEC	me. 100g ⁻¹	30	High	12-25
Olsen P	me. 100g ⁻¹	99	High	30-60
Ca	me. 100g ⁻¹	20.4	High	6.0-12.0
Mg	me. 100g ⁻¹	3.35	High	1.00-3.00
K	me. 100g ⁻¹	1.65	High	0.60-1.20
Na	me. 100g ⁻¹	0.18	Adequate	0.00-0.40
Plant available N	Kg. ha ⁻¹	115	Adequate	100-150

One composite sample was made up of twenty sub-samples.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2016.

Table 7.5 Pre-treatment leaf nutrient status (% DW) 14 DABB on 29th September 2016 in 'Zesy002' vines grown in the commercial orchard at Haumoana, Hawke's Bay in the 2016/2017 season.

Nutrients	% DW	Level	*Optimum range
N	1.70	Low	2.0-2.8
K	1.20	Low	2.1-2.9
Ca	1.50	Adequate	1.40-2.30
Mg	0.26	Adequate	0.25-0.40

Values are averages, n=10, leaf = 4.

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2016.

Pre-treatment flower count was recorded after bud-break and kept uniform to avoid variation and the effect of crop load. There was no significant difference between the foliar treatments; foliar control and K₂SO₄ (106±1) and foliar KNO₃ (105±1) (Sig. 0.936). Foliar K sprays developed mild burning at the leaf margins, sparse leaf necrotic lesions and fruit blemishes on the surface of fruit which were faded and disappearing later (46 days after full bloom, DAFB) during the growing season (Figure 7.1).



Figure 7.1 The visual symptoms of (a) fruit blemishes by the foliar KNO_3 (b) K_2SO_4 (c) typical leaf marginal burning by the foliar K_2SO_4 and (d) the foliar KNO_3 .

Foliar K_2SO_4 and KNO_3 significantly increased leaf chlorophyll concentration by 35 % and 58 %, respectively, compared to the FC (Table 7.6). This may be possibly due to increased leaf area due to K nutrition (Possingham, 1980; Sale, 1997). Foliar KNO_3 significantly improved photosynthetic performance compared to FC. Likewise, foliar KNO_3 significantly increased net photosynthesis, stomatal conductance and leaf transpiration by 20 %, 30 % and 31 % respectively, compared to foliar K_2SO_4 . Stomatal conductance values are within the range observed by other studies in ‘Zesy002’ vines (Black et al., 2011). The significant improvement by foliar KNO_3 may be attributed to the combined effect of N and K (Barzegar et al., 2020; Hu et al., 2019; Xie et al., 2020). The internal CO_2 and leaf temperature were similar by all foliar treatments however, leaf transpiration was significantly higher by foliar KNO_3 compared to foliar K_2SO_4 and FC.

Both foliar K treatments significantly increased leaf N and K uptake at 60 and 133 DAFB compared to the FC (Table 7.7). The readily absorbed K from both foliar treatments may have adjusted the osmoticum and increased the import of water and nutrient from roots (Hsiao & Lauchli, 1986). Foliar KNO_3 significantly increased leaf N uptake compared to foliar K_2SO_4 treatment (Table 7.7). The higher N uptake by

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foliar KNO_3 may possibly be due to the synergistic interaction between N and K. Likewise, foliar KNO_3 significantly increased leaf K uptake compared to foliar K_2SO_4 (Table 7.7). Comparatively low K uptake by foliar K_2SO_4 may be due to low solubility of K_2SO_4 (Elam et al., 1995). Likewise, Buwalda & Smith, (1991) associated low K uptake to the low solubility of soil-applied K_2SO_4 in kiwifruit vines. The higher N and K uptake by foliar KNO_3 compared to foliar K_2SO_4 presumably reflects higher absorption of N and K by foliar KNO_3 . The study conducted by Morton, (2013) in kiwifruit quantified the amount of spray retained on the fruit surface and potentially available for absorption into the fruit. Fruits were dipped in the foliar spray and water solution and weighed before and after dipping and used the difference in weight to estimate N and K absorbed to the fruit surface by foliar treatments. Morton, (2013) observed 7.5 % increase of N per fruit by foliar KNO_3 due to the direct fruit absorption. Both foliar K treatments showed no effect on the uptake of Ca and Mg by leaf tissues in 'Zesy002' vines.

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Table 7.6 Effect of foliar control (FC), foliar K₂SO₄ and foliar KNO₃ treatments on leaf chlorophyll concentration, net photosynthesis, stomatal conductance, leaf internal carbon dioxide (CO₂), transpiration rate and leaf temperature in ‘Zesy002’ vines at 61 DAFB in the 2016/2017 season in the commercial orchard at Haumoana, Hawke’s Bay, New Zealand.

Parameters	Units	Foliar control	Foliar K ₂ SO ₄	Foliar KNO ₃	Sig.
Leaf chlorophyll	µg. cm ⁻² leaf	6.8±4.6c	10.7±0.5b	13.4±0.6a	<0.000
Net photosynthesis	µmol CO ₂ . m ² s ⁻¹	11.24±0.19c	15.25±0.30b	18.27±0.38a	<0.000
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.14±0.01c	0.20±0.01b	0.26±0.01a	<0.000
Internal CO ₂	µmol CO ₂ . mol ⁻¹ air	243.5±7.5a	243.2±10.7a	248.1±6.4a	0.852
Transpiration	mmol	1.88±0.12c	2.53±0.16b	3.32±0.19a	<0.000
Leaf temperature	°C	20.7±0.1a	20.8±0.2a	20.5±0.1a	0.316

Values are averages and standard errors, n=10, leaf = 2. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 7.7 Leaf nutrient status (% DW) in ‘Zesy002’ vines at 61 and 133 DAFB by foliar control (FC), foliar K₂SO₄ and foliar KNO₃ treatments in ‘Zesy002’ vines at 61 DAFB in the 2016/2017 season in the commercial orchard at Haumoana, Hawke’s Bay, New Zealand.

Nutrients (% DW)	61DAFB				133DAFB			
	Foliar control	Foliar K ₂ SO ₄	Foliar KNO ₃	Sig.	Foliar control	FoliarK ₂ SO ₄	Foliar KNO ₃	Sig.
N	1.90±0.09c	2.48±0.05b	3.85±0.10a	<0.000	1.60±0.15c	2.10±0.15b	2.80±0.15a	0.001
K	1.40±0.11c	2.78±0.05b	3.40±0.05a	<0.000	1.30±0.05c	1.83±0.05b	2.04±0.01a	<0.000
Ca	1.82±0.01a	1.83±0.01a	1.85±0.01a	0.440	1.74±0.01a	1.69±0.02a	1.72±0.02a	0.240
Mg	0.38±0.01a	0.35±0.02a	0.37±0.01a	0.437	0.28±0.01a	0.25±0.01a	0.24±0.01a	0.294

Values are averages and standard errors, n = 10, leaf = 4. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

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Both foliar K treatments significantly increased fruit N and K uptake at-harvest compared to the FC in 'Zesy002' vines (Table 7.8). This suggests foliar K was readily available for absorption and improved nutrient acquisition (Fageria et al., 2009). Foliar KNO₃ significantly increased fruit N and K uptake compared to foliar K₂SO₄. This confirms synergistic interaction between N and K (Fageria, 2001; Malvi, 2011). Both foliar K treatments showed no significant effect on fruit Ca and Mg uptake compared to the FC.

Table 7.8 Fruit nutrient status (mg.100g⁻¹ DW) at-harvest in 'Zesy002' vines at 133 DAFB by foliar control (FC), foliar K₂SO₄ and foliar KNO₃ treatments in the 2016/2017 season in the commercial orchard at Haumoana, Hawke's Bay, New Zealand.

Nutrients (mg.100g ⁻¹ DW)	Foliar control	Foliar K ₂ SO ₄	Foliar KNO ₃	Sig.
N	516±22c	556±5b	617±3a	<0.000
K	1412±5c	1499±1b	1538±1a	<0.000
Ca	63±28a	61±7a	62±3a	0.702
Mg	46±1a	45±2a	44±1a	0.584

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of twenty-three fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

At-harvest (133 DAFB) leaf size and count, cane length and diameter, and fruit count were recorded. The leaf to fruit ratio was calculated using leaf and fruit number (Table 7.9). Foliar K showed no significant effect on cane length and diameter, fruit count, and leaf to fruit ratio. This suggests individual vine vigour was uniform between the treatments. The fruit count on treatment canes was uniform suggesting there was no compromise between crop load and fruit quality. Foliar K₂SO₄ and KNO₃ significantly increased leaf size by 38 % and 93 %, respectively, compared to foliar FC. Likewise, both foliar K treatments significantly increased number of leaves compared to the FC. This is in agreement with Dkhil et al., (2011) and may be attributed to the increased bioavailability of essential nutrients (Marschner, 2012) by foliar K applications. The readily absorbed foliar K may have promoted the cell elongation and turgor pressure. It had been reported that leaf elongation was attributed to the involvement of K in plant water relationships alteration (Jordan-Meille & Pellerin, 2004).

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Table 7.9 Effect of foliar treatments on leaf characteristics, cane length and diameter and fruit count at-harvest in 'Zesy002' vines at 133 DAFB by foliar control (FC), foliar K₂SO₄ and foliar KNO₃ treatments in the 2016/2017 season in the commercial orchard at Haumoana, Hawke's Bay, New Zealand.

Parameters	Units	Foliar control	Foliar K ₂ SO ₄	Foliar KNO ₃	Sig.
Leaf size	cm ²	93±0.5c	128±9.1b	180±2.7a	<0.000
Leaf count	l. m ⁻²	259±2c	267±1b	272±2a	<0.000
Cane length	cm	290±0a	291±2a	291±1a	0.919
Cane diameter	mm	14.4±1.4a	14.5±0.3a	14.3±0.3a	0.942
Fruit count	Per cane	64±1a	65±1a	66±1a	0.268
Leaf: fruit		4.07±0.31a	4.12±0.05a	4.14±0.04a	0.305

Values are averages and standard errors, n=10. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Both foliar K treatments significantly increased at-harvest (133 DAFB) fruit fresh weight, SSC and FDM compared to the FC in 'Zesy002' vines (Table 7.10). Foliar KNO₃ significantly increased fruit fresh weight, firmness, FDM and TZG compared to foliar K₂SO₄. This suggests that possibly the high nitrate supply from foliar KNO₃ increased the sink strength of the fruit and allowed the fruit to import more assimilate from the shoots (Morton, 2013). The other possibility is that the photosynthetic performance is increased therefore, more output in sugars is observed. The improved photosynthetic performance by the KNO₃ may be associated with the synergistic interaction between N and K (Barzegar et al., 2020; Fageria, 2001; Hu et al., 2019; Xie et al., 2020). This suggests photosynthetic performance and biomass production may be affected by the K formulation. Since biomass production is dependent on source strength which is a function of source size (leaf area) and source activity (rate of photosynthesis) (Marschner, 2012).

Table 7.10 Standard fruit quality at-harvest in 'Zesy002' vines at 133 DAFB by foliar control (FC), foliar K₂SO₄ and foliar KNO₃ treatments in the 2016/2017 season in the commercial orchard at Haumoana, Hawke's Bay, New Zealand.

Parameters	Units	Foliar control	Foliar K ₂ SO ₄	Foliar KNO ₃	Sig.	*Clearance report
Fresh Weight	g	112.9±1.2c	122.5±2.9b	130.1±2.3a	<0.000	117.3
Size Class	-	33	30	27	NA	33
Firmness	KgF	6.03±0.17b	6.32±0.14b	7.60±0.29a	<0.000	7.9
SSC	°Brix	9.76±0.09c	11.60±0.10a	10.22±0.09b	<0.000	7.8
FDM	%	14.91±0.30c	16.35±0.83b	17.80±0.07a	0.002	17.7
Grade value (TZG)	%	0 % (1)	25 (3)	85 (6)	NA	85 (6)

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of twenty-three fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- The clearance report (07-04-2017) was provided by the orchard manager.

7.3.1 Compared to grower practice

In this experiment the clearance report provided by the grower is considered as grower practice (GP) and the comparisons were not made on statistical basis. The actual pack-out result for this research block harvested on 07-04-2017 showed fruit size 124.8 g, size class 29 and FDM 17.7. Compared to the GP both foliar K formulations increased SSC. Foliar KNO_3 increased fruit size and SSC and showed similar fruit firmness and FDM compared to the GP. It is important to note that foliar sprayed fruits were harvested on 19-03-2017 and commercial harvest for GP was 07-04-2017. Experimental fruits were harvested sixteen days earlier and demonstrated higher fruit size and SSC and similar FDM compared to GP. At-harvest fruit size was improved by 4 % and 11 % by foliar K_2SO_4 and foliar KNO_3 , respectively, compared to the GP. At-harvest SSC was increased by 31 % and 49 %, respectively, by foliar K_2SO_4 and foliar KNO_3 compared to the GP. The nutrient fertiliser input through foliar sprays was only a fraction 5 Kg K ha⁻¹ compared to soil-applied fertilisation 103 Kg K ha⁻¹ (Table 7.2). Yet the improvement in nutrient uptake, photosynthetic response and at-harvest fruit quality was significantly higher by foliar K treatments compared to GP. This suggests that existing nutrient management practices can further be optimised to gain higher returns with less environmental risks.

7.4 Conclusion

The early foliar K application during the growing season in 'Zesy002' vines was an effective strategy to increase N and K absorption and improved both the photosynthetic performance and at-harvest fruit quality. Foliar KNO_3 formulation was more effective to increase nutrient uptake, photosynthetic performance, and at-harvest fruit quality compared to foliar K_2SO_4 formulation. Foliar application is an effective and sustainable strategy and confirms with the statement 'feed the plant not the soil' by carefully following the four 'rights': right time, right rate, right formulation and right target organ.

8 Foliar-applied potassium nitrate improved photosynthetic performance, nutrient uptake and at-harvest fruit quality in 'Zesy002' kiwifruit¹

8.1 Introduction

The optimum growth of kiwifruit vines is dependent on the good supply of mineral nutrients (Sale, 1997). Mineral nutrients regulate physical and chemical processes and act as catalysts in reactions, help regulate cell sap acidity and are constituents of the cell walls and organelles (Marschner, 2012). The deficiency or excess of mineral nutrients may negatively impact physiological processes such as photosynthesis and respiration and consequently reduces metabolites required for the plant growth, therefore can be detrimental to fruit quality (Warrington & Weston, 1990). Nitrogen is a macro-element in plant nutrition and highly mobile in plants (Marschner, 2012). Nitrogen regulates both C and N metabolism and directly affects the photosynthetic response. A linear relationship exists between N and plant growth rate (Marschner, 2012). Potassium is involved in many physiological and biochemical processes in plants such as enzyme activation, cellular membrane transport processes and assimilate translocation, anion neutralisation; which is essential for the maintenance of membrane potential and osmotic potential regulation; which is one of the important mechanisms in the control of plant water relations, turgor maintenance and growth, regulation of photosynthetic apparatus, phloem loading and unloading and sugar transport (Marschner, 2012). In kiwifruit, fruit K is positively correlated with at-harvest fruit quality (Katrina, 2005). The unavailability of K during the fruit maturation stage may limit translocation and utilisation of nutrients and assimilates in kiwifruit vines. The uptake of K through soil-applied K fertilisation may be limited by factors such as K fixation in New Zealand soils, and leaching losses due to high rainfall event at soil level.

¹Part of this chapter has been published in New Zealand Kiwifruit Journal Hashmatt, M, H. Kerckhoffs and Lowe, T (2019). Foliar boost for Zesy002. New Zealand Kiwifruit Journal, October/November 2019. (Appendix4).

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There are several factors limiting the uptake of K from soil-root-fruit pathway and may be critical for the developing fruit during the growing season. The nutrient losses through soil-applied fertilisation can be high under unfavourable circumstances and may add to economic and environmental concerns. As a general practice, N and K fertilisers are applied in large amounts (150-250 Kg N ha⁻¹ and 250-350 Kg K ha⁻¹) in the kiwifruit orchards. However, excessive N and K fertilisation negatively impacts fruit quality. High input of K fertilisation causes loss of acidity, increases pH, less stability during storage and reduces colour of grape juice (Hunsche et al., 2003; Morris et al., 1983). Excessive N input negatively impact fruit colour, firmness and increased storage disorders in apples, apricots, pears and citrus (Daugaard & Grauslund, 1999; Drake et al., 2002; Dris et al., 1999; Kingston, 1992; Little, 1992; Sanchez et al., 1995). In kiwifruit, to date no studies conducted to report the effect of excessive K fertilisation on fruit quality but there are reports of excessive N fertilisation adversely affecting fruit quality such as reduced firmness and increased incidence of botrytis storage rots (Prasad & Spiers, 1992; Sher & Yates, 1992).

8.1.1 Problem statement

It is well-established that N and K are the most important macro-nutrients required in large amounts by the kiwifruit vine. However, applying more nutrient fertilisers than the requirement at a time contributes to environmental pollution and the orchard running costs. In addition, high input of N and K can also negatively affect the availability and uptake of other nutrients at soil level. An efficient and balanced orchard nutrient management plan need to match the plant demand in a timely fashion in both a sound economically and environmentally manner.

8.1.2 Objectives

The main objective was to increase N and K uptake by leaf and fruit tissues to meet the demand of the kiwifruit vines during the growing season without driving excessive vegetative growth. The other objectives were to: (i) increase the photosynthetic performance, (ii) fruit growth rate and (iii) improve at-harvest fruit quality in 'Zesy002' vines grown on commercial orchards across New Zealand.

8.1.3 Hypothesis

Foliar applications of KNO_3 applied at regular intervals from fruit set through to fruit developmental stages may improve N and K uptake, fruit growth rate, photosynthetic performance and consequently, improve at-harvest fruit quality.

8.2 Materials and methods

Foliar-applied K experiments were conducted in the 2017/2018 season in 'Zesy002' vines grown in three commercial orchards at Te Puke and Paengaroa, Bay of Plenty, and Haumoana, Hawke's Bay, New Zealand. The grower's targeted crop load was 60 fruit m^{-2} in each orchard. Six applications of foliar treatments (foliar control and foliar KNO_3) were applied after full bloom to selected canes in a randomised block design with ten replicates in each orchard (Figures 8.1, 8.2 and 8.3). Foliar treatments were applied early morning (7.00 a.m. NZDST). The foliar KNO_3 was applied at an application rate of 1 % K (w/v). The pH of the final foliar solutions (foliar control and foliar KNO_3) was adjusted to 5.5 by using an acidifying surfactant (Spray-aide™; active ingredient 780 g/L alkylaryl polyxyethylene glycol phosphate ester).

Foliar-applied potassium nitrate

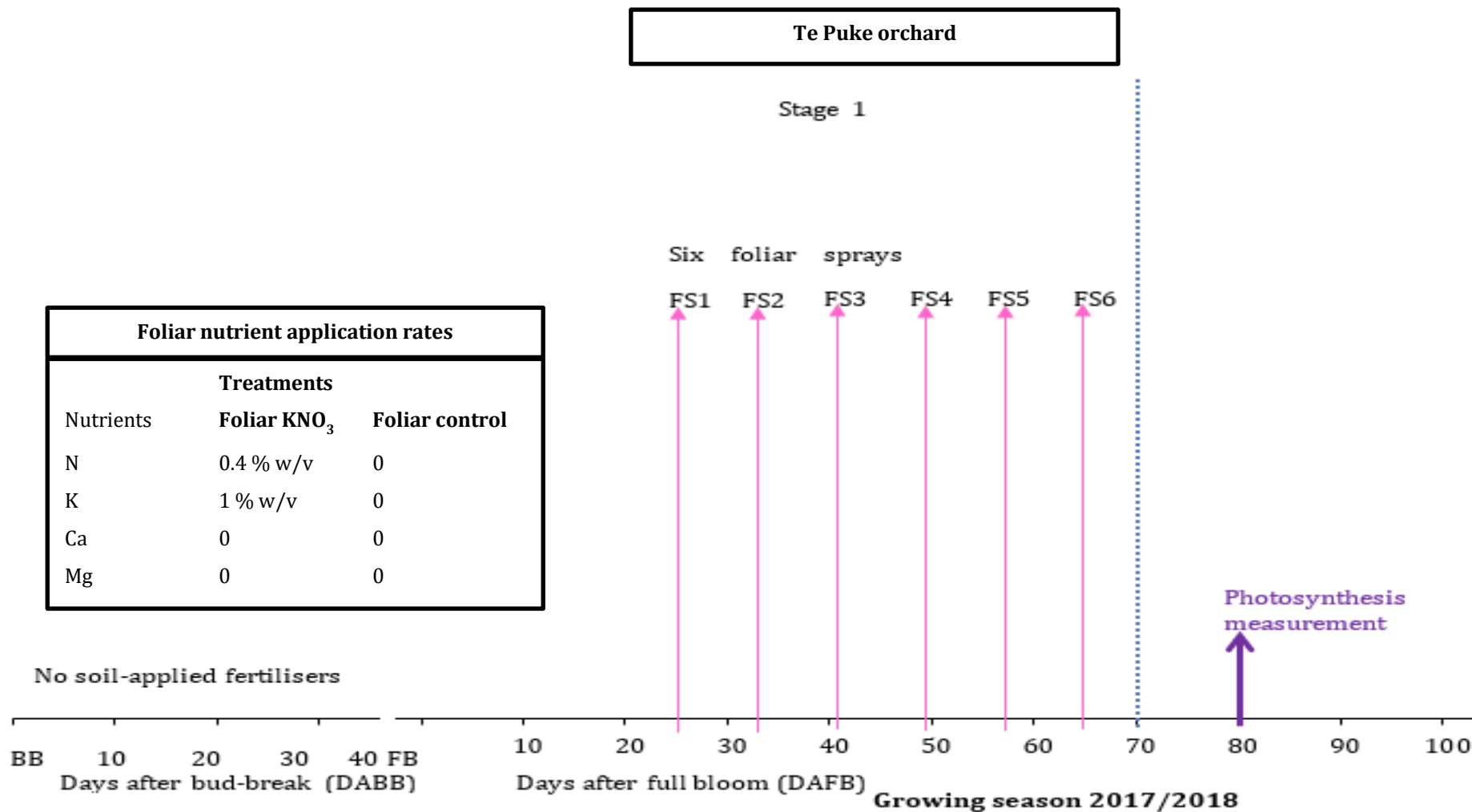


Figure 8.1 Foliar treatment application rate and time, and the time of photosynthesis measurement in the 2017/2018 season in the commercial orchard in Te Puke, Bay of Plenty, New Zealand. Six foliar sprays were applied after fruit set through to 65 DAFB (stage 1) in 'Zesy002' vines.

Foliar-applied potassium nitrate

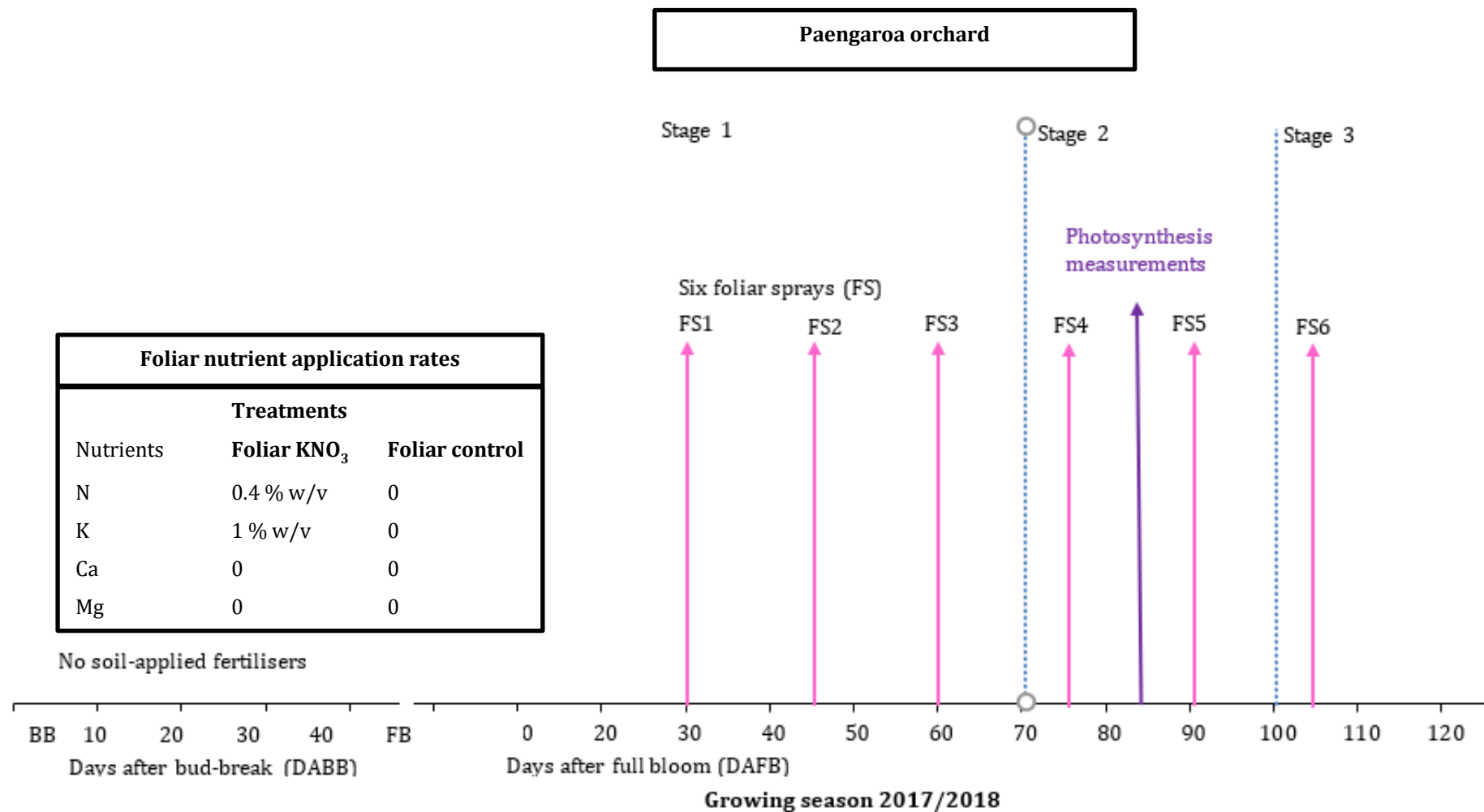


Figure 8.2 Foliar treatment application rate and time, and the time of photosynthesis measurement in the 2017/2018 season in the commercial orchard in Paengaroa, Bay of Plenty, New Zealand. Six foliar sprays were applied after fruit set through to 105 DAFB (stage 3) in 'Zesy002' vines.

Foliar-applied potassium nitrate

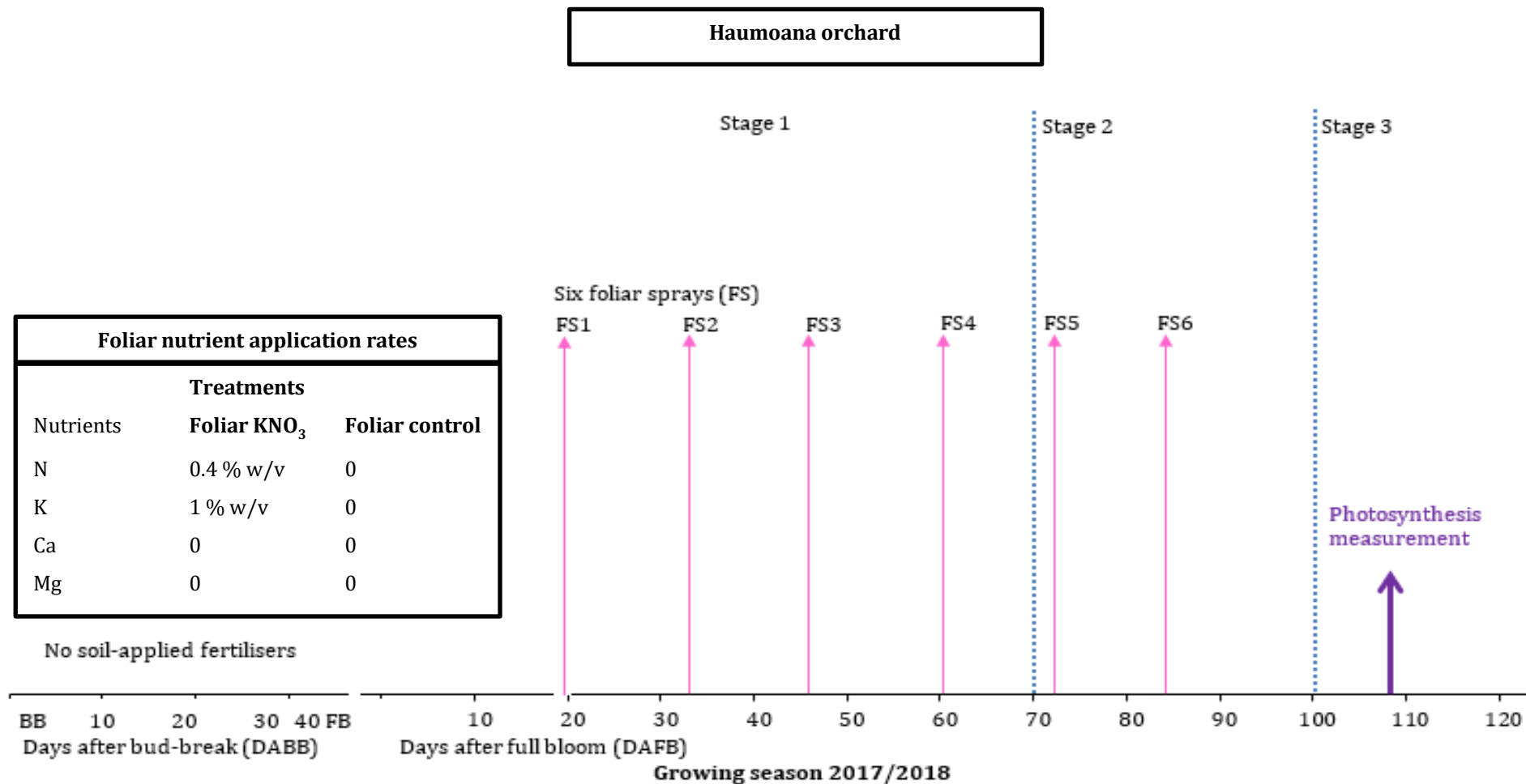


Figure 8.3 Foliar treatment application rate and time, and the time of photosynthesis measurement in the 2017/2018 season in the commercial orchard in Haumoana, Hawke’s Bay, New Zealand. Six foliar sprays were applied after fruit set through to 85 DAFB (stage 2) in ‘Zesy002’ vines.

Foliar-applied potassium nitrate

For comparison, leaf and fruit samples were taken in same time fashion from vines next to research block under the current grower's management and termed as 'grower practice' (GP). The experimental vines including the GP in each orchard also received soil fertilisation employed by the orchard management of each individual orchard during the growing season (Table 8.1). All foliar experiments received no soil-applied fertilisation. For comparison foliar applied nutrient rates (% w/v) are converted to soil application rate (Kg ha⁻¹) taking into consideration the rate, volume and frequency of foliar nutrient fertiliser applications. The total nutrient fertiliser input through soil and foliar applied methods is presented in Table 8.1.

Table 8.1 The total input of mineral nutrient fertilisers (Kg. ha⁻¹) applied through soil and foliar methods and the application time used by grower practice and foliar experiment in the 2017/2018 season in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty, New Zealand.

Nutrients	*Te Puke grower Kg. ha ⁻¹	**Paengaroa grower	***Haumoana grower	****Soil-applied	Foliar-applied	Total input
N	112	27	35	0	2	2
	Aug	Sept	Oct		Oct-Jan	
K	172	118	150	0	5	5
	Aug	Sept	Sep & Nov		Oct-Jan	
Ca	72	7.2	0	0		0
	Aug	Sept				
Mg	28	3.1	25	0		0
	Aug	Sept	Sep			

*- The soil-applied fertiliser formulations used by the grower at the Te Puke orchard were; Sulphate of potassium, Gypsum, Dical8, Ammonium sulphate nitrate, Iron sulphate, Zinc sulphate, Brimstone sulphur and Kieserite.

** - The soil-applied fertiliser formulations used by the grower at the Paengaroa orchard were; Sulphate of potassium and calcium ammonium nitrate.

*** - The soil-applied fertiliser formulations used by the grower at the Haumoana orchard were; Sulphate of potassium, sulphate of ammonia and Kieserite.

**** - The soil-applied fertiliser formulation used by the foliar K experiment at BOP orchards was calcium ammonium nitrate and at the Haumoana orchard was sulphate of ammonia. Therefore, no soil-applied Ca on the Haumoana orchard.

Standard soil and leaf nutrient testing (pre-treatment) were conducted in each orchard. Fruit growth rate was estimated using dimensional measurements as described by Minchin et al., (2003) from fruit set through to harvest in each orchard. Leaf chlorophyll concentration was recorded using hand-held Spadmeter (see section 2.5) and then determined by spectrophotometry according to the method of Lichtenthaler & Wellburn, (1983). The photosynthetic measurements were

Foliar-applied potassium nitrate

recorded by using a Licor portable photosynthesis system Model (LI-6400, LI-COR, Inc., Lincoln, Nebraska, USA) (see section 2.5).

Leaf and fruit samples were taken near commercial harvest date in each orchard for nutrient analysis and standard fruit quality assessment (see sections 2.6 and 2.7). Thirty fruit samples were taken randomly from each replicate on the same day of the commercial harvest 27-03-2018 (146 DAFB) at the Paengaroa orchard, near the commercial harvest 19-04-2018 (163 DAFB) at the Te Puke and 17-03-2018 (136 DAFB) at the Haumoana orchard. Fruit samples were wrapped in polythene liners stored in Zespri provided trays and then transported to the cool storage facilities at the Horticultural Unit, Massey University, Palmerston North. Fruit samples were then stored for 2-3 days at 1 °C and transported to the AgFirst Laboratory facilities in Hawke's Bay for standard at-harvest fruit quality assessment. Fruit samples from the Haumoana orchard were directly transported to AgFirst Laboratory within an hour of harvest. Statistical analysis (ANOVA) was carried out with the help of IBM SPSS Statistics 24 version. Treatment differences were tested at $P \leq 0.05$ using ANOVA. Pairwise Least Significant Difference (LSD) tests were used to compare treatments where significant differences were found.

8.3 Results and discussion

Standard soil testing showed ideal soil physical and chemical properties for both Te Puke and Haumoana commercial orchards (Table 8.2). Soil exchangeable nutrients K, Ca and Mg were relatively low at the Paengaroa orchard. Plant available nitrogen was low at both Bay of Plenty commercial orchards (BOP) at Te Puke and Paengaroa. Pre-treatment leaf nutrient analysis at 20 DABB in 'Zesy002' vines showed low leaf K and Ca at BOP orchards and adequate leaf nutrient status at the Haumoana orchard (Table 8.3).

Foliar-applied potassium nitrate

Table 8.2 Pre-treatment soil properties in ‘Zesy002’ vines in July 2017 in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty and at Haumoana, Hawke’s Bay, New Zealand in the 2017/2018 season.

Parameters	Units	Te Puke	Level	Paengaroa	Level	Haumoana	Level	*Optimum range
pH	pH Units	6.8	High	6.5	Ideal	6.2	Adequate	5.8-6.5
BD	g. mL ⁻¹	0.86	Adequate	0.8	Adequate	0.81	Adequate	0.6-1.00
CEC	me. 100g ⁻¹	21	Ideal	18	Adequate	31	High	12-25
Olsen P	me. 100g ⁻¹	42	Adequate	50	Adequate	98	High	30-60
Ca	me. 100g ⁻¹	15.0	High	3.2	Low	20.1	High	6.0-12.0
Mg	me. 100g ⁻¹	2.19	Ideal	1.0	Low	3.36	High	1.00-3.00
K	me. 100g ⁻¹	0.68	Adequate	0.51	Low	1.64	High	0.60-1.20
Na	me. 100g ⁻¹	0.05	Ideal	0.01	Low	0.17	Adequate	0.00-0.40
Plant available N	Kg. ha ⁻¹	84	Low	100	Low	125	Adequate	100-150
Organic matter	%	10.0	Adequate	8.0	Low	9.1	Adequate	7.0-17.0
Base saturation								
Ca	%	72	Ideal	67	Adequate	68	Ideal	55-67
Mg	%	10.6	Adequate	12.5	Adequate	10.5	Adequate	10-14
K	%	3.3	Low	6.00	Adequate	5.5	Adequate	5-7
Total	%	85.9		85.5		84		

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

Table 8.3 Pre-treatment leaf nutrient status (% DW) at 20 DABB in ‘Zesy002’ vines in the 2017/2018 season in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty and Haumoana, Hawke’s Bay, New Zealand. One composite sample

Nutrients (% DW)	Te Puke	Level	Paengaroa	Level	Haumoana	Level	*Optimum range
N	2.40	Adequate	2.42	Adequate	2.7	Adequate	1.8-2.8
K	1.50	Low	1.24	Low	2.4	Adequate	1.8-3.1
Ca	1.30	Low	1.12	Low	1.90	Adequate	1.60-3.20
Mg	0.29	Adequate	0.37	Adequate	0.31	Adequate	0.25-0.50

*- The respective level for each parameter is based on the normal range found in this crop and at this time of the year as provided by an accredited laboratory, Hill Laboratories Limited 2017.

Foliar-applied potassium nitrate

The estimated fruit growth rate was significantly increased by the foliar KNO_3 (5 Kg K ha⁻¹) right after the second spray and maintained through to harvest compared to FC in 'Zesy002' vines grown on the commercial orchards at BOP and Haumoana (Figure 8.4, Figure 8.5 and Figure 8.6). The increased fruit growth rate may be attributed to the synergistic effect of K on nitrogen metabolism (Coskun et al., 2017). The growth curve was double sigmoidal, the first rapid increase in fruit growth rate (due to cell division then cell expansion together with rapid accumulation of organic acids, (Richardson & Currie, 2007)) was observed after fruit set through to 70 DAFB (Stage 1) followed by a period of slow growth (Stage 2) from 70 through to 100 DAFB. The second rapid increase in fruit growth rate (due to cell expansion and rapid accumulation of sugars (Liang, 1984)) was observed from 100 DAFB and maintained through to harvest (Stage 3) in 'Zesy002' vines grown on commercial orchards at Bay of Plenty and Hawke's Bay regions. The increase in fruit size is slow during stage 2 due to rigid cell walls, from stage 3 (fruit maturity) cell wall loosening is the primary event initiating cell expansion (Cosgrove, 1987). Therefore, rainfall events and irrigation by orchard managers during stage 3 often contribute to increased fruit size in kiwifruit vines. Cell wall loosening involves the acidification of the apoplast resulting in proton extrusion from the cytoplasm and in to the apoplast by membrane bound ATPase (Hager et al., 1971). Therefore, proton extrusion is dependent on K presence in the apoplast because K^+ uptake balances the release of H^+ in order to keep steady plasma membrane potential (Mengel & Kirkby, 1987).

Foliar-applied potassium nitrate

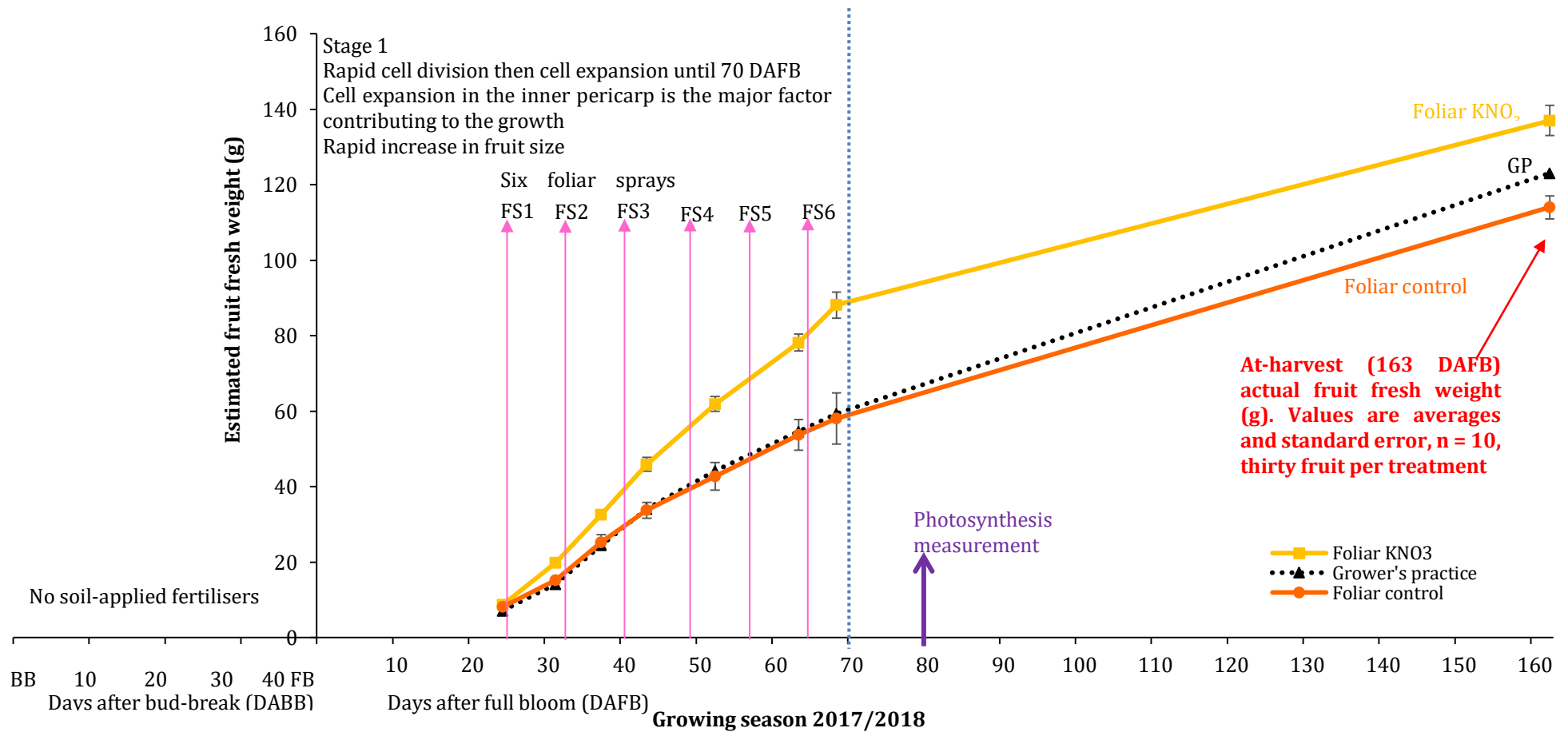


Figure 8.4 Effect of foliar control (FC) and foliar KNO₃, and grower practice (GP) on estimated fruit size (g) from fruit set through to harvest in 'Zesy002' vines grown in the commercial orchard at Te Puke, Bay of Plenty in the 2017/2018 season. Values are averages and standard error bars, n=10, four fruit per treatment. Bud-break was on 25-09-2017, full bloom was at 43 DABB on 07-11-2017 and the commercial harvest was at 163 DAFB on 19-04-2018. At-harvest actual fruit weight (g), values are averages and standard error bars, n = 10, thirty fruit per treatment.

Foliar-applied potassium nitrate

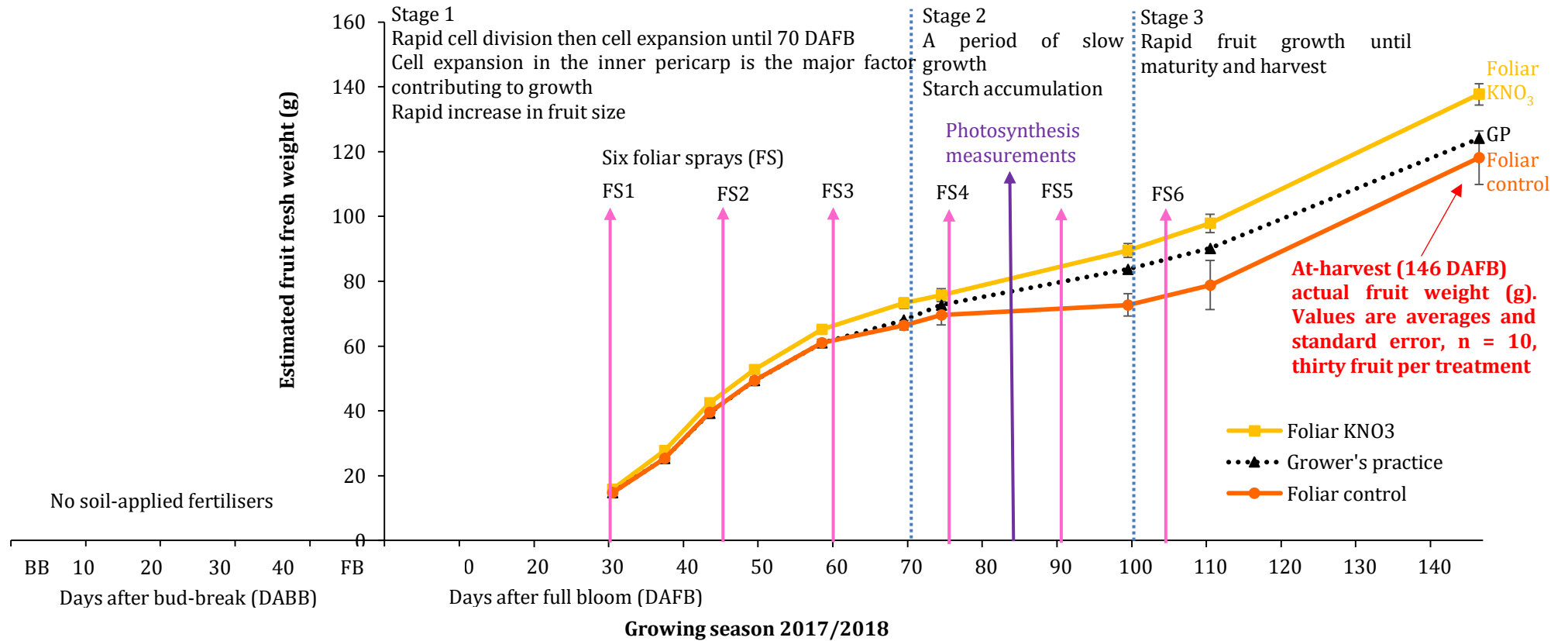


Figure 8.5 Effect of foliar control (FC) and foliar KNO₃, and grower practice (GP) on estimated fruit size (g) from fruit set through to harvest in 'Zesy002' vines grown in the commercial orchard at Paengaroa, Bay of Plenty in the 2017/2018 season. Values are averages and standard error bars, n=10, four fruit per treatment. Bud-break was on 11-09-2017, full bloom was at 51 DABB on 01-11-2017 and the commercial harvest was at 146 DAFB on 27-03-2018. At-harvest actual fruit weight (g), values are averages and standard error bars, n = 10, thirty fruit per treatment.

Foliar-applied potassium nitrate

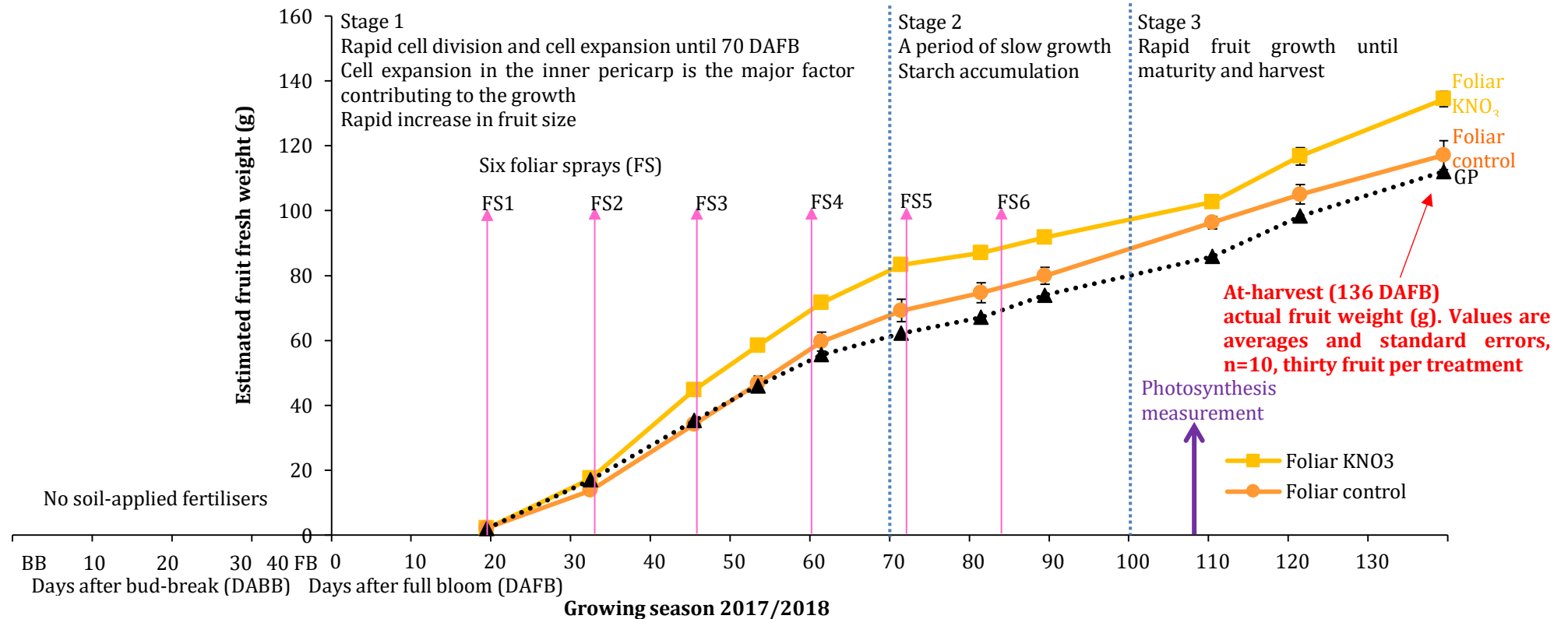


Figure 8.6 Effect of foliar control (FC) and foliar KNO₃, and grower practice (GP) on estimated fruit size (g) from fruit set through to harvest in 'Zesy002' vines grown in the commercial orchard at Haumoana, Hawke's Bay in the 2017/2018 season. Values are averages and standard error bars, n=10, four fruit per treatment. Bud-break was on 15-09-2017, full bloom was at 43 DABB on 28-10-2017 and the commercial harvest was at 136 DAFB on 17-03-2018. At-harvest actual fruit weight (g), values are averages and standard error bars, n = 10, thirty fruit per treatment.

Foliar-applied potassium nitrate

The photosynthetic performance (leaf chlorophyll, net photosynthesis, stomatal conductance and leaf transpiration) was significantly increased by the foliar KNO_3 compared to the FC in 'Zesy002' vines grown on each commercial orchard at BOP and Hawke's Bay (Tables 8.4 and 8.5). This is in agreement with Sritontip et al., (2003) in the tropical fruit longan (*Dimocarpus longan*). The foliar KNO_3 significantly increased leaf chlorophyll in the range of 37-77%, net photosynthesis (39-43%), stomatal conductance (33-42 %) and leaf transpiration (19-32%) in 'Zesy002' vines grown on each commercial orchard at BOP and Hawke's Bay. This improvement may be attributed to the beneficial effect of combined N and K nutrition (Barzegar et al., 2020; Hu et al., 2019; Xie et al., 2020). Internal CO_2 and leaf temperature were similar by all foliar treatments in each commercial orchard.

The uptake of N and K by leaf and fruit tissues was significantly increased by the foliar KNO_3 compared to the FC in each commercial orchard at BOP and Hawke's Bay (Table 8.6, Table 8.7, Table 8.8 and Table 8.9). This may be attributed to the readily available N and K through the foliar feeding (since no soil N and K input) possibly showing synergistic effect on nutrient uptake (Fageria et al., 2009; Fageria, 2001; Lester et al., 2005; Malvi, 2011; Southwick et al., 1996). This also suggests that the requirement of K in kiwifruit vines can possibly be met by the foliar K applications, although it is a fraction (5 Kg K ha^{-1}) compared to soil-applied K input ($250\text{-}350 \text{ Kg K ha}^{-1}$). Other factors such as previously high soil N and K input, soil organic matter mobilisation, the buffering capacity of soils and vine reserves may have contributed to meet the nutrient demand of kiwifruit vines.

The uptake of Ca and Mg by leaf and fruit tissues was not affected by the foliar KNO_3 in each commercial orchard. This suggests the competitive effect of high input of K at soil level on Ca and Mg uptake through soil-applied fertilisation may be avoided and the use of the foliar K application do not affect availability of Ca and Mg at soil-root-fruit pathway in 'Zesy002' vines. This indicate the foliar nutrient fertiliser as a potential strategy to reduce antagonistic nutrient interactions and other factors limiting nutrient uptake at soil-root-fruit pathway such as low soil acidity and low soil temperature, K fixation in soils of New Zealand and long-distance transport of nutrients to the fruit.

Foliar-applied potassium nitrate

Table 8.4 Effect of foliar control (FC) and foliar potassium nitrate (KNO₃), and grower practice (GP), on leaf chlorophyll concentration, net photosynthesis, stomatal conductance, leaf internal carbon dioxide (CO₂), transpiration rate and leaf temperature in 'Zesy002' vines at Te Puke and Paengaroa orchard.

Parameters	Units	Te Puke (80 DAFB)				Paengaroa (83 DAFB)			
		FC	Foliar KNO ₃	Sig.	*GP	FC	Foliar KNO ₃	Sig.	*GP
Leaf chlorophyll	µg. cm ⁻²	11.5±0.5 b	15.7±0.3 a	<0.000	14.9±0.5	10.3±0.2 b	16.9±0.3 a	<0.000	15.5±0.3
Net photosynthesis	µmol CO ₂ . m ² s ⁻¹	10.09±0.28 b	14.03±0.25 a	<0.000	10.09±0.28	10.57±0.20 b	14.94±0.48 a	<0.000	12.88±0.40
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.24±0.03 b	0.34±0.02 a	0.009	0.17±0.01	0.15±0.01 b	0.20±0.01 a	0.001	0.17±0.01
Internal CO ₂	µmol CO ₂ . mol ⁻¹ air	291.5±6.0 a	284.3±4.9 a	0.369	270.64±8.76	250.9±5.9 a	240.4±4.4 a	0.175	243.4±5.4
Transpiration	mmol	3.77±0.27 b	4.57±0.21 a	0.033	3.29±0.24	2.50±0.03 b	2.97±0.06 a	<0.000	2.64±0.09
Leaf temperature	°C	25.5±0.1 a	25.4±0.1 a	0.216	27.54±0.33	22.7±0.2 a	22.1±0.3 a	0.079	21.9±0.7

Values are averages and standard errors, n=10. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 8.5 Effect of foliar control (FC) and foliar potassium nitrate (KNO₃), and grower practice (GP), on leaf chlorophyll concentration, net photosynthesis, stomatal conductance, leaf internal carbon dioxide (CO₂), transpiration rate and leaf temperature in 'Zesy002' vines at the Haumoana orchard.

Parameters	Units	Foliar control	Foliar KNO ₃	Sig.	*GP
Leaf chlorophyll	µg. cm ⁻² leaf	11.1±1.0 b	19.7±1.1 a	<0.000	14.29±0.64
Net photosynthesis	µmol CO ₂ . m ² s ⁻¹	10.26±0.47 b	14.67±0.48 a	<0.000	12.47±0.54
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.17±0.02 b	0.23±0.02 a	0.001	0.20±0.02
Internal CO ₂	µmol CO ₂ . mol ⁻¹ air	266.8±7.3 a	267.6±3.6 a	0.927	265.3±2.9
Transpiration	mmol	3.39±0.30 b	4.46±0.21 a	0.009	3.78±0.19
Leaf temperature	°C	22.2±0.6 a	22.3±0.5 a	0.887	22.3±0.6

Values are averages and standard errors, n=10. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- The GP was not analysed statistically.

Foliar-applied potassium nitrate

Table 8.6 Leaf nutrient status (% DW) at-harvest in 'Zesy002' vines by foliar control (FC) and foliar potassium nitrate (KNO₃), and grower practice (GP), in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty.

Nutrients (% DW)	Te Puke (163 DAFB)				Paengaroa (146 DAFB)			
	FC	Foliar KNO ₃	Sig.	*GP	FC	Foliar KNO ₃	Sig.	*GP
N	2.10±0.12 b	4.9±0.1 a	<0.000	3.83±0.11	1.32±0.10 b	2.92±0.04 a	<0.000	2.94±0.41
K	1.85±0.04 b	4.6±0.1 a	<0.000	2.70±0.04	1.12±0.07 b	3.84±0.04 a	<0.000	2.21±0.04
Ca	1.12±0.11 a	1.4±0.1 a	0.069	2.05±0.05	1.37±0.09 a	1.34±0.09 a	0.856	1.50±0.18
Mg	0.41±0.19 a	0.4±0.1 a	0.799	0.52±0.02	0.31±0.06 a	0.43±0.18 a	0.539	0.34±0.03

Values are averages and standard errors, n = 5, one composite sample per treatment each made up of twenty leaves. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 8.7 Leaf nutrient status (% DW) at-harvest in 'Zesy002' vines by foliar control (FC) and foliar potassium nitrate (KNO₃), and grower practice (GP), in the commercial orchard at Haumoana, Hawke's Bay.

Nutrients (% DW)	FC	Foliar KNO ₃	Sig.	*GP
N	1.51±0.07 b	3.07±0.05 a	<0.000	2.80±0.07
K	1.44±0.06 b	2.63±0.07 a	<0.000	2.43±0.05
Ca	1.63±0.03 a	1.64±0.04 a	0.704	1.80±0.07
Mg	0.32±0.05 a	0.31±0.03 a	0.914	0.46±0.05

Values are averages and standard errors, n = 5, one composite sample per treatment each made up of twenty leaves. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- The GP was not analysed statistically.

Foliar-applied potassium nitrate

Table 8.8 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in 'Zesy002' vines by foliar control (FC) and foliar potassium nitrate (KNO₃), and grower practice (GP), in the commercial orchards at Te Puke and at Paengaroa, Bay of Plenty.

Nutrients (mg. 100g ⁻¹ DW)	Te Puke (163 DAFB)				Paengaroa (146 DAFB)			
	FC	Foliar KNO ₃	Sig.	*GP	FC	Foliar KNO ₃	Sig.	*GP
N	515±8b	970±5a	<0.000	698±9	503±6b	885±3a	<0.000	511±10
K	1285±29b	1570±19a	<0.000	1357±35	1037±25b	1604±17a	<0.000	1245±35
Ca	29±4a	27±3a	0.659	46±1	22±5a	19±4a	0.623	35±7
Mg	38±5a	39±5a	0.872	74±2	25±7a	26±5a	0.965	31±3

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of thirty dried fruit slices. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 8.9 Fruit nutrient status (mg. 100g⁻¹ DW) at-harvest in 'Zesy002' vines by foliar control (FC) and foliar potassium nitrate (KNO₃), and grower practice (GP), in the commercial orchards at Haumoana, Hawke's Bay.

Nutrients (mg. 100g ⁻¹ DW)	FC	Foliar KNO ₃	Sig.	*GP
N	525±5b	610±4a	<0.000	573±7
K	1272±9b	1385±7a	<0.000	1328±5
Ca	50±4a	54±4a	0.448	66±4
Mg	35±3a	34±4a	0.829	42±3

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of thirty dried fruit slices. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- The GP was not analysed statistically.

Foliar-applied potassium nitrate

At-harvest fruit quality was significantly improved by the foliar KNO_3 application in 'Zesy002' vines compared to the FC in each orchard at BOP and Hawke's Bay in the 2017/2018 season (Tables 8.10 and 8.11). The foliar KNO_3 application significantly increased fruit fresh weight and SSC, and significantly reduced green flesh colour compared to the FC treatment at BOP orchards (Table 8.10). This also suggests that the foliar KNO_3 application was advancing fruit maturity and is in agreement with Lester et al., (2005) reporting that the foliar K sprayed fruits matured two-days earlier than not-sprayed fruits in muskmelon. They also reported strong positive correlation between fruit K concentration and sugar accumulation. However, it is unclear whether this is a direct effect of increased phloem unloading in fruits or an indirect effect due to increased C assimilation in source leaves. In addition, the foliar KNO_3 lowered the fruit size class and increased TZG and had similar FDM compared to the FC in each orchard. Fruit firmness was significantly increased by the foliar KNO_3 compared to the FC at the Te Puke orchard (Table 8.10). This is in agreement with Lester et al., (2005) reporting the foliar K increased fruit firmness in muskmelon at-harvest. At the Haumoana orchard, the foliar KNO_3 significantly increased fruit fresh weight by 15 % compared to the FC treatment (Table 8.11). Likewise, the foliar KNO_3 significantly increased FDM, and showed similar fruit firmness, SSC and green flesh colour compared to the FC (Table 8.11). The fruit count at-harvest was similar by all foliar treatments in each orchard, possibly because flower number was managed at the start to achieve uniform crop load, this suggests fruit quality improvement was not influenced by the crop load.

Foliar-applied potassium nitrate

Table 8.10 Standard fruit quality at-harvest in 'Zesy002' vines by foliar control (FC) and foliar potassium nitrate (KNO₃), and grower practice (GP) in the 2017/2018 season in the commercial orchards at Te Puke and Paengaroa, Bay of Plenty, New Zealand.

Parameters	Units	Te Puke (163 DAFB)					Paengaroa (146DAFB)				
		FC	Foliar KNO ₃	Sig.	*GP	*Clearance report	FC	Foliar KNO ₃	Sig.	*GP	
Fresh weight	g	113.6±2.8 b	136.8±4.1 a	<0.000	123.1±2.5	124.9	118.2±3.5 b	137.7±2.3 a	<0.000	124.1±0.9	
Size class		33	27	NA	30	30	33	27	NA	30	
Firmness	KgF	6.42±0.10 b	6.86±0.11 a	0.012	6.23±0.05	6.20	7.19±0.11 a	7.35±0.11 a	0.314	6.94±0.09	
SSC	°Brix	10.00±0.26 b	10.71±0.16 a	0.031	8.38±0.22	8.50	7.55±0.33 b	7.88±0.24 a	0.438	7.21±0.41	
FDM	%	17.39±0.22 a	17.57±0.11 a	0.535	17.30±0.05	17.40	16.97±0.19 a	17.30±0.22 a	0.265	16.87±0.39	
Grade value (TZG)	%	65 (5)	85 (6)	NA	65 (5)	65 (5)	45 (4)	65 (5)	NA	45 (4)	
Green flesh colour	°H	102.9±0.4 a	102.4±0.2 a	0.301	103.6±0.1	107.8	104.5±0.5 a	104.2±0.4 a	0.575	104.9±0.9	
Fruit count	Per cane	58±3 a	59±6 a	0.839	1505±156	Ninety fruit	68±5 a	69±6 a	0.870	1271±130	

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of thirty fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

Table 8.11 Standard fruit quality at-harvest in 'Zesy002' vines at 136 DAFB by foliar control (FC) and foliar (KNO₃), and grower practice (GP) in the 2017/2018 season in the commercial orchards at Haumoana, Hawke's Bay, New Zealand. Clearance report on 15-03-2018.

Parameters	Units	FC	Foliar KNO ₃	Sig.	*GP	*Clearance report
Fresh weight	g	117.1±4.5 b	134.4±2.4 a	0.003	112.1±4.3	118.0
Size class	-	33	27	NA	33	30
Firmness	KgF	9.08±0.1 a	9.12±0.1 a	0.748	8.91±0.04	8.7
SSC	°Brix	5.48±0.0 a	5.52±0.1 a	0.668	5.33±0.09	5.2
FDM	%	17.16±0.12 b	17.55±0.10 a	0.021	17.44±0.32	18.2
Grade value (TZG)	%	65 (5)	85 (6)	NA	65 (5)	90 (7)
Green flesh colour	°H	107.6±0.4 a	107.5±0.4 a	0.849	108.8±0.6	110.9
Fruit count	Per cane	128±10 a	132±6 a	0.729	818±60	Ninety fruit

Values are averages and standard errors, n = 10, one composite sample per treatment each made up of thirty fruits. Differences are considered significant at P<0.05. Different letters beside values within rows denote significant differences.

*- Both GP and clearance report were not analysed statistically.

8.3.1 Comparison to grower practices

The foliar KNO_3 increased fruit growth rate compared to the GP in each orchard at Te Puke (Figure 8.4), Paengaroa (Figure 8.5) and Haumoana (Figure 8.6). Likewise, the foliar KNO_3 improved the photosynthetic performance of 'Zesy002' vines compared to the GP in each orchard at Te Puke and Paengaroa (Table 8.4), and Haumoana (Table 8.5). In addition, the uptake of N and K by both leaf and fruit tissues was increased by the foliar KNO_3 compared to the GP in each orchard (Tables 8.6, 8.7, 8.8 and 8.9). The foliar KNO_3 showed bigger fruit with higher TZG, firmness, SSC, and FDM, and lower size class and green flesh colour compared to the GP at BOP orchards (Table 8.10). Higher SSC and lower green flesh colour probably indicate that the foliar KNO_3 was advancing fruit maturity. Likewise, the foliar KNO_3 showed bigger fruit, higher TZG, firmness, SSC, and FDM, and lower size class and green flesh colour compared to the GP at the Haumoana orchard (Table 8.11). This suggests the current grower's nutrient management practices in these orchards can be optimised by the foliar nutrient applications to improve vine physiology and at-harvest fruit quality in 'Zesy002' vines.

8.4 Conclusion

The foliar KNO_3 applications significantly increased fruit growth rate, nutrient uptake, photosynthetic performance and at-harvest fruit quality in 'Zesy002' vines grown in commercial orchards at Bay of Plenty and Hawke's Bay. The foliar KNO_3 increased fruit size and TZG, and advanced fruit maturity at BOP orchards. The foliar KNO_3 applications has the potential to further maximise fruit quality gains and orchard returns in a sustainable fashion with less environmental impact.

9 General discussion and future recommendations

The kiwifruit industry of New Zealand and its co-operative marketing body (Zespri International Limited) is on track to grow global sales revenue to \$4.5 B by 2025 with approximately total sales of 235 M trays based on current supply forecast. The industry has a strong drive towards sustainability and is also committed to produce high quality fruit and pays a premium to growers based on fruit dry matter percentage (FDM). However, due to the global pandemic the assessment of FDM was suspended in 2020 to ensure minimum contact. To maintain a year-round global supply, the fruit must be capable of having long-term storage potential. The overall key goal for the industry is to produce excellent fruit with an excellent taste profile with excellent storage properties in a sustainable way (Zespri, 2020a). High fruit dry matter percentage (FDM) is correlated with sweetness (Burdon et al., 2004), one of the main characteristics the consumer is after, therefore, Zespri incentivise that by paying a premium for high dry matter percentage (Zespri, 2020a).

Nutrient management is a primary factor involved in fruit quality and therefore a key orchard management tool for orchardists to maximise fruit quality as one of their important production goals. The strategic focus of this research was to optimise nutrient usage in orchards through efficient use of resources to produce top-quality fruit. Different nutrient management strategies were compared to indicate best practice nutritional inputs (applied during 2016-2019 seasons) designed specifically for the 'Zesy002' kiwifruit cultivar. It considered the soil and climate characteristics of the main kiwifruit growing regions, and the orchard management practices in commercial orchards across New Zealand. For example, the high input of K fertilisers, sandy loam soils, which are acidic in nature, combined with other cultural practices such as root pruning might all reduce uptake of Ca by the kiwifruit vines. The research presented in this thesis was conducted to address two main issues related to nutrient management in the NZ 'Zesy002' production system. (1) increase Ca nutrition and (2) optimise K nutrition in both the leaf and fruit. In addition, the foliar application of nutrient fertilisers was used as a target-specific strategy to reduce the amount of fertiliser input in a sustainable fashion.

9.1 Increasing calcium nutrition

Counter-active effect of high potassium input on calcium

Literature suggests that increasing K supply at the soil level has a counteractive effect (so-called ion antagonism) on the uptake of Ca ions. Chiu & Bould, (1976) observed antagonistic interactions between K and Ca uptake in strawberry plants and demonstrated that high K supply reduced translocation of both labelled and non-labelled Ca, which resulted in leaf tip burning, runner and petiole browning, and deformed fruit. In addition, scanning electron microscopy showed that cells were irregular in structure and some cells collapsed. They suggested for normal fruit development and prevention of leaf tip burn an adequate supply of Ca was critical. It is well-established that Ca has a functional role in the formation, development and quality of the fruit and that limited Ca nutrition potentially negatively affects fruit quality at-harvest and post-harvest. The antagonistic effect of K on Ca uptake was also reported by Gunes et al., (1998) and showed that increasing the rate of K fertilisation decreased Ca concentration in tomato plants. Likewise, Job et al., (2019) reported that K fertilisation (100-400 Kg K ha⁻¹) reduced leaf Ca and Mg concentration in potato plants. In kiwifruit, high K fertiliser input is a common management practice that may have similar implications on the Ca nutrition status. In addition, soil and climatic characteristics of the main kiwifruit growing region, Bay of Plenty, together with the vigorous growing habit of kiwifruit vines might limit Ca nutrition and as a consequence fruit quality at-harvest and post-harvest is potentially affected.

Three strategies were used in this thesis to increase the Ca nutritional status in 'Zesy002' vines. The main collective aim was to reduce the counteractive effect of the high supply of soil-applied K fertiliser on the availability and uptake of Ca in 'Zesy002' vines. Soil-applied Ca and K fertilisers were therefore separated either in a spatially or temporally fashion in order to increase the availability of Ca for uptake by avoiding direct ion antagonism without reducing K fertilisation rates (Chapters 3 and 4, respectively). The third strategy intended to avoid ion antagonism was to foliar-apply Ca, which involved the use of specifically target leaf and fruit directly to increase the direct absorption of Ca by leaf and fruit tissues (Chapter 5).

9.1.1 Spatial vs temporal fertiliser separation strategy

These comparisons between experiments are not made on statistical basis and presented only to discuss response of each treatment/strategy. Because of the high demand of K in kiwifruit vines it was decided not to reduce K input but instead to design and explore new methods/strategies to avoid the counteractive effect of high K on the availability and uptake of Ca in 'Zesy002' vines. To date, no research has been conducted in spatial and temporal separation of fertiliser inputs to avoid an antagonistic interaction between Ca and K in plants. Many researchers attempted to reduce the antagonistic interaction by reducing only the rate of K input.

Both spatial and temporal separation of Ca and K fertilisers increased Ca and Mg uptake by root, leaf and fruit tissues in 'Zesy002' vines (sections 3.3 and 4.3). This suggests that the counteractive effect of high K supply (up to 300 Kg K ha⁻¹) on the uptake at the soil level of Ca and Mg was reduced (Fageria, 2001; Jakobsen, 1993b). It can be concluded that by separating the Ca and K fertiliser both in a spatial and temporal fashion, the availability of Ca and Mg for uptake by root was increased, and therefore the Ca and Mg levels in leaf and fruit tissues were also increased in 'Zesy002' vines.

The spatial separation (SS) of Ca and K fertilisers also increased fruit N uptake, however the temporal separation strategy did not affect this. The not-temporal separation strategy increased fruit N uptake due to the counter-ion balance effect (Tables 4.7 and 4.13) suggesting that just one simultaneous and combined application of N, Ca and K fertilisers significantly increased fruit N uptake in 'Zesy002' vines. SS strategy further increased N uptake in leaf and fruit tissues compared to the not-temporal separation strategy. This suggests the SS treatment enhanced the synergistic interaction of N and Ca, and N and K which increased the N uptake. This is because N fertiliser was applied to both sides of the vine and all fertilisers were applied at the same time. Based on these findings, it can be suggested that in fruit crops, the spatial separation strategy could be used effectively to increase fruit Ca and/or N nutrition. This is in agreement with Hou et al., (2019) reporting that the combined application of N and K significantly increased N uptake and nutrient use efficiency in rice plants resulting in a higher grain yield. In a recent review Srivastava et al., (2019) suggested that a two-way regulatory relationship

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exists between NO_3^- and K^+ , which regulate demand, uptake, and root-to-shoot translocation of each other. Likewise, Coskun et al., (2017) reported a positive correlation between K^+ and NO_3^- and both increase acquisition of each other probably due to the improved charge balance and the activation of enzymes in the nitrate assimilation pathway by K^+ . Both NO_3^- and K^+ can be stored in large quantities in the vacuole and potentially electrically counter-balance one another and can be quickly remobilised as required by the plant. They also used the 'Dijkshoorn-Ben Zioni model' to explain that NO_3^- uses K^+ as counter-ion in order to be transported from root to shoot in the xylem (Coskun et al., 2017). Others have reported that Ca has potentially a direct and positive effect on N assimilation and promotes the uptake and N-use efficiency, in addition to activation of enzymes involved in N assimilation (Ali et al., 1991; Fenn et al., 1994; Lopez-Lefebvre et al., 2000). Similarly, Madani et al., (2013) reported that soil-applied Ca fertilisers increased N content in papaya seedlings. Aslam et al., (1995) reported that soil Ca supply increased the net NO_3^- uptake potentially by reducing NO_3^- efflux. They observed that Ca depletion increased NO_3^- efflux at acidic pH, thereby reducing net NO_3^- uptake, and this effect was reversed by the addition of Ca. Possibly Ca^{2+} is required for the maintenance of membrane selectivity for ion uptake and ion retention by plant cells. Ca^{2+} increased the net uptake of NO_3^- and other inorganic and organic solutes due to its contribution to: cation-anion balance by acting as a counter-ion and osmoregulation by acting as a secondary messenger in the cell (Epstein & Bloom, 2005; Marschner, 2012; Saito & Uozumi, 2020; White & Broadley, 2003).

The spatial separation of Ca and K fertilisers also significantly increased the photosynthetic performance compared to the not-spatial separation (Table 3.11). On the other hand, the temporal separation of Ca and K fertilisers showed no improvement in the photosynthetic performance in 'Zesy002' vines compared to the not-temporal separation treatment (Table 4.11). This suggests that the application of N, Ca and K fertilisers together at once, but in a spatially separated fashion (separation of Ca and K fertilisers) did significantly improve the photosynthetic performance. It can be suggested that the temporal strategy is less robust compared to our spatial strategy. The significance of Ca in regulating photosynthetic

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performance in plants is well-established in the literature (Brand & Becker, 1984; Hochmal et al., 2015; Hu et al., 2018; Tan et al., 2011; Wang et al., 2019a). Possibly this could be due to the synergistic effect of Ca and K on the uptake of N. Because the spatial separation strategy significantly increased the leaf NO_3^- uptake as shown in the Figure 3.3 (Cechin & Valquilha, 2019; Wang et al., 2020). The uptake of leaf NO_3^- was significantly higher in the spatial separation strategy compared to the temporal separation strategy (Figure 4.2). Even although leaf xylem NO_3^- was significantly higher in temporal separation compared to not-temporal separation strategy from 20 through to 60 DAFB, similar photosynthetic performance at 85 DAFB was observed in both temporal and not-temporal separation strategy. This suggests that the temporal separation of K fertiliser from N and Ca fertilisers has no effect on the photosynthetic performance of 'Zesy002' vines.

Both spatial and temporal separation strategies in orchard grown 'Zesy002' vines showed that the treatment differences were already established regarding Ca and NO_3^- accumulation in the leaf xylem sap and were maintained from 20 through to 60 DAFB (Figures 3.2, 3.3, 4.1 and 4.2). The accumulation of Ca in the leaf sap remained constant from 20 through to 60 DAFB. On the other hand, the accumulation of NO_3^- in the leaf sap significantly declined from 20 through to 60 DAFB, possibly due to N remobilisation from leaf to fruit tissues (Mills et al., 2008). Higher Ca and NO_3^- leaf sap values were observed in the spatial separation experiment at the Te Puke orchard compared to the temporal separation experiment at the Paengaroa orchard. This was possibly due to the low overall nutrient status and lower fertiliser input at the Paengaroa orchard (Table 9.1). In addition, a denser canopy was observed at the Te Puke orchard compared to the relatively sparse canopy at the Paengaroa orchard, possibly due to low nutrient input and possibly some nutrient deficiency in this orchard (Tables 5.3, 5.4 and 9.1). Regarding at-harvest fruit quality, both spatial and temporal separation strategies increased fruit firmness, SSC and FDM compared to not-spatial and not-temporal strategies, respectively, in 'Zesy002' vines (Tables 3.8, 3.15, 4.8 and 4.14). This suggests that increased Ca nutrition effectively improved the overall nutrient uptake and also removed the internal competition, consequently improved at-harvest fruit quality. Spatial and temporal separation of Ca and K fertilisers conducted in pot grown 'Zesy002' vines grafted on to 'Bruno' and

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'Bounty' rootstocks showed similar response in terms of nutrient uptake and at-harvest fruit quality, therefore, in this study, results from only 'Bruno' grafted pot grown vines were presented.

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Table 9.1 Comparison of the soil-applied nutrient fertiliser application rates by grower practices across NZ and by the research experiments conducted during the course of this study from 2016-2019 used in different strategies. The current grower practices, foliar Ca and foliar KNO₃ in each orchard are highlighted in grey, blue and green, respectively.

Nutrients (Kg. ha ⁻¹)	Current grower practice in each orchard							Research experiments							
	Te Puke			Paengaroa	Haumoana			Spatial & temporal	Foliar Ca			Soil-applied K	Foliar KNO ₃		
	2016	2017	2018	2016	2016	2017	2018	2017	2016	2017	2018	2016-2019	2016	2017	2018
N	126	112	126	30	37	35	35	50	50	50	50	50	50	50	50
	July, Oct & Nov	Aug	Aug & Nov	Sep	Oct			20 DABB	BB	20 DABB		20 DABB	20 DABB		
	No foliar-applied N according to our knowledge												2 Kg N ha ⁻¹ by foliar sprays (Nov-Jan)		
K	328	172	186	250	103	150	150	300	300	300	300	300	0	0	0
	July, Oct & Nov	Aug	Aug & Nov	Sep	Sep	Sep & Nov		20-60 DABB	20 DABB and FB	20 DABB		20 DABB			
	No foliar-applied K according to our knowledge												5 Kg K ha ⁻¹ by foliar sprays (Nov-Jan)		
Ca	284	72	105	50	0	0	0	200	7.4	0	0	200	7.4	7.4	7.4
	July, Oct & Nov	Aug	Aug & Nov	Sep				20 DABB	BB			20 DABB	20 DABB		
	No foliar-applied Ca according to our knowledge								5 Kg Ca ha ⁻¹ by foliar sprays (Nov-Jan)						
Mg	98	28	28	30	0	25	20	3.7	3.7	0	0	3.7	0	0	0
	July, Oct & Nov	Aug	Aug & Nov	Sep		Sep		20 DABB	BB			20 DABB			
	No foliar-applied Mg according to our knowledge														

9.1.2 Soil-applied vs foliar-applied calcium

Comparisons between these experiments are not based on statistical significance. The foliar Ca application showed higher uptake of Ca by leaf and fruit tissues compared to both soil-applied Ca strategies: spatial and temporal separation of soil Ca and K fertilisers (Tables 3.12, 3.13, 4.12, 4.13, 5.7 and 5.8). The observed and accompanied improvement in photosynthetic performance may be attributed to the direct increased leaf Ca uptake with the foliar Ca compared to the soil-applied Ca fertiliser strategies. The foliar Ca application showed similar improvements regarding at-harvest fruit quality to soil-applied Ca strategies. This is noteworthy, because the foliar Ca treated vines had not received similar quantities of soil-applied Ca as in spatial and temporal separation strategies (Table 9.1). The rate of Ca application through the foliar sprays (3-5 kg Ca ha⁻¹) was only a fraction of soil-applied Ca (200 Kg Ca ha⁻¹). Yet the improvement regarding nutrient uptake, photosynthetic performance and at-harvest fruit quality was either improved or similar compared to the soil-applied Ca fertilisation. This suggests that the foliar Ca by-passed limitations associated with the uptake of Ca at the soil-root-fruit pathway (Figure 9.1). In addition, the direct absorption of the foliar Ca through leaf and fruit tissues may have been enhanced due to structural features typical of 'Zesy002' vines such as stomata on the abaxial side of the leaf and a relatively thin and hairless fruit epidermal layer with high surface conductance. In addition, foliar Ca applications improved net photosynthesis, stomatal conductance and fruit quality attributes at-harvest in 'Zesy002' vines. This is consistent with other reports that the pre-harvest foliar Ca sprays increased fruit Ca, improved fruit quality at-harvest, reduced the incidence of physiological disorders, and delayed fruit ripening during storage in a wide range of fruit crops including strawberry, stone fruit, blueberry, pomegranate, grape, apple and tomato (Cheour et al., 1990; Crisosto et al., 2000; Davarpanah et al., 2018; Elmer et al., 2007; Gerbrandt et al., 2019; Haghi et al., 2019; Kaya et al., 2002; Lötze et al., 2008; Semida et al., 2019; Singh et al., 2007). In conclusion, fruit quality indices such as nutrient status, fruit size and firmness were potentially improved by the foliar Ca applications.

Both spatial and temporal separation strategies showed also higher Mg uptake compared to the foliar Ca in 'Zesy002' vines in the 2017/2018 season. The foliar Ca

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treated vines did not receive any soil Mg input unlike the spatial and temporal fertiliser separation strategies receiving soil Mg input through calcium ammonium nitrate formulation (Table 9.1). In the 2016/2017 season, the foliar Ca experiments also received Mg through soil-applied calcium ammonium nitrate formulation (Table 9.2). Therefore, in the 2016/2017 season, the foliar Ca treatments showed higher fruit Mg compared to the 2017/2018 season. Another possible reason may be potentially reduced counteractive effect of K fertilisation since the soil K fertiliser was applied 20-days after the application of calcium ammonium nitrate fertiliser in the 2016/2017 season. Also, fruit Ca uptake was higher in the 2016/2017 season compared to the 2017/2018 season. Possibly because a fraction of Ca was applied through soil N fertiliser formulation; calcium ammonium nitrate in the 2016/2017 season. In conclusion, the improved nutrient uptake by foliar Ca application strategy might be attributed to the leaf anatomy of kiwifruit with anomocytic stomata on the lower side of the leaf surface which makes it perfect for foliar nutrient application.

9.1.2.1 Foliar calcium and photosynthesis

Only a small change in the free cytosolic Ca^{2+} concentration can trigger signal transduction on temporal basis and is associated with downstream events of physiological processes in plants (Thor, 2019). The foliar Ca treatments were increasing Ca at leaf and fruit level and were quite likely able to generate a moderate Ca effect on stomata in Asiatic dayflower (Atkinson et al., 1989). We speculate, in our experiments foliar Ca applications caused a long-term physiological response, which is fundamentally different than increasing short-term free Ca^{2+} concentration such as stomatal inhibition.

In our study, all the foliar treatments including control received soil-applied N and K, so the increased leaf chlorophyll may demonstrate the effect of Ca nutrition either alone or in combination with N and K fertilisers. Similarly, Wasan et al., (2011) reported that application of N alone and/or in combination with Ca significantly increased leaf area and total chlorophyll compared to control in figs. Momen et al., (2015) reported addition of N, Ca and Mg increased rate of photosynthesis in sugar maple trees compared to only N or only Ca+Mg receiving trees. These results are consistent with Ahmad et al., (2016) reporting that Ca only supplied plants significantly increased total chlorophyll by 7 % and protein concentration by 9 %

than plants receiving only K. Combining both Ca and K significantly increased chlorophyll a and b, total chlorophyll, proline, protein and flavonoids concentration than Ca only and K only treated plants. They also demonstrated the combined effect of Ca and K supplementation on increasing total chlorophyll concentration by 40 % relative to control plants. Thus, the improvement in chlorophyll concentration and photosynthetic CO₂ assimilation may be due to the combined effect of Ca and K nutrition (Tables 5.5 and 5.6). The proposed combined effect needs to be tested using the foliar Ca only and the foliar K only with their respective the foliar controls under zero soil input of N, K and Ca fertilisers. The improved photosynthetic performance may be due to a strong regulatory role of Ca in both enzyme activation (Plieth, 2005; Trewavas, 2013) and photosynthesis (Mignani et al., 1995). Supplemental Ca increased the photosynthetic capacity through stomatal regulation and thus increased growth rate in *Cassia angustifolia* (Arshi et al., 2006).

9.1.2.2 Pre-harvest foliar calcium and fruit quality after storage

The foliar Ca applications significantly improved fruit quality indices such as weight loss, firmness retention, SSC, FDM after thirty-day storage at 1 °C in ‘Zesy002’ vines at the Paengaroa orchard in the 2016/2017 season (Chapter 5). In the 2017/2018 season, a storage trial (conducted by a post-graduate student at the School of Food and Advanced Technology, Massey University, Palmerston North) showed that the foliar Calbit® application increased the tensile strength compared to the foliar control (results unpublished). The effect of the pre-harvest foliar Ca applications on the long-term storage potential of the fruit needs further investigation.

9.1.2.3 Comparison of fruit quality at-harvest and after storage by foliar calcium application

The comparison shows that the foliar Ca improved fruit quality at-harvest and after thirty-day storage at 1 °C in ‘Zesy002’ vines at the Paengaroa orchard (Table 9.2). Although, both experiments were conducted during different seasons and not compared based on statistical significance, the comparison is only made to indicate the beneficial effects of the foliar Ca on nutrient uptake and fruit quality (size and firmness). Other fruit quality characteristics such as SSC and FDM were also increased. The uptake of nutrients Ca and Mg was higher in the 2016/2017 season

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compared to the season 2017/2018. This is possibly due to the additional soil Ca input in the 2016/2017 season as mentioned in the Table 9.2.

Table 9.2 Comparison of the foliar Ca experiments conducted in 2016/2017 and 2017/2018 seasons at the Paengaroa orchard regarding total nutrient fertiliser input (Kg. ha⁻¹), fertiliser formulation, nutrient uptake (mg. 100g⁻¹ DW) and standard fruit quality in each season.

Parameters	Units	At-harvest (2017/2018)		After thirty-day storage at 1°C (2016/2017)	
		Foliar Calbit	Foliar CaCl ₂	Foliar Calbit	Foliar CaCl ₂
Nutrient fertiliser input (Kg. ha⁻¹)					
Total N =Soil+foliar	Kg. ha ⁻¹	50=50+0	50=50+0	50=50+0	50=50+0
		Sulphate of ammonia		Calcium ammonium nitrate	
Total K= Soil+foliar		300=300+0	300=300+0	300=300+0	300=300+0
		Sulphate of potassium		Sulphate of potassium	
Total Ca=Soil+foliar		5=0+5	5=0+5	12.4=7.4+5	12.4=7.4+5
				Calcium ammonium nitrate	
Total Mg=Soil+foliar		0	0	3.7=3.7+0	3.7=3.7+0
				Calcium ammonium nitrate	
Fruit nutrient status (mg. 100g⁻¹ DW)					
N		580±8.9	598±14.8		
K		1554±25.6	1547±16.3	1438±7.6	1683±7.3
Ca		96±5.7	103±11.1	129±0.6	144±0.4
Mg		30±4.9	29±7.2	64±0.3	69±0.3
Standard fruit quality attributes					
Fruit fresh weight	g	132±2.8	142±7.8	143±5.7	155±4.4
Size class	-	27	27	25	22
Firmness	KgF	8.29±0.26	7.75±0.04	4.22±0.24	4.75±0.25
SSC	°Brix	7.62±0.30	7.41±0.31	13.04±0.30	12.87±0.24
FDM	%	17.3±0.1	17.2±0.2	17.7±0.4	17.1±0.3
Grade value (TZG)	%	65 (5)	65 (5)	85 (6)	65 (5)

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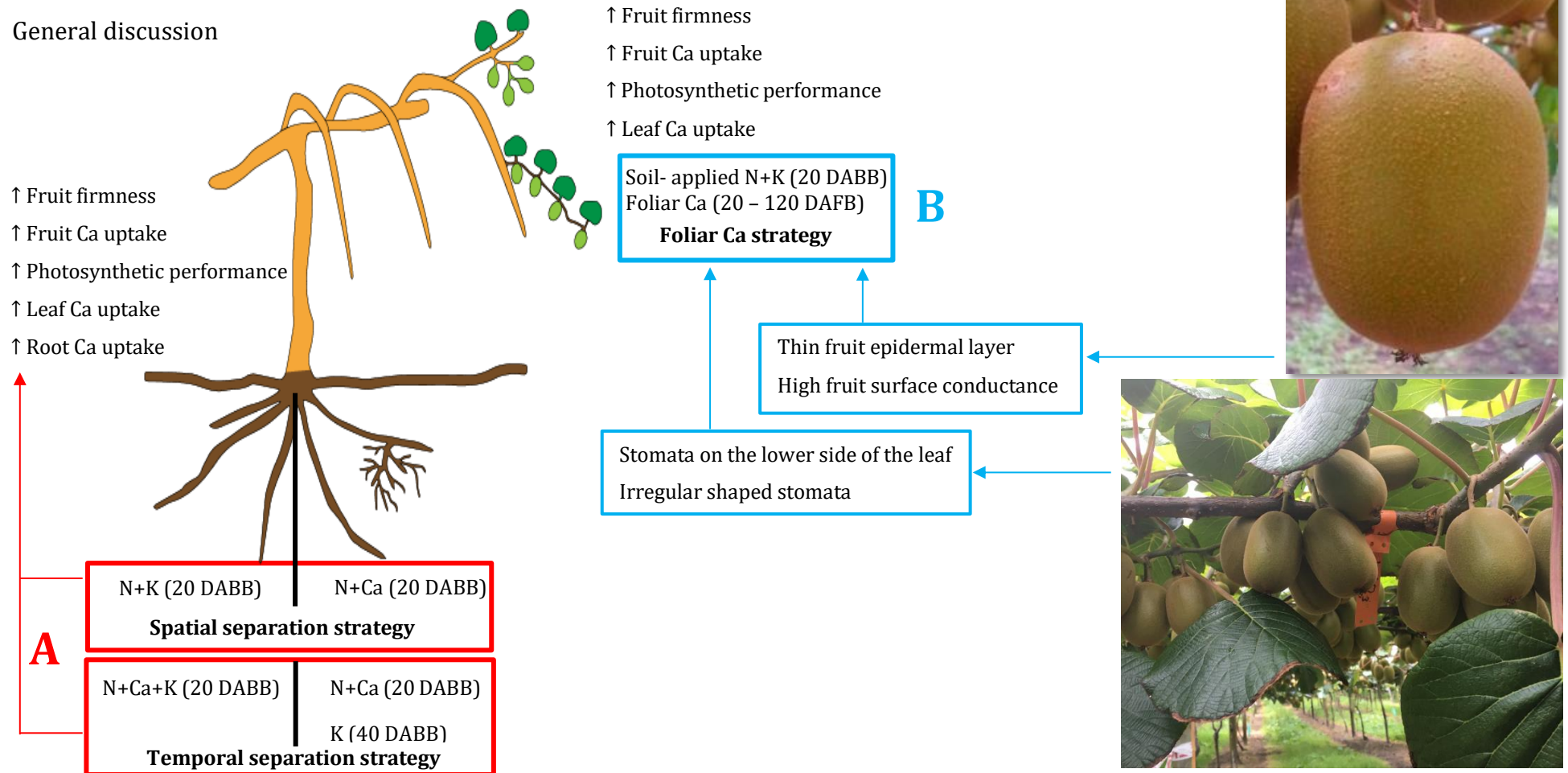


Figure 9.1 Comparison of the soil-applied Ca strategies (spatial and temporal separation of Ca and K fertilisers) to the foliar Ca strategy. With the main aim to increase Ca uptake in 'Zesy002' vines. (A) Spatial and temporal separation strategies reduced the counteractive effect of K on the uptake of Ca by root, leaf and fruit tissues in 'Zesy002' vines. Therefore, improved vine physiology and at-harvest fruit quality. (B) Foliar Ca strategy increased the direct absorption and uptake of Ca by leaf and fruit tissues due to the presence of irregular shaped stomata on the lower side of the leaf and thin epidermal fruit layer with high surface conductance. Foliar Ca strategy avoided limitations in Ca uptake from soil-root-fruit pathway. Therefore, improved vine physiology and at-harvest fruit quality with less input of soil fertilisation.

9.2 Optimising potassium nutrition

Potassium regulates stomatal conductance, enzyme activity, osmotic potential, loading of photosynthates, and therefore improves fruit sink strength (Marschner, 2012). To optimise the management of K nutrition both soil and foliar applied K fertiliser research experiments were conducted in 'Zesy002' vines grown on commercial orchards across New Zealand. Soil-applied K treatments were applied for three consecutive seasons from 2016 to 2018. Different application times (BB, FB and 70 DAFB), rates (full and split dose soil K), and the foliar fertiliser formulations (K_2SO_4 and KNO_3) in different orchards were investigated (Chapters 6, 7 and 8).

9.2.1 Soil-applied potassium

In the soil-applied K experiments, both soil N and Ca fertilisers were applied at 20 DABB in one application during the growing season (Tables 6.1 and 6.2). Soil-applied K was applied in one application either at BB or FB or 70 DAFB and in split applications at BB, FB and 70 DAFB during 2016-2019 seasons. In addition, a true control without any nutrient input was included in the experiment. First year (2016/2017) results showed certain trends but not significant. However, these responses became pronounced and statistically significant in year two (2017/2018) and year three (2018/2019) in our experiments within the research trials at three commercial orchards in the Bay of Plenty and Hawke's Bay. The statistically not significant results after year one may quite likely be attributed to high nutrient buffering capacity of the orchard soils and/or different fruit sampling size in previous seasons.

The split and early K applications at BB showed higher fruit growth rates from fruit set through to harvest compared to late K application at 70 DAFB. Both split and early K applications showed lower fruit Ca and Mg, fruit firmness, lower green flesh colour and higher fruit SSC, compared to mid and late K applications. Both groups split and early vs mid and late K are highlighted red in Tables 6.5, 6.6, 6.7 and 6.8. This demonstrates the temporal separation response and confirms the results from Chapter 4 (Tables 4.6, 4.7, 4.8, 4.12, 4.13 and 4.14), where we observed late application of K fertiliser and early application of Ca fertiliser increased leaf and fruit Ca intake and fruit firmness at-harvest. This also suggests a positive link between

fruit Ca and fruit firmness in 'Zesy002' vines. Both mid and late K applications showed higher fruit Ca and Mg, fruit firmness but lower SSC and higher green flesh colour indicating fruit immaturity compared to early and split K applications. Both split and early K applications were advancing fruit maturity compared to mid and late K. These findings suggest that application of time of soil K fertilisation has the potential to affect fruit maturity. Depending on the orchard goals, harvest windows can either be delayed or shortened by the time of soil K fertiliser application.

9.2.2 Foliar potassium formulation

A foliar K experiment was conducted in the 2016/2017 season in a commercial orchard at Haumoana, Hawke's Bay, New Zealand (Chapter 7). The main research question was to identify the best foliar K formulation for 'Zesy002' vines. The foliar KNO_3 significantly increased the source efficiency (photosynthetic performance) and source size (both leaf area and leaf number) compared to the foliar K_2SO_4 (Tables 7.6 and 7.9). Likewise, the foliar KNO_3 showed significantly higher N and K, similar Ca and Mg intake by leaf and fruit tissues during the growing season in 'Zesy002' vines (Tables 7.7 and 7.8). Morton, (2013) provided some tentative evidence on the effectiveness of foliar KNO_3 compared to foliar K_2SO_4 on the improvement of fruit quality at-harvest in 'Hayward' kiwifruit. Therefore, at-harvest fruit quality was significantly improved by the foliar KNO_3 (Table 7.10). The synergistic interaction between N and K due to the counter ion balance effect and the involvement of K as enzyme activator in nitrogen metabolism and photosynthesis (Srivastava et al., 2019) potentially improved nutrient uptake and at-harvest fruit quality in 'Zesy002' vines. Srivastava et al., (2019) suggested that a two-way regulatory relationship exists between NO_3^- and K^+ . Both regulate demand, uptake, and root to shoot translocation of each other in plants. They further suggested the use of combined N and K fertilisers would deliver beneficial effects due to counter ion balancing compared to universal NPK fertilisation. They suggested that the combined N and K fertilisation would improve returns and avoids greenhouse gases emission arising potentially due to excess N fertilisers in soils with low K status.

9.2.3 Soil-applied split potassium vs foliar-applied potassium

The foliar applied KNO_3 vines showed higher N and K uptake, fruit firmness and SSC at-harvest compared to soil-applied split K application in the growing seasons from 2016 to 2019 across New Zealand in 'Zesy002' vines (Chapters 6, 7 and 8). The foliar-applied KNO_3 received only a fraction of soil-applied fertilisation input as mentioned in Table 9.1 and yet the improvement in photosynthetic performance, and fruit quality gains were higher (Tables 9.3, 9.4 and 9.6). In addition, the foliar application is a sustainable strategy with considerably less input of soil N fertilisation therefore, reduced nitrate leaching and environmental impact than soil-applied fertilisation. Morton, (2013) quantified run-off through foliar applied urea to the soil under the vine and reported 2 % of the volume applied equivalent to a combined total of 1.8 Kg N ha^{-1} and considered it not significant as an additional N source to the vines.

In conclusion, foliar nutrient fertiliser application strategy improved the uptake of nutrients which might be attributed to the leaf anatomy of kiwifruit with anomocytic stomata on the abaxial side of the leaf increasing nutrient absorption and therefore, making it perfect for foliar nutrient application. These research findings strongly suggest that foliar nutrient fertiliser application is potentially a promising strategy to reduce the input of soil-applied nutrient fertilisers as shown in Table 9.1, in addition, nutrient uptake, photosynthetic performance and the fruit quality gains are increased (Chapters 5, 7 and 8).

9.3 Calcium and potassium in kiwifruit orchard

In soils, K is present in solution and in exchangeable, mineral and fixed forms (Figure 9.2). A large amount of K in NZ soils is fixed thus making it unavailable for plant uptake. In the kiwifruit production system, mineral K fertilisation, leaf fall and pruning, soil organic matter mineralisation increases the pool of readily-available K. Excess K fertilisation displaces Ca ions from the exchange sites of the soil colloid, which together with high rainfall events in free draining soils can cause significant Ca leaching losses. Soil Ca fertilisation during winter months in kiwifruit orchards would potentially leach out due to rainfall and could not be available for plant uptake. Kiwifruit vines have high K requirement, which is often associated with improved fruit quality (improved fruit size, high FDM and improved flesh colour).

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In kiwifruit orchards, growers traditionally apply excessive rates of K fertilisers (250-350 Kg K ha⁻¹) close to bud-break (BB) and full bloom (FB). In this study, soil K fertiliser was applied at the rate of 300 Kg ha⁻¹ from BB through to 70 DAFB. In the foliar K experiments, K fertiliser was sprayed in a series of applications from fruit set through early fruit developmental stages. Possibly, the improved at-harvest fruit quality indices such as fruit size, SSC and FDM as shown in Tables 7.10, 8.10 and 8.11 due to foliar K applications may be attributed to the continuous supply of K through to secondary growth stage.

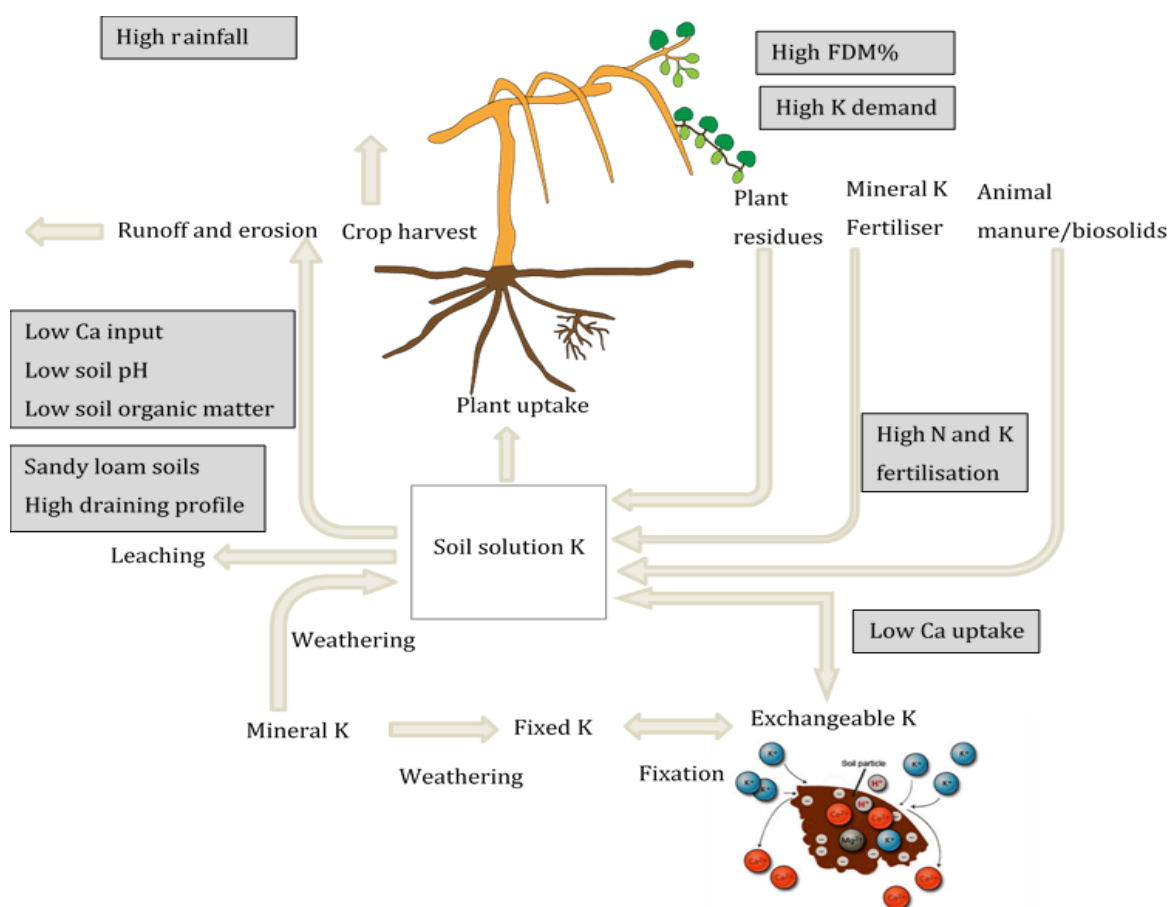


Figure 9.2 Calcium and potassium interaction in the production of kiwifruit.

9.4 Comparison to grower practices

9.4.1 Different nutrient management practices across NZ

Nutrient management practices often differ between commercial orchards across New Zealand. Even within regions, like the two commercial orchards at Te Puke and Paengaroa (both located within the Bay of Plenty region) used in our studies, contrasting nutrient management practices were observed (Table 9.1). Both Paengaroa and Haumoana orchards were using low N fertiliser application rates

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(30-37 Kg N ha⁻¹) compared to Te Puke orchard and general industry practice. Possibly to reduce N leaching losses and to control vigour. On the other hand, the Te Puke orchard was using >100 Kg N ha⁻¹ (typical industry practice of 150-250 Kg N ha⁻¹ which may potentially increase fruit softening during storage). However, leaf N was low in grower practice at 20 through to 60 DAFB. But leaf N was higher at-harvest presumably due to the additional late season N fertilisation in the Te Puke orchard in the 2017/2018 season. Regarding K fertilisation, both BOP orchards were using higher application rates (172-386 Kg K ha⁻¹) compared to the Haumoana orchard using moderate rates (100-150 Kg K ha⁻¹). Similarly, both BOP orchards were applying high Ca input (50-284 Kg Ca ha⁻¹) compared to the Haumoana orchard with zero Ca input because the Haumoana orchard soils were rich in Ca. On the other hand, BOP soils were generally deficient in overall nutrients and acidic in their native state (Molloy et al., 1998). This strongly suggests that significant orchard performance gains could potentially be achieved using informed nutrient management strategies as a tool to improve fruit quality.

9.4.2 Nutrient fertiliser strategies vs current grower practices

In each commercial orchard, research experiments were conducted with the main objectives to: (i) increase Ca nutrition, (ii) optimise K fertilisation in the leaf and fruit, (iii) reduce input of soil-applied nutrient fertilisers and (iv) improve photosynthetic performance and at-harvest fruit quality. Considering these objectives, the fertiliser application rate, timing and method were different compared to the respective grower's nutrient management practice employed in the three commercial orchards. In addition, our research focus was to increase photosynthetic performance in 'Zesy002' vines and to minimise vegetative growth later during the season. Therefore, soil N fertilisers were applied at bud-break (BB) in research experiments in each commercial orchard (Table 9.1). The N fertiliser formulation was different in both BOP orchards (calcium ammonium nitrate) than the Haumoana orchard (sulphate of ammonia). Low input of soil-applied N (50 Kg N ha⁻¹) was used contrasting to historical recommendations of 150-250 Kg N ha⁻¹ and current grower practices, which were highly variable for each orchard. In addition, the foliar urea (results not presented) and KNO₃ were used. Growers at Te Puke and Paengaroa orchards had applied N fertiliser early in July and August with highly

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varying application rates $>100 \text{ Kg N ha}^{-1}$ at Te Puke and $<50 \text{ Kg N ha}^{-1}$ at the Paengaroa orchard (Table 9.1). The BB in these orchards was typically around 2-3rd week of September. The foliar KNO_3 application rate was equivalent to $1\text{-}2 \text{ Kg N ha}^{-1}$ and was only a fraction of soil-applied N in GP in each orchard. However, fruit N uptake was significantly improved through the foliar application compared to GP in each orchard (Tables 7.8, 8.8 and 8.9). At the Te Puke orchard, leaf N concentration was 4.9 and 3.8 % DW by the foliar KNO_3 and GP, respectively (Table 8.6). Likewise, fruit N concentration at-harvest was 970 ± 5 and $698 \pm 9 \text{ mg. } 100\text{g}^{-1} \text{ DW}$ for the foliar KNO_3 and GP treatments, respectively (Table 8.7).

It is also important to note that six sprays of the foliar KNO_3 were applied from fruit set through to 70 DAFB. It could be suggested to apply N close to BB through to fruit developmental stages either in split dose through soil application or through the foliar sprays to meet the N demand of kiwifruit vines and may potentially help to avoid possible leaching risks. At-harvest fruit quality indices (Tables 3.15, 4.14, 7.10, 8.10 and 8.11) indicated that applying higher amounts of N by GP may not necessarily increase the fruit quality and production, and significant improvement in fruit quality may be achieved by fine-tuning fertiliser application timing, amount, formulation and targeted placement and complies with the concept of 4Rs (right amount, right time, right place and right formulation) nutrient stewardship (Bryla, 2020). To meet high K demand in kiwifruit vines, soil K fertilisers were applied (300 Kg K ha^{-1}) in our experiments at BB, FB and 70 DAFB either in full or split dose in the form of SOP in each commercial orchard. Likewise, soil Ca was applied (200 Kg K ha^{-1}) in one full dose in the form of gypsum. The foliar N, K and Ca were applied at regular intervals at the rate of 0.5 and 1 % in different formulations in each orchard during the growing season. Foliar nutrient fertiliser application rates were applied at merely a fraction ($2\text{-}5 \text{ Kg ha}^{-1}$) compared to the soil-applied nutrient fertilisation, yet the improvement in at-harvest fruit quality (size, firmness, SSC and FDM) was potentially higher compared to the GP and soil-applied fertilisation strategies.

9.4.3 Photosynthetic performance and nutrient uptake vs GP

Compared to grower practice (GP) each employed experimental strategy used during this study showed significantly higher photosynthetic performance and nutrient uptake in each orchard (Table 9.3). Although, photosynthetic performance

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was measured at 9:00 am to 2:00 pm on different days (due to time constraints and number of vines) by each strategy in each orchard. Table 9.3 is showing only the nutrient management strategies which were measured on the same day together with the GP in each orchard (spatial and GP at the Te Puke, temporal and GP at the Paengaroa, and the foliar KNO_3 and GP at the Haumoana orchard). It is suggested that the experimental strategies improved nutrient uptake either by reducing the negative interaction among nutrients and/or due to the direct absorption of nutrients through leaf and fruit surfaces. The improved nutrient uptake possibly contributed to improved leaf chlorophyll, and better regulated stomatal conductance and leaf transpiration. Consequently, the strategies improved net photosynthetic CO_2 assimilation. It is well-established in literature that nutrient fertilisation (N, Ca, Mg and K) alone or in combination regulates photosynthetic apparatus, stomatal conductance, transpiration, activates enzymes involved in photosynthesis and therefore, regulates photosynthetic CO_2 fixation (Hochmal et al., 2015; Hu et al., 2019; Saito & Uozumi, 2020; Tan et al., 2011; Wang et al., 2019a; Xie et al., 2020).

9.4.4 At-harvest fruit quality vs grower practice

9.4.4.1 Te Puke (2017/2018)

Compared to grower practice, nutrient input of the research experiments demonstrated bigger fruit size which pertains to less fruit count per tray, increased fruit firmness, SSC and FDM that translates to increased TZG/premium payments (Table 9.4). In addition, the green flesh colour was lowered by nutrient strategies compared to the GP. This suggests nutrient strategies: spatial separation of soil Ca and K fertiliser, the foliar Ca and the foliar K, were possibly advancing fruit maturity compared to grower practice. This emphasises that the right amount and right time of nutrient fertiliser applications have much potential to improve at-harvest fruit quality and increase orchard gate returns. Among all strategies, the highest value in fruit fresh weight (140 ± 2), FDM (18.3 ± 0.2) and lower green flesh colour (101.8 ± 0.2) was observed by the soil-applied split K application. The highest SSC value was observed by the foliar KNO_3 compared to all other strategies used at the Te Puke commercial orchard. The foliar KNO_3 application also showed higher fruit firmness compared to the GP suggesting counteractive effect of soil K on Ca uptake can be

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reduced by the foliar K. However, fruit Ca concentration was not significantly increased by the foliar KNO_3 , it could be suggested that the improved fruit firmness may be attributed to the improved cell turgidity (Thomas et al., 2008).

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Table 9.3 Comparison of the photosynthetic performance by different fertiliser nutrient input strategies to grower practices at each orchard in the 2017/2018 season in 'Zesy002' vines. The current grower practices, foliar Ca and foliar KNO₃ in each orchard are highlighted in grey, blue and green, respectively. The photosynthetic measurements were carried on the same day for GP and spatial at Te Puke, GP and temporal at Paengaroa and GP and foliar KNO₃ at Haumoana orchards.

Parameters	Units	Grower practices			Spatial	Temporal	Foliar Ca	Foliar Ca	Foliar KNO ₃		
		Te Puke	Paengaroa	Haumoana	Te Puke	Paengaroa	Te Puke	Paengaroa	Te Puke	Paengaroa	Haumoana
Leaf chlorophyll	µg. cm ⁻²	14.9±0.5	15.5±0.3	14.3±0.6	17.3±0.4	17.5±0.3	18.8±1.1	17.9±0.5	15.7±0.3	16.9±0.3	19.7±1.1
Net photosynthesis	µmol CO ₂ . m ⁻² s ⁻¹	10.09±0.28	12.88±0.40	12.47±0.54	14.17±0.22	16.15±0.37	17.15±0.24	15.95±0.09	14.03±0.25	14.94±0.48	14.67±0.48
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.17±0.01	0.17±0.01	0.20±0.02	0.30±0.03	0.22±0.01	0.42±0.02	0.44±0.04	0.34±0.02	0.20±0.01	0.23±0.02
Internal CO ₂	µmol CO ₂ . mol ⁻¹ air	270.6±8.8	243.4±5.4	265.3±2.9	271.1±8.5	243.7±2.8	298.7±3.8	303.5±5.4	284.3±4.9	240.4±4.4	267.6±3.6
Transpiration	mmol	3.29±0.24	2.64±0.09	3.78±0.19	5.10±0.35	2.95±0.09	3.05±0.11	3.65±0.20	4.57±0.21	2.97±0.06	4.46±0.21
Leaf temperature	°C	27.5±0.3	21.9±0.7	22.3±0.6	27.7±0.1	21.4±0.4	20.3±0.1	22.2±0.1	25.4±0.1	22.1±0.3	22.3±0.5

The data was not analysed statistically.

Table 9.4 Comparison of the standard at-harvest fruit quality by different fertiliser nutrient input strategies to grower practices (GP) at the Te Puke orchard in the 2017/2018 season in ‘Zesy002’ vines. The desirable improved values for each quality parameter are highlighted in yellow.

Best practice nutritional strategies			Increasing Ca nutrition		Optimising K	
Parameters	Units	GP	Spatial	Foliar Ca	Split K	Foliar KNO ₃
Fresh weight	g	123±3	133±20	133±3.6	140±2	137±4
Size class	-	30	27	27	25	27
Firmness	KgF	6.2±0.1	7.2±0.1	6.8±0.1	6.4±0.1	6.9±0.1
SSC	°Brix	8.4±0.2	10.2±0.1	10.1±0.2	10.5±0.2	10.7±0.2
FDM	%	17.3±0.1	17.6±0.1	17.7±0.2	18.3±0.2	17.6±0.1
Grade value (TZG)	%	65 (5)	85 (6)	85 (6)	90 (7)	85 (6)
Green flesh colour	°H	103.6±0.1	102.4±0.2	102.3±0.2	101.8±0.2	102.4±0.4

The data was not analysed statistically.

9.4.4.2 Paengaroa (2017/2018)

All nutrient input strategies (temporal separation of soil Ca and K, the foliar Ca and the foliar K) increased fruit size, firmness, SSC, FDM and TZG, and lowered green flesh colour compared to the GP (Table 9.5). Among all strategies used in this orchard, the foliar Ca showed larger fruit and lower green flesh colour compared to other strategies. Temporal separation of Ca and K fertilisers showed highest values for fruit firmness, SSC and FDM compared to other strategies. No soil-applied K experiment was conducted in the 2016/2017 season in this orchard as vines were converted to strip male configuration.

Table 9.5 Comparison of the standard at-harvest fruit quality by different fertiliser nutrient input strategies to grower practices (GP) at the Paengaroa orchard in the 2017/2018 season in ‘Zesy002’ vines. The desirable improved values for each quality parameter are highlighted in yellow.

Best practice nutritional strategies			Increasing Ca nutrition		Optimising K
Parameters	Units	GP	Temporal	Foliar Ca	Foliar KNO ₃
Fresh weight	g	124±1	136±2	142±8	138±2
Size class	-	30	27	25	27
Firmness	KgF	6.9±0.1	8.0±0.2	7.8±0.0	7.4±0.1
SSC	°Brix	7.2±0.4	8.1±0.0	7.4±0.3	7.9±0.2
FDM	%	16.9±0.4	17.4±0.1	17.2±0.16	17.3±0.2
Grade value (TZG)	%	45 (4)	65 (5)	65 (5)	65 (5)
Green flesh colour	°H	104.9±0.9	104.4±0.3	103.7±0.3	104.2±0.4

The data was not analysed statistically.

9.4.4.3 Haumoana (2017/2018)

Since the Haumoana orchard soils in Hawke's Bay were rich in Ca (Tables 6.3 and 7.4) and no Ca deficiency was observed in 'Zesy002' vines therefore, no soil-applied strategy was used to increase Ca nutrition. The foliar Ca was used only to investigate the beneficial effects on Ca rich soils in seasons 2017/2018 and 2018/2019 (results briefly presented in Chapter 5).

All experimental strategies showed larger fruit size, SSC and lower green flesh colour compared to the GP at the Haumoana orchard (Table 9.6). The foliar Ca showed higher fruit firmness value compared to other strategies used in this orchard. Soil-applied split K showed higher SSC, FDM, TZG, and lower green flesh colour value compared to other nutrient management strategies used in this orchard. Amongst all the commercial orchards, the highest value of fruit firmness was observed by the foliar Ca at the Haumoana orchard. This suggests beneficial additional effects of Ca nutrition in terms of fruit firmness could be substantially increased even at Ca rich orchard soils.

Table 9.6 Comparison of the standard at-harvest fruit quality by different fertiliser nutrient input strategies to grower practices (GP) at the Haumoana orchard in the 2017/2018 season in 'Zesy002' vines. The desirable improved values for each quality parameter are highlighted in yellow.

Best practice nutritional strategies			Increasing Ca nutrition	Optimising K	
Parameters	Units	GP	Foliar Ca	Split K	Foliar KNO ₃
Fresh weight	g	112±4	129±3	134±0.3	134±2
Size class	-	33	27	27	27
Firmness	KgF	8.9±0.0	9.4±0.1	8.8±0.1	9.1±0.1
SSC	°Brix	5.3±0.1	5.4±0.1	5.8±0.2	5.5±0.1
FDM	%	17.4±0.3	17.1±0.1	17.7±0.3	17.2±0.1
Grade value (TZG)	%	65 (5)	65 (5)	85 (6)	65 (5)
Green flesh colour	°H	108.8±0.6	107.1±0.5	105.9±0.9	107.5±0.4

The data was not analysed statistically.

It can be suggested that the nutrient management strategies used in our research could potentially increase \$12,000 to \$20,000 per hectare of income for the grower based on the estimate by Snelgar et al., (2012) per gram increase in fruit weight.

9.5 Mechanisms

The different nutrient management strategies employed in this study significantly increased nutrient uptake in 'Zesy002' vines. The increased nutrient uptake (N, Ca, Mg and K) may have improved ion balance, water uptake, photosynthetic performance, transpiration, carbohydrate metabolism, protein synthesis, assimilate translocation, turgidity, phloem loading/unloading and sugar accumulation into fruit tissues (Figure 9.3) (Epstein & Bloom, 2005; Hepler, 2005; Hu et al., 2019; Marschner, 2012; Saito & Uozumi, 2020; Shen et al., 2017; Srivastava et al., 2019; White & Broadley, 2003). In kiwifruit, a strong positive correlation was reported between fruit Ca and auxin (Sorice et al., 2011). The increased fruit Ca potentially transduced auxin and cytokinin signals and therefore, increased cell division and cell expansion (Gao et al., 2019). The increased fruit Ca may have been potentially stored in cell wall as Ca-pectate thereby increasing fruit firmness (Hocking et al., 2016; Poovaiah et al., 1988). The improved fruit firmness may help reducing incidence of disease/pest therefore, potentially improving fruit storage quality (and delaying fruit softening). The interlocked Ca-pectate in fruit cell walls may potentially inhibit the production of ethylene during storage hence, increasing storage life of the fruit (Hocking et al., 2016; Poovaiah et al., 1988).

9.5.1 Increased Ca nutrition due to soil-applied spatial and temporal separation of Ca and K fertilisers

It is suggested that the counteractive effect of K on the uptake of both Ca and Mg was potentially significantly reduced therefore, elevated Ca nutrition in leaf and fruit of 'Zesy002' vines (Fageria, 2001; Jakobsen, 1993b; Johansen et al., 1968b). In addition, the synergistic interaction between Ca and N due to counter ion balance effect potentially increased N uptake (Wright, 2005). The root Ca and Mg concentration was increased and possibly due to increased transpiration, Ca and Mg were translocated via xylem to leaf and fruit tissues (Figure 9.3) (Ding et al., 2006; Domagała-Swiatkiewicz et al., 2019; Fageria, 2001; Garcia et al., 1999; Jakobsen, 1993b; Morton et al., 2008; Rhodes et al., 2018). The increased leaf N possibly potentially increased leaf chlorophyll concentration and rate of photosynthesis (Bassi et al., 2018; Hikosaka & Terashima, 1995). The improved photosynthetic performance possibly translated to increased photosynthates and their

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translocation from leaf to the fruit (Trankner et al., 2018; Wang et al., 2018a). Possibly the increased carbohydrate metabolism, starch synthesis and sugar accumulation might potentially increase fruit SSC and dry matter accumulation (Bybordi & Shabanov, 2010; Marschner, 2012). The increased fruit N, Ca and Mg might potentially increase cell turgidity, Ca-pectate and therefore, increased fruit firmness at-harvest (Demarty et al., 1984; Hocking et al., 2016).

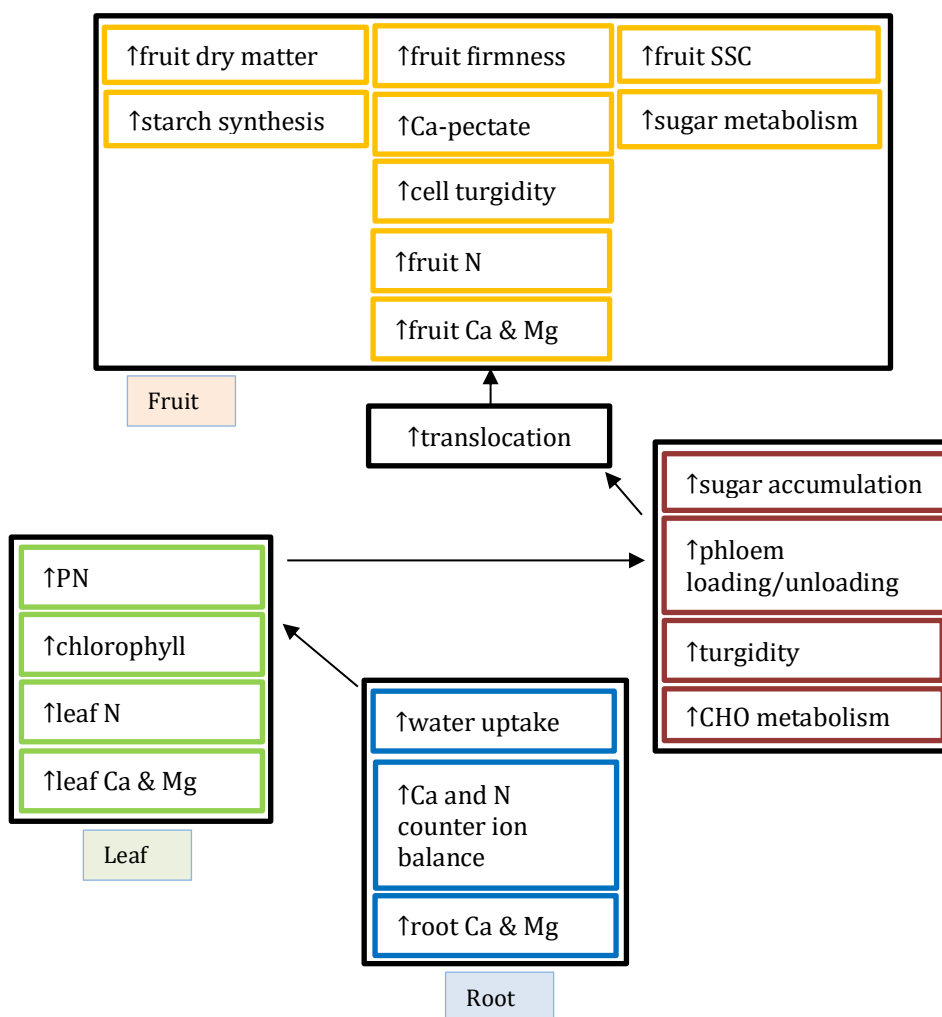


Figure 9.3 Illustration of mechanisms involved in improving photosynthetic performance and at-harvest fruit quality by increasing Ca nutrition in the root, leaf and fruit due to spatial and temporal separation of Ca and K fertilisers at soil level. Mechanisms at root level shown in blue, at leaf level in green, at fruit level in orange and physiological processes shown in maroon coloured shapes.

9.5.2 Increased Ca nutrition due to foliar Ca application

It is suggested that the foliar Ca applications increased leaf Ca concentration that enhanced leaf chlorophyll concentration, leaf transpiration and stomatal conductance, therefore, rate of photosynthetic CO₂ assimilation increased (Figure

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9.4) (Wang et al., 2019b). The increased fruit Ca either due to the direct foliar Ca absorption through relatively thin fruit epidermal layers and/or due to increased translocation from leaf to the fruit potentially increased Ca-pectate and/or cell turgidity and therefore, improved fruit firmness at-harvest (Buchanan et al., 2015; Faust, 1989; Hirschi, 2004; Kou et al., 2015; Naradisorn et al., 2004; Poovaiah, 1986). The increased fruit size from fruit set through to harvest may be attributed to the hormonal signalling effect of Ca on growth hormones such as cytokinin and auxin and potentially increased cell division and cell expansion (Sorice et al., 2011).

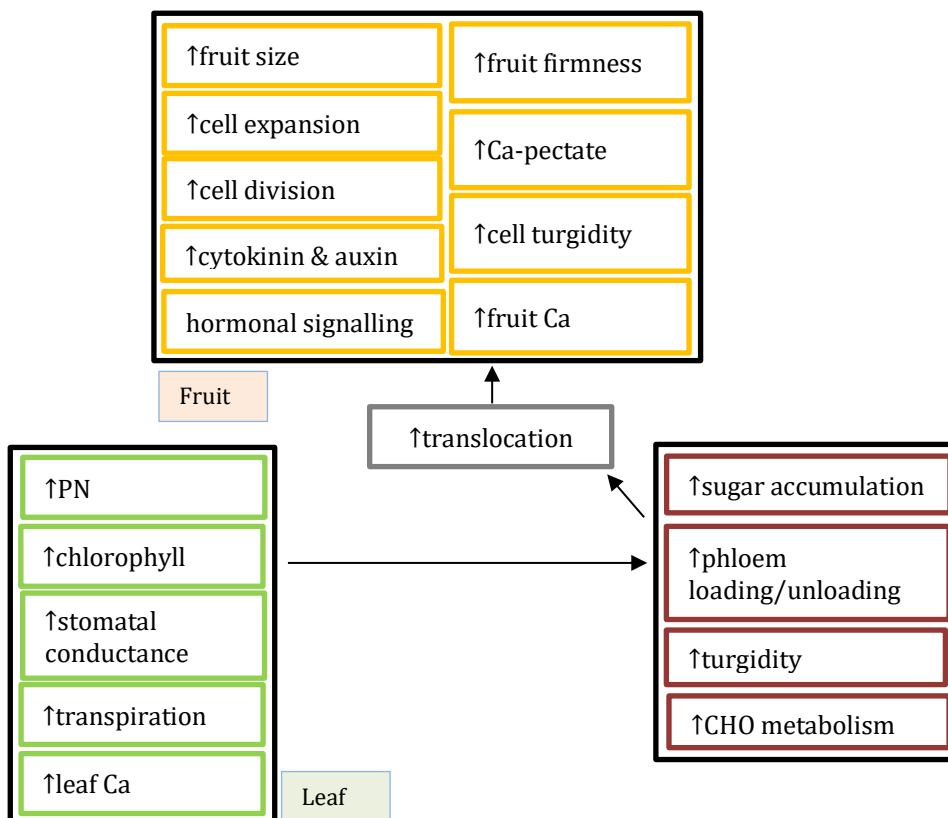


Figure 9.4 Illustration of mechanisms involved in improving photosynthetic performance and at-harvest fruit quality by increasing Ca nutrition in the leaf and fruit due to pre-harvest foliar Ca application. Mechanisms at leaf level shown in green, at fruit level shown in orange and physiological processes shown in maroon coloured shapes.

9.5.3 Increased N and K nutrition due to foliar KNO_3 application

It could be suggested that the foliar KNO_3 applications during fruit growth and developmental stages increased N and K uptake in leaf and fruit tissues. The foliar KNO_3 potentially increased leaf N and K concentration, leaf chlorophyll, leaf transpiration and stomatal conductance (Figure 9.5) (Srivastava et al., 2019). Therefore, the net photosynthetic CO_2 assimilation was increased by the foliar KNO_3

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compared to the not sprayed/unfertilised treatment (Barzegar et al., 2020; Hu et al., 2019; Xie et al., 2020). Possibly the translocation of photosynthates and N and K increased from leaf to the fruit. Therefore, fruit N and K concentration was increased. The increased fruit SSC may be attributed to the increased starch synthesis and sugar metabolism in the fruit. The increased fruit K might improve cell turgidity and therefore, fruit firmness was improved (Thomas et al., 2008). It is important to note that the foliar KNO_3 had no effect on Ca and Mg concentration in the leaf and fruit tissues. The increased fruit growth rate from fruit set through to harvest suggest increased phloem unloading into the fruit potentially regulated by K. Increased fruit K possibly improved ion balance, cell turgidity and sugar import into the fruit tissues thereby, increased fruit SSC. Shen et al., (2017) documented that increasing K fertilisation induced hormonal signalling, regulated reactive oxygen species (ROS), K uptake and sugar/acid metabolism in leaf and fruit tissues during fruit development and maturation stages in pear. They reported that low K fertilisation directly reduced nutrient uptake, growth and development and affected metabolic pathways in leaf and fruit tissues. As a result, downregulated the expression of genes involved in K transporters and channels, sugar metabolism. The long-term low K fertilisation resulted in reduced sugar metabolism in fruit tissues. High K improved leaf photosynthesis and increased nutrient and carbohydrate translocation from leaf to fruit tissues. They demonstrated the mechanistic regulation of some genes involved in improving fruit quality by supplying K fertilisation (Shen et al., 2017).

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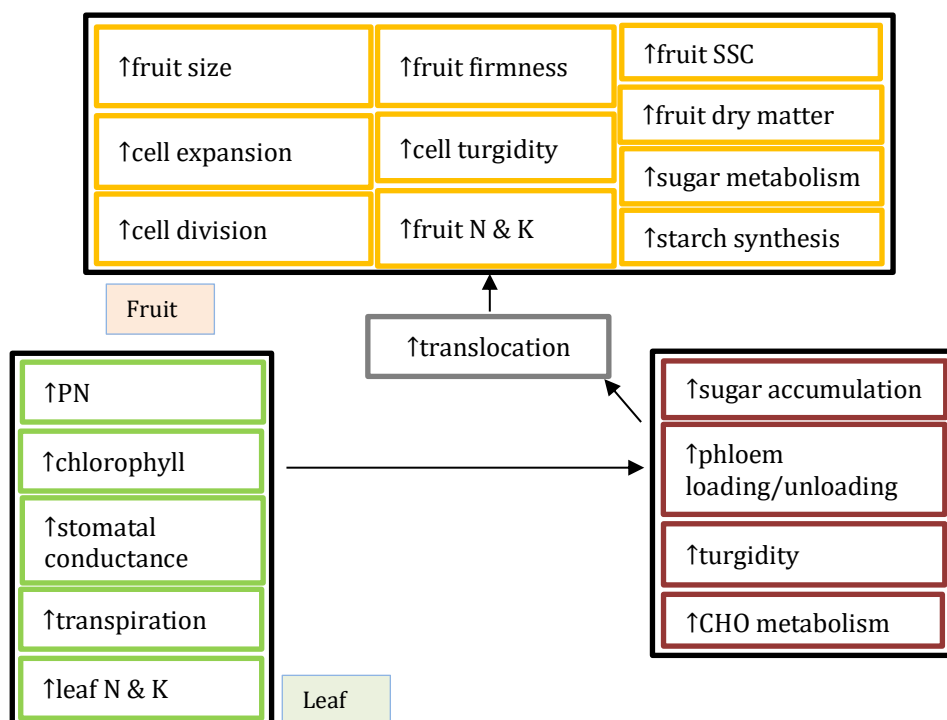


Figure 9.5 Illustration of mechanisms involved in improving photosynthetic performance and at-harvest fruit quality by increasing N and K nutrition in the leaf and fruit due to pre-harvest foliar KNO_3 application. Mechanisms at leaf level shown in green, at fruit level in orange and physiological processes shown in maroon coloured shapes.

9.6 Research implications

These findings could be easily applied in the orchard, either spatial or temporal separation of Ca and K fertilisation, or the use of supplementary foliar Ca and K fertilisation could be very easily adapted to the existing fertilisation programs. For example, fertiliser spreaders could be modified to side dress K to the weed-strip or broadcast K to alternate rows, while Ca could be broadcast over the whole orchard floor. Temporal separation strategy could also be easily applicable in the orchard by applying Ca fertiliser at BB and delay application of K fertiliser until closer to full bloom. Foliar Ca and K applications could also be easily included in early season spray programs.

The research findings of this study have significant implications to establish early canopy and photosynthetic CO_2 fixation in different kiwifruit cultivars such as 'Zesy002', 'Red19' and 'Hayward'. The research is applicable in horticultural fruit crops aimed to increase N and Ca nutrition. In addition, harvest window could be shortened or delayed by optimising soil K fertilisation.

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The foliar macro nutrient application at low levels appears to be a promising target specific fertilisation method in horticultural fruit crops. In addition, orchard managers should implement a specific soil- and foliar applied nutritional programs as a robust tool to increase fruit yield (number and size) and improve fruit quality (high fruit dry matter and firmness) at-harvest with long-term storage potential. The targeted nutrition could potentially improve vine physiology (nutrient uptake, photosynthetic performance and hydraulic response), fruit physiology (fruit growth rate, starch synthesis, sugar metabolism, and nutrient and dry matter accumulation) during the growing season. It could potentially reduce pest and disease incidence and physiological disorders (pre and post-harvest). In addition, the fruit maturity could be advanced along with fruit quality gains (fruit size, soluble solids and dry matter). The storage potential of the fruit (reduced rate of fruit softening) may be improved. Targeted nutrition might potentially improve sustainability through reduction in nutrient input and leaching losses. Consequently, the orchard gate returns are increasing.

9.6.1 Future research recommendations

Future research is recommended to investigate effects of these experimental strategies on vine physiology (photosynthesis, hydraulic conductance and uptake and translocation of macronutrients) and fruit quality at- and post-harvest in orchards following the general industry recommended nutrient management practices. Since orchards selected in this study were not the representative of the general standard industry or typical grower practice.

In this study research work was conducted on relatively low N soils and there is need to verify this work on higher N soils. It is important to investigate, if the improvement in photosynthetic performance, nutrient uptake and fruit quality could be achieved in high N soils. There is immediate need to further demonstrate the work done in this study on a larger scale with 'Zesy002', while revisiting this new knowledge in 'Hayward', in orchards with varying soil nutrient baselines such as low and high N soils. There is also a need to test the effectiveness of reduced fertiliser nutrient input on the shoot vigour which mainly competes with fruit for C and also increases pruning costs. This study has shown that early and split soil K fertiliser applications advanced fruit maturity in 'Zesy002' kiwifruit, therefore, it is

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recommended to investigate the effect of application time of soil K fertiliser on fruit maturity in other cultivars. This study has also shown that it is possible to significantly elevate fruit Ca concentration in the fruit, however, the effectiveness of elevated fruit Ca on the storage potential of the fruit needs to be tested.

For future research work it is recommended to integrate soil and foliar applied strategies and also incorporate other nutrients such as Mg, Mn and Zn to further optimise nutrient uptake, vine physiology and fruit quality indices such as fruit size, firmness, soluble solids, dry matter and colour development during the growing season, at-harvest and during storage. To quantify the effect of nutrient fertiliser input on the soil characteristics, leaching potential, vine physiology and fruit quality, it is recommended to monitor soil physical and chemical properties, macro and microclimate in the orchard, vine physiology such as photosynthetic efficiency, hydraulic conductance and nutrient uptake, xylem and phloem sap, fruit growth rate, water uptake and dry matter accumulation after fruit set through to harvest. It is recommended to monitor and quantify the concentration and activity of hormones such as cytokinin and auxin both at cellular and organ level. In addition, monitoring the fruit quality characteristics such as water loss, fruit firmness, ethylene production, soluble sugars, fruit dry matter and nutrient concentration during the long-term storage is also recommended. Further research would help understand the physiological response of these strategies in varying conditions, with the potential to be used as a key tool to increase production of high-quality fruit with less fertiliser input and environmental risks in a sustainable fashion.

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Appendix 1
Plant Science Central Conference
“Plants in a Changing Environment”

Massey University, 4 – 6 July 2017



Please **indicate**: Oral Presentation Poster

Current challenges in ‘Zesy002’ kiwifruit nutrient management research

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Key Words Kiwifruit, Nutrient Management, Gold

The current nutrient management practices for Gold (G3) need to be optimized in a sustainable manner to potentially improve fruit production with an assurance of high-quality standards and minimal impact on environment. This study will take into consideration the current nutrient management practices and is aimed to manage vine growth and develop best nutrient management practices to optimize fruit quality and production and preserve environmental quality with cost-effective inputs. It needs profound understanding of source-sink relationship, effective application methods for different nutrients and their interaction, environmental impact and cost efficiency. The paper will focus on the role of nitrogen (N) and potassium (K) and their interaction with other Calcium (Ca) on nutrient uptake and availability, vine growth and quality of fruit. Specifically, this paper will discuss the effect of different forms, rates, and timing of application of soil and foliar applied N, K and Ca fertiliser on production and fruit quality. The paper will also discuss the nutrient budgeting and approaches to minimize environmental footprints.

Appendix 2

Symposium

School of Agriculture and Environment November 2018

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Abstract

The sustainable production of high-quality fruit is the primary concern for the kiwifruit industry of New Zealand to maintain its position in the competitive global market. A gold kiwifruit variety 'SunGold' has received much praise especially in the European market for its sweet and juicy taste, after its launch in a wake to survive the aftermath of a bacterial disease. The current project was designed to find the best nutrient management practices for the sustainable production of high quality 'SunGold' kiwifruit at harvest. The trials were conducted in commercial orchards with contrasting characteristics located in Bay of Plenty, Hawke's Bay and Palmerston North. Different rates, time and method of nutrient application were evaluated. This manuscript will provide an insight to the nutrient application strategies specifically designed to address the particular nutrient management issue and also to attain optimum production of quality fruit at harvest. The highlights from different strategies adopted for the past two years will be presented and discussed.

Key Words: SunGold, nutrient management, fruit quality, at harvest

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Appendix 3
Plant Science Central Conference
“Plants for a Brighter Future”

Massey University, 2 – 4 July 2019



Please **indicate**: Oral Presentation Poster

Which foliar potassium fertiliser improves fruit growth and quality of ‘Zesy002’ kiwifruit at-harvest?

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Key Words: Foliar Potassium, Nutrient Management, Fruit Quality, Zesy002, Kiwifruit

Abstract

This study was aimed to answer a key question: which foliar potassium (K) fertilisers efficiently provide K to kiwifruit vines? The role of external K application to increase acquisition and absorption of mineral nutrients in horticultural crops is well established. Potassium increases photo-assimilate translocation from source-to-sink and consequently improves fruit quality at harvest and is sometimes referred to as the “quality nutrient”. The experiment was conducted on a commercial orchard in 2016 in Haumoana, Hawke’s Bay. We used foliar potassium nitrate (KNO₃) and potassium sulphate (K₂SO₄) at an application rate of 1% K (w/v, pH 5.5) along with a buffer control. The foliar treatments were hand sprayed seven days before full bloom and repeated five times at an interval of ten days. Foliar treatments were applied to selected canes on each vine in a randomised block design with ten replicates. The results showed that foliar KNO₃ fertiliser significantly increased size, count and chlorophyll content of the leaf and net

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photosynthesis and significantly increased leaf nutrient content 60 and 132 days after full bloom compared to K_2SO_4 and control. Both K fertilisers significantly increased leaf nutrient content compared to before foliar application. Foliar KNO_3 significantly increased fruit fresh weight, firmness, dry matter content and nutrient content of Zesy002 kiwifruit at harvest compared to foliar K_2SO_4 . It can be concluded that foliar KNO_3 improved nutrient acquisition and utilisation and photosynthetic response of the kiwifruit vine and efficiently increased sink size and strength, assimilate production and translocation from source to sink. As a consequence, fruit quality at harvest was significantly improved.

Appendix 4

Foliar boost for Zesy002

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Background

Foliar application of fertilisers can facilitate target-specific fast nutrient absorption and assimilation. This will help with deficiencies or boost nutrients in periods of high demand by the plant. The use and potential benefits of foliar applications in kiwifruit are relatively unknown yet foliar applications have the potential to further optimise nutritional inputs to developing fruits. Foliar applications as a form of precision horticulture has high potential for improving sustainable practises with benefits to the environment by reducing nutrient leaching losses (Bindraban et al., 2015; Fageria et al., 2009).

This study investigated the application of potassium nitrate (KNO_3) which delivers two macro nutrients (K&N) to the plant: (i) Potassium (K) strongly influences fruit size, firmness, sugar content, and dry matter thus sometimes referred to as “quality nutrient” in fruit crops. As fruit growth progresses, developing fruits turn into strong sinks for potassium and competes with other sinks, like leaves. If soil-applied potassium is limited during fruit maturation stage this may limit translocation and utilisation of other nutrients and assimilates into kiwifruit vines. Therefore, fruit potassium concentration (K %) is important to maintain the fruit quality in kiwifruit at-harvest. (ii) The second macro nutrient, nitrogen (N) is well established to increase the rate of photosynthesis and yield. The external application of nitrogen fertilisers is documented to increase vegetative growth and fruit size in kiwifruit. However, increased vegetative growth often competes with fruits and reduces dry matter accumulation into the fruit and negatively affects fruit quality.

This study was conducted to determine the effectiveness of foliar potassium fertiliser applied after full bloom on nutrient acquisition, photosynthetic response and at-harvest fruit quality in ‘Zesy002’ kiwifruit.

Methods

The experiment was carried out on a commercial orchard in the 2017/2018 season in Te Puke, Bay of Plenty. The orchard was on typical Te Puke loam soils with no

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irrigation. The targeted crop load was 60 fruit m⁻². Foliar potassium nitrate was applied at a rate of 1% K (w/v, pH 5.5) along with a buffer-only control. Foliar treatments were applied fourteen days after full bloom and repeated five times at an interval of seven to ten days. Foliar treatments were applied to selected canes till runoff on each vine in a randomised block design with ten replicates. For comparison, leaf and fruit samples were taken from vines next to research block under current grower's management practices, termed as 'grower practice' and also received soil fertilisers mentioned in (Table 1).

Table 1 Soil and Foliar nutrient fertiliser application rate (Kg. ha⁻¹) and time of application.

Nutrients (Kg. ha ⁻¹)	*Grower		**KNO ₃ foliar		Control foliar	
	Soil	Foliar	Soil	Foliar	Soil	Foliar
N	112 Aug	0	50 Sep	1.64 Nov-Jan	0	0
K	172 Aug/Nov	0	0	4.57 Nov-Jan	0	0
Ca	72 Aug	0	7.4 Sep	0	0	0
Mg	28 Aug	0	0	0	0	0

*- The forms of fertiliser used by the grower were; Sulphate of potassium, Gypsum, Dical8, Ammonium sulphate nitrate, Iron sulphate, Zinc sulphate, Brimstone sulphur, Kieserite.

** - The forms of fertiliser for the foliar treatment were; calcium ammonium nitrate for the soil and potassium nitrate for the foliar.

Thirty fruit samples were taken randomly from each replicate a day before commercial harvest at 163 days after full bloom. Statistical analysis (ANOVA) was carried out with the help of IBM SPSS Statistics 24 version.

Results

Foliar-applied potassium nitrate fertiliser significantly increased leaf size, chlorophyll content, stomatal conductance and net photosynthesis compared to grower practice and foliar control (Table 2). There was also some mild leaf burning on the marginal drip edges of some leaves in the foliar K treatment. Any burned area was not included in the leaf area calculations, and the effect is shown in (Figure 1b).



Figure 1 The visual effects of (a) foliar control and (b) foliar-applied potassium to ‘Zesy002’ vines 43 days after full bloom in commercial orchard in Te Puke, Bay of Plenty. Note: some marginal leaf burns in the foliar K treatment.

Both leaf and fruit nutrient results showed that the foliar-applied potassium nitrate significantly increased leaf and fruit nitrogen (N %) and potassium (K %) compared to grower practice and the foliar control.

Table 2 Effect of the foliar treatments on leaf characteristics, photosynthetic performance, and leaf and fruit nutrient status in ‘Zesy002’ kiwifruit. Values are averages with standard errors, n=10. Differences are considered significant at $P<0.05$. Different letters beside values within rows denote significance at $P<0.05$ for each parameter.

Parameters	Units	Grower	KNO ₃ foliar	Control foliar
Leaf size	cm ²	103.7±7.0 b	114.4±5.0 a	101.9±6.7 b
Leaf chlorophyll	µg. cm ⁻²	14.9±0.5 b	15.7±0.3 a	11.5±0.5 c
Net photosynthesis	µmol CO ₂ . m ⁻² s ⁻¹	10.1±0.3 b	13.8±0.2 a	10.1±0.3 b
Stomatal conductance	mol H ₂ O. m ⁻² s ⁻¹	0.17±0.01 b	0.28±0.02 a	0.19±0.03 b
Leaf N	% DW	3.80±0.10 b	4.94±0.09 a	2.10±0.12 c
Leaf K		2.70±0.06 b	4.56±0.05 a	1.85±0.04 c
Fruit N	mg.100g ⁻¹ DW	698±10 b	970±5 a	515±8 c
Fruit K		1357±35 b	1570±19 a	1285±29 c

At-harvest results showed that the foliar-applied potassium nitrate significantly increased fruit quality compared to grower practice and the foliar control (Figure 2). The foliar potassium nitrate significantly increased both fruit fresh weight and firmness by 11 % and significantly increased soluble solids content (SSC) by 26 % compared to grower practice. Fruit dry matter (%) was in a similar range of 17.4-17.5 for all treatments.

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In contrast to the KNO_3 foliar treatment, the control foliar treatment had decreased chlorophyll, leaf and fruit N and K compared to grower practice. In addition, fresh weight was also down in these fruits.

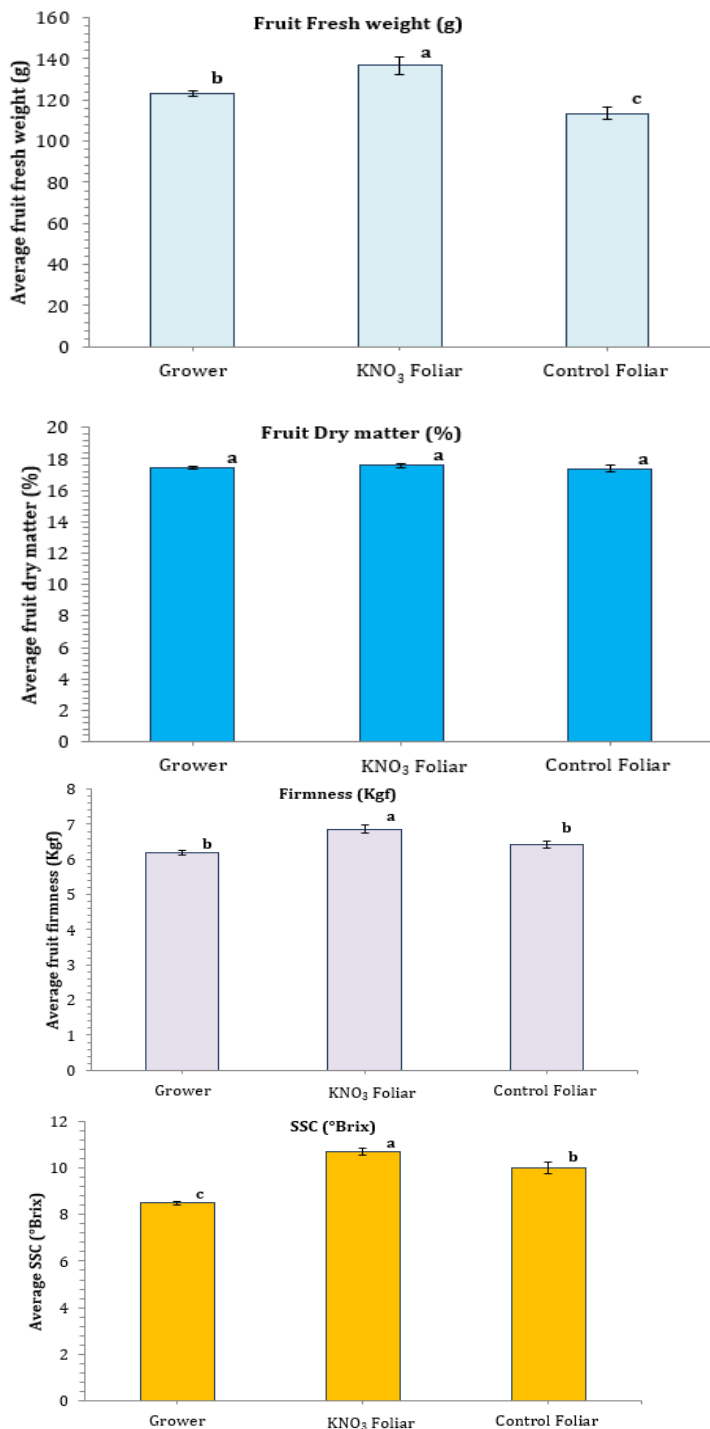


Figure 2 Standard fruit quality at-harvest in 'Zesy002' vines. Values are averages, $n = 10$, fruit = 30. SSC is soluble solids concentration. Differences are considered significant at $P < 0.05$. Different letters beside columns denote significance at $P < 0.05$ for each parameter.

Discussion

The vines in the KNO₃ foliar treatment received only a fraction of the fertiliser that was received by grower practice. Yet the foliar application of potassium nitrate early in the growing season increased critical factors like leaf area and photosynthetic rate in the leaves of the treated vines. This translated into increased fruit size, firmness and SSC at-harvest. There was no significant difference in dry matter, but the treatment did support a net increase in productivity compared with both grower practice and the foliar control.

This study supports the strategy of supplementing existing nutrient management practices with the foliar applications. The changes in photosynthetic rate in the leaves was highly significant and is questionable if high rates of fertiliser applied via the soil could achieve this sort of result.

One of the main advantages of the foliar fertiliser application is the possibility of reducing the overall application of fertiliser leading to more sustainable practices and improving environmental outcomes due to lower leaching rates of nutrients. We have additional trials that are currently being analysed and they appear to further support these results. The use of the foliar fertilisers in kiwifruit is a promising strategy to improve the at-harvest fruit quality.

Future recommendations

For future research we like to investigate effects of the foliar potassium application at a larger scale on contrasting orchards (low and high nitrogen status) on photosynthetic response and at-harvest fruit quality in 'Zesy002' vines. Further long-term storage trials will help to assess the effectiveness of these treatments on postharvest quality.

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