Storage Potential of Kiwifruit from Alternative Production Systems

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Abstract

The effects of nine soil treatments on the storage potential of 'Hayward' kiwifruit were examined over three consecutive seasons at sites in Palmerston North and Te Puke, New Zealand (NZ). The treatments comprised three ground covers (*viz.* bare, grass and mulch), in factorial combination with three fertiliser regimes (*viz.* conventional, organic and organic plus (= organic + gypsum)). Each season, several fruit and vine attributes were measured at harvest and the subsequent softening behaviour of fruit was evaluated during storage. In the second and third seasons, several soil, fruit and vine attributes were also monitored before harvest. At both sites, significant and consistent differences were observed in many of the soil attributes that were measured. In particular, conventional plots often contained more inorganic nitrogen (N) and potassium (K) than organic and organic plus plots while organic plus plots nearly always contained more calcium (Ca) than conventional plots. Bare soil consistently contained less moisture, and experienced higher 2.00 pm and lower 6.00 am temperatures, than covered soil, while the mulch increased the surface rooting of vines. The soil amendments also had some consistent, though not statistically significant, effects on the mineral composition of vines, especially in the third season. In particular, fruit and leaves from conventional plots tended to contain more N and K but less Ca than those from organic and organic plus plots while fruit and leaves from grass plots consistently contained less N than those from bare and mulch plots. Of all the soil amendments, grass had the largest effect on fruit storage behaviour i.e. fruit associated with that amendment were consistently firmer throughout storage and developed significantly less soft patches than fruit from bare and mulch plots. Although fruit from conventional plots tended to soften slightly more rapidly and develop more soft patches than fruit from organic and organic plus plots, the differences were never significant. Generally, soil, vine and fruit attributes did not differ significantly with the interaction of ground cover and fertiliser regime.

In addition to the above work, in 1996 only, fruit were sampled from ten pairs of organic and conventional (i.e. Kiwigreen) orchards throughout the Bay of Plenty in NZ, to compare the responses of those fruit to typical postharvest handling and storage regimes and their compositional attributes. Generally, fruit from conventional orchards were harvested more mature, as indicated by soluble solids concentrations (SSC), although the average firmness of fruit from the two systems did not differ significantly. The average concentrations of N, K, magnesium (Mg) and phosphorous (P) in fruit did not differ significantly with production system. However, organic fruit often contained

more Ca with the average difference being on the borderline of significance. Despite differences in maturity, whole fruit softening did not differ significantly with production system. On the other hand, fruit from organic orchards nearly always developed less soft patches than fruit from conventional orchards with the average difference being significant. This difference may have been partly due to the difference in the Ca concentration of fruit. Typical postharvest handling practices, compared to harvesting directly into trays, did not significantly affect whole fruit softening but did significantly decrease the incidence of soft patches, for reasons that are not clear. Across all the grower lines, the incidence of soft patches was significantly and negatively associated with the average concentrations of Ca in fruit. Combinations of other fruit attributes (i.e. SSC, initial firmness and the concentrations of N and Mg) with Ca concentration, produced indicators that were very strongly associated with the incidence of soft patches. These attributes would appear to be important in the development of soft patches. If these relationships are subsequently shown to be consistent, then they could form the basis for a predictive tool that would allow at-harvest segregation of fruit lines with different storage potentials.

In all of the current work, fruit that developed soft patches consistently contained less Ca than healthy fruit. It therefore seems that enhancing the Ca content of fruit could be beneficial to fruit storage life. However, it appears that under some conditions at least, the uptake of minerals, particularly Ca, may be constrained at the root level and so manipulating the soil environment may not always guarantee an improvement in the storage potential of kiwifruit.

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Table of Contents

List of Figures

Chapter 2 Literature Review

Chapter 3 Soil Amendments and the Storage Potential of Kiwifruit

Chapter 4 Pairwise Comparison of the Storage Potential of Organically and Conventionally Grown Kiwifruit

Chapter 5 General Discussion

List of Tables

Chapter 2 Literature Review

Chapter 3 Soil Amendments and the Storage Potential of Kiwifruit

List of Symbols and Abbreviations

- SP	=	without soft patches
µL	=	microlitre
[Ca]	=	calcium concentration ($mmol.kg^{-1}$)
[K]	=	potassium concentration ($mmol.kg^{-1}$)
[Mg]	=	magnesium concentration ($mmol.kg^{-1}$)
[N]	=	nitrogen concentration ($mmol.kg^{-1}$)
[P]	=	phosphorous concentration ($mmol.kg^{-1}$)
+ SP	=	with soft patches
ANOVA	=	analysis of variance
B	=	boron
C_2H_4	=	ethylene
Ca	=	calcium
CA	=	controlled atmosphere storage
$CaCl_2$	=	calcium chloride
$CaNO_3$	=	calcium nitrate
cm	=	centimetre
CMM	=	Complementary Michaelis-Menten
CO_2	=	carbon dioxide
COO^-	=	carboxyl group
CPPU	=	N-(2-chloro-4-pyridyl)-N'-phenylurea
CPRR	=	Centre for Postharvest and Refrigeration Research
Cu	=	copper
cvs.	=	cultivars
DF	=	degrees of freedom
dwt	=	dry weight (kg)
f	=	firmness (N or kgf)
F.O.B.	=	free on board
FCU	=	Fruit Crops Unit

fwt	=	fresh weight (kg)
g	=	gram
galA	=	galacturonic acid
GLM	=	general linear model
H_2SO_4	=	sulphuric acid
ha	=	hectare
HCl	=	hydrochloric acid
HR	=	HortResearch
HRGP	=	hydroxyproline-rich glycoprotein
K	=	potassium
KCl	=	potasssium chloride
kg	=	kilogram
kgf	=	kilograms force
L	=	litre
LSD	=	least significant difference
m	=	metre
M	=	molar
Mg	=	magnesium
mL	=	millilitre
mm	=	millimetre
mmol	=	millimole
mol	=	mole
mPa	=	millipascal
MSE	=	mean square error
N	=	Newtons
N	=	nitrogen
n	=	number
N_2	=	nitrogen gas
Na	=	sodium
ND	=	non-destructive

NH_4^+	=	ammonium
NLIN	=	non-linear
NO_3^-	=	nitrate
NZ	=	New Zealand
NZKMB	=	New Zealand Kiwifruit Marketing Board
O_2	=	oxygen
°Brix	=	degrees Brix
°C	=	degrees Celsius
P	=	phosphorous
P	=	probability
PG	=	polygalacturonase
PGRS	=	plant growth regulator sprays
PME	=	pectinmethylesterase
RH	=	relative humidity (%)
RLD	=	root length density ($m.L^{-1}$)
rpm	=	revolutions per minute
SE	=	standard error
SP	=	soft patch
Sr	=	strontium
SS	=	soluble solids
SSC	=	soluble solids concentration (°Brix)
t	=	time (days)
T	=	temperature (°C)
w / w	=	weight per weight
XET	=	xyloglucan endotrans-glycosylase
Zn	=	zinc

Chapter 1

General Introduction

1.1 Background

Kiwifruit is currently New Zealand's largest horticultural export crop, earning approximately $430 million (F.O.B) in the year ending 30th of June 1998 (Anon., 1999). Each year the return to growers is eroded by the cost of poor storing fruit, which has amounted to tens of millions of dollars in a single season (Abbott, 1996 - personal communication). Clearly, identifying approaches for improving the storage potential of kiwifruit could significantly boost the returns to growers.

At the outset of this programme, anecdotal evidence indicated that organically grown kiwifruit stored substantially better than their conventionally grown counterparts (Martin, 1995 - personal communication). Very little scientific work has compared the quality of kiwifruit from organic and conventional systems although in one study, organic fruit were found to soften less rapidly than conventionally grown fruit (Hasey et al., 1996). Reasons for the purported difference in the storage behaviour of organic and conventional kiwifruit are unknown but, presumably, the difference could relate to differences in fruit susceptibility to low temperature injury (Lallu and Yearsley, 1995) or to mechanical injury that occurs at harvest (Davie et al., 1994). These effects must be mediated through some difference in fruit composition, structure or levels of infection with storage pathogens at harvest. For example, differences in long term storage potential have been shown to be associated with mineral nutrition, especially nitrogen (N) and calcium (Ca) nutrition - generally, fruit high in N and / or low in Ca have been found to store less well than fruit low in N and / or high in Ca (Banks et al., 1995; Cheah, 1989; Costa et al., 1997; Davie et al., 1994; Hasey et al., 1996; Johnson et al., 1997; King et al., 1987; Lallu and Yearsley, 1995; Prasad and Spiers, 1991; Tagliavini et al., 1995). It should bepossible to manipulate the growing environment of kiwifruit to enhance some attributes responsible for subsequent storage behaviour.

Some novel experimental approaches have been adopted to enhance the storage behaviour of kiwifruit through enhancing known mechanisms responsible for nutrient uptake by the growing fruit. For example, in one study, the concentration of Ca and the storage potential of fruit were enhanced by applying a drying oil to the fruit. This work was based upon the proposition that such a treatment would stimulate transpiration through the fruit skin and hence draw more calcium-rich xylem sap into the fruit (Davie, 1997). The improvements in storage behaviour obtained were consistent with the conceptual model upon which this work was based. However, in the same study, applying oils to the whole vine had a detrimental effect on the water status of the whole vine and consequently on the Ca status of the fruit. While such reductionist approaches may identify the mechanisms responsible for biological phenomena, there is no guarantee that such approaches will provide viable solutions in commercial practice. With this in mind, the current programme adopted a more integrated and holistic approach to exploring the effects of orchard-scale treatments for improving the storage potential of kiwifruit. This was linked to aspects of the organic production system that are likely to be responsible for improving the storage potential of fruit.

Specifications for organic fruit production comprise so many aspects that adopting a totally organic regime and comparing it to a nearby conventional production system would inevitably be subject to multiple criticisms from a scientific perspective and by advocates of organic production. For example, the absence of spraying of pesticides on the organic block would necessitate large spatial separation of the two regimes, thereby introducing all sorts of additional uncontrolled variation and creating scope for ambiguities in resulting experimental data. It would be more scientifically sound to identify one aspect of the growing environment that differs between the two production systems which seems likely to contribute substantially to differences in fruit storage potential and which could be tested rigorously in an experimental fashion.

Substantial differences in soil characteristics are strong candidates for affecting many aspects of vine function, including the uptake of nutrients, especially Ca. Differences in fertiliser regimes adopted by organic and conventional growers are likely to contribute

to differences in soil characteristics as are differences in orchard floor management. Based upon this premise, this programme examined the effects of ground covers, in combination with organic and inorganic fertiliser regimes, on fruit, vine and soil attributes with an emphasis on fruit storage behaviour. The hypothesis underlying the programme was that ground covers would improve the surface rooting of vines making any nutrients added to the soil surface, particularly Ca, more accessible. It was anticipated that this research would identify a fertiliser regime and / or ground cover that could be used to enhance the storage potential of kiwifruit. Through the intensive and comprehensive monitoring conducted as part of the approach, I expected to be able to identify aspects of causality and their interactions in this system. Through these insights, it was anticipated that a holistic and integrated conceptual model would be developed of the means by which treatments affected storage behaviour. In 1996, this programme also compared the response of fruit from paired conventional and organic production systems to typical postharvest handling and storage regimes and measured compositional attributes. This allowed quantification of inherent differences in fruit that would have been built into them by the time they were harvested and which may be responsible for the purported differences in storage behaviour.

This programme combined approaches previously established by the Centre for Postharvest and Refrigeration Research (CPRR) at Massey University in Palmerston North, NZ. These included the assessment of fruit responses to handling at harvest, in terms of storage behaviour, and postharvest responses to preharvest treatments involving mineral nutrition. The combined approach, coupled with collaboration with The Horticultural & Food Research Institute of New Zealand (Hort+Research), addressed a number of issues of critical importance to growers.

1.2 Structure of thesis

The remainder of this thesis is divided into 5 major chapters. The contents of these chapters are outlined below.

- Chapter 2: Literature review. This discusses the nature of softening in kiwifruit, the mechanisms involved and the factors affecting it. The broad aim of the review was to identify strategies that could be adopted to minimise fruit storage losses. Prediction and management of variation in fruit softening behaviour is also briefly discussed.

- Chapter 3: Soil amendments and the storage potential of kiwifruit. This chapter describes the trial set up in 1995 to examine the effects of combinations of organic and inorganic soil amendments on soil, vine and fruit attributes. The trial was conducted at two sites and run over three consecutive seasons.

- Chapter 4: Comparison of the storage potential of kiwifruit from conventional and organic production systems. Findings from the 1996 pairwise comparison of organic and conventional fruit storage potential are presented here. A description of storage indicators that appear to have great potential for managing the inherent variability in the storage potential of kiwifruit is also included in this chapter.

- Chapter 5: General discussion. This chapter draws together all the major findings and conclusions made throughout the duration of the programme in an attempt to present an overall picture of the effects of alternative production systems on soil, fruit and vine attributes, particularly storage potential. The management of fruit variability and recommendations for further research are also presented.

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Chapter 2

Literature Review

2.1 Introduction

New Zealand's kiwifruit industry loses millions of dollars each year through poor storing fruit. Premature softening is particularly a problem. Fruit losses during long-term storage could be alleviated considerably by manipulation of those factors thought to be responsible for the development of premature softening. At the same time, storage losses could be minimised by identifying at or close to harvest, lines of fruit which are likely to soften prematurely - these lines could then be marketed ahead of fruit predicted to soften less rapidly. The purpose of this review is to characterise the softening process in kiwifruit and to identify factors that are likely to contribute to premature softening so that strategies can be developed for minimising fruit storage losses. Prediction of fruit softening behaviour is also briefly discussed.

2.2 Softening of kiwifruit

2.2.1 Introduction

Hayward kiwifruit (*Actinidia deliciosa* (A.Chev) C.F. Liang et A.R. Ferguson), the predominant commercially grown cultivar in NZ, can be stored for up to a year at 0°C as a result of slow ripening after harvest (Cotter et al., 1991). Each season, a proportion of the overall crop is predisposed to premature softening which may be localised in the form of soft patches or affect whole fruit. Fruit that soften excessively have short shelf lives, are much less desirable to consumers and are more susceptible to mechanical damage and microbial decay during handling. Several factors, both pre- and postharvest, may affect the rate of softening and textural changes in kiwifruit (Arpaia et al., 1987; McDonald, 1990).

The relationship between firmness and time is critical to the industry's ability to deliver fruit of appropriate firmness to its customers. Lines of fruit will not be exported if the mean firmness (measured by penetrometer) falls below the export threshold level of 11.8 N (Newtons) or 1.2 kgf (kilograms force); individual fruit must all be firmer that 9.81 N or 1.0 kgf (Hopkirk et al., 1989; Lallu, 1994; Lallu, 1997).

2.2.2 Dynamics

The firmness of kiwifruit at harvest is generally in the range of 60 - 110 N but they are not considered to be eating-ripe until the firmness is in the range of about 4 - 10 N (MacRae et al., 1990). Hence, a large decrease in fruit firmness takes place after harvest before the fruit is ready to eat. The loss of fruit firmness or softening in kiwifruit usually occurs in a characteristic manner with four distinct phases (Figure 2.1). The first phase of softening (I) is a period of stability in which there is very little change in firmness. This is followed by a period of acceleration (II) in which the largest change in fruit firmness occurs. The third phase, which usually begins at about 20 N depending on the line of fruit and season, represents a deceleration in softening. The fourth and final phase of softening represents another period of acceleration during which time the fruit become over-ripe. In late harvested fruit, there is usually no lag period (I) and the fruit immediately pass through the rapid phase of softening (II; MacRae et al., 1989b; MacRae et al., 1990). However, the final phase of softening (IV) in late harvested fruit begins, if at all, later than in early harvested fruit. So while early harvested fruit stored for a short period can be firmer than late harvested fruit stored for the same period of time, the firmness of late harvested fruit tends to be greater at the end of longer-term storage than early harvested fruit stored for the same period of time.

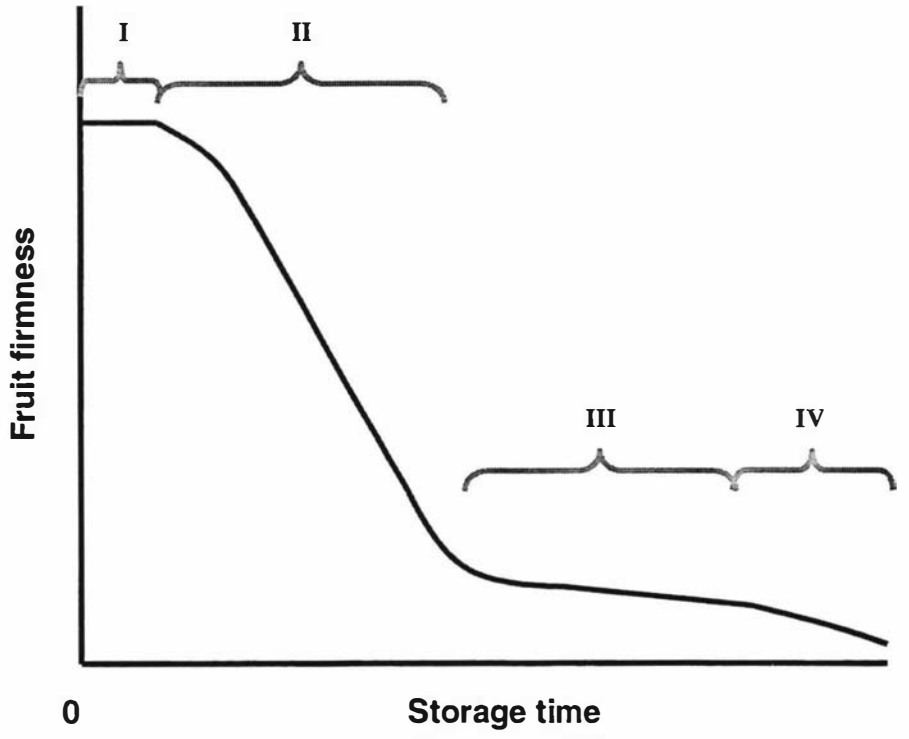

Figure 2.1 The softening behaviour of kiwifruit and its four phases: I comprises a period of stability, II involves a period of acceleration, III represents a period of deceleration and IV involves another period of acceleration.

2.2.3 Characterisation

There is currently a dearth of information in the literature regarding the modelling of firmness changes in fruits during storage. In one study with 'Elstar' apples, a dynamic model was developed that described the decrease in firmness during different types of storage conditions, based on a general knowledge of how firmness is affected by chemical and biochemical reactions, and on the strict and fundamental application of fundamental kinetics (Tijskens et al., 1997). Similarly, in another study with peaches, a mathematical model for fruit firmness was developed based on an understanding of the underlying chemical and physical properties that contribute to the observed firmness of biological tissue (Tijskens et al., 1998). In kiwifruit, changes in fruit firmness during storage have been measured in several studies, predominantly to elucidate differences in the effects of various treatments on softening behaviour or to compare different methods of measuring firmness (Davie et al., 1996; Gerasopoulos et al., 1996; Harker et al., 1990; Harker and Hallett, 1994; Hopkirk et al., 1990; Lallu et al., 1989; Lallu, 1994; Lallu, 1997; MacRae et al., 1989b; McGlone et al., 1997). Although the general nature of kiwifruit softening has been well established (Section 2.2.2), mathematical models that characterise this behaviour have not been published. This is surprising given that such models could potentially be used to predict softening behaviour in alternative scenarios. The softening pattern of harvested kiwifruit is frequently hyperbolic in nature. This is particularly so for mature fruit that do not typically exhibit the lag phase in softening commonly found in immature fruit. In recent times, this type of softening behaviour has been described using modified forms of the Gompertz and Michaelis-Menten functions (Davie et al., 1991 - unpublished). The problem with these models is that not all fruit softening follows a simple hyperbolic relationship with time. Consequently, more sophisticated models may be required to characterise the softening behaviour of fruit. One means by which this could be achieved would be to use segmented models in which two or more equations are joined to describe different regions of the x-space (De Silva, 1999 - personal communication). Segmented models have previously been used to characterise biological processes, particularly in forestry (Fialho and Ledur, 1997; Mayaka, 1994; Conners, 1989; Max and Burkhart, 1976).

2.2.4 Soft patches

According to the New Zealand Kiwifruit Marketing Board (NZKMB), a soft patch is defined as a localised area on kiwifruit below the minimum acceptable firmness threshold level of approximately 10 N (measured by penetrometer) for the relevant time period (from September onwards), tested between 0 and 5°C. Soft patches occur when the localised pericarp tissue becomes soft, in advance of the surrounding tissue. Water-soaking of the softened area sometimes becomes visible through the skin in very ripe kiwifruit (Finch and Hopkirk, 1987). Soft patches have been associated with physical factors (e.g. impacts at grading or compression during storage) as well as physiological factors (Banks et al., 1995; Finch and Hopkirk, 1987; Hopkirk and Finch, 1989).

Like bitter pit in apples (Ferguson, 1984), soft patches in kiwifruit could be associated with low concentrations of calcium in fruit (Banks et al., 1995). Ca sprays and dips have increased the concentrations of Ca in kiwifruit (Davie et al., 1996) and reduced the incidence of soft patches (Davie, 1997). There seems to be considerable potential value in increasing the Ca content of kiwifruit to enhance their storage behaviour.

2.2.5 Mechanisms of fruit softening

2.2.5.1 Introduction

Many physiological processes in kiwifruit purportedly contribute to fruit softening including cell wall swelling and breakdown, the hydrolysis of starch, and a decrease in water and osmotic potential (Arpaia et al., 1987; Fischer and Bennett, 1991; Redgwell and Fry, 1993; Shackel et al., 1991). Of these, probably the most important physiological change leading to the softening of kiwifruit, and for that matter many other fruits, is the loss of cell wall integrity, particularly the dissolution of pectin structures. The nature of plant cell walls is therefore central to understanding of the softening process.

2.2.5.2 Cell wall structure of plants

A number of models of the plant cell wall have been proposed (Carpita and Gibeaut, 1993; Keegstra et al., 1973). However, there is very little information regarding specific interactions between different cell wall polymers within the wall and so these models are subject to conjecture; they therefore do not provide a reliable basis for predicting the chemical nature of cell wall change in ripening fruit (Harker et al., 1997). Despite this limitation, cell walls can be generally described as consisting of crystalline cellulosic microfibrils embedded in an amorphous paracrystalline matrix of other polysaccharides and proteins. Specifically, the major cell wall constituents are cellulose, hemi-celluloses, pectins, glycoproteins and other polysaccharides (Aspinall, 1980; Jackman and Stanley, 1995; Melford and Dey, 1986; Tucker and Mitchell, 1993). Carbohydrate fractions account for approximately 90 – 95 % of the plant cell wall and protein about 5 – 10 % (Gross, 1990). The cell wall polysaccharides confer two important but apparently opposing properties on the cell wall. The first is plasticity, which enables the wall to expand during cell enlargement, while the second is rigidity which confers strength and determines cell shape. This versatility is a consequence of the unique nature of the integrated cell wall chemistry (Harker et al., 1997).

Cellulose

Cellulose polymers make up the crystalline microfibril phase of plant cell walls and are essentially the strengthening and protective component of cells constituting 20 – 30 % of the dry weight of cell walls (Colvin, 1980; Varner and Lin, 1989). Chemically, cellulose molecules are linear homopolymers of glucose joined by glycosidic bonds (i.e. β-1,4-linked glucan chains; Richmond, 1991). The average cellulose molecule consists of 2,500 glucose units (Redgwell and Harman, 1988). Cellulose polymers bind with each other via intercellular hydrogen-bonds to form the highly structured microfibril phase of the cell wall around which the other cell wall polymers are organised.

Pectins

Pectins or polyuronides are the first cell wall substances to be laid down in newly formed cells following division and are present in the middle lamella of mature cells. Pectins determine strength and flexibility of cell walls in ripening fruit (Cutsem and Messiaen, 1993). Unlike the homogenous cellulose molecules, pectin molecules are heterogenous and may consist of up to 12 different kinds of sugar units (Redgwell and Harman, 1988). The major group of pectins in plant cell walls comprises the homogalacturonans - polymers of galacturonic acid (galA) units joined by α-1,4-links (Vian and Reis, 1991). Other common pectins include rhamnogalacturonans (homogalacturonans with rhamnose residues), galactans (polymers of galactose sugars), and arabinans (polymers of arabinose sugars). Bonding of pectin chains leads to the formation of pectic gel and depending on the pectin may involve co-ordinate bonding with Ca ions or hydrogen bonding and hydrophobic interactions (Fry, 1988; Pressey, 1977; Thakur et al., 1997). The ordered association of pectin chains in cell walls resulting from ionic linkages via Ca bridges is described as the "egg-box" model (Huber and O'Donoghue, 1993; Poovaiah et al., 1988).

In fruit, pectins are the predominant substances that are solubilised and depolymerised during the ripening process and consequently play a significant role in the softening behaviour of fruit (Maclachlan and Carrington, 1991).

Hemicelluloses

These heterogeneous polymers consist of β-1,4-linked linear backbones of glucose with short side chains of various monosaccharides e.g. xylose, arabinose, glucose, galactose, mannose and glucuronic acid (Aspinall, 1973; Hayashi, 1989; Vian and Reis, 1991). Quantitatively, hemicelluloses make up 30 – 40 % of the cell wall by covalently linking to pectin or by non-covalently hydrogen-bonding to cellulose of the microfibril phase (Hall, 1981).

Glycoproteins

Cell walls usually contain major structural proteins making up to 10 % of the wall. The best-characterised cell wall structural protein has a high proportion of the amino acid hydroxyproline and is known as the hydroxyproline-rich gylcoprotein (HRGP) or extensin (Cassab and Varner, 1988). Soluble proteins are also associated with the cell wall including peroxidases which are important enzymes that catalyse phenolic cross-links between macromolecules such as hemicelluloses (Lamport, 1980).

Other polysaccharides

Other polysaccharides which may be associated with plant cell walls include lignin, callose, waxes, arabinogalactans and glucomannans (Aspinall, 1980). These substances have varying roles in the cell wall ranging from the reduction of water loss to the prevention of pathogen invasion.

2.2.5.3 Cell wall degradation

Enzymatic interactions

Several changes occur in the cell wall chemistry of the outer cortex of kiwifruit during softening. During the initial rapid phase of fruit softening (Figure 2.1), large amounts of pectins are solubilised in the cell wall, leading to dissolution of the middle lamella between cells and, subsequently, cell separation and softening of tissue. Interestingly, in the case of kiwifruit, the solubilised pectin remains in the same long chains that are present in the insoluble cell wall (MacRae and Redgwell, 1992). Furthermore, pectin solubilised early in softening is characterised by its high molecular weight, similar to that of pectin remaining bound within cell walls suggesting very little structural modification is necessary for solubilisation (MacRae and Redgwell, 1992). Change in pectin solubility also accompanies softening during the ripening of many other fruits including apples, pears, peaches, and tomatoes (Ahmed and Labavitch, 1980; Ben-Arie and Sonego, 1979; Chapman and Horvat, 1990; Cutillas-Iturralde et al., 1993; De Veau et al., 1993; Fischer and Bennett, 1991; Gross, 1989; Hobson, 1981; Huber and O'Donoghue, 1993; Ketsa and Daengkanit, 1998; Lazan et al., 1995; McCollum et al.,

1989; Murayama et al., 1998; O'Donoghue et al., 1997; Shalom et al., 1993; Shalom et al., 1996; Siddiqui and Bangerth, 1996).

Pectin solubilisation appears to be the result of enzymatic cleavage of linkages between various cell wall polymers. In a number of fruits, the enzyme polygalacturonase (PG) was considered to be a key enzyme leading to pectin solubilisation primarily due to its ubiquitous nature and temporal association with ripening. However, molecular work during the last decade, particularly with tomato, has indicated that PG may not always be the primary limitation to the rate of fruit softening (Giovannoni et al., 1989; Giovannoni et al., 1992; Gross, 1990; Smith et al., 1988). For example, when the PG gene was introduced into a non-ripening mutant tomato (*rin*), the rate of softening, ethylene production and colour development did not increase markedly (Giovannoni et al., 1989). Also, blocking PG expression by transformation with the antisense gene for PG only partially prevented fruit softening (Carrington et al., 1993; Kramer et al., 1992) or did not prevent it all (Schuch et al., 1991; Smith et al., 1988). Other work with tomato (DellaPenna et al., 1990) suggests that the solubilisation of pectin and its subsequent depolymerisation or degradation are separate manifestations of the same process catalysed by a PG isozyme (Redgwell et al., 1992).

In further softening of kiwifruit, additional pectin is solubilised and there is a reduction in the molecular weight of the solubilised polymers, but not in those polymers still retained in the cell walls. This suggests that although the enzyme PG is involved in depolymerising solubilised pectin (i.e. polyuronide degradation), it may not be a major factor in the actual pectin solubilisation process. It therefore appears that PG (specifically the endo-form in kiwifruit) is involved predominantly in the later stages of kiwifruit softening, after pectin has been solubilised (MacRae and Redgwell, 1992).

PG appears to act only on de-esterified (solubilised) pectin substrates (Pressey, 1977) and it seems to catalyse the hydrolytic cleavage of α-1,4-galacturonan linkages in the polygalacturonic acid polysaccharides of pectin (Fischer and Bennett, 1991). To achieve this, PG must act in conjunction with other pectic enzymes which are responsible for the

initial de-esterification and solubilisation of pectic material (Labavitch, 1981). An important enzyme thought to be responsible for pectin de-esterification in cell walls is pectinmethylesterase (PME) which catalyses de-methylation of the C6 carboxyl group of galacturonosyl residues in cell wall pectin (Fischer and Bennett, 1991). The de-esterification of pectin molecules is thought to enhance the activity of PG by making pectin molecules more accessible for hydrolysis (Koch and Nevins, 1989; Pressey and Avants, 1982; Seymour et al., 1987).

In ripening apple, pectin solubilisation is the only degradative activity in cell walls shown to correlate with the presence or absence of softening (Bartley and Knee, 1982; Klein et al., 1990). However, there is insufficient PG in apples to account for the extent of pectin solubilisation (Bartley and Knee, 1982) Furthermore, it appears that PME activity in apples does not always correlate with loss of firmness (Klein et al., 1995; Yoshioka et al., 1992). Still, it has been suggested that the de-esterification process itself, regardless of the catalysing agent, is closely linked with apple fruit softening (Knee, 1978; Yoshioka et al., 1992) although there is some evidence contrary to this (Klein et al., 1995).

A 10 % de-esterification of cell wall pectin has been found early in kiwifruit softening in response to the natural ripening gas ethylene (Redgwell et al., 1990) while the activity of PME has been found to increase 2 to 3-fold during exposure to ethylene (Wegrzyn and MacRae, 1992), correlating well with substrate response (MacRae and Redgwell, 1992). De-esterification of cell walls continues throughout softening of kiwifruit, while the activity of PME decreases to undetectable levels. A glycoprotein inhibitor of PME has been demonstrated in kiwifruit (Balestrieri et al., 1990), the quantity of which increases as fruit ripens (Wegrzyn and MacRae, 1992). However, increases in PME activity during ethylene treatment were not correlated with corresponding decreases in the level of the inhibitor. These results suggest that transient increases in PME are a response to ethylene exposure, rather than the normal sequence of events during fruit ripening (Wegrzyn and MacRae, 1992). If this is the case, then

PME action may be a key to the rapid softening in kiwifruit induced by exposure to ethylene (Lallu et al., 1989; MacRae and Redgwell, 1992).

An increase in cell wall swelling accompanies the softening of kiwifruit (Hallett et al., 1992; Redgwell and Percy, 1992; Redgwell et al., 1992; Redgwell and Fry, 1993). Such swelling has also been observed during the softening of other fruits including apple and pear (Ben-Arie et al., 1979), avocado (Platt-Aloia et al., 1980; Platt-Aloia and Thomson, 1981; Redgwell et al., 1997), tomato (Crookes and Grierson, 1983), and nectarine (King et al., 1989). With kiwifruit, there is little or no swelling of the cell wall during the initial rapid phase of softening. Instead, cell wall expansion appears to reach a maximum in the second phase of softening (Hallett et al., 1992) after most of the cell wall pectin has been solubilised, leaving mostly cellulose, hemicellulose and some highly galactosylated (galactose-containing) pectin such as galactan (MacRae and Redgwell, 1992). This suggests that the swelling of cell walls in kiwifruit is due to changes in the cellulose-hemicellulose-high molecular weight pectic portion of the cell wall.

As yet, it is not clear whether cell wall swelling is a consequence of fruit softening or whether fruit softening contributes to cell wall swelling. Recent evidence suggests that cell wall swelling is a result of changes to the viscoelastic properties of the cell wall during pectin solubilisation (Redgwell et al., 1997). It appears that swelling in kiwifruit is associated with the movement of water into voids left in the cellulose-hemicellulose network by the solubilised pectin. Other elements of cell wall modification involving the site and mechanism of pectin solubilisation and / or the cellulose-xyloglucan complex are also thought to contribute to swelling (Redgwell et al., 1997). Cell wall swelling in kiwifruit is thought to be associated with a decrease in the size of cell wall hemicelluloses (Redgwell et al., 1990), especially xyloglucan. It has been proposed that xyloglucan molecules attach to the cellulose microfibrils of cell walls and serve as cross-links (Hayashi, 1989). Degradation or depolymerisation of xyloglucans would facilitate sliding of two adjacent microfibrils (Sakurai and Nevins, 1997) and therefore cell swelling. Changes in the size of cell wall hemicelluloses during softening have also

been reported in tomato (Tong and Gross, 1988), strawberry (Huber, 1984), hot pepper (Gross et al., 1986) and muskmelon (McCollum et al., 1989). These findings suggest hemicellulase and cellulase enzymes have an important role in fruit softening especially in fruits such as persimmons, peppers, muskmelons and berries where the contribution of PG to pectin metabolism are thought to be negligible during softening (Abeles and Takeda, 1989; Abeles and Takeda, 1990; Cutillas-Iturralde et al., 1993; Gross et al., 1986; McCollum et al., 1989). In kiwifruit, correlations have been found between wall swelling and increased activity of the enzyme XET (xyloglucan endotrans-glycosylase). XET catalyses both the splitting and linking of xyloglucan molecules and is therefore favoured as a reconnecting enzyme involved in the rearrangement of xyloglucans to accommodate cell growth (Redgwell and Fry, 1993). The role of XET during kiwifruit ripening is unclear with much still to be learned about the mechanism of its action and its physiological function.

Substantial losses of neutral sugars such as galactose from cell walls, through the action of hemicellulases, occurs during the ripening of many fruits including apples, pears, peppers, nectarines, peaches, melons, squash, berries, and tomatoes (Bartley, 1974; Carrington and Pressey, 1996; Gross and Wallner, 1979; Gross and Sams, 1984; Gross, 1990; Kim et al., 1991; Sethu et al., 1996; Seymour et al., 1990; Shalom et al., 1996). With kiwifruit, studies have shown that initiation of galactose loss from the cell wall is one of the first events during fruit softening (Redgwell et al., 1990; Redgwell et al., 1992); up to 70 % of the total cell wall galactose in kiwifruit may be lost during softening (Redgwell et al., 1992). However, the loss of cell wall-associated galactose from excised outer-pericarp discs of kiwifruit has no consistent effect on the loss of firmness or the degree of pectin solubilisation (Redgwell and Harker, 1995). This indicates that while galactose loss from the cell walls of kiwifruit may be an important event in the process that leads to fruit softening, it may not be sufficient for pectin solubilisation and fruit softening (Redgwell et al., 1997).

It has been postulated that the enzyme β-galactosidase, which is capable of removing galactose from cell wall polysaccharides in fruit (Ross et al., 1993; Ross et al., 1994), is

involved in the softening of kiwifruit. β-galactosidase may attack the neutral galactose side chains of pectic polysaccharides; shortening of these side chains could lead to loosening of the wall matrix (and cell swelling), and provide a more favourable environment for endo-hydrolases such as PG to act on the backbone of the pectic polysaccharides (Ross et al., 1993). However, contradictory findings regarding the relationship between galactose loss and β-galactosidase activity in maturing and ripening kiwifruit (Ogawa et al., 1990; Wegrzyn and MacRae, 1992) have thrown the role of β-galactosidase in fruit softening into contention. Further work is required to elucidate more clearly the role of other enzymes like β-galactosidase in fruit softening particularly using natural substrates to avoid possible interference from enzymes other than those of interest (MacRae and Redgwell, 1992).

Non-enzymatic interactions

Historically, non-enzymatic mechanisms of fruit softening have been explained on the basis of the central role of Ca in pectin chemistry. Other cations, such as magnesium (Mg) and strontium (Sr) have also been implicated in the mechanisms of fruit softening but their effects in maintaining fruit firmness have been less pronounced (Sams and Conway, 1993). Significant amounts of the total Ca in plants is associated with cell walls (Poovaiah, 1993) - the rest is found mostly in the vacuoles and cytosols of cells where it predominates in signal transduction pathways (Brady, 1987). In mature kiwifruit, 20 – 30 % of the total Ca in fruit tissue occurs as calcium oxalate (Harker and Hopkirk, 1989). Ca in this form is unlikely to become available to the fruit during the ripening process (Harker et al., 1990). Divalent Ca ions form cross-links in cell walls between the negatively charged carboxyl groups (COO^-) of homogalacturonan chains in the pectic fraction to form the previously mentioned "egg-box" structure (Hobson, 1981; Huber, 1983; Knee and Bartley, 1981). This extensive cross-linking facilitates packing of pectic polymers in the middle lamella and may also restrict the access of hydrolytic exo-enzymes (particularly glycosidases; Glenn and Poovaiah, 1990) responsible for the degradation of cell wall polymers. The presence of Ca in cell walls essentially retards cell wall breakdown, an effect usually expressed as a delay in fruit softening (Poovaiah et al., 1988).

2.2.5.4 Synthesis of cell wall polymers

Most studies of cell wall changes during ripening have concentrated on degradative aspects with the possible role of synthetic processes having been largely ignored. However there is some evidence indicating that the synthesis of cell wall polymers during ripening could contribute to the softening of fruits including kiwifruit. For example, the synthesis of some cell wall polymers was reduced while other cell wall polymers continued to be synthesised during the ripening of apple fruit (Knee, 1978). Experiments with ripening tomato have also indicated continued turnover of cell wall polymers during fruit softening (Greve and Labavitch, 1991; Gross, 1990; Tong and Gross, 1988). Although mature and ripe kiwifruit are also able to synthesise cell wall polymers during ripening, this does not appear to be related to the softening process (Reid et al., 1996).

2.2.5.5 Starch degradation

Conversion of starch to sugars occurs during the softening of many crops including banana (Kojima et al., 1994). In kiwifruit, the degradation of starch may have some effect on the early stages of softening by altering cell turgor (Arpaia et al., 1987; Beever and Hopkirk, 1990; Bonghi et al., 1996); as starch degrades, cell osmotic pressure increases which may influence cell wall flexibility. It was demonstrated that as kiwifruit softened on the vine from 98 to 77 N, the starch content decreased by 20 % without any detectable change in cell wall composition (Redgwell et al., 1992). It has been suggested that starch grains themselves may influence firmness measurements by confronting a penetrometer with a physical barrier (MacRae and Redgwell, 1992) although this is difficult to envisage given that the size of starch grains is presumably minute, relative to the size of a penetrometer head.

2.2.5.6 Other mechanisms

Most research on the softening of kiwifruit and many other crops has focused on changes in the cell wall *per se*. However, other cellular processes may contribute to the

softening process including changes in the 3D structure of tissue, membrane permeability, and water loss (Stow, 1993). For example, it has been hypothesised that the softening process in tomato is the result of turgor loss as well as altered cell wall integrity, concurrently with physiological changes in cell membranes and symplast / apoplast relations (Shackel et al., 1991). Furthermore, non-enzymatic deaggregation of pectin may occur in tomato due to changes in the ionic strength of the cell wall solution. Non-enzymatic mechanisms of pectin depolymerisation, and perhaps mechanisms that acidify the cell wall during ripening, could influence the firmness and softening of fruits. However, further detailed studies on the structure and architecture of cell wall polymers are required before such mechanisms can be seriously considered (Gross, 1990).

Findings by Arpaia et al. (1987) and Hatfield and Knee (1988) indicate the potential for starch hydrolysis in kiwifruit to increase cell turgor thereby reducing cell cohesion and firmness. The extent to which this would occur would depend on the strength of cell walls and the level of cell wall degradation. There is also some evidence indicating that high rates of water loss from kiwifruit may hasten softening (McDonald and Harman, 1982). The reasons for this are unclear.

2.2.6 Differences between type of tissue and cell wall regions

Softening of individual fruits may differ with location and / or the type of tissue involved. For example, papaya (*Carica papaya*) fruit softens differentially in relation to position of the tissue i.e. the inner mesocarp tissue is softer, and its firmness decreases more rapidly during ripening than that of the outer mesocarp tissue (Lazan et al., 1995). The edible part of kiwifruit is composed of three different tissues - the core, the seed area (or inner cortex or inner pericarp) and the flesh under the skin (or outer cortex or outer pericarp; MacRae, 1988). The behaviour of each of these tissues can affect fruit softening. The outer cortex of kiwifruit softens before the core of the fruit (MacRae et al., 1989a) and is associated with a greater rate of galactose and galacturonic acid loss

from the cell wall of the outer pericarp (Redgwell et al., 1990). Furthermore, ultrastructural investigations have indicated that cell wall swelling reaches a maximum in the outer cortex earlier than in the core (Hallett et al., 1992). The inner cortex has been shown to differ from both the outer cortex and the core in its cell wall composition (Hallett et al., 1992; Redgwell et al., 1990) and appearance (Hallett et al., 1992) during ripening. Given these differences, there may be variation in the respective contributions of different fruit tissues to overall fruit softening (MacRae and Redgwell, 1992). Variation in the firmness of outer cortex tissue is likely to contribute the greatest to variation in fruit softening as measured by a penetrometer, which only penetrates the fruit to a depth of 11 mm.

At the cellular level, there are indications that some parts of cell walls are more resistant to substantial cell wall changes than other parts. In particular, the plasmodesmatal regions of ripe kiwifruit (of which there are many) remain similar to those at harvest with no apparent swelling or breakdown of the associated middle lamella (Hallett et al., 1992). In both apples and pears, the plasmodesmatal regions of cell walls maintained their structural integrity throughout the ripening process (Ben-Arie et al., 1979). Cell wall analyses in kiwifruit have shown a preferential loss of the less highly branched pectins as ripening progresses (Redgwell et al., 1992). It seems that some of the remaining highly branched pectin is associated with the undegraded plasmodesmatal regions (Hallett et al., 1992). It therefore appears that the plasmodesmatal regions of cell walls are resistant to the biochemical processes that affect the remainder of cell walls implying pre-programming during wall deposition (MacRae and Redgwell, 1992). Therefore, elucidation of the details behind this pre-programming of resistance could reveal other approaches for the manipulation of fruit softening.

2.2.7 Conclusions

Softening of kiwifruit typically consists of two phases. The first phase involves the largest changes in firmness and is accompanied by considerable breakdown of cell walls due predominantly to the solubilisation of pectin and the degradation of hemicelluloses.

The second slower phase of softening can be attributed mostly to the depolymerisation of solubilised pectin and the loss of sugars from the cell wall (MacRae and Redgwell, 1992). Kiwifruit has provided valuable insights into the mechanisms of fruit softening during ripening. Further research on processes such as galactose loss, pectin solubilisation, cell wall swelling and changes in hemicelluloses should help clarify the role of these cell wall changes in kiwifruit softening. Concomitant research into the other processes which may contribute to fruit softening, such as osmotic adjustment and cell wall turnover, will further allow the relative importance of these different ripening processes in fruit softening to be evaluated (MacRae and Redgwell, 1992).

2.3 Factors affecting the storage behaviour of kiwifruit

2.3.1 Preharvest factors

2.3.1.1 Introduction

Several preharvest factors may influence the storage behaviour of kiwifruit during storage, particularly the softening behaviour. Generally however, studies dealing with preharvest factors have not been conclusive on the matter of an involvement of them in premature softening. Preharvest factors that are likely to have a role in the storage behaviour of kiwifruit are discussed here.

2.3.1.2 Cultivar

Storage behaviour of kiwifruit differs substantially between cultivars. Of the cultivars initially selected in NZ, 'Hayward' softens much less rapidly than others such as 'Bruno', 'Monty' and 'Abbott'. Although 'Abbott' and 'Bruno' may yield more heavily than 'Hayward', and 'Bruno' is a more acceptable cultivar for processing, the keeping qualities and fresh-market attractiveness of 'Hayward' fruit makes this the predominant commercially grown cultivar in New Zealand (Beever and Hopkirk, 1990). The

mechanisms responsible for differences in the storage behaviour of these cultivars are not known.

2.3.1.3 Environmental factors

Packhouse managers in New Zealand have indicated that fruit from different orchards can vary considerably in storage behaviour (Trevelyan, 1998; White, 1998 - personal communications). Furthermore, the storage behaviour of fruit from within the same orchard may differ from year to year. Presumably, this variation could be due to differences in environmental factors although there is little published evidence to support this. That said, temperatures experienced during autumn have been found to affect fruit quality (Hopkirk et al., 1989). For example, fruit grown under increased temperatures, between mid-March and mid-May were harvested with lower soluble solids concentrations (SSC) but higher starch concentrations (Hopkirk et al., 1989). However, the same fruit had greater SSC than control fruit after long-term storage. It appears that fruit grown under increased autumn temperatures accumulate more total carbohydrate, which is converted to soluble solids during storage. Minimum temperatures during the growing season strongly influence fruit maturation as cool nights tend to favour the accumulation of soluble solids in fruit. However, it is not clear whether minimum temperatures *per se* are important or whether it is mean temperatures or the magnitude of differences between maximum and minimum temperatures that is important (Seager et al., 1996). Other environmental factors may influence the storage behaviour of kiwifruit but these have yet to be examined in any detail.

2.3.1.4 Production system

World-wide, there is an increasing concern over the use of synthetic chemicals in fruit production. Consequently, 'organic' and 'biodynamic' fruit production systems are becoming more prominent. These rely on crop rotation, crop residues, manures, off-farm organic wastes, mechanical cultivation, mineral bearing rocks, and biological pest control to maintain soil fertility and productivity, supply plant nutrients, and control

weeds, insects, and other pests (DeEll and Prange, 1992). In contrast, conventional systems adopt the use of synthetic fertilisers, pesticides, herbicides, fungicides and plant growth regulators.

Differences in the management practices of organic and conventional production systems are likely to contribute to differences in the quality of crops and their subsequent storage behaviour. Very little work has compared the quality of kiwifruit from organic and conventional systems although in one study, organically grown fruit were found to be as firm or firmer than conventionally grown fruit at harvest and four months after storage (Hasey et al., 1996). This difference may have been related the nitrogen source, which resulted in lower leaf nitrogen concentrations in the organic leaves. Further studies are required to confirm this. Anecdotal evidence from NZ in recent years further indicates kiwifruit from organic orchards store better than fruit from their conventional counterparts (Church, 1997; Martin, 1995 – personal communications).

Comparisons of organic and conventional production systems for other crops have revealed little or no differences in the quality and / or composition of crops (Reinken, 1987; Ruger, 1984). For example, differences were observed in the concentrations of some minerals (e.g. N and Ca) in the foliage of organically and conventionally grown peach trees but the quality of the fruit from those trees did not differ significantly (Rader et al., 1985). Furthermore, organically grown apples were found to have higher SSC than conventionally grown apples but no differences were observed in any other quality attributes including firmness and titratable acids content (DeEll and Prange, 1992). However, more conventionally grown apples (cvs. 'Cortland' and 'McIntosh') were found to be marketable after storage than organically grown apples (DeEll and Prange, 1993) which was largely due to a higher incidence of storage rots in the organically grown apples. Production method did not affect fruit Ca or Mg concentrations of these same apples although organically grown apples had higher phosphorous (P) and potassium (K) concentrations and lower N concentrations than conventionally grown apples. In another comparison of organic and conventional

production methods, apple fruit from the organic systems were found to be of poorer quality (Beyer, 1986).

In comparative studies on yield, researchers have generally found reduced yields from organic systems (Gliessman et al., 1996; Rader et al., 1985; Reinken, 1987; Ruger, 1984). Differences in yields can be attributed to differences in the quantity and quality of fertilisers being applied to each system, with more readily available nitrogen typical of conventional systems. Poorer yields from organic systems have been attributed to insect and disease problems (Vossen et al., 1994).

Differences between the quality and composition of fruit from organic and conventional systems could be expected to arise from differences in soil properties of the two systems. In particular, organic systems have been found to improve the organic matter content, structure and microbial activity of the soil (Gerhardt, 1997; Reganold, 1988). However, there is not much information comparing other soil properties of organic and conventional systems.

2.3.1.5 Soil management

Many studies have compared the effects of various soil management practices on soil, plant and fruit attributes (Tables 2.1 and 2.2). These practices have usually been typical of organic and conventional systems. Here, the effects of fertilisers and ground covers on fruit quality and storage behaviour are emphasised. The effects of soil management on the quality and storage behaviour of kiwifruit *per se* have been largely unexplored and so the majority of the information presented here pertains to other crops.

Fertilisers

Both inorganic and organic fertilisers (including composts) have had diverse and often inconsistent effects on the attributes of many fruits and vegetables. For example, supplementary organic fertilisers were found to decrease the sugar content of 'Cox's Orange Pippin' apples in one study (Wolstenholme et al., 1997). However, in another

study, poultry and chicken manure were found to increase the acid content of 'Cox's Orange Pippin' apples, whereas cattle manure decreased and poultry manure increased the acid content of 'Golden Delicious' apples (DeEll and Prange, 1992). Furthermore, potatoes grown with organic fertilisers were found to contain more total sugars than vegetables grown with mineral fertilisers (Schuphan, 1974). The growth and production of apricot trees on a very sandy soil was significantly increased by a preplant urban waste compost and a waste material mulch from the tea industry (Kotze and Joubert, 1992). However, fruit size, leaf and fruit composition did not differ despite large differences in yield. Compost application increased the cation-exchange and water-holding capacities of the soil, while improved tree performance was probably due to improved utilisation of applied fertilisers and irrigation water. In other work, peach trees treated with nitrogen-containing fertilisers were found to be more vigorous and productive than trees treated with an organic seaweed product (Rader et al., 1985).

Ground covers

Like fertilisers, ground covers have reportedly had many effects on the physical, biological and chemical properties of soil (Table 2.1) and have subsequently influenced plant growth and fruit quality. In particular, improved moisture conservation and moderation of soil temperatures are nearly always associated with the use of ground covers.

Extreme cycling of temperatures is commonly associated with bare soil as a result of high solar heat input during the day, followed by high rates of heat escape through the evening and night. In contrast, mulches (especially organic types) have an insulating and moderating effect on soil temperature by reducing both solar heat input during the day and heat escape at night (Hogue and Neilsen, 1987). Soil temperature under grass has generally been intermediate (several degrees Celsius cooler in the summer and warmer in the winter) relative to year-round cultivation or mulch (Weller, 1971). Mulches, especially organic types such as straw, tend to improve moisture conservation in the underlying soil thereby increasing the specific heat of the soil-water mixture and reducing temperature changes per unit heat absorbed or lost (Walsh et al., 1996b).

Table 2.1 Effects of ground covers on various soil properties, relative to soil maintained free of a cover.

Effects	Ground covers	References
Increased exchangeable calcium, potassium, phosphorous and boron	Hay straw	Merwin and Stiles, 1994
	Hay mulch	Sitton et al., 1959
	Wheat straw	Wander and Gourley, 1943
Water content / conservation improved	Waste from the tea industry	Kotze and Joubert, 1992
	Geotextile; straw	Walsh et al., 1996b
Diurnal fluctuations in temperature reduced	Sawdust; straw; wooldust	Hartley and Rahman, 1994
	Waste from the tea industry	Kotze and Joubert, 1992
Biological activity increased	Wood chip mulch + polypropelene fabric	Warner, 1997
Water infiltration improved	Sod (fescue)	Welker and Glenn, 1988
Organic matter content increased	Wood chip mulch + polypropelene fabric	Warner, 1997
	Sod (fescue)	Welker and Glenn, 1988
Surface rooting increased	Straw; sawdust	Baker, 1943
	Straw mulch	Hogue and Neilsen, 1987
	Black polyethylene; black paper	Knavel and Mohr, 1967
	Straw mulch	White and Holloway, 1967
Radial spread of roots increased	Sawdust mulch	Patten et al., 1988
Improved / more vigorous root growth	Pine bark mulch	Wolstenholme et al., 1997
Soil structure and aeration improved	Sod (fescue)	Welker and Glenn, 1988

An actively growing sod competes with trees for water throughout the growing season, which can become critical in non-irrigated areas (Tukey and Schoff, 1963). The extent of soil moisture depletion varies with the vigour, rooting depth, and frequency of mowing of the grass (Hogue and Neilsen, 1987). Although grass competes for water, it improves other soil physical properties as reflected by decreased soil bulk density and increased soil porosity (Atkinson and Herbert, 1979). Decreased bulk density means an increase in the total pore space available for root growth and an increase in water holding capacity, which in turn can lead to an improvement in moisture conservation (Hogue and Neilsen, 1987).

Mulching has generally improved the moisture status of the soil (Hogue and Neilsen, 1987), which is likely to be a consequence of both improved infiltration and reduced evaporation (Greenham, 1953). Increased infiltration might increase leaching but reductions in surface runoff and soil erosion in mulched orchards (Haynes, 1981) suggest a net soil and moisture conservation benefit (Hogue and Neilsen, 1987). The type of mulch is likely to influence the degree of soil moisture conservation. For example, absorbent mulches such as sawdust have been found to reduce rainfall penetration (Turk and Partridge, 1947).

Herbicide-treated orchard soils have generally been found to have lower soil moisture deficits than grassed soils (Haynes, 1980). However, very little has been written about the effect of herbicides compared to other management systems (Hogue and Neilsen, 1987).

Sod covers can supply high amounts of potentially available N to the soil by the return of clippings but the concentrations of ammonium and nitrate made available have been found to be very low because of mineralisation (Hogue and Neilsen, 1987). Generally, herbicided soil has been found to contain more N and P than grassed soil. In contrast, K concentrations do not appear to differ between grassed and herbicided soil (Hogue and Neilsen, 1987). Relative to other orchard floor management practices such as cultivation and mulching, extractable P does not appear to be increased by sod. Also, significantly

greater exchangeable Ca and Mg, but not K, has been found in the soil of sodded orchards, compared to that of herbicided or tilled orchards, as a result of less leaching (Hogue and Neilsen, 1987).

Considerable amounts of N can be added to the soil by organic mulches although this depends on the C : N ratios of the mulching material (the lower the ratio, the more N that is available). The availability of P and K has also generally increased upon applications of decomposable mulches. The effects of organic mulches on the concentrations of Ca and Mg in the soil have been inconsistent (Hogue and Neilsen, 1987).

In terms of plant growth, ground covers (particularly mulches) have reportedly increased the yields of many crops including avocado (Wolstenholme et al., 1997), blueberry (Schmidt, 1989), plantain (Salau et al., 1992), lemon (Nath and Sarma, 1992), apple (Jazbec, 1977; Niggli and Potter, 1986; Shabanova, 1984), capsicum (Roe et al., 1994), tomato (Famoso and Bautista, 1983; Srivastava et al., 1984; Wien and Minotti, 1987) and strawberry (Rebandel and Przysiecka, 1981)[1]. In other studies, mulches such as sawdust and straw have had negligible effects on tree growth and fruit yield (Hartley and Rahman, 1994). In contrast to mulches, living ground covers (e.g. sod grasses) have tended to reduce the yields of a number of crops including cabbage (Kostewicz and Stephens, 1994) and apple (Beyer, 1986; Merwin and Stiles, 1994; Walsh et al., 1996b). Such reductions are presumably the result of competition from ground covers for water and nutrients, particularly nitrogen (Haynes and Goh, 1978; Walsh et al., 1996a).

Few trials have examined the effects of ground covers *per se* on the quality and composition of crops including kiwifruit. With apples, grass covers have tended to reduce the level of storage disorders and improve the retention of firmness (Johnson, 1986; Johnson and Samuelson, 1990; Maslov and Khalekova, 1994; Perring and Pearson, 1986). However, there have been instances where grass covers have increased

[1] See Table 2.1 for examples of the types of ground covers that have increased yields.

the level of disorders in apple (Perring and Pearson, 1986). Mulching (with pine bark) has reduced the incidence of physiological disorders (particularly seed coat death and pedicel 'ringneck') in avocado (Wolstenholme et al., 1997).

Mulches have reportedly had a number of significant effects on plant nutrient composition as summarised in Table 2.2. However, there have been instances where mulches have had only minor effects on leaf and fruit nutrient analysis (Hartley and Rahman, 1994). Living ground covers have also had significant effects on plant composition, and in particular, grass sods have tended to reduce the N content of leaves (Merwin and Stiles, 1994; Welker and Glenn, 1988) and fruit (Hulme, 1956; Johnson and Samuelson, 1990). Again, this is presumably the result of competition from the grass for available nitrogen. Grass covers have also consistently increased the concentration of P in apple fruit (Perring, 1984b) while, in contrast, overall herbicide management has reduced the concentration of P in apple fruit (Johnson et al., 1983; Johnson and Samuelson, 1990; Perring, 1984a). Grass covers have also increased the concentrations of Ca in apple fruit (Johnson and Samuelson, 1990) although this was probably an indirect effect given that the fruit from grass plots were smaller and so their Ca contents may have been less diluted by growth.

Table 2.2 Effects of mulches on plant nutrient composition, relative to soil maintained free of a cover, unless stated otherwise.

Increased concentrations of K in apple leaves	Hay straw	Merwin and Stiles, 1994
Reduced concentrations of Ca in apple fruit and leaves	Wheat straw (relative to cultivation with cover crops)	Wander and Gourley, 1943
Increased concentrations of Ca in mandarin leaves	Jungle tree leaves	Mustaffa, 1988
Increased concentrations of N, P, K, Mg, Ca, Cu and B in tomato shoots	Black and clear plastic mulch	Wien and Minotti, 1987

2.3.1.6 Irrigation

Irrigation and water stress practices have had a number of effects on the quality of fruits. For example, the colour and flesh soluble solids of apple have been improved by water stress (Lotter et al., 1985; Proebsting et al., 1984) albeit at the expense of fruit size (Lotter et al., 1985). The effects of water stress on the storage behaviour of fruits are inconsistent with beneficial effects reported in some cases (Swain, 1984) and no (Smittle et al., 1992) or even deleterious (Proebsting et al., 1984) effects reported in other cases. These inconsistencies may have arisen because water stress advanced fruit maturity at the time of harvest, and the experimental procedures and statistical analyses adopted did not correct for potential effects such as this on fruit storage behaviour (Reid et al., 1996).

The effects of irrigation on the storage behaviour of kiwifruit also appear inconsistent. Experiments conducted in the Bay of Plenty, NZ, showed no effect of irrigation on kiwifruit storage life, even when fruit size was increased (Davison, 1979; Hopkirk, 1983). However, the reliability of these reports is questionable given that so few experimental details were given and treatments were not replicated in the orchard. Contrary to these reports, withholding irrigation for the full growing season of kiwifruit was found to improve fruit firmness during storage, although this was accompanied by a significant decrease in fruit size (Reid et al., 1996). Withholding irrigation until midsummer, resulting in mild water stress, also improved the retention of firmness in fruit without affecting fruit size (Reid et al., 1996). However, the early stressed and fully irrigated treatments in this work differed very little in terms of either the total amounts of irrigation water applied or the amount of water stress experienced (as indicated by yields and mean fruit size). In one experiment, the early stress treatment differed from the controls only in that the first irrigation was delayed from 20 December until 10 January. It was concluded from this work that provided timing and weather are right, withholding irrigation for even just a short period can be sufficient to improve stored fruit firmness without reducing fruit size.

The mechanisms by which withholding early season irrigation affects fruit storage behaviour are unclear. Nevertheless, it is possible that any differences in fruit firmness between irrigation treatments are related to differences in pericarp cell size especially given that cell expansion is usually very sensitive to water stress (Hsiao, 1973). In one study however, early water stress treatments improved the retention of firmness but did not affect final fruit size indicating that changes in pericarp cell sizes alone are unlikely to be responsible for improvements in fruit storage behaviour (Reid et al., 1996).

Withholding irrigation may influence fruit storage behaviour through its effects on plant hormones. Roots are important sources of cytokinins (Letham, 1994), a group of hormones which when applied to growing kiwifruit may decrease fruit firmness, although the effects may not persevere during storage (Patterson et al., 1993; Iwahori et al., 1988). Given that withholding irrigation has decreased the growth of kiwifruit roots, it is possible that water stress may improve firmness by decreasing root growth and therefore the export of cytokinins to fruit (Reid et al., 1996).

Irrigation and water stress practices may further affect storage behaviour of fruits through changes in fruit chemical composition (Reid et al., 1996). For example, the amount of Ca in apple fruit has been shown to be greater from irrigated trees than from controls (Goode et al., 1978), indicating that soil moisture is important for the transport of mineral ions to and through plants. Such changes in fruit composition early in fruit development could have important effects upon storage behaviour without compromising fruit size.

2.3.1.7 Fruit position and shading

A number or investigations have revealed that the storage performance of fruits differs with canopy position. For example, stone fruit grown under a high-light environment (outside canopy) was demonstrated to have a longer shelf life (storage and market), with a lower incidence of internal breakdown (IB), than fruit grown under a low light environment (inside canopy; Crisosto et al., 1997b). Similarly, kiwifruit shaded by

canopy during growth have been found to soften more quickly (Hopkirk, 1987). Kiwifruit from shaded positions of the canopy have also been associated with lower mean fresh weight (Snelgar et al., 1991; Tombesi et al., 1993), soluble solids concentration (Antognozzi et al., 1995; Snelgar et al., 1991; Tombesi et al., 1993) and chlorophyll content (Antognozzi et al., 1995; Tombesi et al., 1993).

With kiwifruit, the nature of the fruiting cane and the number of fruit per bud could affect fruit softening behaviour. At harvest, soft fruit are mostly associated with short terminating shoots located in the lower levels of the canopy, irrespective of their position in the vine (Lallu, 1994). Usually these shoots have shorter internodes, bear less fruit and have smaller or no leaves relative to stronger non-terminating shoots higher in the canopy. Vine management should therefore be directed to reduce the numbers of weak, terminating shoots in the canopy (Lallu, 1994).

Generally, kiwifruit from near the ends of leaders tend to have higher soluble solids than fruit from nearer the centre of the vine while fruit from the proximal ends of canes, near the leader, tend to have higher soluble solids than fruit from the distal ends of the canes. For fruit near the leader, fruit from canes tend to have more soluble solids than fruit from spurs, especially in pergola orchards. Furthermore, fruit from T-bar trained vines tend to contain more soluble solids than fruit from pergolas (Pyke et al., 1996). Despite differences in the maturity of fruit from different positions in the vine, the relationship between fruit firmness and fruit position is not clear although it seems that there is little effect of fruit position on ultimate fruit softness (Pyke et al., 1996).

2.3.1.8 Fruit mineral nutrition

Important minerals

Fruit mineral composition, and in particular Ca concentration, is believed to contribute significantly to the storage behaviour of many fruits including kiwifruit. The role of Ca in fruit storage behaviour is discussed in Section 2.4; only the importance of other minerals in the storage behaviour of fruit is discussed here.

N is a key mineral that seemingly affects the quality and storage behaviour of kiwifruit with high concentrations having been found to be detrimental (Cheah, 1989; Costa et al., 1997; Johnson et al., 1997; King et al., 1987; Mowatt et al., 1993; Prasad et al., 1988; Prasad and Spiers, 1991). Application of N can result in larger fruit (Costa et al., 1997) which presumably could dilute the contents of other critical components in the fruit important to storage behaviour, such as Ca.

K has also been strongly implicated in the storage behaviour of fruits. In apples for example, high concentrations of K, and occasionally Mg, especially in proportion to the concentration of Ca in fruit, have been associated with the incidence of disorders (Ben, 1995). However, there is little evidence implicating K with variation in the storage behaviour of kiwifruit.

The storage behaviour of fruits may also be affected by P. For example, phosphate sprays have increased the concentration of P in apple fruit and at the same time have reduced the incidence of storage disorders and reduced the rate of softening (Yogaratnam and Sharples, 1982; Webster and Lidster, 1986). In contrast, firmer kiwifruit have been found to contain less P than softer kiwifruit (Mowatt et al., 1993). Furthermore, kiwifruit with soft patches have been found to contain more phosphate than healthy fruit (Davie, 1997). The availability of other minerals may impact on the P nutrition of fruits and therefore storage behaviour. For example, the concentration of P in 'Cox's Orange Pippin' apple fruit has been reduced by the application of N fertiliser (Perring, 1984a). The effects of other fertilisers on the P nutrition of kiwifruit and subsequent storage behaviour have yet to be explored in detail.

Other minerals (e.g. Boron) may directly influence the storage behaviour of kiwifruit, though research on these has largely been ignored in favour of the minerals already mentioned here.

The uptake and assimilation of minerals

One of the major limiting steps in the uptake of nutrients by plants is the rate at which nutrients move through the soil to the surface of roots. Hence, the distribution of the roots through the soil, and particularly the total length of roots capable of nutrient uptake, have considerable influence on the absorption of those nutrients which are present in the soil solution in very low concentrations, such as P and K (Smith et al., 1988). The uptake of Ca in particular is restricted to the younger unsuberized parts of roots and therefore, it is important to ensure plants have healthy root systems with new growth if sufficient Ca is to be taken up (Himelrick and McDuffie, 1983; Ferguson et al., 1987).

The concentration of nutrients usually varies considerably with the depth of the soil, as a consequence of fertiliser placement, decomposition of plant litter at the soil surface, and nutrient uptake by the plant (Metson and Blakemore, 1968). Although roots often proliferate in regions of high fertility (Drew and Saker, 1975), only 20 – 30 % of the total root length of a kiwifruit vine is in the surface 200 mm of the soil, where nutrient concentrations are greatest (Buwalda, 1987). Nutrient uptake per unit length of root is likely to be much greater near the soil surface than deeper in the soil (Smith et al., 1988). It is unlikely that the rate of nutrient uptake is constant throughout the year (Smith et al., 1988). For most nutrients, over 65 % of the annual quantity of nutrient accumulation in the deciduous components of the vine occurs during the first 10 weeks of growth after bud break, whereas the remaining 35 % occurs over the subsequent 20 weeks (Smith et al., 1987; Smith et al., 1988). While a large proportion of the annual uptake of nutrients occurs early in the season, the mobilisation of nutrients stored in the vine from previous seasons may also contribute significantly to the demands of the deciduous components of the vine at that time of the year (Smith et al., 1988). For example, sufficient quantities of N, K, P and Mg can be mobilised from laterals to support 20 – 40 % of the leaves on the vine during the first 30 days of growth after bud break (Smith et al., 1987).

In addition to the buffering effects of nutrient reserves in the vine, the rate of nutrient uptake may also be influenced by environmental variables. For example, soil temperature appears to influence the concentration of K in kiwifruit leaves in spring indicating that the uptake of K is temperature-dependent (Smith et al., 1987). This may be the result of an increase in plant available forms of K in the soil that has been shown to occur with an increase in soil temperature (Thomas and Hipp, 1968).

It appears that the uptake of minerals from the soil by kiwifruit vines predominantly occurs early in the growing season and for a given length of root, is most prolific near the soil surface, where nutrient concentrations are greatest. Therefore, it may be possible to manipulate the mineral nutrition of kiwifruit vines by supplementing the soil with minerals early in the season and by increasing the surface rooting of vines.

2.3.1.9 Fruit maturity

The storage life of kiwifruit, and in particular whole fruit softening, appears to be strongly linked to fruit maturity as indicated by the soluble solids concentrations (Harman, 1981). Generally, more mature fruit will remain firmer after long term storage even though they are often softer at harvest than less mature fruit. However, there doesn't seem to be a consistent relationship between localised softening (i.e. resulting in soft patches) and maturity (Davie, 1997), which suggests that whole and localised fruit softening may involve different mechanisms.

Several orchard factors may influence the maturation of kiwifruit on vines. These include: climate and soil type (Pailly et al., 1995), particularly temperature (Section 2.3.1.3); crop load and shading of fruit (Beever and Hopkirk, 1990); the position of fruit in the canopy (Pyke et al., 1996); and the training system (Beever and Hopkirk, 1990). Variation in any of these factors between sites and seasons could therefore be expected to produce differences in the storage potential of fruit.

Commercially, main crop kiwifruit in NZ are harvested with a minimum maturity index of 6.2 % SSC. Fruit that are harvested with SSC less than 6 % do not store as well as more mature fruit and do not develop good flavour (Beever and Hopkirk, 1990). It is recommended that fruit intended for long-term storage be harvested with a maturity index between 7 and 10 (Hopkirk et al., 1986) although delaying harvesting increases the risk of damage from frosts and winter storms (Beever and Hopkirk, 1990).

2.3.1.10 Fruit size

Typically, small kiwifruit soften more rapidly than medium or large kiwifruit which may be linked to differences in fruit maturity rather than other aspects of fruit composition (Hopkirk, 1987); small fruit tend to have lower SS at harvest (Hopkirk, 1987) and would therefore be expected to soften more quickly than large fruit (Section 2.2.2). Larger fruit tend to store and taste better than smaller fruit and are also more popular in overseas markets (Hopkirk, 1987).

2.3.2 Postharvest factors

In addition to preharvest factors, a number of factors are reported to affect the storage behaviour of kiwifruit after their removal from the vine. These are briefly discussed below.

Mechanical damage

Compression and impact forces on fruit associated with normal harvesting and handling have been found to have significant negative effects on their quality during storage (Banks et al., 1993; Davie, 1997). Localised softening (resulting in the development of soft patches) especially seems to be exacerbated by mechanical damage. Kiwifruit can become damaged at harvest and thereafter, not just when fruit become soft. However, softer fruit appear to be more susceptible to mechanical damage (Davie, 1997). Mechanical damage appears to be restricted to localised softening and does not seem to influence whole fruit softening (Davie, 1997).

Storage temperature

Once kiwifruit have been harvested and packed they are placed in coolstorage, often for long periods. Conditions within coolstores could therefore significantly affect fruit quality. As for most fruits, temperature has a major effect on the rate of ripening. Respiration rates decrease as fruit temperature is reduced from ambient to 0°C (Fukuiet al., 1976; Heatherbell, 1975). The rate of fruit softening in the first few weeks after harvest is also reduced at lower temperatures. At 0°C, packed fruit soften rapidly from a flesh firmness of *c.* 80 N to 30 N in 4 to 6 weeks (Beever and Hopkirk, 1990). Thereafter, the rate of softening slows considerably. However, at 20°C, the initial rate of softening is only slightly greater than that at 0°C, but this rate is maintained, and fruit soon become fully then overripe (Beever and Hopkirk, 1990). Hence, kiwifruit are typically stored at 0°C to maximise their storage life.

Controlled atmosphere storage

Like temperature, the atmospheric composition of coolstores can have a dramatic influence on the storage life of fruit. Consequently, much research has been carried out in the area of controlled atmosphere (CA) storage and its impact on the quality of kiwifruit. Controlled atmospheres, particularly those high in CO_2, have retarded the rate of softening in many fruits including peaches (Anderson et al., 1969), nectarines (Olsen and Schomer, 1975), and pipfruit (Bramlage et al., 1977). Controlled atmospheres have also retarded softening in kiwifruit (Basiourny, 1998; McDonald and Harman, 1982; Crisosto et al., 1997a; McDonald and Harman, 1982) although storage in atmospheres containing more than 10 % CO_2, especially for long periods, has proven detrimental to fruit quality (Harman and McDonald, 1983; Irving, 1992). Several workers have investigated the effects of different CO_2 : O_2 atmospheres on the retention of flesh firmness in kiwifruit (Harman and McDonald, 1983; McDonald and Harman, 1982; Minnis, 1976). The most successful atmosphere for kiwifruit appears to be 5 % CO_2 : 2 % O_2. Under this regime, kiwifruit can be stored 2 - 3 months longer than air-stored fruit (McDonald and Harman, 1982).

Recently, the quality of 'Hayward' kiwifruit from New Zealand, stored for 3 months in controlled atmospheres of 2 % O_2 and 5 % CO_2, or in air in open bins, did not differ significantly on arrival in Europe (Parmentier and Proft, 1997). Therefore, it appears that CA storage has no advantage or disadvantage over air storage regarding the shelf life behaviour of kiwifruits on the European market. The only advantage of CA storage is that it can give more flexibility at the time of industrial grading and packing in New Zealand (Parmentier and Proft, 1997).

Ethylene

The benefits of CA storage in maintaining flesh firmness are significantly reduced by the presence of ethylene (C_2H_4). Contamination of storage atmospheres with as little as 0.1 $\mu L.L^{-1}$ C_2H_4 has severely reduced the effectiveness of CA storage in maintaining kiwifruit firmness (McDonald and Harman, 1982). Furthermore, an C_2H_4 concentration as low as 0.01 $\mu L.L^{-1}$ has reduced the storage potential of kiwifruit by over 50 % (Jeffery and Banks, 1996). It appears that continuous exposure to C_2H_4 promotes softening in kiwifruit, although it seems that short-term exposure is not in itself a major problem. The response of kiwifruit to C_2H_4 is dependent on maturity at harvest, concentration, exposure time and temperature. Cooling fruit reduces the response to ethylene but often fruit are exposed to C_2H_4 prior to coolstorage (Lallu, 1994).

Water loss

Water loss from kiwifruit, resulting in visible shrivelling of fruit (Beever and Hopkirk, 1990), may also affect the storage life of fruit. The initial stages of softening may be influenced as much by turgor changes as by the degradation of cell walls (Arpaia et al., 1987). Hatfield and Knee, 1988 proposed that apple firmness was influenced by cell turgor, with water loss leading to greater cell cohesion during ripening; the loss of cohesion between cells in the control fruit may have been due to an increase in the amounts of air space between cells caused by the cells being more spherical at high turgor (Davie, 1997). It is possible that in kiwifruit the hydrolysis of starch may increase cell turgor thereby reducing cell cohesion and firmness. However, water loss appears to enhance the softening of kiwifruit. For example, fruit stored with relative

humidity (RH) levels above 95 % softened less rapidly than those stored at 80 – 85 % RH (McDonald and Harman, 1982). The mechanism involved in this effect is unclear. Commercially, water loss and shrivel are not usually major problems as fruit are enclosed in polyethylene liners to retain a high humidity around the fruit.

Postharvest diseases

The manifestation of postharvest diseases during storage, especially *Botrytis cinerea* (which causes stem end rot) may also have considerable effects on the storage behaviour of kiwifruit. Such diseases may accelerate fruit softening in neighbouring, non-infected fruit (Brook, 1991; Manning and Pak, 1993) through stimulation of C_2H_4 production in infected fruit (Niklis et al., 1993).

There is anecdotal evidence in the kiwifruit industry that storage rot incidence is highest in lines of fruit that are graded, packed and coolstored immediately after harvest and much lower in lines of fruit that are not graded and packed until some days after harvest. The practice of "curing" is now commonly used successfully in the kiwifruit industry to minimise the occurrence of postharvest diseases during storage. Curing involves leaving fruit in ambient conditions for a short period after harvest and prior to being packed and placed in coolstorage (Pennycook and Manning, 1992)

2.4 Calcium (Ca) and fruit storage behaviour

2.4.1 Introduction

Ca is an integral component of cell walls and plays an important role in many of the metabolic processes affecting fruit ripening and postharvest storage life. A deficiency in Ca causes or exacerbates a host of physiological disorders in a range of fruits and vegetables (Table 2.3) while pre- and postharvest Ca treatments have reduced the incidence of physiological disorders and improved the retention of firmness during

storage in many fruits and vegetables including kiwifruit (Basiourny, 1998; Buescher and Hudson, 1984; Ferguson, 1984; Gerasopoulos et al., 1996; Glenn and Poovaiah, 1990; Harker et al., 1990; Hopkirk et al., 1990; Prasad and Spiers, 1991; Siddiqui and Bangerth, 1995a; Siddiqui and Bangerth, 1995b). Furthermore, a number of studies have found significant associations between Ca concentrations in kiwifruit and subsequent storage behaviour (Banks et al., 1995; Davie and Banks, 1994; Mowatt and Banks, 1992; Prasad et al., 1990; Prasad and Spiers, 1991; Resnizky and Sive, 1993; Tagliavini et al., 1995). For these reasons, the importance of Ca to the storage behaviour of fruit and the factors that influence the Ca nutrition of plants is discussed here in some detail.

2.4.2 The manifestation of Ca-related physiological disorders

Ca disorders exhibit a range of symptoms, but are often the result of cell membrane and wall dysfunction, causing tissue collapse and symptoms such as bitter pit in apple and various other tissue browning disorders. Disorders are often expressed as a result of physiological stress caused by prolonged storage at low temperature although some disorders, such as bitter pit, are obvious at harvest or upon immediate ripening (Hofman and Smith, 1993).

In a number of fruits, Ca is not evenly distributed throughout the mesocarp. Consequently, those regions of fruit low in Ca tend to be susceptible to the development of physiological disorders, as is the case with soft-nose in mango (Burdon et al., 1991). However, the relationship between Ca and physiological disorders at the tissue level in some fruits (e.g. mango and apple) is conflicting i.e. higher concentrations of Ca have been found in disordered tissues when compared to healthy tissues (Perring, 1995; Gautam and Lizada, 1984; Perring, 1984c; Perring, 1986). These contradictory findings may be the result of mineral redistribution, which occurs as disorders develop. It is possible that disordered tissue may sequester Ca from adjacent mesocarp tissue as it spreads, thus depleting the mineral content of that tissue. Hence, identifying the

mechanism(s) responsible for the development of disorders in fruit may not be possible simply by examining disordered tissue.

Table 2.3 Ca-related physiological disorders of fruits and vegetables.

Crop	Disorder	Reference
Apple	Bitter pit	Ferguson et al., 1990; Fallahi et al., 1997
	Cork spot	Richardson and Lombard, 1979
	Jonathan spot	Dris et al., 1998
	Lenticel blotch	Haynes, 1990
	Senescent breakdown	Bramlage et al., 1990
		Fallahi et al., 1997
		Fallahi et al., 1997
Avocado	End spot	Shear, 1975b
Beans	Hypocotyl necrosis	Shear, 1975b
Cabbage	Tipburn	Tibbitts and Palzkill, 1979
Celery	Blackheart	Cox and Dearman, 1978
Brussel sprouts	Internal browning	Shear, 1975b
Lettuce	Tipburn	Barta and Tibbitts, 1991
Mango	Soft nose	Burdon et al., 1991
Pears	Cork spot	Tomala and Trzak, 1994
Peppers	Blossom end rot	Morleyet al., 1993
Strawberry	Leaf tipburn	Shear, 1975b
Tomato	Blossom end rot	Adams and Ho, 1995

2.4.3 The role of Ca in fruit softening

Ca treatments are thought to retard softening by preventing the loss of Ca ions from the middle lamellae and / or by preventing the loss of Ca binding sites (Poovaiah et al., 1988). However, there is evidence that the effect of Ca in maintaining intact middle lamella does not appear to be its direct ionic effect but rather some other specific effect (Siddiqui and Bangerth, 1995a; Siddiqui and Bangerth, 1996). Ca may have an indirect role in maintaining fruit firmness i.e. its extensive cross-linking with pectic polymers

may restrict access of hydrolytic enzymes to wall components. This may prevent the liberation of pectins covalently attached to hemicelluloses and retain the attachment of the middle lamella with the primary wall, thereby maintaining cell cohesion and fruit firmness (Siddiqui and Bangerth, 1996). Furthermore, Ca has reportedly lowered the activity of enzymes by reducing their secretion or regulating protein synthesis (Ferguson, 1984). Ca may therefore maintain fruit firmness by reducing the synthesis and / or activity of cell wall degrading enzymes. For example, reduced activity of ß-D-galactosidase and greater fruit firmness was reported in Ca treated apples after 20 days of storage (Siddiqui and Bangerth, 1995a), despite the lack of significant differences in these attributes at harvest. Ca may also influence fruit softening by raising cell turgor through an osmotic effect (Zocchi and Mignani, 1995).

In plants, Ca has a role in several diverse physiological processes including growth hormone action, osmoregulation, pollen tip growth, cation transport, cell polarity, cell division, ripening and the development of disorders (Bangerth, 1979; Poovaiah et al., 1988; Poovaiah, 1993). Given this, Ca treatments may have many other direct and indirect effects on fruit softening behaviour, though the extent to which these contribute to the fruit softening process relative to the interactions of Ca with cell walls is not known.

2.4.4 Assimilation and translocation of Ca in plants

Generally, it is assumed that transpiration has little influence on nutrient translocation as most nutrients can move in both the xylem and phloem of plants (Tibbitts, 1979). However, strong evidence indicates that the transport of Ca preferentially occurs in the xylem of plants where the rate of translocation depends on the transpiration rate (Allaway, 1976; Banuelos et al., 1987; Giulivo, 1990; Hofman and Smith, 1993; Pate and Hocking, 1978; Smith et al., 1987; Tibbitts, 1979; Wiersum, 1961). Transpiration rates differ between different types of plant tissue. For example, fruits of plants that have a low incidence of stomata (through which transpiration occurs) transpire only

small amounts of water and therefore accumulate very little Ca (Tibbitts, 1979). In comparison, leaves of plants tend to have a lot of stomata, which presumably facilitate the accumulation of Ca in plants. Given that Ca transport and distribution in plants depends primarily on their transpiration rate, it may be possible to manipulate the distribution of Ca to fruit and leaves by changing the ratio of fruit : leaf in plants - methods of achieving this are discussed later.

Considerable evidence indicates that the uptake and movement of Ca in plants involves exchange and deposition reactions with conducting tissue (Armstrong and Kirkby, 1979; Bell and Biddulph, 1963; Biddulph et al., 1961; Ferguson and Bollard, 1976; Geijn and Petit, 1979; Geijn et al., 1979; Hanger, 1979; Hanson, 1984; Jacoby, 1967; Marschner, 1986; Millikan and Hanger, 1966; Shear and Faust, 1970; Thomas, 1967; Vang-Petersen, 1980). Ca is thought to be adsorbed by the negatively-charged exchange sites of vessel cell walls of xylem and to move upward in the transpirational stream by a series of exchange reactions. The exact nature of the exchange sites is not fully understood, but logical sites suggested include lignin (Ito and Fujiwara, 1967; Shear and Faust, 1970), the proteins of protoplasmic membranes (Ginzburg, 1961), and the head groups of membrane phospholipids (Himelrick and Ingle, 1981). The mobility of Ca in the xylem is promoted by the presence of other divalent cations, such as Mg, which are also adsorbed on exchange sites (Himelrick and McDuffie, 1983). High concentrations of chelating compounds (e.g. EDTA), or malic or citric acids may also promote Ca movement in plants (Ferguson and Bollard, 1976; Millikan and Hanger, 1965; Shear and Faust, 1970) by binding with Ca to produce uncharged or negatively charged Ca-complexes (Bradfield, 1975) that could reduce the degree of adsorption of Ca onto the negatively charged exchange sites of xylem. Therefore, it seems plausible that the mobility of Ca in plants may be promoted by nutritional treatments which increase the concentration of organic acids in the xylem sap. For example, the leaves, petioles, stems and roots of tomato plants grown with N supplied as nitrate had higher organic acid contents than those supplied with N as ammonium (Kirkby and Mengel, 1967).

Ca is notoriously immobile in the phloem of plants (Ferguson, 1979; Hanson, 1984; Raven, 1977; Raven, 1986). However, there is some evidence that Ca may be transported in the phloem (Faust and Klein, 1974; Himelrick and McDuffie, 1983; Jones et al., 1983; Jones et al., 1986; Marschner, 1974; Millikan and Hanger, 1965; Millikan and Hanger, 1969; Priestley, 1976; Ringoet et al., 1968; Stebbins and Dewey, 1972; Tommes and Van Die, 1964; Vang-Petersen, 1980; Wieneke, 1979). There is also some evidence that Ca is transported in the cortex of plants (Biddulph et al., 1961). However, phloem and cortex transport probably occurs only when Ca is saturated in other Ca-conducting tissue (Milthorpe and Moorby, 1969; Wiersum, 1961). The Ca content of the phloem and cortex of plants is generally very low (Bangerth, 1979; Ferguson, 1980b; Hanson, 1984; Marschner, 1986; Wiersum, 1961; Wiersum, 1979a; Wiersum, 1979b) and therefore probably contributes very little to the overall accumulation of Ca by fruit. Difficulties such as the loading of Ca into phloem and the low solubility of Ca in phloem sap exclude phloem as being a major transport route for Ca (Himelrick and McDuffie, 1983; Raven, 1986).

Once deposited in the leaves and fruit of plants, Ca often becomes highly immobile (Himelrick and McDuffie, 1983; Millikan and Hanger, 1965; Rinnie and Langston, 1960; Shear and Faust, 1970; Simon, 1978) and is only remobilised under special conditions such as very hot, dry weather (Bramlage, 1994; Wilkinson, 1968), highly humid conditions (Tromp and Oele, 1972) or when roots are subjected to Ca deficiency (Greene and Bukovac, 1968). The lack of Ca remobilisation in plants is probably the result of phloem immobility of Ca (Addiscott, 1974; Epstein, 1972; Goor and Wiersma, 1974; Marschner, 1974; Zimmermann, 1960). As a consequence of the lack of Ca remobilisation, organs with a high demand for Ca, such as growing fruits, must depend on a continuous supply of Ca through root uptake.

2.4.5 Periodicity of Ca uptake by plants

The rate of Ca uptake and distribution varies between crops and cultivars. Nevertheless, the majority of the final Ca content of many fruits, including kiwifruit, accumulates within 4 - 8 weeks after full bloom which usually coincides with the period of fruit cell division (Clark and Smith, 1991; Ford and Quinlan, 1979; Kotze and de Villiers, 1989; Mason and Whitfield, 1960; Qui et al., 1995; Quinlan, 1969; Smith et al., 1988; Wilton, 1991). This early period of rapid Ca uptake may occur because young fruit have a high surface area : volume ratio and permeability to water (Cline and Hanson, 1992) which is conducive to a high rate of transpiration.

After the initial period of rapid Ca uptake, Ca accumulation declines and the Ca concentration in fruit declines as dilution occurs (Ferguson, 1980a; Rogers and Batjer, 1954). In a number of crops, the drop off in Ca accumulation is probably associated with a number of changes accompanying fruit growth - the surface area : volume ratio of fruit decreases; the fruit cuticle becomes more lipophilic; fruit stomata become less dense and functional; and the ratio of leaf : fruit number and surface area increases (Cline and Hanson, 1992). All these changes are likely to reduce fruit transpiration and therefore Ca accumulation in fruit. Furthermore, the fall off in Ca movement into fruit is most likely associated with a shift from xylem to phloem (which has a low concentration of Ca) as the major supply route of water and assimilate to fruit (Clark and Smith, 1988; During et al., 1987; Ferguson, 1980a; Himelrick and McDuffie, 1983; Lang, 1990). It has also been suggested that the fall off in Ca movement into fruit may be associated with xylem dysfunction during growth (During et al., 1987). Given the fall off in Ca accumulation, the final Ca concentration of fruit is determined by the rate of the initial uptake and the rate of dilution (Faust, 1986). Other research has found that Ca transport into fruit continues evenly throughout the entire growing season (Haynes and Goh, 1980; Tomala et al., 1989) although this may have occurred because of abnormal climatic and soil factors during Ca uptake.

2.4.6 Factors influencing the Ca status of fruit

2.4.6.1 Introduction

Several factors influence the uptake and assimilation of Ca in fruit. Much of the research carried out in this area has been with pipfruit and there is limited information regarding the factors influencing the Ca status of kiwifruit. Consequently, much of the information presented here relates to apple research, though many of the principles are general enough to be applicable to kiwifruit.

2.4.6.2 Other minerals and fertilisation

Introduction

The addition of fertiliser to soil is commonly practised on orchards to provide additional mineral nutrients that enhance the yield and quality of fruit. However, fertilisers may have direct and indirect, and positive and negative effects on the availability of Ca and its uptake from the soil. Various fertilisers that are commonly used on orchards are discussed here as are their effects on the Ca nutrition of trees.

Boron (B)

B is considered an essential element for plant growth and is important in carbohydrate translocation with effects on transpiration (through the control of sugar and starch formation), cell development and elongation, carbohydrate metabolism, amino acid formation, and protein synthesis (Gupta, 1979; Tisdale et al., 1985). B may also have an indirect role in pectin and cell wall formation (Chermsiri et al., 1995; Huguet, 1964).

In apple, an increase in the Ca concentration of fruit has been associated with an increase in the B concentration of the same fruit (Faust and Shear, 1968). Furthermore, B sprays have increased the movement of Ca into the leaves of apple seedlings (Shear and Faust, 1970) while both foliar and soil applications of B in apple orchards have increased fruit Ca concentrations (Dixon et al., 1973).

The mechanisms by which B may enhance Ca transport in plants are not clear. It may indirectly affect Ca uptake by affecting transpiration (Chermsiri et al., 1995). B may also assist in maintaining more plant Ca in a soluble form (Marsh and Shive, 1941) which may enhance Ca uptake. Furthermore, B may indirectly affect Ca uptake by affecting root growth through its role in carbohydrate metabolism (Shear, 1980).

B accumulates in older leaves and is not retranslocated. Therefore, like Ca, a constant supply of B must be available to plants; adequate soil moisture is important - a shortage or excess may induce boron deficiency (Shear, 1980). To be effective, B must be available at the time of greatest demand by fruit for Ca. The variability between sites and years in response to B indicates that B sprays are likely to be effective only when the availability of B or Ca, or both, are restricted by soil content or moisture conditions (Shear, 1980).

Calcium and liming

Information concerning the effects of soil-applied Ca fertilisers on the mineral status of fruit crops is limited. Generally, Ca fertilisation has had minor effects on the Ca status of fruit (Boon et al., 1966; Wilton, 1991; Wooldridge, 1994). Ca fertilisation increased fruit Ca content in a few apple cultivars and one pear cultivar (Maas et al., 1994; Raese and Staiff, 1990), but those increases were associated with a sandy soil which probably had a very low Ca content to begin with. It may be that Ca fertilisation will only be useful to crops in particular circumstances such as those being grown on sandy soils.

Liming itself makes virtually no Ca directly available to trees because of its low solubility, but it maintains soil pH at a level at which Ca may be more available to tree roots (Bramlage, 1994; Wooldridge, 1994). On the other hand, liming may also induce trace-element deficiencies which may decrease Ca uptake by trees. Thus, increasing the soil pH cannot be relied on as a means by which fruit Ca content can be increased (Wooldridge, 1994).

Nitrogen (N)

The form of N applied to roots may influence the Ca status of plants. In particular, N available as nitrate (NO_3^-) supplies an easily absorbed companion anion for Ca (Shear, 1980). On the other hand, N available as ammonium (NH_4^+) ions impairs the Ca status of plants (Wilcox et al., 1973), presumably as a result of cationic competition, especially in terms of root uptake (Kirkby, 1979; Shear, 1975b; Shear, 1980). Ammonium ions also inhibit water uptake (Quebedeaux and Ozbun, 1973), which may reduce Ca uptake. Furthermore, ammonium ions reduce the soil pH (Shear and Faust, 1971) which increases the availability of metallic ions such as aluminium that reduce Ca uptake (Clarkson and Sanderson, 1971; Johnson and Jackson, 1964). Ammonium ions are also absorbed preferentially over nitrate ions and actually inhibit nitrate uptake by blocking nitrate reductase activity in the roots (Faust, 1986; Shear, 1975a; Shear, 1980).

Substantial quantities of ammonium and nitrate can be added to the soil through the application of N fertilisers such as urea (46 % N; McLaren and Cameron, 1996). Soil processes such as N fixation (i.e. the conversion of inert atmospheric N_2 gas into plant available N) and mineralisation (i.e. the release of N from plant residues, soil organic matter and other organic materials by the activity of a wide range of soil organisms) can also supply the soil with ammonium and nitrate (McLaren and Cameron, 1996).

Decreases in the N content of the soil throughout the season can be attributed to a number of processes that occur in the soil. For example, ammonium is depleted in the soil by plant uptake and the process of nitrification that transforms it into nitrate (McLaren and Cameron, 1996). Ammonium ions can also be adsorbed by cation exchange reactions on to the surface of clays and organic matter in the soil. This exchangeable ammonium is available to plants and is protected from leaching. However, ammonium ions can be held by certain 2:1 type clay minerals (e.g. vermiculite) in a non-exchangeable fixed form which is an important mechanism for retaining NH_4^+ ions in the soil (McLaren and Cameron, 1996). Nitrate is removed from the soil by plant uptake, immobilisation, denitrification and leaching - immobilisation is the process by which micro-organisms take up mineral N and incorporate it into their

own bodies. Denitrification involves the reduction of NO_3^- to gaseous forms of N under anaerobic conditions (McLaren and Cameron, 1996).

Once N is taken up by the roots of plants, it is transported in the xylem as non-protein amino acids which move by exchange in the same manner as inorganic cations, thus competing with Ca for exchange sites in the xylem (Shear, 1980). Therefore, N transport from roots might be expected to facilitate Ca transport by liberating more Ca for movement in the transpiration stream.

N uptake during early fruit development stimulates shoot growth which provides a preferential sink for Ca and further reduces Ca transport into fruit. Adding N to plants also increases fruit N significantly, whereas the Ca content may not change. This may create a high N : Ca ratio which appears to be important in the development of certain storage disorders such as bitter pit in apples (Ferguson and Watkins, 1989; Shear, 1980). In addition, the larger fruit size produced by high N would be expected to result in lower fruit Ca concentrations through dilution. High N may also reduce root growth (Shear, 1975a) which may reduce the absorption capacity of plants. Therefore, excessive N (especially ammonium) applications should be avoided, particularly early during fruit development.

Potassium (K) and magnesium (Mg)

K and Mg appear to antagonise the uptake and effects of Ca in plants (Kotze, 1996; Wilton, 1991; Bangerth, 1979) presumably as a result of cationic competition. Furthermore, fruit high in both these minerals have been found to be more susceptible to storage disorders (Bramlage et al., 1980; Kirkby and Pilbeam, 1984; Shear, 1975a; Ferguson et al., 1987). It has been suggested that the ratios of Mg and K to Ca are important to storage behaviour although this doesn't appear to be the case over the whole range of Ca contents (Ferguson and Watkins, 1989) i.e. if the Ca content is high enough then high concentrations of Mg and K are unlikely to result in greater incidence of disorders. The effects of Mg and K on the Ca nutrition of kiwifruit have yet to be explored in any detail.

Phosphorus (P)

In apples, it has been found that the steady uptake of Ca may be facilitated by increasing the availability of phosphate early in the growing season (Jakobsen, 1979). However, too much phosphate may risk precipitation of calcium phosphate and result in a Ca deficiency (Jakobsen, 1979; Shear, 1980). The effect of phosphorous on the Ca status of kiwifruit has yet to be determined even though there is some anecdotal evidence indicating that fruit with less P store better than fruit with more P (Section 2.3.1.8).

Other minerals

The effects of other mineral elements on the quality and Ca status of fruits are largely unknown, especially in the case of kiwifruit. However, some work on other fruit has been carried out in this area. For example, sprays of both zinc (Zn) and copper (Cu) have increased Ca concentrations and reduced the incidences of storage disorders in pipfruit (Shear, 1980), which is contrary to what one might expect from such potentially competing cations. It is possible that Zn and Cu may release bound Ca from various chelating and complexing agents (lignin, organic acids, proteins) for other cellular activities (Shear, 1975b; Shear, 1980).

The presence of minor elements such as Zn in fruit could be an important factor in determining the quality of fruit at harvest but to date little work has been carried out in this area.

2.4.6.3 Root growth

Vigorous root growth may influence the Ca status of kiwifruit by enhancing shoot growth, which would increase the competition between leaves and fruit for Ca. On the other hand, extensive root systems may benefit the Ca status of fruit by acquiring a greater proportion of the total Ca in the soil. Therefore, a balance between shoot growth and root activity seems likely to be important for the Ca nutrition of fruit.

2.4.6.4 Ground covers

The effects of ground covers on the Ca status of kiwifruit are unknown. Nevertheless, ground covers could potentially enhance the Ca status of fruit by improving the water status of soil, which may assist the mass flow of nutrients to and through plants - insufficient moisture reduces mineral absorption (Bramlage, 1993). Ground covers may also improve the surface rooting of trees (Section 2.3.1.5) and compete with plants for N in the soil (Haynes, 1981), which may improve the Ca nutrition of fruit. Furthermore, ground covers may increase the amount of available Ca in the soil (Merwin and Stiles, 1994; Sitton et al., 1959; Wander and Gourley, 1943) which could further enhance the Ca status of fruit.

2.4.6.5 Rootstocks and interstocks

Very little work has looked at the effect of the physiological interactions of scions, interstocks and rootstocks on nutrient uptake in crops. However, differences in Ca accumulation by a variety of fruit trees have been associated with differences in rootstocks and interstocks (Autio, 1991; Autio et al., 1991; Awad and Kenworthy, 1963; Barroso and Renaud, 1994; Bould and Campbell, 1970; Brown and Cummins, 1989; Bukovac et al., 1958; Fallahi, 1992; Hanson and Perry, 1989; Jackson and Blasco, 1975; Jones, 1976; Kruczynska et al., 1989; Poling and Oberly, 1979; Reddy et al., 1989; Rom et al., 1991; Rozpara et al., 1989; Sistrunk and Campbell, 1966; Smith and Kohne, 1992; Tukey et al., 1962; Ugolik and Holubowicz, 1989; Ystaas, 1990).

The kiwifruit industry in NZ is based on the 'Hayward' cultivar, which is typically grown on 'Bruno' seedlings. Recently, the effects of rootstock and 'Hayward' scion interactions on the field performance of kiwifruit vines have been studied with differences found in the productivity of scions on different stocks (Cruz-Castillo et al., 1997). However, the effects of stocks on the mineral status of kiwifruit have not been studied in any detail.

2.4.6.6 Climatic factors

Of all the climatic factors influencing Ca uptake by plants, relative humidity (RH) is considered to be the most important because of its effect on transpiration. Generally, as RH increases, transpiration and Ca uptake by fruit (Banuelos et al., 1987; Cline and Hanson, 1992) and leaves (Ehret and Ho, 1986; Sud et al., 1995; Tromp and Oele, 1972) decreases. However, relatively humid conditions at night favour the transport of Ca into fruit, due to the development of root pressure (Banuelos et al., 1987; Tachibana, 1991) which has been shown to be important for the transport of Ca in crops such as cabbage (Palzkill and Tibbitts, 1977; Tibbitts and Palzkill, 1979), strawberry (Bradfield and Guttridge, 1979; Guttridge et al., 1981), and tomato (Armstrong and Kirkby, 1979; Bradfield and Guttridge, 1979).

The effects of other climatic factors on Ca uptake by plants, especially kiwifruit, have yet to be explored. However, it seems reasonable to speculate that high levels of temperature, radiation and wind will increase Ca uptake of plants by increasing transpiration. For example, high temperature has assisted Ca uptake in tea leaves (Sud et al., 1995). It also seems reasonable to assume that high humidities caused by high levels of precipitation would reduce transpiration and therefore Ca uptake.

2.4.6.7 Pollination and seed number

Limited research has been carried out investigating the effects of pollination and seed number on the Ca status of kiwifruit. This is surprising given the associations that have been found between pollination, seed number and the Ca status of apples. In particular, it seems that the Ca concentration of apple fruit generally increases with seed number (Bramlage et al., 1990; Bramlage, 1994; Brookfield et al., 1992a; Brookfield et al., 1993; Tomala and Dilley, 1991). It appears that seeds somehow enhance the translocation of Ca into apple fruit (Bramlage et al., 1990).

Auxins produced by seeds (Luckwill, 1953) have been linked to the accumulation of Ca in fruit. Ca transport in plants is acropetal (upwards) and is closely linked to the

basipetal (downwards) transport of auxin (Banuelos et al., 1987; De Guzman and Dela Fuente, 1984a). Greater seed number in fruit may result in more auxin production and transport, which in turn may enhance Ca transport into fruit (Bramlage et al., 1990). This suggestion is reinforced by numerous investigations which have noted an increase in the Ca concentration of fruit associated with the application of auxins to fruit and trees (Goren, 1993; Poniedzialek et al., 1988; Tomala and Dilley, 1990; Xie et al., 1992). Also, the application of auxin transport inhibitors, such as TIBA, has decreased the accumulation and concentration of Ca in tomatoes, apples, sunflowers, peas and beans (Bangerth, 1976; Banuelos et al., 1987; Benson and Stahly, 1972; Himelrick and Ingle, 1981; Oberly, 1973; Stahly and Benson, 1970; Stahly and Benson, 1976; Stahly and Benson, 1982; Stahly, 1986; Tomala and Dilley, 1991; Wieneke et al., 1971). The mechanism(s) by which auxins stimulate Ca uptake by fruits is unclear although it has been proposed that somehow auxins alter the activity of membranous Ca efflux pumps (Kubowicz et al., 1982). Auxins have also been shown to induce the production of tracheary (i.e. xylem) elements in plants (Soumelidou et al., 1994), which may also influence the uptake of Ca.

It appears that a mutual relationship exists between auxin and Ca transport i.e. each substance promotes the transport of the other (Bangerth, 1976; Banuelos et al., 1987; De Guzman and Dela Fuente, 1984a; De Guzman and Dela Fuente, 1984b). Ca may facilitate the transport of auxins in plant tissue because it is an important component of cell membranes where auxin transport sites are found (Dela Fuente and Leopold, 1973). In addition, Ca may aid in the transport of auxins via a stimulus-secretion mechanism in which the passive influx of Ca into cells (caused by an environmental stimulus) may stimulate a secondary messenger which is involved in auxin transport (De Guzman and Dela Fuente, 1984a).

It has been suggested that the apparent relationship between seed number and the Ca status of apple fruit is merely correlative rather than causal and that seed number may be only an indicator of the effectiveness of pollination (Brookfield et al., 1994; Volz et al., 1993). Furthermore, it has been suggested that the effect of improved pollination on

the Ca status of apple fruit occurs by increasing the proportion of fruit which are spur and terminally borne (which often have a high Ca status) rather than through any direct effects of seeds *per se* (Volz et al., 1993). However, this has yet to be confirmed. The apparent association between seed number and Ca accumulation in apple fruit emphasises the importance of pollination and fruit set to final fruit quality. Pollination may be equally important in the Ca nutrition of kiwifruit.

2.4.6.8 Irrigation

Given that the uptake and assimilation of Ca by plants is linked strongly to transpiration (Section 2.4.4), the moisture status of the soil and therefore irrigation could impact significantly on the Ca status of fruit. However, the effects of irrigation on the Ca status of kiwifruit are not well known.

The amount of Ca in apple fruit has been shown to be greater for fruit from irrigated trees than for those from controls (Wilkinson, 1968) which indicates soil moisture is important in the transport of mineral ions to and through plants. Irrigation also tends to favour root development in the surface layers of the soil (Goode and Hyrycz, 1964; Goode et al., 1978) which probably aids in mineral uptake.

Irrigation (or rainfall), when temperature and light are not limiting assimilation, appears necessary for effective Ca accumulation (Wilkinson, 1968). However, full or excessive irrigation may promote vegetative growth and large fruit size thereby reducing fruit Ca concentrations by competition and dilution respectively.

Although managing soil water content may be important in the mineral nutrition of fruit trees, the extent of irrigation required to maximise Ca accumulation by fruits, including kiwifruit, requires further elucidation.

2.4.6.9 Vine vigour and leaf area

An excessively high leaf : fruit ratio of plants may cause low fruit Ca concentrations given that leaves and new shoot growth are more competitive for available Ca than developing fruit. Pruning may therefore benefit the Ca status and quality of fruit by reducing the leaf : fruit ratio of plants. Pruning may also increase the exposure of fruit to radiation and increase transpiration, further improving their Ca status. Pruning has improved the Ca status of many apple and pear cultivars (Baker, 1943; Bunemann and Struklec, 1980b; Bunemann and Struklec, 1980a; Lord and Greene, 1982; Olszewski and Mika, 1990; Perring and Preston, 1974; Preston and Perring, 1974; Raese, 1994; Struklec, 1990; Struklec, 1994; Tomala and Dilley, 1990) and has increased the firmness of kiwifruit at harvest (Chouliaris et al., 1995).

In apples, spur and bourse shoot leaves provide a powerful attraction for Ca to spurs and associated fruit due to strong transpirational forces. A reduction in bourse or primary leaf area of fruiting spurs has reduced Ca accumulation in developing apple fruit (Ferguson and Watkins, 1989; Ferguson and Triggs, 1990; Ferree and Palmer, 1982; Jones and Samuelson, 1983; Proctor and Palmer, 1991; Schumacher and Stadler, 1993; Tustin and Ferguson, 1993; Volz et al., 1993; Volz et al., 1994). In kiwifruit, the leaves of fruiting canes may also attract Ca to associated fruit and so any reduction in the leaf area in fruiting zones could be detrimental to the Ca status of fruit.

2.4.6.10 Fruit position and shading

In apple, the position of fruit in the canopy affects mineral content (Brookfield et al., 1992b). For example, fruit higher in the canopy tend to have less Ca (and more Mg and K) than fruit lower in the canopy (Barritt et al., 1987; Ferguson and Triggs, 1990; Haynes and Goh, 1980; Jackson et al., 1971). This positional difference may be due to the vigorous and competitive shoot growth associated with the upper regions of the tree (Volz et al., 1993) or to a lower supply of Ca to the upper regions of the canopy (Jackson et al., 1971). Apple fruit higher in the canopy also tend to be larger (Ferguson

and Watkins, 1989; Jackson et al., 1971; Sharples, 1973) which may dilute the Ca content of fruit. Also, terminal apple fruit tend to have more Ca than fruit towards the inside of the canopy (Kazimierz and Pawel, 1998; Volz et al., 1993; Volz et al., 1994). This positional difference may be due to greater exposure of terminal fruit to radiation (i.e. less shading) and therefore greater transpiration, xylem sap flow and Ca influx into fruit; terminal clusters may also have more neighbouring leaves than inner spurs, which may assist xylem sap cycling and Ca input into fruit (Volz et al., 1993; Volz et al., 1994).

The effects of position on the Ca status of kiwifruit are not known. However, shading of kiwifruit vines during the growing season has consistently reduced the firmness of harvested fruit (Antognozzi et al., 1995; Biasi et al., 1995; Poovaiah et al., 1988; Tombesi et al., 1993) which may have been due to a reduction in the influx of Ca into fruit as a result of lower transpiration rates.

2.4.6.11 Crop load and thinning

Considerable evidence (mostly pertaining to Braeburn) demonstrates that the Ca status of pipfruit decreases as crop load decreases (Anon., 1993; Bartholomew, 1992; Craig, 1992; Crutchley, 1994; Ferguson et al., 1990; Johnson, 1992; Park, 1993; Volz et al., 1991; Volz et al., 1992). This effect may be due to the dilution of the Ca contents in larger fruit associated with light cropping trees. However, fruit from light cropping trees tend to have a lower Ca status than fruit of similar size from heavy cropping trees (Wilton, 1991). This indicates that mineral differences in fruit from light and heavy cropping trees might also arise from factors such as differences in spur type, fruit / shoot ratios, fruit growth rates, and water relations (Ferguson et al., 1990; Ferguson and Watkins, 1991; Ferguson and Watkins, 1992).

The method and timing of thinning of fruit may have large effects on the final quality of harvested fruit through its effects on crop load. For example, in one investigation with apple, between-cluster thinning at full bloom increased final fruit size and reduced fruit

Ca concentrations (Volz et al., 1994). However, in the same investigation, within-cluster thinning substantially increased fruit size, with little effect on crop load, but did not affect fruit Ca concentrations. The reason for this is unknown and merits further investigation to enable a more robust model of this important area of horticultural physiology to be constructed.

Given the impact that the timing and method of thinning in apple has had on the Ca status of fruit, it seems likely that thinning practices of kiwifruit could significantly affect the Ca status of fruit.

2.4.6.12 Plant growth regulators

Plant growth regulator sprays (PGRS) are widely used in the fruit industry for reducing vegetative growth, enhancing flowering and yield, and improving fruit quality. Commonly used PGRS include the growth retardant paclobutrazol (PP333 or Cultar), auxins (e.g. NAA and Carbaryl), gibberellins and cytokinins (e.g. promalin (GA_{4+7} plus BA (cytokinin)), and daminozide (succinic acid-2,2-dimethyl hydrazide, Alar). Recently these PGRS have been implicated in the Ca nutrition of fruit owing to their diverse effects on plant growth and development.

PP333 has been shown to improve the Ca status of fruit in a range of crops including peach (Hu and Ding, 1993) and apple (Goren, 1993; Greene, 1986; Greene, 1991; Guzewski, 1993; Hu and Huang, 1992; Johnson and Quinlan, 1986; Luo et al., 1989; Miller and Swietlik, 1986). Auxin sprays have also improved the Ca status of fruit (Goren, 1993; Guzewski, 1993; Poniedzialek et al., 1988; Tomala and Dilley, 1990) as has daminozide (which is now prohibited for use in NZ; Ashby and Looney, 1968; Himelrick et al., 1976; Himelrick and Pollard, 1977; Himelrick and Pollard, 1978; Ibrahem et al., 1983; Martin et al., 1968). Promalin sprays on the other hand have consistently reduced Ca concentrations in fruit (Granger and Looney, 1983; Greene et al., 1982; Looney, 1979).

Apart from auxins, most PGRS are thought to have exerted their effect on the Ca status of fruit through the manipulation of fruit size (Bramlage, 1993), although some do reduce the vegetative growth of trees (Himelrick and Pollard, 1978; Rizzolo et al., 1993) which would be expected to reduce competition between fruit and foliage for Ca. PGRS which reduce fruit size, such as paclobutrazol and daminozide (Elfving et al., 1987; Curry and Williams, 1986; Mir et al., 1996), have little potential to produce large fruit with enhanced Ca content. Similarly, PGRS that increase fruit size, such as gibberellins and cytokinins (Cruz Castillo, 1994; Currie, 1997; Ogata et al., 1989), may result in the dilution of the Ca content of fruit thereby limiting their ability to produce large fruit with greater Ca contents. However, it is possible that the use of auxins combined with these may produce larger fruit with greater Ca contents.

The effects of cytokinins on the productivity of kiwifruit vines and fruit quality have recently been studied. In one investigation, CPPU (a diphenylurea derivative cytokinin) increased fruit yield (Lewis et al., 1996) while in another investigation, CPPU increased both yield and fruit size (Antognozzi et al., 1996). CPPU has also increased the green colour of fruit flesh and advanced and / or accelerated the fruit ripening process without negative effects on the storability of the fruits and their quality at the end of the ripening process (Antognozzi et al., 1996). CPPU appears to modify the carbohydrate metabolism of fruit, increasing the soluble sugars and starch content throughout fruit growth. The effects of cytokinins, such as CPPU, on the mineral status of kiwifruit have yet to be explored in any detail.

PGRS are not used commercially in the kiwifruit industry and so their effects on fruit quality and the Ca status of fruit are not as well known as in other crops such as apples. Furthermore, increasing consumer awareness of pesticides and other potentially harmful substances used in the primary sector will limit the use of PGRS in the future and so there seems little scope for using PGRS to improve the quality of kiwifruit.

2.4.6.13 Conclusions

The Ca status of kiwifruit vines and fruit is likely to be the result of interactions between several diverse factors. In other crops, the effects of many of those factors on the Ca nutrition of fruit are well known; considerably less is known about their specific effects on the Ca status of kiwifruit. However, if those effects could be clearly identified, then alternative management strategies could be developed to enhance the Ca status of fruit which in turn, could lead to improvements in the storage potential of kiwifruit.

2.4.7 Ca treatments and their effectiveness

In several investigations, Ca treatments have significantly increased the Ca content of many fruits including apple (Chittenden et al., 1973; Drake et al., 1979; Hewett and Watkins, 1991; Lidster et al., 1978b; Lidster et al., 1978a; Looney, 1977; Watkins et al., 1989), pears (Richardson and Lombard, 1979; Sugar et al., 1992; Walsh et al., 1996b) and kiwifruit (Davie et al., 1996; Gerasopoulos et al., 1996; Siddiqui and Bangerth, 1995a; Siddiqui and Bangerth, 1996). Preharvest Ca sprays are commonly used to enhance the Ca content of fruits, though they are not always effective, and may need to be applied many times throughout the growing season. Preharvest spraying of kiwifruit with Ca solutions, has generally not been successful in improving the storage behaviour of fruit with high concentrations (above 2 % approx.) causing damage to fruit, especially when calcium nitrate ($CaNO_3$) sprays were applied during the early stages of fruit development (Harker et al., 1990). However, significant reductions in fruit softening and extensions in the storage life of kiwifruit have been achieved by spraying with calcium chloride ($CaCl_2$; Gerasopoulos et al., 1996).

Many fruits, particularly pipfruit, are dipped after harvest in Ca solutions but this is expensive and again, is damaging to kiwifruit at high concentrations. For example, Hopkirk et al. (1990) reported that $CaCl_2$ postharvest dips reduced the rate of softening during storage of kiwifruit at 0°C, while concentrations above 2 % increased skin pitting

(Moras and Nicolas, 1987). The reduction in softening and the development of skin pits following dipping in Ca solutions may vary from orchard to orchard depending on the initial quality of the harvested fruit (Harker et al., 1990).

Attempts to increase the Ca content in fruit by applying lime or other Ca salts to the soil have largely been unsuccessful (Poling and Oberly, 1979; Wilton, 1991; Wooldridge, 1994; Scudellari et al., 1997). Reasons for this are unclear but perhaps Ca that is applied to the surface of the soil is not accessible to the majority of the root system because it resides deep in the soil. In orchards, Ca content can vary considerably horizontally and vertically in the soil; most of the Ca is concentrated near the soil surface where the soil organic contents are highest and it is likely that much of the Ca applied in fertilisers is also retained here (Tillman, 1994). Plant roots rely predominantly on Ca being carried to them in the soil water being taken up by the plant. Kiwifruit can take up water from considerable depths in the soil and therefore the amounts of soil Ca throughout the rootzone may be more important than the amounts right at the soil surface (Tillman, 1994). If the soil surface is relatively dry and vines are drawing water from deeper in the soil profile than fertiliser Ca near the soil surface may be effectively unavailable to the plant (Tillman, 1994). The availability of Ca in the soil and its uptake by plants may also be affected by other nutrients in the soil particularly nitrogen, potassium, magnesium and sodium (Tillman, 1994).

2.5 Ca and the prediction of fruit storage behaviour

Given that Ca has been established as a major factor contributing to fruit storage behaviour, it seems logical that the concentration of endogenous Ca in fruit may be a useful indicator of fruit storage behaviour. However, to date little or no correlation has been found between Ca concentrations and the firmness of fruits (Harker et al., 1990; Hopkirk et al., 1990; Smith et al., 1991), although a significant relationship has been reported between Ca in kiwifruit and the rate of softening (Prasad et al., 1989).

The absence of a clear relationship between fruit Ca concentrations and firmness in kiwifruit may be due to the naturally high concentrations of Ca present in kiwifruit. Other fruit crops that are susceptible to Ca deficiencies contain much lower Ca concentrations e.g. apples contain about a tenth of the amount in kiwifruit (Harker et al., 1990). It is also possible that a relationship exists between only certain critical fractions of Ca and fruit firmness. As discussed previously, Ca is an integral component of cell walls that increases the rigidity of cell walls and promotes cohesion of neighbouring cells. However, a large proportion of the Ca in kiwifruit is associated with Ca oxalate crystals or with seeds (Ferguson, 1980a; Ferguson et al., 1980). Therefore the cell wall fraction of Ca in kiwifruit may be a better predictor of fruit firmness than total fruit Ca. However, separation of Ca into physiologically active and inactive (using acetic and hydrochloric acids) fractions has offered little advance over measurement of total Ca concentration as a predictor of storage quality before harvest (Clark and Smith, 1991; Hopkirk et al., 1990).

Although Ca has been shown to influence the storage behaviour of kiwifruit, Ca concentration *per se* is a poor indicator of fruit storage behaviour. However, the combination of Ca concentration with other fruit compositional attributes may provide better indicators of fruit storage behaviour. For example, a strong relationship was found between leaf petiole N (%) and the rate of fruit softening and an even stronger relationship was found when fruit Ca was included in the model (Prasad et al., 1989).

2.6 General conclusions

Considerable losses have occurred in the kiwifruit industry through poor storing fruit and, in particular, fruit that soften prematurely. The softening behaviour of fruit must be mediated through their composition at harvest. For example, the concentrations of soluble solids and minerals in fruit have been linked to softening behaviour. Several preharvest and postharvest factors have been found to influence the softening behaviour of kiwifruit presumably by altering the composition of fruit at harvest. However, the exact nature of those changes is not clear.

The concentration of Ca in fruit has been strongly linked to the storage behaviour of many fruits including kiwifruit. Therefore, factors that influence the Ca nutrition of vines and fruit are likely to significantly affect the storage behaviour of kiwifruit. Two such factors may be ground cover and fertiliser regime, both of which have affected several soil and plant attributes, including mineral content. The effects of these two factors, in combination with each other, on soil, vine and fruit attributes, were examined in the current work.

In addition to improving the storage behaviour of kiwifruit, fruit losses could be minimised by segregating lines of fruit at harvest based on predictions of their storage potential. There seems to be considerable potential for linking combinations of fruit attributes at harvest to the final quality of fruit.

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Chapter 3

Soil Amendments and the Storage Potential of Kiwifruit

3.1 Introduction

This chapter outlines the major experimental part of this programme. The study was aimed at characterising the inter-relationships involved in the fruit-vine-soil system that may link to the reported variability in the storage behaviour of kiwifruit from different sources and in particular from organic and conventional properties (Section 2.3.1.4). Specifically, this work tested the proposition that differences in the soil characteristics of organic and conventional orchards are likely to affect many aspects of vine function, including the uptake of minerals, which could in turn affect the storage potential of fruit (Section 2.3.1.8). Furthermore, it was hypothesised that differences in the soil characteristics of organic and conventional orchards were likely to arise from differences in the use of fertilisers and ground covers. In other studies, significant differences in soil characteristics have arisen from the use of different fertilisers and ground covers, which in turn have impacted on the quality of crops (Section 2.3.1.5). This work therefore set out to examine the effects of combinations of organic and inorganic soil amendments (i.e. fertilisers and ground covers) on soil, vine and fruit attributes over three consecutive seasons at two sites i.e. Massey University, Palmerston North and HortResearch, Te Puke. The HortResearch site was chosen given that the majority of kiwifruit in NZ are grown in that region and so any effects of the soil amendments there would have greater industry relevance. Historically however, fruit from that site have stored well. Therefore, the trial was also conducted at the Massey site, given that fruit from there have tended to store less well and that improvements in storage behaviour were expected to be more pronounced there. Conducting the trial at the Massey site also allowed soil, vine and fruit attributes to be monitored frequently throughout each season.

3.2 Description of trial

3.2.1 Treatments

In the spring of 1995 (October), nine soil amendment treatments were established at each of two sites i.e. the Fruit Crops Unit (FCU) Orchard, Massey University, Palmerston North and the HortResearch Research Orchard, Te Puke[2]. Each treatment was a factorial combination of one of three levels of each of two factors. Factor A comprised bare (Figure 3.1), grass (Figure 3.2) and mulch (Figure 3.3) ground covers while factor B comprised conventional, organic and organic plus regimes. The nine treatments (A – I) were as follows:

A	Bare	Conventional
B	Bare	Organic
C	Bare	Organic plus
D	Grass	Conventional
E	Grass	Organic
F	Grass	Organic plus
G	Mulch	Conventional
H	Mulch	Organic
I	Mulch	Organic plus

At both sites, bare plots were maintained free of weeds by the application of glyphosate as required. Grass plots were established and maintained by sowing rye grass seed and mowing monthly with the return of clippings to plots. Mulch plots were established by covering the soil with 100 mm of solid barley straw with minimum visible breaks.

[2] The soil at the Massey site is a yellow-brown (silt) loam that is well drained with moderate levels of organic matter. The soil at the HortResearch site is a dark-coloured volcanic (pumice) soil, with relatively high organic matter levels, a coarse texture and low bulk density.

The conventional fertiliser regimes, and the amounts of N in those regimes, were based on the typical requirements of each site. At the Massey site, the conventional regime consisted of 300 kg / ha of urea plus 500 kg / ha of 30 % potassic superphosphate while at the HortResearch site, it consisted of 1000 kg / ha of 30 % potassic superphosphate, 300 kg / ha of urea and 250 kg / ha of potassium sulphate. At both sites, the urea was added in 3 splits of 100 kg / ha; the first application occurred in October when the other fertilisers were applied, the second a few weeks before full bloom (late November) and the third about 10 weeks after full bloom. The organic regime at both sites was typical of that used by organic kiwifruit growers in NZ (Bruce Stowell, 1995 – personal communication) and consisted of 250 kg / ha of reactive phosphate rock, 1 tonne / ha of dolomite, and 2 tonnes / ha of fishmeal. The organic plus regime comprised the organic regime plus 2 tonnes / ha of gypsum (i.e. calcium sulphate)[3].

The approximate amounts of major mineral elements added by each of the fertiliser regimes are presented in Table 3.1.

[3] Gypsum is a relatively soluble fertiliser (more soluble than lime) and is a good source of calcium (24 %) with reasonable mobility through the soil profile (Korcak, 1993). The rate of gypsum used was typical of that used in NZ orchards.

Table 3.1 Total amounts (kg / ha) of major mineral elements added by each fertiliser regime to each plot at the Massey and HortResearch sites in October, 1995. N = nitrogen; P = phosphorous; K = potassium; S = sulphur; Ca = calcium; Mg = magnesium.

Fertiliser regime	Mineral element					
	N	P	K	S	Ca	Mg
Conventional						
- Massey	138	35	75	40		
- HortResearch	138	70	250	97.5		
Organic	200	112.5	8	2.5		100
Organic plus	200	112.5	8	402.5	480	100

Each of the fertiliser regimes was applied to a plot (Section 3.2.2). Initially, the fertiliser regimes were applied to each plot before the ground covers but in subsequent years, they were applied on top of the already established ground covers.

Figure 3.1 A section of a bare plot at the Massey site maintained free of weeds by the application of glyphosate as required.

Figure 3.2 A section of a grass plot at the Massey site. Mowing occurred at monthly intervals with the return of clippings to the plot.

Figure 3.3 A section of a mulch plot at the Massey site. In the first season, barley straw was used but in subsequent seasons, bark (illustrated) was used.

3.2.2 Experimental design and field layout

Each of the nine treatments was replicated three times at each site using a randomised complete block design providing a total of 27 plots or experimental units per site. Each plot at the Massey site consisted of 4 female vines ('Hayward' on cutting-grown vines; planted in 1991 and grafted in 1992) spaced at 2.5 m x 5 m and T-bar trained (Sale and Lyford, 1990). Plots were separated by a single male (predominantly Chieftain, M51 and some M56) guard vine. Down rows, treatments were applied to plots from the trunk of one male vine, through the experimental vines to the trunk of the next male vine. Across rows, treatments were applied within the boundaries of the canopy. Each plot at the HortResearch site consisted of 2 female vines ('Hayward' on 'Bruno' seedling rootstocks; planted 1981 and grafted in 1982) spaced at 6 m x 3 m[4] and pergola trained (Sale and Lyford, 1990). Each pair of vines (or plot) was separated from neighbouring plots by a single male ('Matua', M61, M59, M54, M62 and M52) guard vine between rows and a single female guard vine down rows. Down rows, treatments were applied to plots from the trunk of one female guard vine, through the pair of experimental vines, to the trunk of the next female guard vine. Across rows, treatments were applied from the trunk of one male guard vine, through the experimental vine, to the trunk of the next male guard vine.

3.2.3 Orchard management

Throughout the trial, the management practices adopted at both sites, including pruning and thinning, were typical for each site and consistent across all treatment plots. Pest control at both sites followed the standard 'Kiwigreen' programme (Anon., 1996).

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[4] Each female occupies an area of approx. 30 m^2 because the strip male was kept at 1 m wide.

3.2.4 Maintenance and changes to treatments

At each site, all soil amendments were maintained through the 1995 / 96, 1996 / 97 and 1997 / 98 seasons. During that time, the following amendments were made to treatments in an attempt to maximise differences between the soil characteristics of treatment plots:

- the barley straw mulch used in the 1995 / 96 season decomposed rapidly at both sites and was replaced / overlaid with bark mulch (50 – 70 mm thick after settling) in the two subsequent seasons.
- in the second and third seasons, 5 tonnes / ha of a standardised form of organic compost (KIWIWASTE compost from the Bay of Plenty region, NZ) was included in the organic and organic plus regimes at both sites as such compost is typical of an organic production system. Information regarding the amounts of nutrients in the compost was not available.
- in the third season, fishmeal was not added to the organic and organic plus plots at both sites to reduce the additions of N to the plots.
- to exacerbate differences in the N content of the soil and subsequently in the vines, twice as much urea (i.e. 600 kg / ha) was applied to conventional plots at each site in the third season. At the HortResearch site, the urea was added in 3 splits of 200 kg / ha and at similar times to the previous season. At the Massey site, the urea was added in 6 splits of 100 kg / ha at 2 – 3 weekly intervals from late October until the beginning of February.

At the HortResearch site, it was difficult to maintain thick grass swards due to the poor light conditions experienced under the pergola system. Consequently, in early spring prior to each season, more rye grass seed was sown in the grass plots. Thick grass swards were prevalent throughout the entire duration of the trial at the Massey site.

3.3 Materials and methods

3.3.1 Soil, vine and fruit monitoring

3.3.1.1 Introduction

Treatments were established only 8 months before the first harvest in May of 1996 and were therefore not expected to have been in place long enough to exert any major effects on vine or fruit attributes before the first harvest. Therefore, no pre-harvest monitoring of soil, vine or fruit attributes occurred in the first growing season (i.e. the 1995 / 96 season). Considerable monitoring was undertaken in the two subsequent seasons particularly in the 1996 / 97 season.

3.3.1.2 Soil monitoring

The following soil attributes were monitored prior to and / or at harvest in the 1996 / 97 and 1997 / 98 seasons:

- soil temperature (^{o}C)
- soil moisture content (% w / w)
- soil inorganic nitrogen (i.e. ammonium (NH_4^+) and nitrate(NO_3^-)) content ($mmol.kg^{-1}$)
- soil solution cation concentrations ($mmol.L^{-1}$)

At the Massey site, sampling of soil temperature and moisture content in the 1996 / 97 season occurred fortnightly from leaf emergence until harvest while in the 1997 / 98 season, sampling occurred monthly. In both seasons, the inorganic nitrogen content of the soil and the concentrations of cations in the soil solution were measured at monthly intervals from a month prior to full bloom until harvest. At the HortResearch site, sampling of soil attributes in both seasons occurred on just two occasions i.e. 8 weeks after full bloom and at harvest.

At both sites, the soil moisture content, inorganic nitrogen content and concentrations of cations in the soil solution were monitored at two depths in the 1996 / 97 season (i.e. 0 – 30 mm and 30 – 75 mm) but just one depth (i.e. 0 – 30 mm) in the 1997 / 98 season. In the 1996 / 97 season, the concentrations of cations in soil solution from treatment A (bare and conventional), C (bare and organic plus), G (mulch and conventional) and I (mulch and organic plus) plots were determined. In the 1997 / 98 season, the concentrations of cations in soil solution from treatment D (grass and conventional) and F (grass and organic plus) plots were also determined.

Approximations of the minimum and maximum soil temperatures of plots at both sites were obtained by conducting measurements at 6.00 am and 2.00 pm respectively on each occasion that sampling occurred (David Scotter, 1996 – personal communication). Temperatures were measured using a handheld digital thermometer and probe (Digi-thermo, Quartz) and on each occasion, five random spot measurements were made per plot with the tip of the probe inserted to a depth of 100 mm from the soil surface. Soil moisture and nitrogen contents were determined by taking 5 random cores per depth per plot while the concentrations of cations in soil solution were determined by taking 20 random cores per depth per plot. Cores were collected using a 1 m long soil corer, 30 mm in diameter. Subsequently, cores taken from each depth per plot were mixed together to provide composite samples for each depth per plot. The moisture content of those samples was determined gravimetrically by recording the initial and final weights of samples before and after oven drying at 105°C for 24 h. Final soil moisture content was calculated as the ratio of the absolute difference between wet weight and dry weight to wet weight. The N content of soil samples was determined by shaking 3 g of fresh soil in 30 mL of 2M KCl for 1 hr and then by centrifuging at 3000 rpm for 2 minutes. The resulting supernatants were then filtered to remove any soil debris. The ammonium and nitrate contents of each filtered sample were subsequently determined colorimetrically (Searle, 1975). The concentrations of cations in the soil solution of fresh soil samples were determined by centrifuging at 12000 rpm for 20 minutes. The resulting supernatants were then vacuum filtered to remove soil debris and then diluted with strontium-caesium solution (2.4 % w / w for each element in 2M HCl). Samples

were subsequently stored at 4°C until their Ca and Mg contents were measured by atomic absorption spectrophotometry and their K contents by emission spectrophotometry (Technicon, 1973).

Throughout this thesis, the term concentration is used when referring to the level of minerals in soil solution (i.e. cation concentrations) while the term content is used when referring to the level of minerals in the whole soil (i.e. inorganic nitrogen content). Also, both soil moisture and inorganic nitrogen contents are expressed per unit of dry soil.

3.3.1.3 Vine and fruit monitoring

The following vine and fruit attributes were monitored at both sites throughout the 1996 / 97 and 1997 / 98 seasons, prior to and / or at harvest:

- the concentrations of minerals (i.e. Ca, Mg, K, N and P) in leaves ($mmol.kg^{1}$), fruit ($mmol.kg^{-1}$) and xylem sap ($mmol.L^{-1}$)
- fruit size (mL)
- root length density ($m.L^{-1}$)

At the Massey site, the concentrations of mineral in fruit, leaves and xylem sap as well as fruit size in the 1996 / 97 season were determined at fortnightly intervals for the first two months after full bloom and thereafter at monthly intervals until harvest. The sampling of sap ceased approximately 100 days after full bloom. In the 1997 / 98 season, sampling of fruit and leaf mineral concentrations occurred monthly from full bloom until harvest while sampling of xylem sap mineral concentrations occurred on just two occasions i.e. 5 and 10 weeks after full bloom. At the HortResearch site, sampling of xylem sap, leaf and fruit mineral concentrations occurred on just two occasions in both seasons i.e. 8 weeks after full bloom and at harvest. At both sites, the root length density of vines was determined in the 1996 / 97 season only; sampling

occurred 8 weeks after full bloom at two depths (i.e. 0 – 30 mm and 30 – 75 mm) with only treatment A, C, G and I plots sampled.

On each occasion that sampling for minerals occurred in both seasons, 2 fruit and 2 leaves (petioles included) were collected from each vine (one from each side) at the Massey site while 4 fruit and 4 leaves (petioles included) were collected from each vine (2 from each side) at the HortResearch site. The position of fruit that was sampled was standardised as being the second fruit (from the basal end of the shoot) on a fruiting lateral, used only if it had a subtending leaf. The position of leaves that were sampled was standardised as being the second leaf past the final fruit on a fruiting lateral. On each occasion, fruit and leaves of a similar size were sample from each plot at both sites. Xylem sap was collected at dawn from vines by drilling a hole (10 mm in diameter and 15 - 20 mm deep) in each trunk (mid-height) and directly inserting a 50 mL syringe into the hole and imposing negative pressures within the trunks. Approximately 10 mL of xylem sap was collected from the trunks of each vine per plot.

For mineral analyses, fruit composite samples (one per plot) were produced by taking thin (10 mm thick) equatorial slices (skin included) from the middle of each of the 8 fruit per plot and homogenising them together. Similarly, all 8 leaves collected from each plot were bulked together (petioles included) and ground to provide composite samples. For each plot, the sap collected from each vine was mixed together to provide composite samples of sap. Subsequently, the concentrations of minerals in approximately 0.5 g homogenised fruit tissue, 0.1 g leaf tissue and 1 mL xylem sap, were determined.

The concentrations of Ca, Mg and K in samples were determined firstly by refluxing with 4 mL of concentrated nitric acid. Refluxing occurred in cation digestion tubes occluded with small glass funnels and at 150°C until the solutions cleared (at least 4 h). Solutions were then boiled dry at 250°C with the remaining residues re-dissolved in 50 mL of strontium-caesium solution (2.4 % w / w for each element in 2M HCl). Samples were subsequently stored at 4°C until their Ca and Mg contents were measured by

atomic absorption spectrophotometry and their K contents by emission spectrophotometry (Technicon, 1973).

For N and P determinations, Kjeldahl digestion solution was prepared by heating 250 g of potassium sulphate and 2.5 g of selenium powder with 2.5 L of concentrated sulphuric acid until the solution cleared. Samples were then digested with 4 mL of this solution in N and P digestion tubes at 350°C until the solutions cleared (4 – 5 h). Once clear, the tubes were allowed to cool before being made up 50 mL with distilled water. Samples were subsequently stored at 4°C until the analysis of N and P occurred colorimetrically at 630 nm and 420 nm respectively (Twine and Williams, 1971).

Fruit growth at both sites was monitored in both seasons by selecting and tagging 8 fruit per plot immediately after full bloom (i.e. 2 and 4 fruit per vine at the Massey and HortResearch sites respectively). The position of selected fruit was standardised as being the first fruit (from the basal end of the shoot) on a fruiting lateral, used only if it had a subtending leaf. Furthermore, tagged fruit were spaced evenly throughout the canopy of each vine. Subsequently, the width, breadth and length of each fruit were measured using digital callipers (Mitutoyo Digimatic, 0 – 150 mm). The volume of each fruit was then calculated using the formula for an ellipsoid volume i.e. $V = 4 / 3\ \pi abc$, where a, b and c are fruit width, length and breadth, respectively (Banks, 1985).

The root length density of vines at both sites in the 1996 / 97 season was determined by taking 75 random soil cores per depth per plot using a 1 m long soil auger, 30 mm in diameter. Subsequently, the 75 cores per depth per plot were mixed together to provide composite samples. These were then washed to remove soil and debris. The total length of the remaining cleaned roots was then measured using a Comair Root Length Scanner.

3.3.2 Fruit assessments at harvest

At the end of each of the three growing seasons, fruit from both sites were harvested when the soluble solids concentration (SSC) of fruit were as close to the commercial

minimum of 6.2 % as practically possible. The SSC of fruit prior to harvest was monitored regularly from 1 May each year by sampling 10 fruit per site per sampling day. At each site, 1 fruit of similar size was sampled from each of 10 randomly selected vines and within each vine, fruit were taken 1 m along a cane that originated 1 m along a leader from the trunk.

At harvest, fruit from each plot at both sites were strip-picked into bins then conventionally graded (following 2 days of curing in ambient conditions). At the same time, the following fruit attributes were measured:

- average SSC (°Brix)
- average flesh firmness (N)
- average fruit size (g), total fruit number and yield (tonnes / ha)

In 1996, the average SSC and flesh firmness of fruit from each plot at both sites was determined on 20 fruit randomly sampled from bins during grading. In 1997 and 1998, fruit were sampled directly from the vines of each plot with the position of sampled fruit standardised as being the second fruit (from the basal end of the shoot) on a fruiting lateral, used only if it had a subtending leaf. Fruit of similar size, that was the average for each site, were sampled from each plot. Subsequently, the total SSC of each fruit was determined by extracting and mixing 2 drops of juice from the 2 cut ends of each fruit into a refractometer (Atago, 0 – 20 %). The flesh firmness of each fruit was measured using a drill-mounted Effegi penetrometer (0 – 12 kgf) fitted with a 7.9 mm head. Two measurements were made per fruit at right angles to each other on pared areas on the equator of the fruit. Both the maturity and flesh firmness of fruit were determined at 20°C.

On each occasion at both sites, total fruit number, yield and the average fruit size was determined by running the fruit from each plot across a Treeways electronic grader.

3.3.3 Monitoring of fruit storage behaviour

During grading in all three years, 12 trays (single-layered with polyliners) of count 36 size fruit were randomly sampled from each plot at both the sites. For each plot, fruit were taken from a number of bins to provide more representative samples. Subsequently, fruit from the HortResearch site were freighted to Massey University and stored in the Plant Growth Unit coolstore; fruit from the Massey site were stored in the same coolstore in 1997 and 1998 but in 1996, were stored in the Fruit Crops Unit coolstore, Massey University. In 1996, fruit were stored at 0°C with a relative humidity (RH) of approximately 90 %, although the ethylene (C_2H_4) levels were not monitored. In subsequent years, fruit were also stored at 0°C with a RH of approx. 90 % and with C_2H_4 levels of less than 0.001 $\mu L.L^{-1}$. In each year, storage temperatures were constantly monitored and maintained by the systems built into each coolstore; manual checks occurred fortnightly using a hand-held thermometer (Digi-thermo, Quartz) and taking ten measurements from randomly selected spots in the coolstores. In 1997 and 1998, ethylene measurements were made every week during the first month of storage and thereafter at monthly intervals. On each occasion, ten 100 µL samples of gas were taken from randomly selected spots in the coolstore and passed through a gas chromatograph (Varian 3400).

Throughout storage in each year, flesh firmness of fruit from both sites was regularly measured, at approximately weekly intervals for the first month then at approximately fortnightly intervals thereafter until the later stages of storage (> 10 weeks) when measuring occurred at 3 - 4 weekly intervals. Towards the end of storage, sampling intervals were shortened to 1 – 2 weeks. The firmness of 12 fruit per plot from each site was measured on each occasion i.e. 1 fruit was sampled from each of the 12 trays per plot to account for any variation between trays. Firmness was measured at 0°C as described above.

After 10 weeks of storage, all trays of fruit from both sites were condition checked and scored for *Botrytis*; infected fruit were removed. At the end of storage (when the

firmness of fruit was as close to 10 N as practically possible), all remaining fruit from both sites were inspected and scored for the presence or absence of soft patches (i.e. localised areas on kiwifruit that have softened prematurely, relative to surrounding tissue). Fruit were inspected in ambient conditions within minutes of their removal from the coolstore. Soft patches were detected by gently moving the fingers of both hands over the surface of each fruit. In 1996 and 1997, the concentrations of minerals in fruit from each plot with and without soft patches were determined by randomly sampling 20 fruit with and 20 fruit without soft patches. Within each category of 20 fruit, thin (10 mm thick) equatorial slices were taken from each fruit and bulked together to give two composite samples per plot. The mineral concentrations of the composite samples were subsequently determined spectrophotometrically and colorimetrically as described above.

3.3.4 Data analysis

Considerable amounts of data were obtained by measuring several variables on each experimental plot or unit at many points in time during the growing seasons (from a statistical perspective, all measurements of a given variable made on the same experimental unit on more than one occasion were considered as 'repeated measures' data). This data was analysed using a *mixed model* approach as it allows for correlation and non-identicality associated with 'repeated measures' data. The MIXED procedure of SAS was used to perform the analyses (Little et al., 1991) using a two factor (i.e. factor A and B) factorial model. For variables that were measured only once on the experimental units (e.g. fruit attributes at harvest), differences were elucidated by subjecting the data to an analysis of variance (ANOVA) using the general linear models (GLM) procedure of SAS (Little et al., 1991). A two factor (i.e. factor A and B) factorial model was used in the analyses.

Differences in the softening behaviour of fruit were determined by identifying non-linear models that best characterised the data and then by comparing the parameters obtained from those models. Models were fitted to the data using the non-linear (NLIN)

procedure of SAS while the parameters obtained from fitting those models were compared by subjecting them to an ANOVA using the GLM procedure of SAS (Little et al., 1991). A two-factor factorial model was used in the ANOVA. The soft patch and *Botrytis* count data were subjected to an ANOVA using the GLM procedure of SAS (Little et al., 1991) and a two-factor factorial design. Where the data appeared to be non-normally distributed, they were appropriately transformed. In cases where transformations did not improve the error structure, the data were subjected to the Genmod procedure of SAS (Little et al., 1991) which assumes a binomial error structure. Differences in the concentrations of minerals in fruit with and without soft patches were elucidated by subjecting the data to an ANOVA using a three-factor factorial model with factor A (ground cover), factor B (fertiliser regime) and soft patch (i.e. plus and minus) as the three factors.

For all variables, site by season interactions were not tested in single overall analyses because large differences were anticipated between sites given the large differences in climate, soil type, age and management of vines. Furthermore, the error degrees of freedom for each site (16) already provided reasonable precision in the analyses.

3.4 Results

3.4.1 Preharvest attributes

3.4.1.1 Soil attributes

Soil temperature

At the Massey site, soil temperatures measured at 6.00 am and 2.00 pm ranged from 12 to 19°C (Figure 3.4) and 10 to 22°C (Figure 3.5) in the 1996 / 97 and 1997 / 98 seasons, respectively. In both seasons, temperatures increased from mid-November until the middle / end of December but then decreased until the middle / end of January only to increase again until late February / early March. Thereafter, temperatures steadily declined until harvest. Throughout both seasons, the 6.00 am temperatures of bare plots

were consistently, and at times significantly, less than those of grass and mulch plots. In contrast, the 2.00 pm temperatures of bare and grass plots, were consistently, and in some cases significantly, greater than those of mulch plots. Differences were less pronounced in the 1997 / 98 season while in both seasons, differences between ground covers declined towards harvest. Averaged across each season, the 6.00 am temperatures of mulch and grass plots were significantly higher than those of bare plots (Table 3.1) while the 2.00 pm temperatures of bare and grass plots were significantly higher than that of mulch plots (Table 3.2). The average 6.00 am and 2.00 pm temperatures did not differ significantly with fertiliser regime or its interaction with ground cover throughout either season (data not shown).

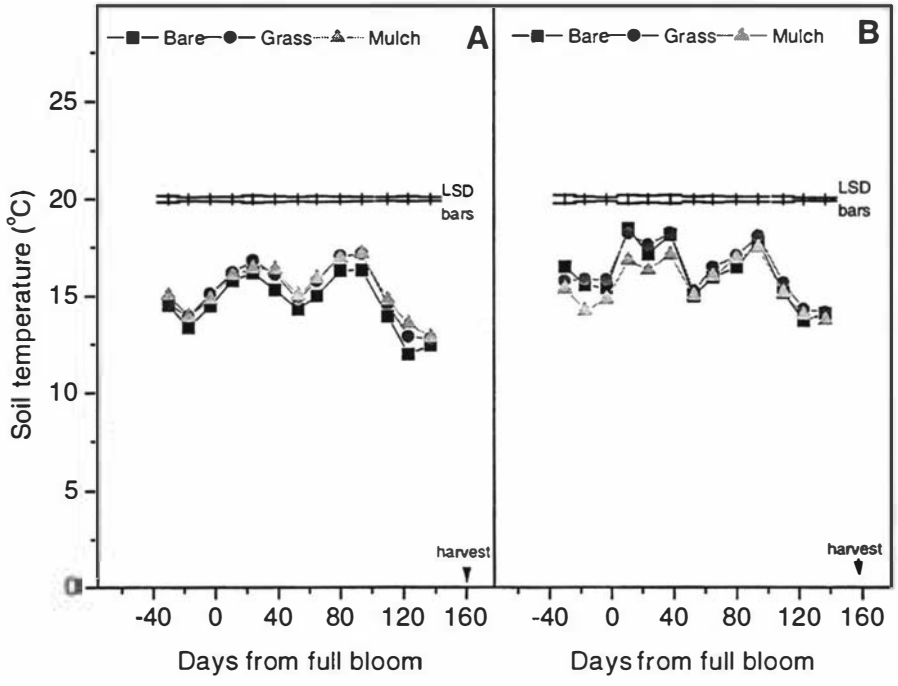

Figure 3.4 Seasonal variation in the average 6.00 am (A) and 2.00 pm (B) soil temperatures of bare, grass and mulch plots at the Massey site during the 1996 / 97 growing season. Sampling occurred at a depth of 100 mm. Each LSD was estimated at the 5 % significance level (n = 9).

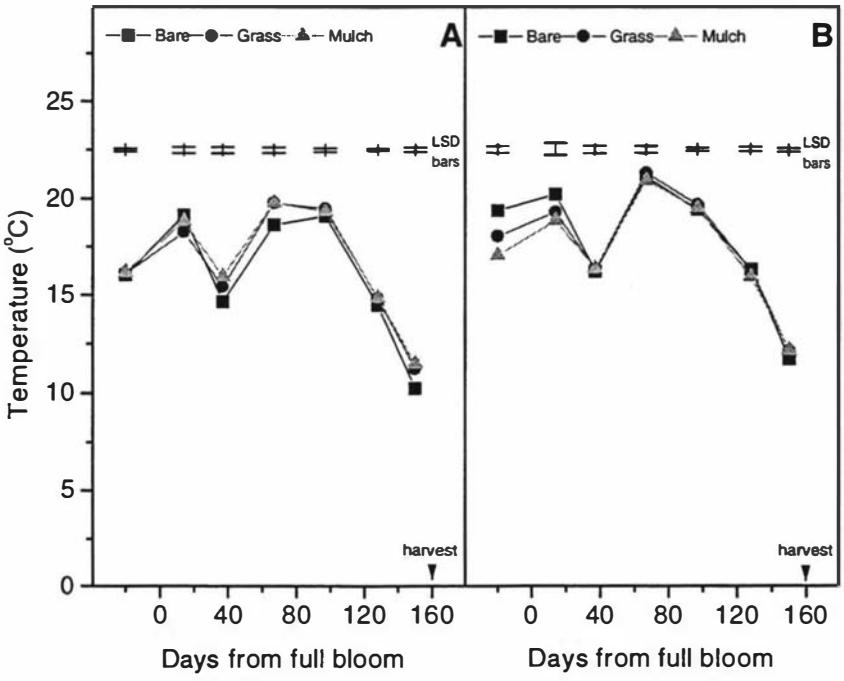

Figure 3.5 Seasonal variation in the average 6.00 am (A) and 2.00 pm (B) soil temperatures of bare, grass and mulch plots at the Massey site during the 1997 / 98 growing season. Sampling occurred at a depth of 100 mm. Each LSD was estimated at the 5 % significance level ($n = 9$).

Table 3.1 6.00 am and 2.00 pm soil temperatures (°C) of bare, grass and mulch plots at the Massey site, averaged across the 1996 / 97 growing season. Sampling occurred at a depth of 100 mm. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	6.00 am	2.00 pm
Bare	14.63 a	16.22 a
Grass	15.22 b	16.44 a
Mulch	15.32 b	15.71 b
SED	0.09	0.10

Table 3.2 6.00 am and 2.00 pm soil temperatures (°C) of bare, grass and mulch plots at the Massey site, averaged across the 1997 / 98 growing season. Sampling occurred at a depth of 100 mm. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	6.00 am	2.00 pm
Bare	16.06 a	17.78 a
Grass	16.46 b	17.59 a
Mulch	16.65 c	17.27 b
SED	0.08	0.11

At the HortResearch site, average 6.00 am and 2.00 pm soil temperatures ranged from 11.5 to 17°C (Table 3.3) and 11.5 to 22°C (Table 3.4) on the two occasions that sampling occurred in the 1996 / 97 and 1997 / 98 seasons respectively. In both seasons, bare plots tended to have significantly lower 6.00 am temperatures than grass and mulch plots while grass plots tended to have greater 2.00 pm soil temperatures than both bare and mulch plots (Tables 3.3 and 3.4). Soil temperature did not differ significantly with fertiliser regime or its interaction with ground cover on both occasions that sampling occurred in either season (data not shown).

Table 3.3 Average 6.00 am and 2.00 pm soil temperatures (°C) of bare, grass and mulch plots at the HortResearch site during the 1996 / 97 growing season, 8 weeks after full bloom and at harvest. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	6.00 am		2.00 pm	
	8 weeks	Harvest	8 weeks	Harvest
Bare	14.63 a	11.95 a	15.96 a	12.76 a
Grass	15.75 b	12.30 b	16.87 b	12.92 a
Mulch	15.92 b	12.32 b	15.84 a	12.69 a
SED	0.15	0.09	0.18	0.10

Table 3.4 Average 6.00 am and 2.00 pm soil temperatures (°C) of bare, grass and mulch plots at the HortResearch site during the 1997 / 98 growing season, 8 weeks after full bloom and at harvest. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	6.00 am		2.00 pm	
	8 weeks	Harvest	8 weeks	Harvest
Bare	20.96 a	12.50 a	21.33 a	11.69 a
Grass	21.31 b	12.70 b	21.57 a	12.02 b
Mulch	20.91 a	12.58 a	20.82 b	11.78 a
SED	0.11	0.05	0.14	0.07

Soil moisture content

On a dry soil basis, the gravimetric soil moisture content of plots at the Massey site ranged from 25 to 45 % (Figure 3.6) and from 23 to 37 % (Figure 3.7) in the 1996 / 97 and 1997 / 98 seasons, respectively. Early in the 1996 / 97 season, the moisture content of the soil tended to be greater than at the same time in the 1997 / 98 season. However, later in both seasons, the moisture content of the soil was similar. In the 1996 / 97 season, the moisture content tended to be greater at 0 – 30 mm than at 30 – 75 mm while in both seasons, the moisture content of mulch plots was consistently and in some instances significantly greater than that of grass and bare plots especially near the soil surface. Similarly, grass plots tended to contain more moisture than bare plots near the soil surface although differences were not usually significant. The magnitude of differences in soil moisture content decreased towards harvest in both seasons. Averaged across each season, the moisture content of mulch plots was significantly greater (approx. 10 – 35 %) than that of grass and bare plots (Tables 3.5 and 3.6). Soil moisture content did not differ significantly with fertiliser regime or its interaction with ground cover throughout either season (data not shown).

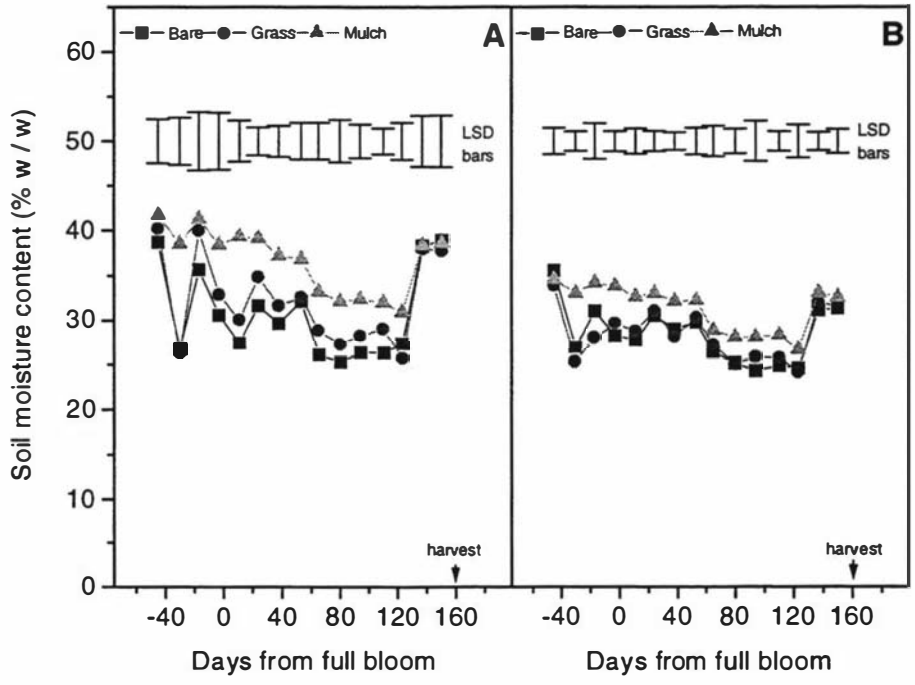

Figure 3.6 Seasonal variation in the average soil moisture content of bare, grass and mulch plots at the Massey site during the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm (A) and 30 – 75 mm (B). Each LSD was estimated at the 5 % significance level ($n = 9$).

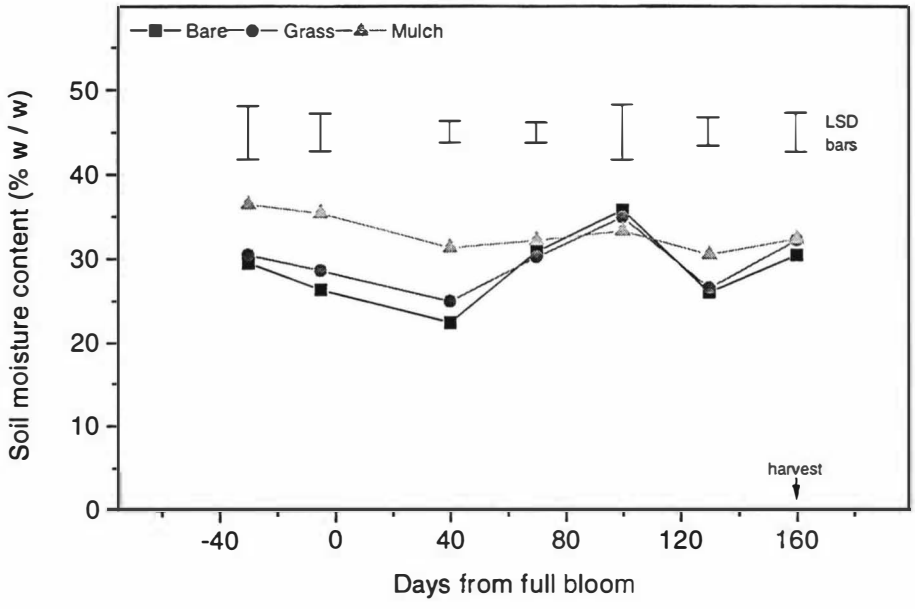

Figure 3.7 Seasonal variation in the average soil moisture content of bare, grass and mulch plots at the Massey site during the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. Each LSD was estimated at the 5 % significance level ($n = 9$).

Table 3.5 Moisture content (% w / w) of bare, grass and mulch plots at the Massey site, averaged across the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm and 30 – 75 mm. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	0 – 30 mm	30 – 75 mm
Bare	31.40 a	28.47 a
Grass	35.28 a b	29.16 a
Mulch	41.86 b	31.45 a
SED	4.32	3.08

Table 3.6 Moisture content of bare, grass and mulch plots at the Massey site, averaged across the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	Moisture content (% w / w)
Bare	28.74 a
Grass	29.67 a
Mulch	33.03 b
SED	1.31

At the HortResearch site, mulch plots tended to contain significantly more moisture than bare and grass plots in both the 1996 / 97 and 1997 / 98 seasons (Tables 3.7 and 3.8). Again, soil moisture content did not differ significantly with fertiliser regime or its interaction with ground cover (data not shown).

Table 3.7 Average moisture contents (% w / w) of soil from bare, grass and mulch plots at the HortResearch site during the 1996 / 97 growing season, 8 weeks after full bloom and at harvest. Sampling occurred at two depths: 0 – 30 mm and 30 – 75 mm. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	0-30 mm		35-75 mm	
	8 weeks	Harvest	8 weeks	Harvest
Bare	55.32 a	45.07 a	45.07 a	48.35 a
Grass	61.23 a	44.56 a	44.56 a	47.78 a
Mulch	72.41 b	51.88 a	51.88 b	54.31 a
SED	4.62	6.76	2.62	3.49

Table 3.8 Average moisture contents (% w / w) of soil from bare, grass and mulch plots at the HortResearch site during the 1997 / 98 growing season, 8 weeks after full bloom and at harvest. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	8 weeks	Harvest
Bare	25.78 a	54.63 a
Grass	27.14 a	53.66 a
Mulch	28.82 a	64.38 b
SED	1.48	2.46

Soil inorganic nitrogen content

At the Massey site, the NH_4^+ and NO_3^- contents of the soil during the 1996 / 97 season decreased from a month prior to full bloom until harvest (Figs. 3.8 and 3.11). In the 1997 / 98 season, the ammonium content increased between the measurements made a few weeks prior to full bloom and a few weeks after full bloom and decreased thereafter, especially in the conventional plots (Figure 3.10). The nitrate content on the other hand, increased until 2 - 3 months after full bloom and then decreased until harvest (Figure 3.13).

At the Massey site, in the 1996 / 97 season and a month prior to full bloom, bare plots contained significantly more ammonium than grass and mulch plots (Figure 3.8) while organic plots contained more ammonium than conventional plots (Figure 3.9), at a depth of 0 – 30 mm. Thereafter, differences in the ammonium content of the soil at that depth diminished. The ammonium content at 0 – 30 mm did not differ significantly with the interaction of ground cover and fertiliser regime throughout the 1996 / 97 season (data not shown). At 30 – 75 mm, the ammonium content did not differ significantly with ground cover, fertiliser regime or the interaction of the two with differences again diminishing towards harvest. Throughout the season at both depths, the concentrations

of ammonium in conventional plots typically increased after the application of urea only to decline again.

Averaged across the 1996 / 97 season, the ammonium content of the soil at both depths did not differ significantly with ground cover or its interaction with fertiliser regime (data not shown). However, at 0 – 30 mm, organic and organic plus plots contained significantly more (about 30 and 40 %, respectively) ammonium than conventional plots (Table 3.9).

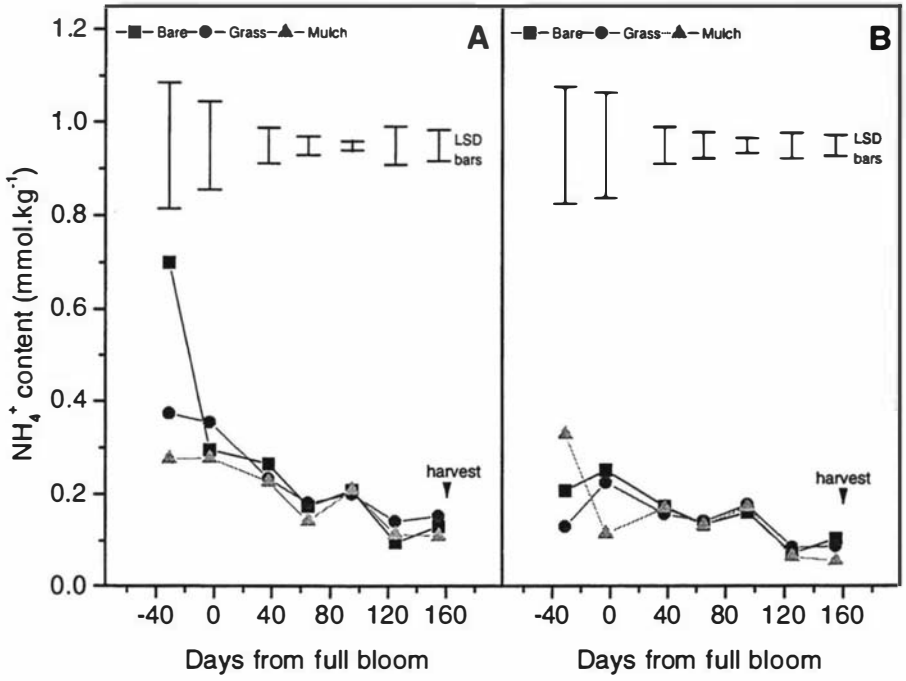

Figure 3.8 Seasonal variation in the average ammonium (NH_4^+) content of soil from bare, grass and mulch plots at the Massey site during the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm (A) and 30 – 75 mm (B). Each LSD was estimated at the 5 % significance level ($n = 9$).

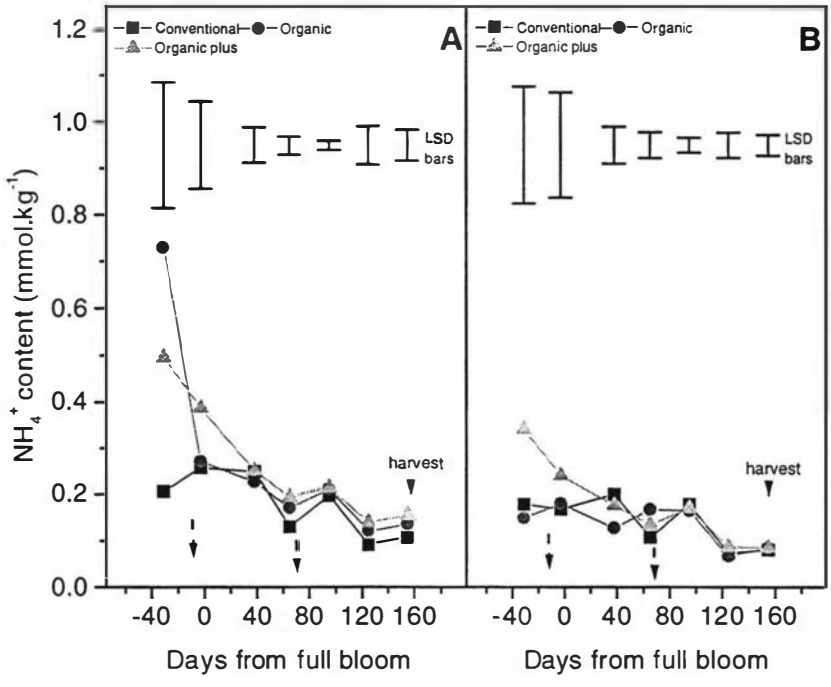

Figure 3.9 Seasonal variation in the average ammonium (NH_4^+) content of soil from conventional, organic and organic plus plots at the Massey site during the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm (A) and 30 – 75 mm (B). The 2 arrows with dashed tails indicate times when urea was applied at a rate of 100 kg / ha. One earlier application of urea, at a rate of 100 kg / ha, is not illustrated. Each LSD was estimated at the 5 % significance level ($n = 9$).

Table 3.9 Ammonium content ($mmol.kg^{-1}$) of soil from conventional, organic and organic plus plots at the Massey site, averaged across the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm and 30 – 75 mm. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	0 – 30 mm	30 – 75 mm
Conventional	0.192 a	0.152 a
Organic	0.256 b	0.146 a
Organic plus	0.273 b	0.180 a
SED	0.029	0.025

Throughout the 1997 / 98 season, the ammonium content of soil at the Massey site did not differ significantly with ground cover or its interaction with fertiliser regime (data not shown). However, in the first 2 months after full bloom, soil from conventional plots contained significantly more ammonium than soil from organic and organic plus plots (Figure 3.10). Thereafter, differences in the ammonium content declined to become non-significant. The two applications of urea on either side of full bloom appeared to increase the concentrations of ammonium in conventional plots however subsequently, the concentrations steadily declined despite two further applications of urea.

Averaged across the 1997 / 98 season, the ammonium content of the soil did not differ significantly with ground cover or its interaction with fertiliser regime (data not shown). However, conventional plots contained more than 5 times as much ammonium as organic and organic plus plots (Table 3.10).

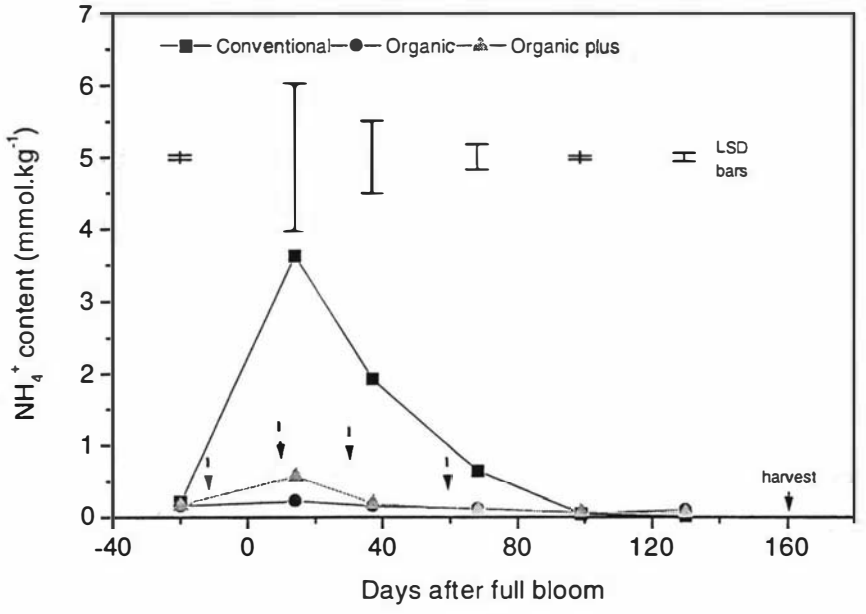

Figure 3.10 Seasonal variation in the average ammonium (NH_4^+) content of soil from conventional, organic and organic plus plots at the Massey site during the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. The 4 arrows with dashed tails indicate times when urea was applied at a rate of 100 kg / ha. Two earlier applications of urea, each at a rate of 100 kg / ha, are not illustrated. Each LSD was estimated at the 5 % significance level (n = 9).

Table 3.10 Ammonium content ($mmol.kg^{-1}$) of soil from conventional, organic and organic plus plots at the Massey site, averaged across the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Ammonium content
Conventional	1.049 a
Organic	0.136 b
Organic plus	0.191 b
SED	0.164

At the Massey site, in the 1996 / 97 season, bare and mulch plots tended to contain more nitrate than grass plots (Figure 3.11). However, the nitrate content did not differ significantly with fertiliser regime (Figure 3.12) or its interaction with ground cover throughout the season (data not shown). The concentrations of nitrate increased transiently after the application of urea during the season.

Averaged across the season, bare plots contained twice as much nitrate as grass and mulch plots at both depths (Table 3.11) while at 30 –75 mm, conventional and organic plus plots contained significantly more (about 40 %) nitrate than organic plots (Table 3.12).

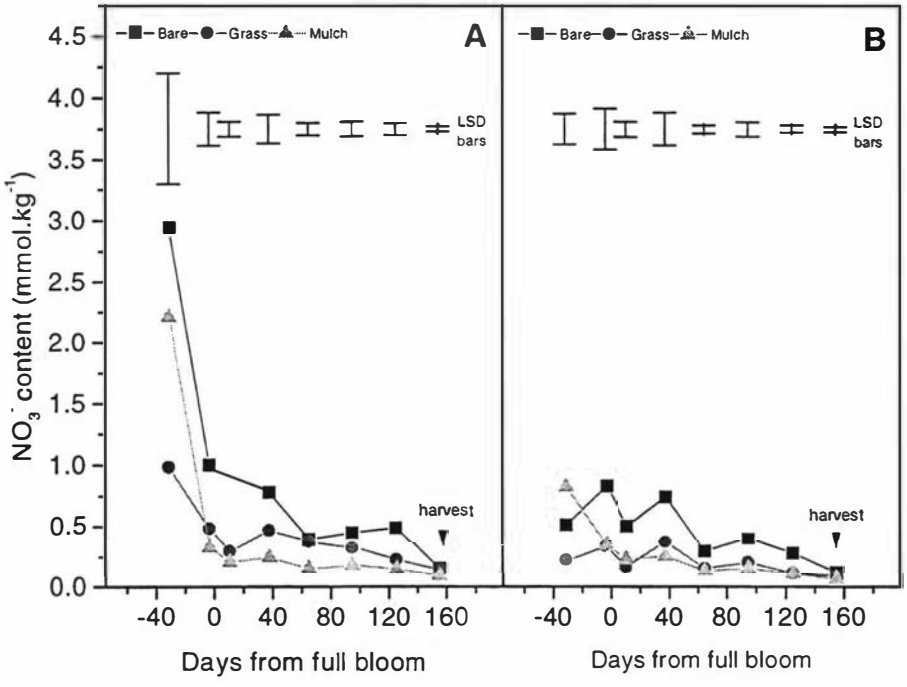

Figure 3.11 Seasonal variation in the average nitrate (NO_3^-) content of soil from bare, grass and mulch plots at the Massey site during the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm (A) and 30 – 75 mm (B). Each LSD was estimated at the 5 % significance level ($n = 9$).

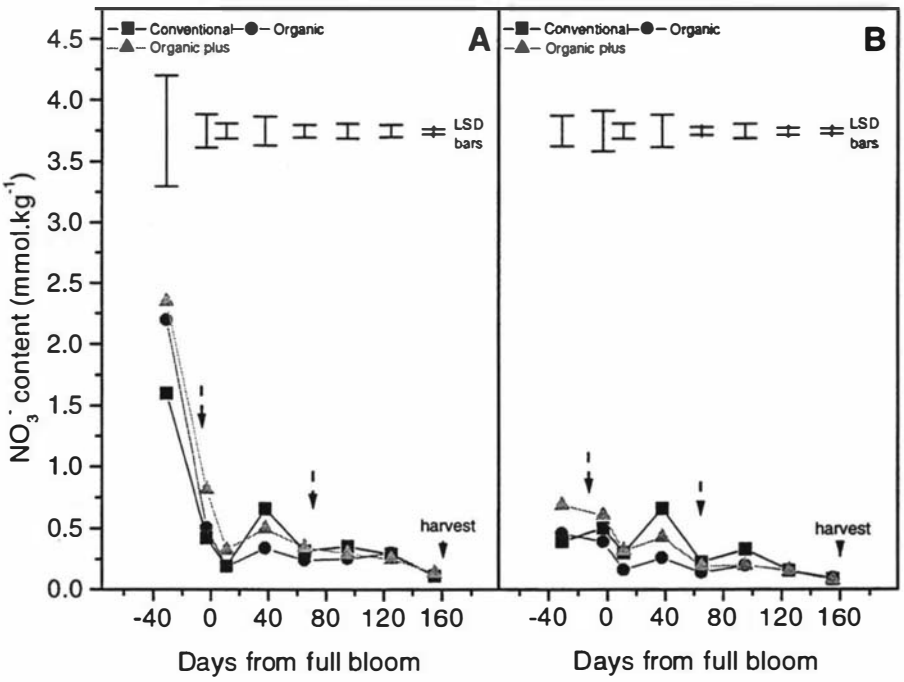

Figure 3.12 Seasonal variation in the average nitrate (NO_3^-) content of soil from conventional, organic and organic plus plots at the Massey site during the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm (A) and 30 – 75 mm (B). The 2 arrows with dashed tails indicate times when urea was applied at a rate of 100 kg / ha. One earlier application of urea, at a rate of 100 kg / ha, is not illustrated. Each LSD was estimated at the 5 % significance level (n = 9).

Table 3.11 Nitrate content (mmol.kg^{-1}) of soil from bare, grass and mulch plots at the Massey site, averaged across the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm and 30 – 75 mm. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	0 – 30 mm	30 – 75 mm
Bare	1.002 a	0.458 a
Grass	0.416 b	0.203 b
Mulch	0.423 b	0.258 b
SED	0.089	0.045

Table 3.12 Nitrate content (mmol.kg^{-1}) of soil from conventional, organic and organic plus plots at the Massey site, averaged across the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm and 30 – 75 mm. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	0 – 30 mm	30 – 75 mm
Conventional	0.576 a	0.340 a
Organic	0.598 a	0.241 b
Organic plus	0.666 a	0.338 a
SED	0.089	0.045

Throughout the 1997 / 98 season at the Massey site, bare plots consistently contained more nitrate than grass and mulch plots (in many instances, twice as much; Figure 3.13). Furthermore, conventional plots consistently contained more nitrate than organic and organic plus plots (2 – 6 times as much), especially in the first 3 months after full bloom (Figure 3.14). Differences were much less around full bloom and late in the season. Averaged across the entire season, bare plots contained almost twice as much nitrate as grass and mulch plots (Table 3.13) while conventional plots contained 4 times as much nitrate as organic and organic plus plots (Table 3.14). The nitrate content of the soil throughout and averaged across the 1997 / 98 season did not differ significantly with the interaction of ground cover and fertiliser regime (data not shown).

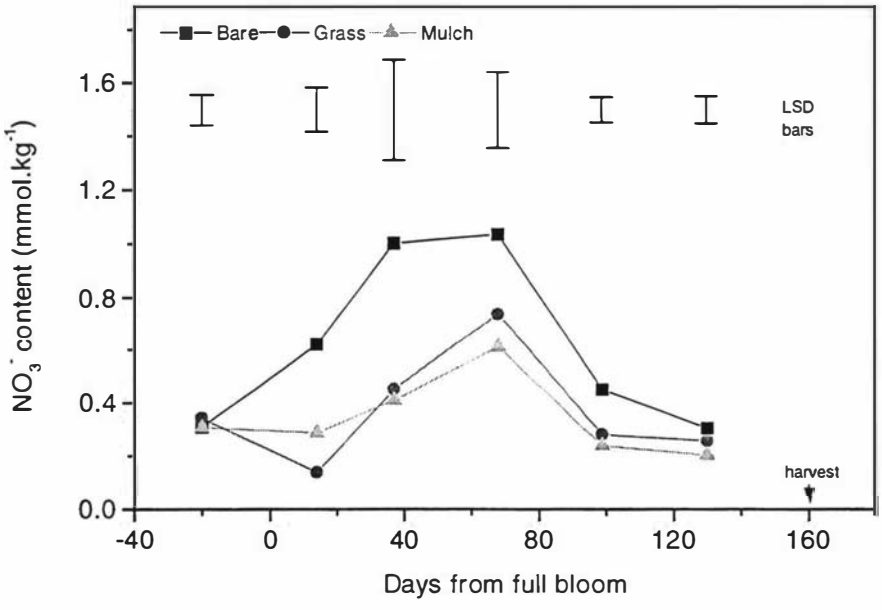

Figure 3.13 Seasonal variation in the average nitrate (NO_3^-) content of soil from bare, grass and mulch plots at the Massey site during the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. Each LSD was estimated at the 5 % significance level ($n = 9$).

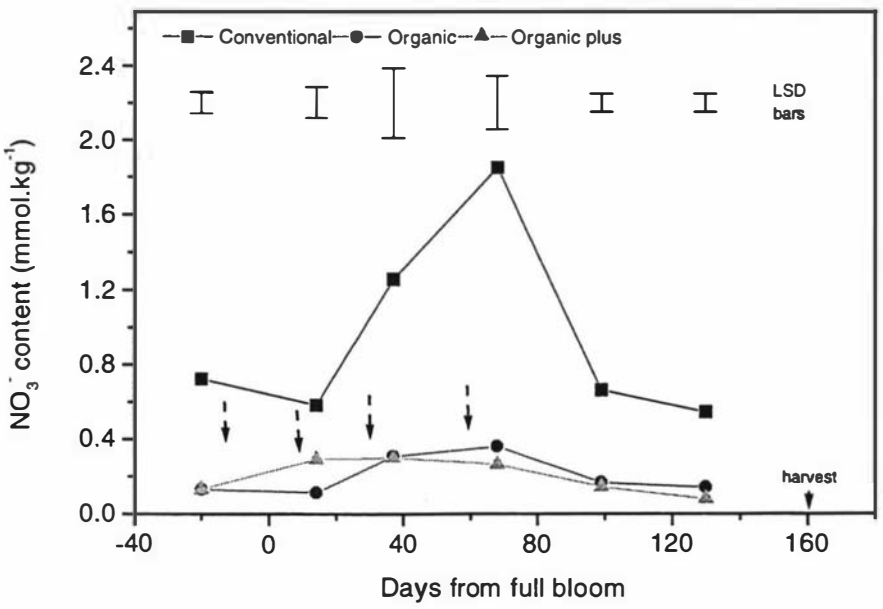

Figure 3.14 Seasonal variation in the average nitrate (NO_3^-) content of soil from conventional, organic and organic plus plots at the Massey site during the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. The 4 arrows with dashed tails indicate times when urea was applied at a rate of 100 kg / ha. Two earlier applications of urea, each at a rate of 100 kg / ha, are not illustrated. Each LSD was estimated at the 5 % significance level ($n = 9$).

Table 3.13 Nitrate content ($mmol.kg^{-1}$) of soil from bare, grass and mulch plots at the Massey site, averaged across the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Nitrate content
Bare	0.646 a
Grass	0.368 b
Mulch	0.343 b
SED	0.080

Table 3.14 Nitrate content ($mmol.kg^{-1}$) of soil from conventional, organic and organic plus plots at the Massey site, averaged across the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Nitrate content
Conventional	0.920 a
Organic	0.236 b
Organic plus	0.202 b
SED	0.080

In the 1996 / 97 and 1997 / 98 seasons, the maximum amounts of inorganic N measured in conventional plots (at 0 – 30 mm) at the Massey site were approximately 9 and 27 kg / ha soil[5], respectively. This represents about 20 and 60 %, respectively, of the amount of N added to those plots in any single application of urea i.e. 100 kg / ha of urea (≈ 50 kg N / ha) was applied on each occasion. Therefore, considerable amounts of the N that was applied appeared to be removed from the soil system (at 0 – 30 mm), especially in the 1996 / 97 season.

At the HortResearch site, the ammonium and nitrate contents of the soil in the 1996 / 97 season did not differ significantly with ground cover, fertiliser regime or the interaction of the two on the two occasions that sampling occurred (data not shown); average contents for the site are presented in Table 3.15. Similarly, in the 1997 / 98 season, the ammonium content of the soil did not differ significantly with ground cover or its interaction with fertiliser regime (data not shown). On the other hand, 8 weeks after full bloom, conventional plots contained 8 times as much nitrate and 4 times as much ammonium as organic and organic plus plots (Table 3.16).

[5] Based on a soil bulk density of approx. 1.3 $g.cm^{-3}$ for the site (Scotter, 1999 - personal communication); calculations not presented.

Table 3.15 Average (± SE) ammonium (NH_4^+) and nitrate (NO_3^-) contents ($mmol.kg^{-1}$) of soil from the HortResearch site during the 1996 / 97 season, 8 weeks after full bloom and at harvest (n = 27). On each occasion, sampling occurred at two depths.

	Depth	8 weeks	Harvest
NH_4^+	0 – 30 mm	0.980 ± 0.053	0.758 ± 0.054
	30 – 75 mm	0.584 ± 0.029	0.527 ± 0.046
NO_3^-	0 – 30 mm	1.472 ± 0.080	1.271 ± 0.067
	30 – 75 mm	0.779 ± 0.068	0.865 ± 0.052

Table 3.16 Average ammonium (NH_4^+) and nitrate (NO_3^-) contents ($mmol.kg^{-1}$) of soil from conventional, organic and organic plus plots at the HortResearch site during the 1997 / 98 season, 8 weeks after full bloom and at harvest. On each occasion, sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test (P = 0.05, n = 3). Means with the same letter do not differ significantly.

	NO_3^-		NH_4^+	
	8 weeks	Harvest	8 weeks	Harvest
Conventional	1.519 a	0.161 a	0.926 a	0.242 a
Organic	0.236 b	0.150 a	0.173 a	0.247 a
Organic Plus	0.209 b	0.143 a	0.179 a	0.250 a
SED	0.098	0.023	0.419	0.032

Soil solution cation concentrations

In the 1996 / 97 season, the concentrations of Ca, Mg, K and sodium (Na) in soil solution at the Massey site declined rapidly from just prior to full bloom until 1 - 2 months after full bloom (Figure 3.15). Thereafter, the concentrations did not change substantially. The pH of the soil solution increased from just prior to full bloom until just after full bloom and thereafter did not change substantially except for an apparent dip approximately 2 months after full bloom. The pH and concentrations of Mg, K and Na at 0 – 30 mm and 30 – 75 mm did not differ significantly with ground cover, fertiliser regime or the interaction of the two throughout the season (data not shown). However, the concentration of Ca in soil solution from bare plots was consistently and often significantly greater than that in soil solution from mulch plots, especially at 0 – 30 mm (Figure 3.16). Likewise, the concentration of Ca in soil solution from organic plus plots was consistently and often significantly greater than that in soil solution from conventional plots (Figure 3.17). These differences diminished towards harvest. The concentration of Ca did not differ significantly with the interaction of ground cover and fertiliser regime throughout the season. Averaged across the season, bare plots contained about 2 times more Ca and 50 % more Mg than mulch plots (Tables 3.17 and 3.18) while organic plus plots contained about 2 - 3 times more Ca and 50 % more Mg than conventional plots (Tables 3.19 and 3.20).

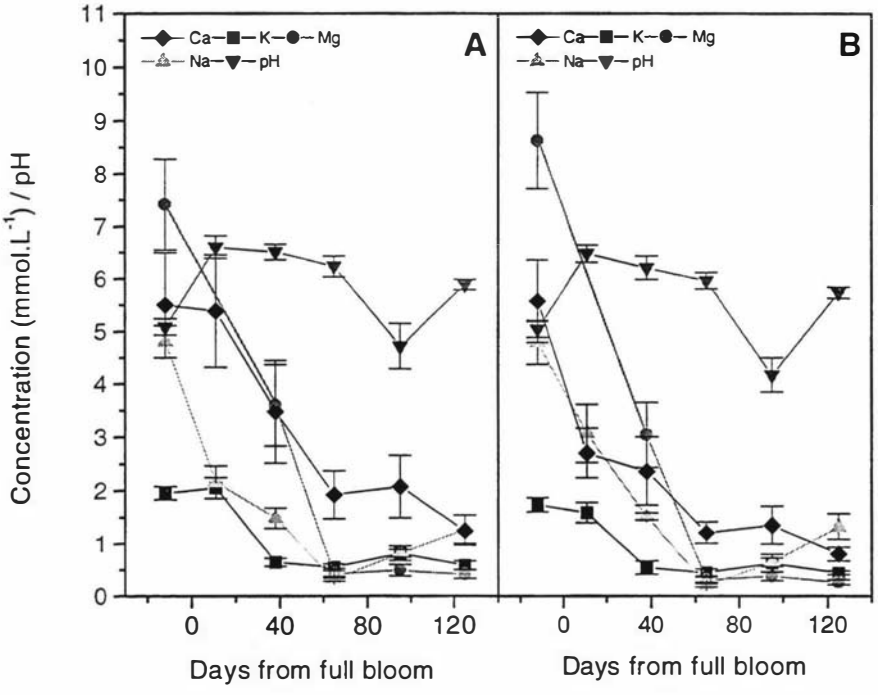

Figure 3.15 Seasonal variation in the average pH and concentrations of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution at the Massey site during the 1996 / 97 growing season. Vertical bars represent standard errors (n = 27). Sampling occurred at two depths: 0 – 30 mm (A) and 30 – 75 mm (B).

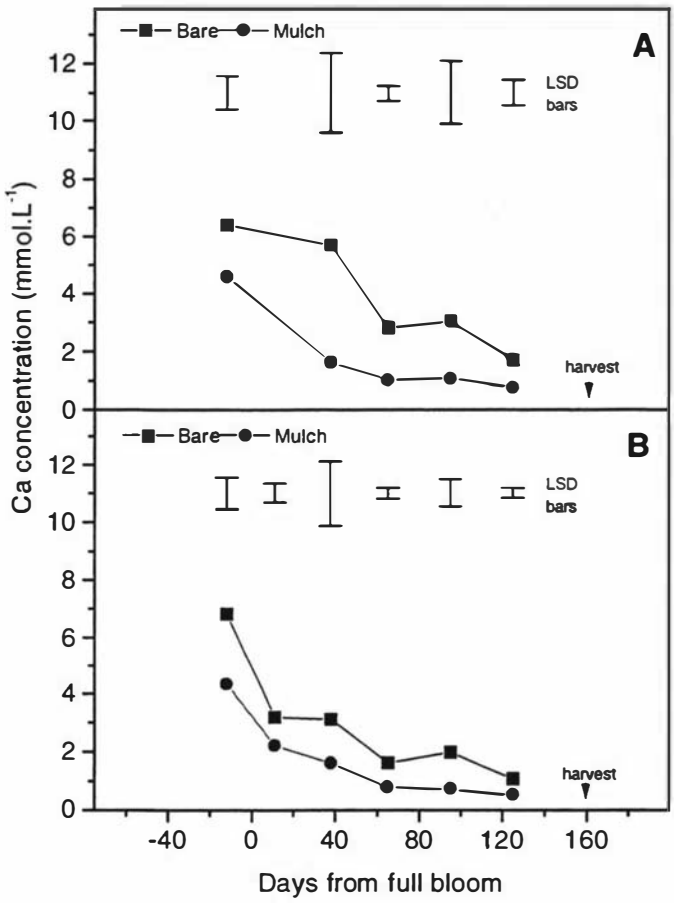

Figure 3.16 Seasonal variation in the average concentrations of calcium (Ca) in soil solution from bare and mulch plots at the Massey site during the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm (A) and 30 – 75 mm (B). Each LSD was estimated at the 5 % significance level ($n = 9$).

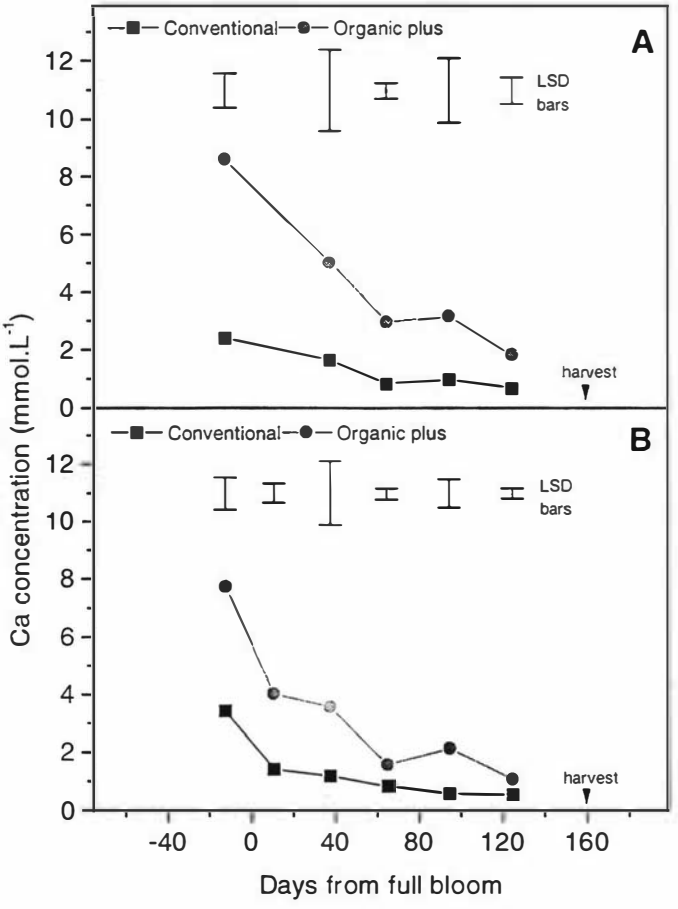

Figure 3.17 Seasonal variation in the average concentrations of calcium (Ca) in soil solution from conventional and organic plus plots at the Massey site during the 1996 / 97 growing season. Sampling occurred at two depths: 0 – 30 mm (A) and 30 – 75 mm (B). Each LSD was estimated at the 5 % significance level ($n = 9$).

Table 3.17 pH and concentrations ($mmol.L^{-1}$) of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from bare and mulch plots at the Massey site, averaged across the 1996 / 97 season. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 6$). Means with the same letter do not differ significantly.

	Ca	Mg	K	Na	pH
Bare	3.80 a	2.81 a	1.05 a	1.69 a	5.44 a
Mulch	1.83 b	2.07 b	0.79 b	1.87 a	5.83 b
SED	0.38	0.27	0.09	0.22	0.14

Table 3.18 pH and concentrations ($mmol.L^{-1}$) of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from bare and mulch plots at the Massey site, averaged across the 1996 / 97 season. Sampling occurred at a depth of 30 – 75 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 6$). Means with the same letter do not differ significantly.

	Ca	Mg	K	Na	pH
Bare	2.97 a	2.62 a	0.94 a	1.61 a	5.42 a
Mulch	1.71 b	1.87 b	0.85 a	1.97 a	5.69 a
SED	0.38	0.26	0.06	0.16	0.18

Table 3.19 pH and concentrations ($mmol.L^{-1}$) of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from conventional and organic plus plots at the Massey site, averaged across the 1996 / 97 season. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 6$). Means with the same letter do not differ significantly.

	Ca	Mg	K	Na	pH
Conventional	1.31 a	1.77 a	0.90 a	1.58 a	5.55 a
Organic plus	4.31 b	3.12 b	0.94 a	1.97 a	5.72 a
SED	0.38	0.28	0.09	0.22	0.14

Table 3.20 pH and concentrations ($mmol.L^{-1}$) of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from conventional and organic plus plots at the Massey site, averaged across the 1996 / 97 season. Sampling occurred at a depth of 30 – 75 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 6$). Means with the same letter do not differ significantly.

	Ca	Mg	K	Na	pH
Conventional	1.33 a	1.73 a	0.86 a	1.59 a	5.44 a
Organic plus	3.34 b	2.76 b	0.93 a	1.99 a	5.67 a
SED	0.27	0.26	0.06	0.16	0.18

In the 1997 / 98 season, the concentrations of Ca, Mg and K in soil solution at the Massey site increased rapidly from prior to full bloom until approximately one month after full bloom, thereafter decreasing rapidly until harvest (Figs. 3.18 and 3.19). In contrast, the concentration of Na in the soil solution increased from prior to full bloom until approximately 2 months after full bloom, after which time the concentration did not change substantially. The pH of the soil solution continually declined across the season albeit only slightly. Throughout the season, soil solution from bare plots consistently contained more Ca than soil solution from grass and mulch plots, especially in the first few months after full bloom (Figure 3.18 A). Furthermore, the solution from grass plots tended to contain more Ca than the solution from mulch plots, although the differences were never significant. Approximately three weeks prior to full bloom, soil solution from organic plus plots contained almost twice as much Ca as soil solution from conventional plots (Figure 3.19 A). Later in the season, the concentration of Ca in soil solution did not differ significantly between conventional and organic plus plots. Unlike Ca, the concentration of Mg in soil solution did not differ significantly with fertiliser regime (Figure 3.19 B). However, in the month after full bloom, solution from bare plots contained significantly more Mg than solution from grass and mulch plots although later in the season there were no significant ground cover differences (Figure 3.18 B). Soil solution from bare and grass plots consistently contained more K than that from mulch plots (Figure 3.18 C) while soil solution from conventional plots consistently contained more K than that from organic plus plots (Figure 3.19 C). Unlike the previous 3 cations, the concentration of Na in soil solution did not differ significantly with ground cover or fertiliser regime during the season, although solution from conventional plots consistently contained more Na than solution from organic plus plots (Figure 3.19 D). The pH of soil solution did not differ significantly with ground cover during the season (Figure 3.18 E). However, the solution from organic plus plots consistently had a significantly higher pH than the solution from conventional plots (Figure 3.19 E). Ground cover and fertiliser regime differences in the concentrations of cations in soil solution diminished towards harvest while in contrast, differences in pH tended to be greater later in the season. Throughout the season, the concentrations of

cations in soil solution, and its pH, did not differ significantly with the interaction of ground cover and fertiliser regime (data not shown).

Averaged across the entire 1997 / 98 season, bare plots at the Massey site contained about 40 and 85 % more Ca than grass and mulch plots, respectively (Table 3.21). Similarly, bare plots contained 40 and 65 % more Mg than grass and mulch plots, respectively. Conventional plots contained 20 and 70 % more Mg and K, respectively, than organic plus plots (Table 3.22) while the average pH of organic plus plots was significantly greater than that of conventional plots.

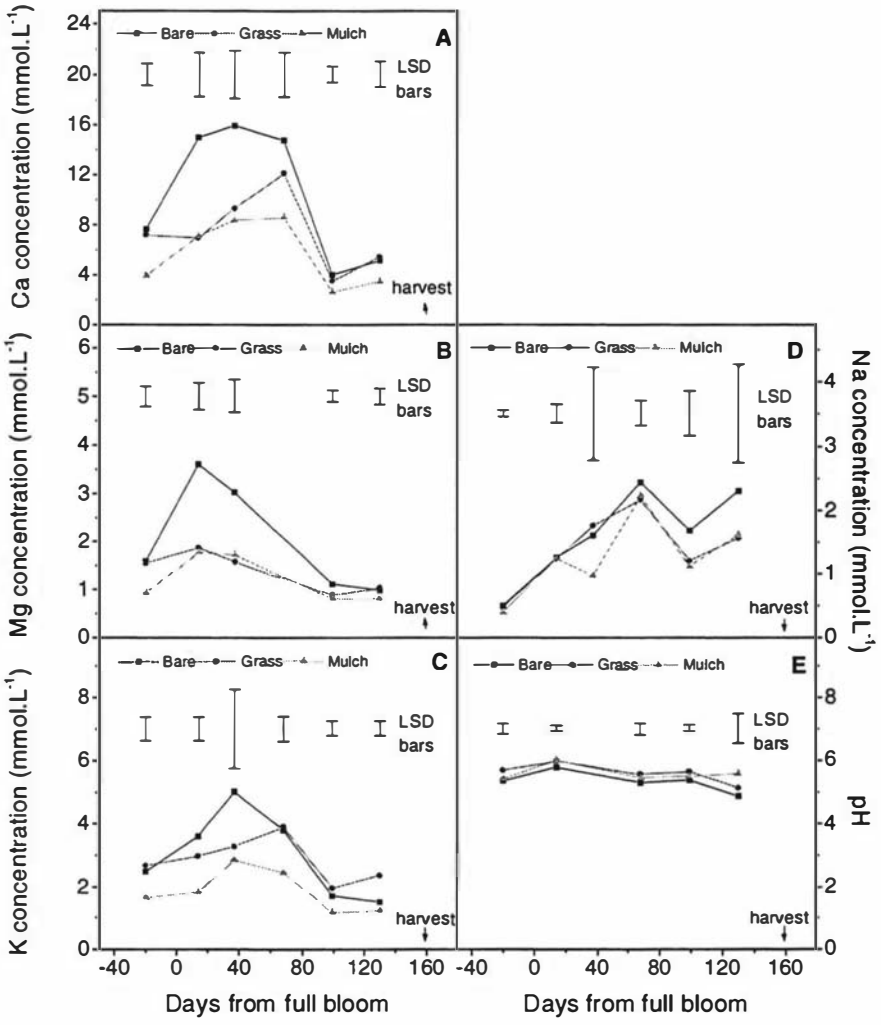

Figure 3.18 Seasonal variation in the average pH and concentrations of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from bare, grass and mulch plots at the Massey site during the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. Each LSD was estimated at the 5 % significance level (n = 9).

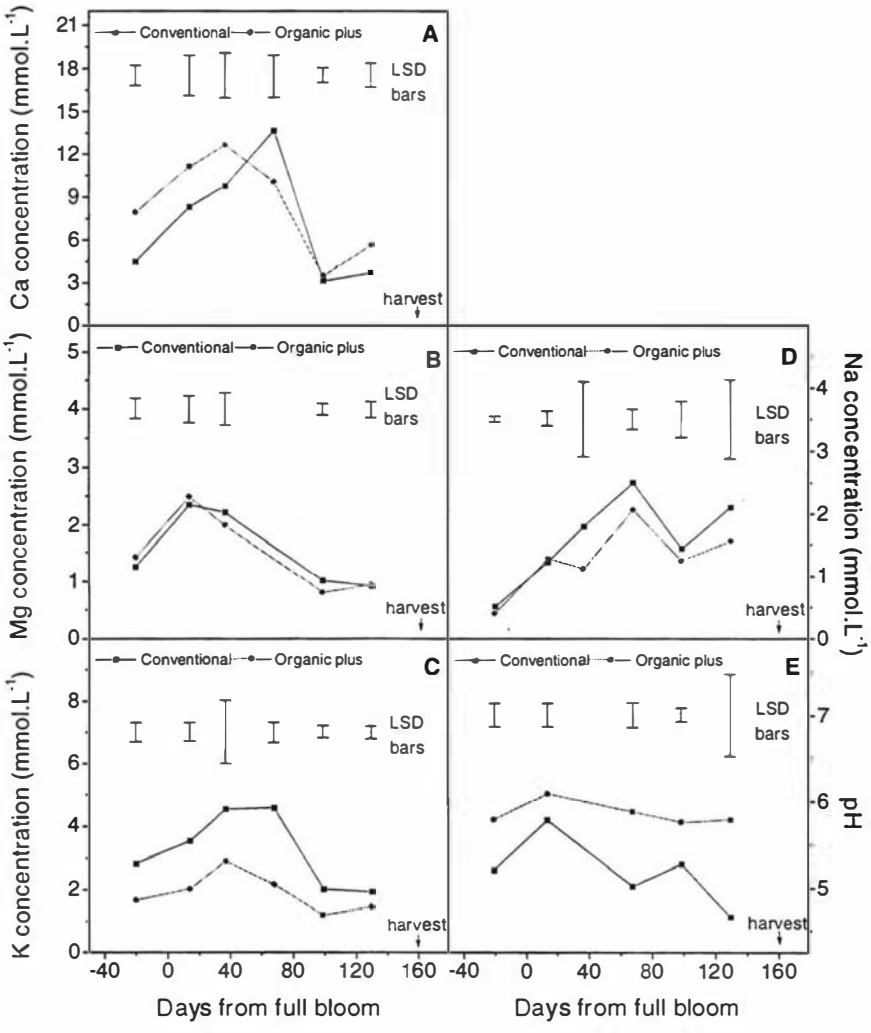

Figure 3.19 Seasonal variation in the average pH and concentrations of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from conventional and organic plus plots at the Massey site during the 1997 / 98 growing season. Sampling occurred at a depth of 0 – 30 mm. Each LSD was estimated at the 5 % significance level (n = 9).

Table 3.21 pH and concentrations ($mmol.L^{-1}$) of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from bare, grass and mulch plots at the Massey site, averaged across the 1997 / 98 season. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 6$). Means with the same letter do not differ significantly.

	Ca	Mg	K	Na	pH
Bare	10.42 a	2.22 a	3.02 a	1.63 a	5.58 a
Grass	7.40 b	1.56 b	2.86 a	1.40 a	5.83 a
Mulch	5.67 b	1.33 b	1.86 b	1.26 a	5.85 a
SED	0.86	0.14	0.33	0.18	0.10

Table 3.22 pH and concentrations ($mmol.L^{-1}$) of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from conventional and organic plus plots at the Massey site, averaged across the 1997 / 98 season. Sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Ca	Mg	K	Na	pH
Conventional	7.18 a	1.85 a	3.25 a	1.59 a	5.45 a
Organic plus	8.47 a	1.56 b	1.91 b	1.27 a	6.05 b
SED	0.86	0.11	0.27	0.15	0.08

At the HortResearch site in the 1996 / 97 season, the concentration of Ca in soil solution from bare and mulch plots did not differ significantly 8 weeks after full bloom. However, at harvest, mulch plots contained 25 - 30 % more Ca than bare plots (Table 3.23). Similarly, soil solution from organic plus plots contained significantly more Ca than that from conventional plots - twice as much 8 weeks after full bloom and 30 % more at harvest (Table 3.24). The pH and concentrations of Mg, K and Na in soil solution did not differ significantly with ground cover, fertiliser regime or the interaction of the two on the two occasions that sampling occurred (data not shown); average values for the site are presented in Table 3.25.

At the HortResearch site, in the 1997 / 98 growing season, soil solution from bare plots, 8 weeks after full bloom, contained 70, 100 and 60 % more Ca, Mg and K, respectively, than soil solution from mulch plots (Table 3.26). At the same time, grass plots also contained 70 % more K than mulch plots while the pH of mulch plots was significantly less than that of grass plots. At harvest, the pH and concentrations of Ca, Mg, and K in soil solution did not differ significantly with ground cover. The Na concentration did not differ significantly with ground cover on either occasion that sampling occurred. Eight weeks after full bloom, soil solution from organic plus plots contained twice as much Ca as that from conventional plots (Table 3.27); at harvest, organic plus plots contained 20 % more Ca than conventional plots. Conventional plots were significantly lower in pH and contained significantly more Mg and K than organic plus plots on both occasions that sampling occurred. Eight weeks after full bloom, conventional plots contained 4 times as much Mg as organic plus plots. The Na concentration of plots did not differ significantly with fertiliser regime on either occasion that sampling occurred. Also, the pH and concentrations of Ca, Mg, K and Na in soil solution did not differ significantly with the interaction of ground cover or fertiliser regime on either occasion that sampling occurred (data not shown).

Table 3.23 Average concentrations ($mmol.L^{-1}$) of calcium in soil solution from bare and mulch plots at the HortResearch site in the 1996 / 97 growing season, 8 weeks after full bloom and at harvest. On each occasion, sampling occurred at two depths: 0 – 30 mm and 30 – 75 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 6$). Means with the same letter do not differ significantly.

	0 – 30 mm		30 – 75 mm	
	8 weeks	Harvest	8 weeks	Harvest
Bare	1.35 a	1.73 a	0.72 a	1.50 a
Mulch	1.26 a	2.26 b	0.93 a	1.86 b
SED	0.36	0.21	0.17	0.11

Table 3.24 Average concentrations ($mmol.L^{-1}$) of calcium in soil solution from conventional and organic plus plots at the HortResearch site in the 1996 / 97 growing season, 8 weeks after full bloom and at harvest. On each occasion, sampling occurred at two depths: 0 –30 mm and 30 – 75 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 6$). Means with the same letter do not differ significantly.

	0 - 30mm		30 - 75mm	
	8 weeks	Harvest	8 weeks	Harvest
Conventional	0.76 a	1.66 a	0.51 a	1.48 a
Organic plus	1.85 b	2.32 b	1.06 b	1.98 b
SED	0.36	0.21	0.17	0.11

Table 3.25 Average (± SE) pH and concentrations ($mmol.L^{-1}$) of magnesium (Mg), potassium (K) and sodium (Na) in soil solution from the HortResearch site in the 1996 / 97 growing season, 8 weeks after full bloom and at harvest (n = 12). On each occasion, sampling occurred at two depths: 0 –30 mm and 30 – 75 mm.

	0-30mm		30-75mm	
	8 weeks	Harvest	8 weeks	Harvest
Mg	0.58 ± 0.07	0.41 ± 0.03	0.43 ± 0.04	0.38 ± 0.02
K	0.57 ± 0.04	0.44 ± 0.03	0.47 ± 0.04	0.48 ± 0.03
Na	0.37 ± 0.10	0.41 ± 0.04	0.41 ± 0.10	0.41 ± 0.05
pH	6.49 ± 0.11	6.69 ± 0.07	6.55 ± 0.12	6.82 ± 0.06

Table 3.26 Average pH and concentrations (mmol.L^{-1}) of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from bare, grass and mulch plots at the HortResearch site in the 1997 / 98 growing season, 8 weeks after full bloom and at harvest. On each occasion, sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test (P = 0.05, n = 6). Means with the same letter do not differ significantly.

		8 weeks	Harvest
Ca	Bare	4.37 a	1.60 a
	Grass	2.98 a b	1.61 a
	Mulch	2.54 b	1.77 a
	SED	0.61	0.16
Mg	Bare	2.20 a	0.34 a
	Grass	1.54 b	0.36 a
	Mulch	1.08 b	0.30 a
	SED	0.23	0.04
K	Bare	2.23 a	0.54 a
	Grass	2.33 a	0.56 a
	Mulch	1.40 b	0.45 a
	SED	0.31	0.09
Na	Bare	2.20 a	1.96 a
	Grass	2.25 a	1.92 a
	Mulch	1.91 a	2.05 a
	SED	0.40	0.15
pH	Bare	5.90 a b	6.10 a
	Grass	5.98 a	6.20 a
	Mulch	5.72 b	5.91 a
	SED	0.07	0.11

Table 3.27 Average pH and concentrations ($mmol.L^{-1}$) of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in soil solution from conventional and organic plus plots at the HortResearch site in the 1997 / 98 growing season, 8 weeks after full bloom and at harvest. On each occasion, sampling occurred at a depth of 0 – 30 mm. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

		8 weeks	Harvest
Ca	Conventional	1.76 a	1.51 a
	Organic plus	4.38 b	1.82 b
	SED	0.51	0.13
Mg	Conventional	2.56 a	0.38 a
	Organic plus	0.65 b	0.28 b
	SED	0.20	0.03
K	Conventional	3.20 a	0.70 a
	Organic plus	0.77 b	0.33 b
	SED	0.24	0.07
Na	Conventional	2.04 a	2.02 a
	Organic plus	2.19 a	1.94 a
	SED	0.32	0.12
pH	Conventional	5.73 a	5.93 a
	Organic plus	6.00 b	6.21 b
	SED	0.06	0.09

3.4.1.2 Vine and fruit attributes

Xylem sap mineral concentrations

At the Massey site, in the 1996 / 97 season, the concentrations of Ca, Mg and K decreased in the first month after full bloom but then increased in the following month (Figure 3.20). Subsequently, the concentrations of Ca and Mg continually decreased while the concentration of K decreased up until about 70 days after full bloom, increasing thereafter. The average concentrations of all three minerals in the xylem sap did not differ with ground cover, fertiliser regime or the interaction of the two throughout the season or when averaged across the entire season (data not shown).

In the 1997 / 98 season, the concentrations of Ca, Mg and K in xylem sap at the Massey site were greater 5 weeks after full bloom than 10 weeks after full bloom and by a factor of 2 in the case of Ca and Mg (Tables 3.28 and 3.29). The concentrations of all 3 minerals did not differ significantly with ground cover, fertiliser regime or the interaction of the two 5 weeks after full bloom. However, 10 weeks after full bloom, sap from bare plots contained significantly more Ca than that from grass plots (Table 3.28) while sap from organic plus plots contained significantly more Mg and K than sap from organic plots (Table 3.29). Furthermore, there was a significant interaction effect between ground cover and fertiliser regime for Ca and Mg, 10 weeks after full bloom. For each of the ground covers, organic plots contained somewhat less Ca and Mg than conventional plots but the difference was less pronounced for grass plots given the lower overall concentrations associated with this cover (Table 3.30). For each of the bare and mulch ground covers, organic plus plots contained more Ca and Mg than organic plots.

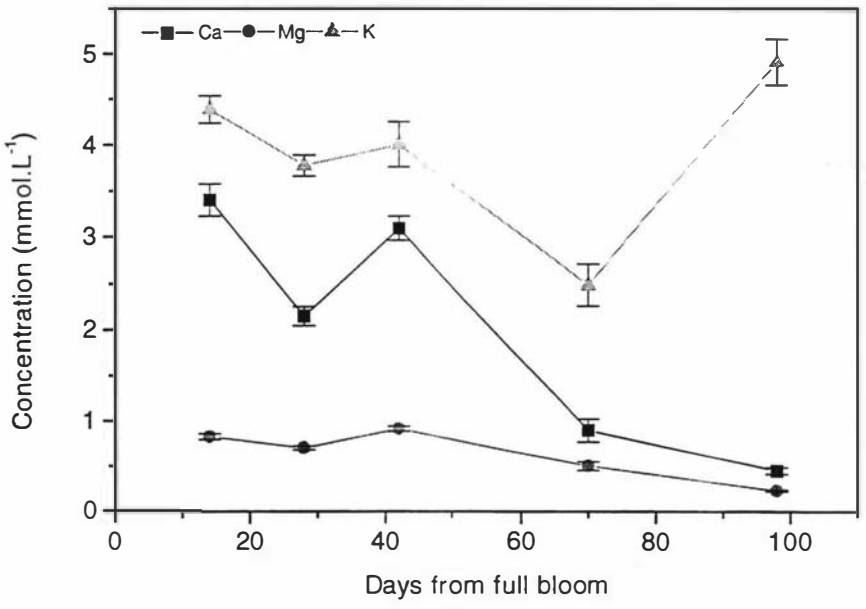

Figure 3.20 Seasonal variation in the average concentrations of calcium (Ca), magnesium (Mg) and potassium (K) in the xylem sap of kiwifruit vines at the Massey site during the 1996 / 97 growing season. Vertical bars represent standard errors ($n = 27$).

Table 3.28 Average concentrations ($mmol.L^{-1}$) of calcium (Ca), potassium (K) and magnesium (Mg) in the xylem sap of kiwifruit vines from bare, grass and mulch plots at the Massey site in the 1997 / 98 growing season, 5 and 10 weeks after full bloom. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Ca		Mg		K	
	5 weeks	10 weeks	5 weeks	10 weeks	5 weeks	10 weeks
Bare	3.18 a	1.54 a	0.70 a	0.46 a	3.16 a	2.47 a
Grass	2.64 a	1.30 b	0.59 a	0.40 a	3.39 a	2.49 a
Mulch	2.92 a	1.41 a b	0.57 a	0.39 a	3.34 a	2.38 a
SED	0.35	0.08	0.06	0.02	0.15	0.23

Table 3.29 Average concentrations ($mmol.L^{-1}$) of calcium (Ca), potassium (K) and magnesium (Mg) in the xylem sap of kiwifruit vines from conventional, organic and organic plus plots at the Massey site in the 1997 / 98 growing season, 5 and 10 weeks after full bloom. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Ca		Mg		K	
	5 weeks	10 weeks	5 weeks	10 weeks	5 weeks	10 weeks
Conventional	3.00 a	1.47 a	0.67 a	0.42 a b	3.17 a	2.49 a b
Organic	2.88 a	1.28 a	0.60 a	0.37 b	3.28 a	2.04 b
Organic plus	2.87 a	1.50 a	0.58 a	0.46 a	3.45 a	2.81 a
SED	0.35	0.08	0.06	0.02	0.15	0.23

Table 3.30 Average concentrations ($mmol.L^{-1}$) of calcium (Ca) and magnesium (Mg) in the xylem sap of kiwifruit vines from treatment A – I plots at the Massey site in the 1997 / 98 growing season. Sampling occurred 10 weeks after full bloom (MSE = 0.02, n = 2).

Treatment	Ground cover	Fertiliser regime	Ca	Mg
A	Bare	Conventional	1.58	0.46
B	Bare	Organic	1.31	0.38
C	Bare	Organic plus	1.72	0.54
D	Grass	Conventional	1.35	0.39
E	Grass	Organic	1.29	0.38
F	Grass	Organic plus	1.27	0.43
G	Mulch	Conventional	1.49	0.41
H	Mulch	Organic	1.23	0.34
I	Mulch	Organic plus	1.50	0.42
		LSD	0.33	0.10

At the HortResearch site, in the 1996 / 97 season, the concentration of Ca in the xylem sap at harvest was twice as much as that 8 weeks after full bloom. In contrast, the concentration of potassium 8 weeks after full bloom was twice as much as that at harvest. The concentration of Mg was similar on the two occasions that sampling occurred. The concentrations of all 3 minerals did not differ significantly with ground cover or its interaction with fertiliser regime on either occasion that sampling occurred (data not shown). Furthermore, the concentrations of Ca and Mg did not differ significantly with fertiliser regime. However, 8 weeks after full bloom, xylem sap from conventional plots contained 30 % more K than that from organic plus plots (Table 3.31).

In the 1997 / 98 season, the concentrations of Ca and K in xylem sap at the HortResearch site 8 weeks after full bloom were twice as much as those at harvest. In contrast, the concentration of Mg at harvest was twice as much as that 8 weeks from full bloom. None of the three minerals differed significantly in concentration with ground cover or its interaction with fertiliser regime on either occasion that sampling occurred (data not shown). Furthermore, the concentrations of Mg and K in sap did not differ significantly with fertiliser regime on either occasion that sampling occurred. However, at harvest, sap from organic plus plots contained 35 % more Ca than sap from organic plots (Table 3.32).

Table 3.31 Average concentrations ($mmol.L^{-1}$) of calcium (Ca), potassium (K) and magnesium (Mg) in the xylem sap of kiwifruit vines from conventional, organic and organic plus plots at the HortResearch site in the 1996 / 97 growing season, 8 weeks after full bloom and at harvest. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	Ca		Mg		K	
	8 weeks	Harvest	8 weeks	Harvest	8 weeks	Harvest
Conventional	0.85 a	2.05 a	0.51 a	0.58 a	2.18 a	0.97 a
Organic	0.73 a	1.95 a	0.54 a	0.58 a	1.82 a b	0.99 a
Organic plus	0.79 a	1.94 a	0.47 a	0.54 a	1.71 b	0.86 a
SED	0.06	0.17	0.07	0.05	0.14	0.07

Table 3.32 Average concentrations ($mmol.L^{-1}$) of calcium (Ca), potassium (K) and magnesium (Mg) in the xylem sap of kiwifruit vines from conventional, organic and organic plus plots at the HortResearch site in the 1997 / 98 growing season, 8 weeks after full bloom and at harvest. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Ca		Mg		K	
	8 weeks	Harvest	8 weeks	Harvest	8 weeks	Harvest
Conventional	1.38 a	0.77 a b	0.51 a	1.08 a	3.10 a	1.33 a
Organic	1.39 a	0.64 a	0.54 a	1.23 a	2.90 a	1.52 a
Organic plus	1.49 a	0.85 b	0.53 a	1.33 a	2.87 a	1.63 a
SED	0.13	0.06	0.05	0.11	0.17	0.13

Throughout the 1996 / 97 and 97 / 98 seasons, no significant associations were observed between the concentrations of minerals (i.e. NH_4^+, NO_3^-, Ca, Mg, K and Na) in soil solution and concentrations of minerals (i.e. Ca. Mg and K) in xylem sap, at either site (data not shown).

Leaf mineral concentrations

At the Massey site, the concentrations of Ca and Mg in leaves in the 1996 / 97 season increased in the first two months after full bloom while those of N and P decreased (Figure 3.21). Thereafter the concentrations of these minerals remained similar while the concentration of K did not change substantially throughout the entire season. In the 1997 / 98 season similar trends in the concentrations of minerals were observed although increases in Ca and Mg were more modest while N and P concentrations declined steadily across the entire season (Figure 3.22).

The concentrations of minerals in leaves at the Massey site did not differ significantly with ground cover, fertiliser regime or the interaction of the two during or when

averaged across the 1996 / 97 season (data not shown). However, the concentration of N in leaves from grass plots was consistently lower than that in leaves from bare and mulch plots while the concentration of P in leaves from bare plots was consistently lower than that in leaves from grass and mulch plots (data not shown).

Similarly, the concentrations of minerals in leaves at the Massey site in the 1997 / 98 season seldom differed significantly with ground cover (Figure 3.22) or fertiliser regime (Figure 3.23) and did not differ significantly at all with the interaction of the two (data not shown). However, leaves from grass plots consistently contained less Ca and N than those from bare and mulch plots, especially near harvest, while leaves from mulch plots consistently contained less Mg than those from bare and grass plots. Also, leaves from organic and organic plus plots consistently contained more Ca and Mg and less K and N than those from conventional plots. Averaged across the 1997 / 98 season at the Massey site, leaves from mulch plots contained significantly more Mg than leaves from bare plots while leaves from bare and mulch plots contained significantly more N than leaves from grass plots (Table 3.33). Furthermore, leaves from conventional plots contained significantly more K and N than leaves from organic and organic plus plots while leaves from organic plots contained significantly more Mg than conventional and organic plus plots (Table 3.34).

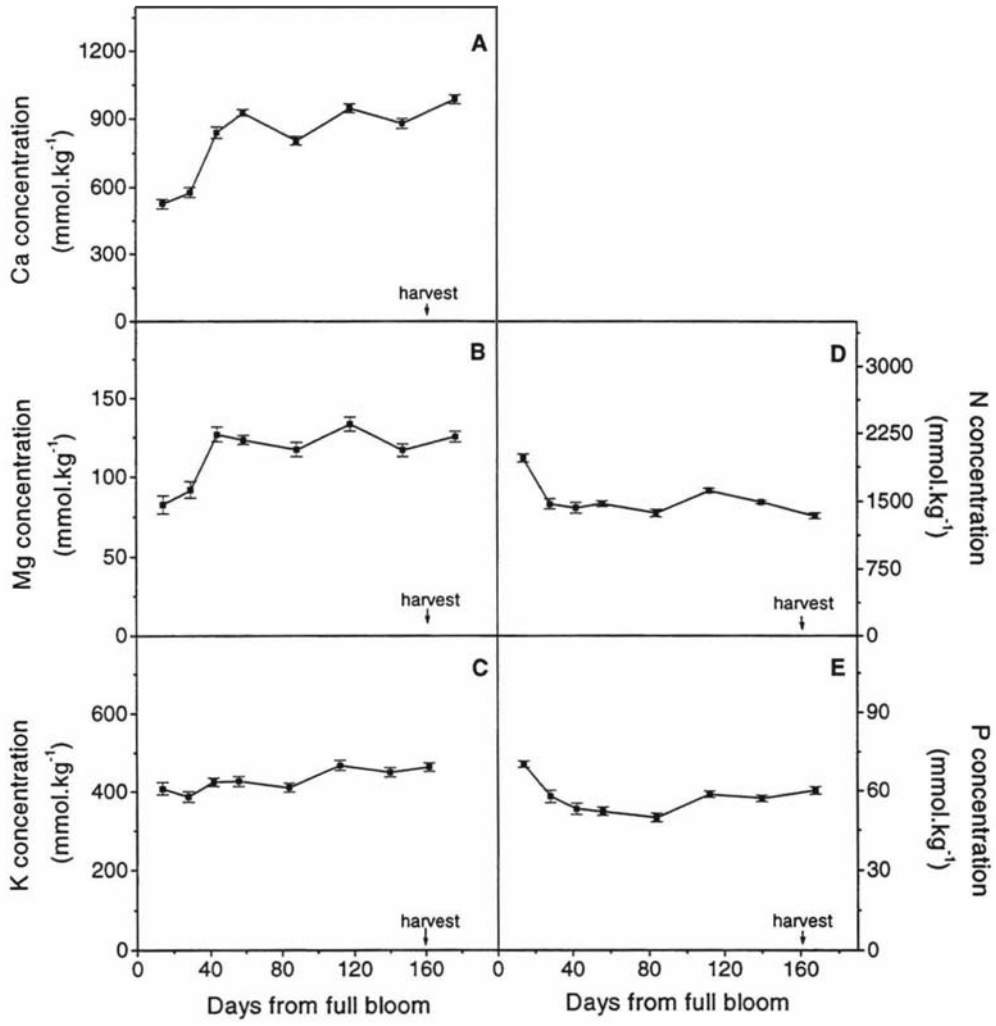

Figure 3.21 Seasonal variation in the average concentrations, on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines at the Massey site during the 1996 / 97 growing season. Vertical bars represent standard errors (n = 27).

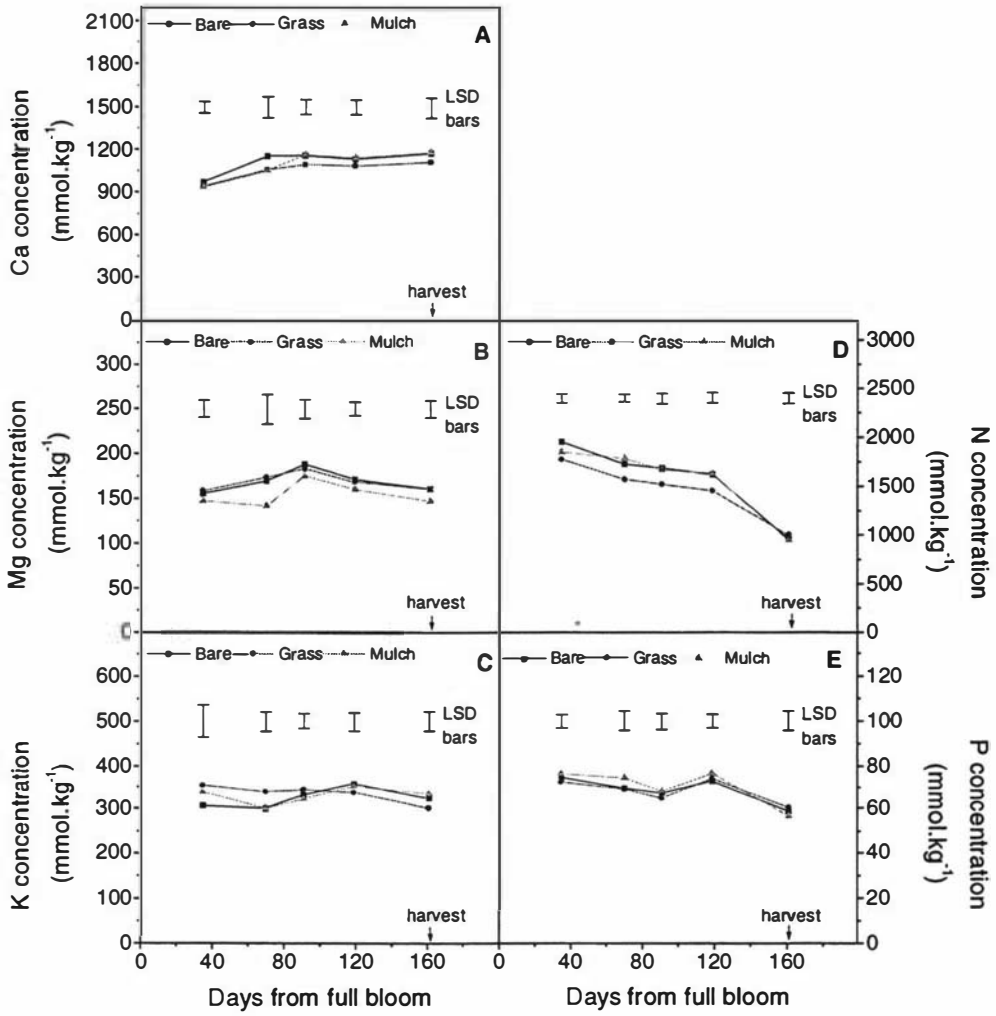

Figure 3.22 Seasonal variation in the average concentrations, on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines from bare, grass and mulch plots at the Massey site during the 1997 / 98 growing season. Each LSD was estimated at the 5 % significance level (n = 9).

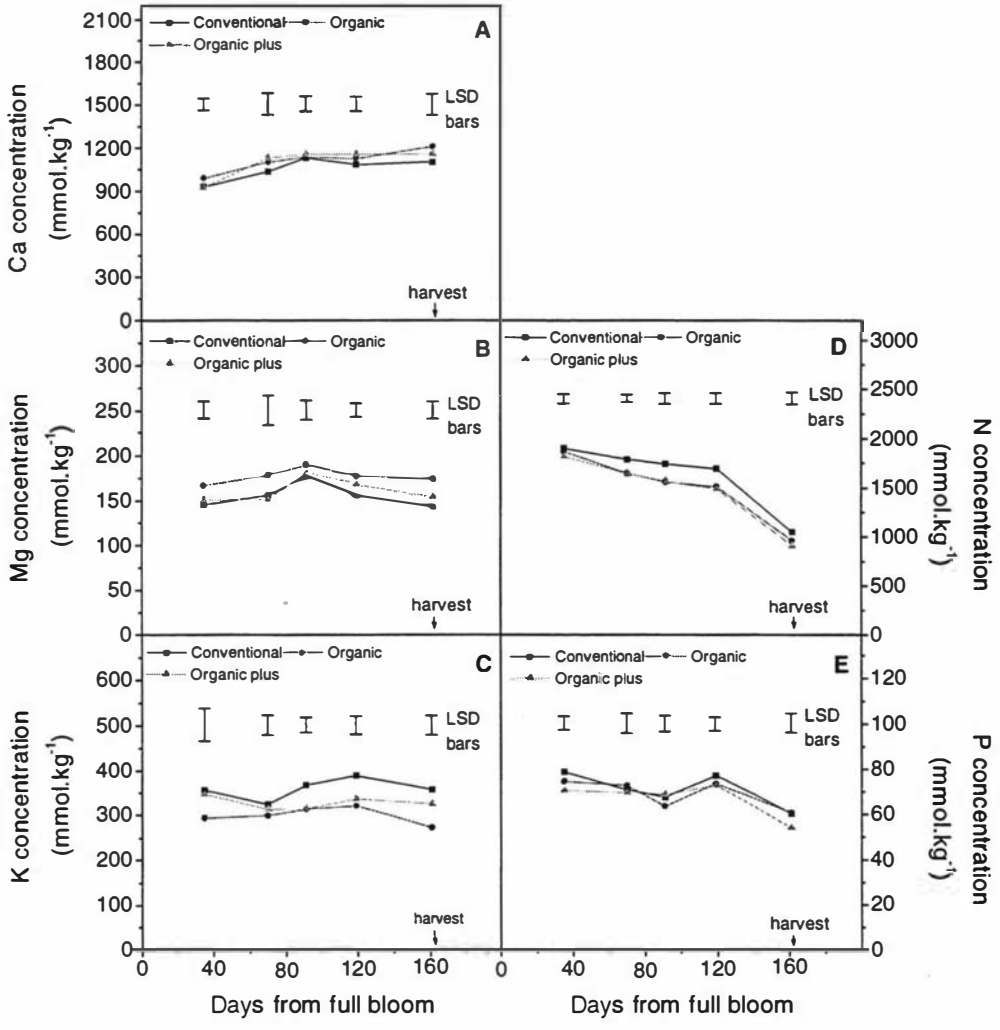

Figure 3.23 Seasonal variation in the average concentrations, on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines from conventional, organic and organic plus plots at the Massey site during the 1997 / 98 growing season. Each LSD was estimated at the 5 % significance level ($n = 9$).

Table 3.33 Concentrations (mmol.kg^{-1}), on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines from bare, grass and mulch plots at the Massey site, averaged across the 1997 / 98 season. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
Bare	1053 a	164 a	398 a	1654 a	72.1 a
Grass	971 a	160 a	412 a b	1462 b	70.3 a
Mulch	1036 a	149 a	413 b	1640 a	76.5 a
SED	31.6	11.2	4.9	29.6	2.69

Table 3.34 Concentrations (mmol.kg^{-1}), on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines from conventional, organic and organic plus plots at the Massey site, averaged across the 1997 / 98 season. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
Conventional	981 a	150 a	430 a	1681 a	73.7 a
Organic	1038 a	168 b	395 b	1537 b	73.4 a
Organic plus	1043 a	154 a	398 b	1539 b	71.9 a
SED	31.6	4.9	11.2	29.6	2.69

At the HortResearch site, in the 1996 / 97 and 1997 / 98 seasons, the concentrations of minerals in leaves were largely unaffected by ground cover and fertiliser regime on the two occasions that sampling occurred. However, in both seasons leaves from mulch plots at harvest contained noticeably more N and P than those from bare and grass plots (Table 3.35 and 3.37) while leaves from organic plus plots contained substantially more Ca than those from conventional plots (Table 3.36 and 3.38). In both seasons, 8 weeks after full bloom, leaves from organic plus plots contained substantially and almost significantly more Ca than those from organic plots. At harvest in the 1996 / 97 season, leaves from organic plots also contained significantly more Mg and less N than leaves from conventional plots (Table 3.36). In both seasons, the concentrations of minerals in leaves did not differ significantly with the interaction of ground cover and fertiliser regime on the two occasions that sampling occurred (data not shown).

Table 3.35 Average concentrations ($mmol.kg^{-1}$), on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines from bare, grass and mulch plots at the HortResearch site in the 1996 / 97 growing season. Sampling occurred 8 weeks after full bloom and at harvest. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

		8 weeks	Harvest
Ca	Bare	794 a	935 a
	Grass	824 a	942 a
	Mulch	763 a	916 a
	SED	35.6	29.5
Mg	Bare	181 a	200 a
	Grass	169 a	180 a
	Mulch	167 a	187 a
	SED	13.3	9.5
K	Bare	581 a	276 a
	Grass	596 a	300 a
	Mulch	594 a	320 a
	SED	29.7	25.0
N	Bare	1685 a b	1292 a
	Grass	1579 a	1285 a
	Mulch	1765 b	1415 b
	SED	68.6	56.5
P	Bare	64.6 a	54.9 a
	Grass	64.5 a	56.8 a
	Mulch	71.3 a	69.3 a
	SED	4.17	7.15

Table 3.36 Average concentrations (mmol.kg^{-1}), on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines from conventional, organic and organic plus plots at the HortResearch site in the 1996 / 97 growing season. Sampling occurred 8 weeks after full bloom and at harvest. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

		8 weeks	Harvest
Ca	Conventional	790 a	883 a
	Organic	759 a	933 a b
	Organic plus	832 a	978 b
	SED	35.7	29.5
Mg	Conventional	172 a	174 a
	Organic	172 a	205 b
	Organic plus	172 a	187 a b
	SED	13.3	9.5
K	Conventional	606 a	312 a
	Organic	581 a	276 a
	Organic plus	584 a	308 a
	SED	29.7	25.0
N	Conventional	1653 a	1476 a
	Organic	1773 a	1232 b
	Organic plus	1623 a	1284 b
	SED	68.6	56.5
P	Conventional	60.2 a	61.2 a
	Organic	74.0 b	60.6 a
	Organic plus	67.0 a b	59.2 a
	SED	4.17	7.15

Table 3.37 Average concentrations ($mmol.kg^{-1}$), on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines from bare, grass and mulch plots at the HortResearch site in the 1997 / 98 growing season. Sampling occurred 8 weeks after full bloom and at harvest. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

		8 weeks	Harvest
Ca	Bare	771 a	915 a
	Grass	896 a	892 a
	Mulch	834 a	875 a
	SED	51.7	59.9
Mg	Bare	199 a	219 a
	Grass	221 a	203 a
	Mulch	204 a	190 a
	SED	15.7	20.6
K	Bare	370 a	226 a
	Grass	376 a	259 a
	Mulch	396 a	276 a
	SED	20.2	24.3
N	Bare	1391 a	1214 a
	Grass	1423 a	1287 a b
	Mulch	1468 a	1399 b
	SED	138.6	64.3
P	Bare	55.4 a	70.2 a
	Grass	66.9 a b	76.5 a
	Mulch	87.1 b	119.9 b
	SED	10.55	8.60

Table 3.38 Average concentrations ($mmol.kg^{-1}$), on a dry weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in the leaves (petioles included) of kiwifruit vines from conventional, organic and organic plus plots at the HortResearch site in the 1997 / 98 growing season. Sampling occurred 8 weeks after full bloom and at harvest. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

		8 weeks	Harvest
Ca	Conventional	809 a	884 a b
	Organic	792 a	811 b
	Organic plus	898 a	988 a
	SED	51.7	59.9
Mg	Conventional	210 a	213 a
	Organic	217 a	195 a
	Organic plus	198 a	205 a
	SED	15.7	20.6
K	Conventional	411 a	267 a
	Organic	372 a	242 a
	Organic plus	359 a	253 a
	SED	20.2	24.3
N	Conventional	1360 a	1368 a
	Organic	1434 a	1280 a
	Organic plus	1484 a	1253 a
	SED	138.6	64.3
P	Conventional	55.0 a	76.6 a
	Organic	77.6 a	100.1 b
	Organic plus	76.2 a	89.9 a b
	SED	10.55	8.60

Fruit mineral concentrations

At the Massey site, the concentrations of Ca, Mg, K, N and P in fruit in the 1996 / 97 season decreased in the first 1 - 2 months after full bloom (Figs. 3.24 and 3.25). Subsequently however, the concentrations of Mg, K, N and P increased until harvest while the concentration of Ca continued to decrease. In the 1997 / 98 season, the trends in the concentrations of minerals from one month after anthesis were similar to those observed in the previous season for the same period (Figs. 3.26 and 3.27). In particular, the concentration of Ca declined while the concentrations of the Mg, K, N and P increased towards harvest. At harvest, the concentrations of Ca, Mg and K and P in fruit were less in the 1997 / 98 season than in the 1996 / 97 season while the concentration of N was similar in both years.

Throughout both seasons, the concentrations of all 5 minerals did not differ significantly with ground cover, fertiliser regime or the interaction of the two. However, in both seasons, fruit from grass plots often contained less N than fruit from bare and mulch plots while fruit from conventional plots often contained more N than fruit from organic and organic plus plots especially late in the season. Also, in the 1997 / 98 season, fruit from grass and mulch plots consistently contained more Ca than those from bare plots, especially in the first few months after full bloom, while fruit from organic and organic plus plots consistently contained more Ca than those from conventional plots, though these differences were not statistically significant.

Averaged across the 1997 / 98 season, fruit from bare and mulch plots at the Massey site contained significantly more N than fruit from grass plots (Table 3.39) while fruit from conventional plots contained significantly more N and K and significantly less Ca than fruit from organic and organic plus plots (Table 3.40). No significant differences were detected in the concentrations of minerals in fruit from the Massey site when averaged across the 1996 / 97 season (data not shown).

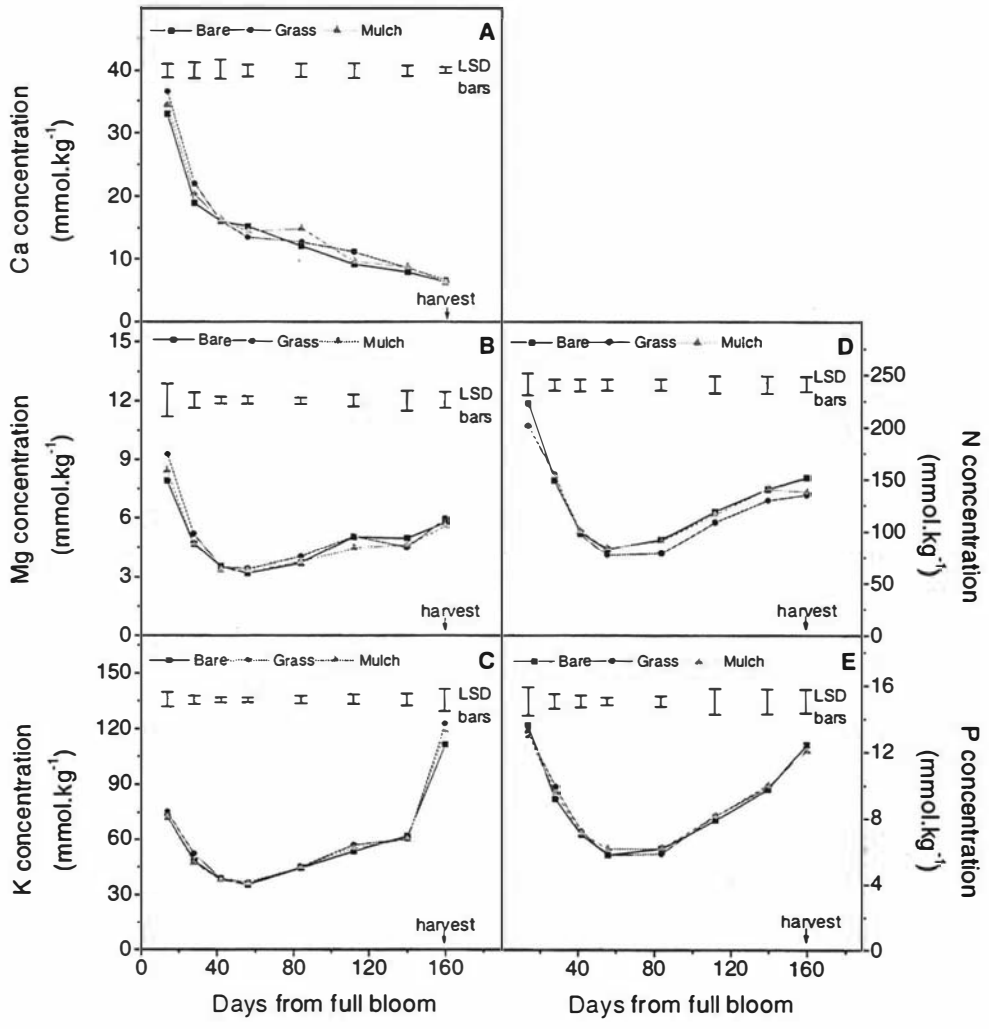

Figure 3.24 Seasonal variation in the average concentrations, on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from bare, grass and mulch plots at the Massey site during the 1996 / 97 growing season. Each LSD was estimated at the 5 % significance level ($n = 9$).

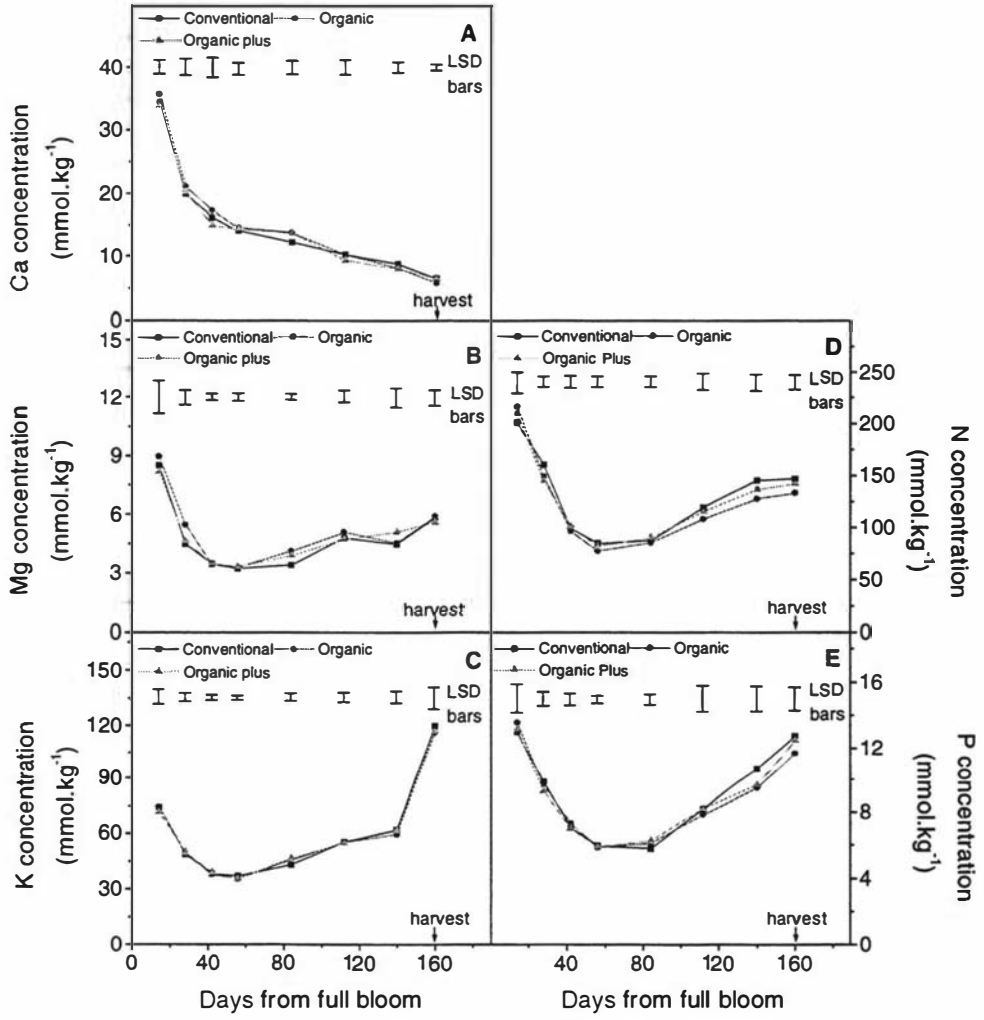

Figure 3.25 Seasonal variation in the average concentrations, on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from conventional, organic and organic plus plots at the Massey site during the 1996 / 97 growing season. Each LSD was estimated at the 5 % significance level ($n = 9$).

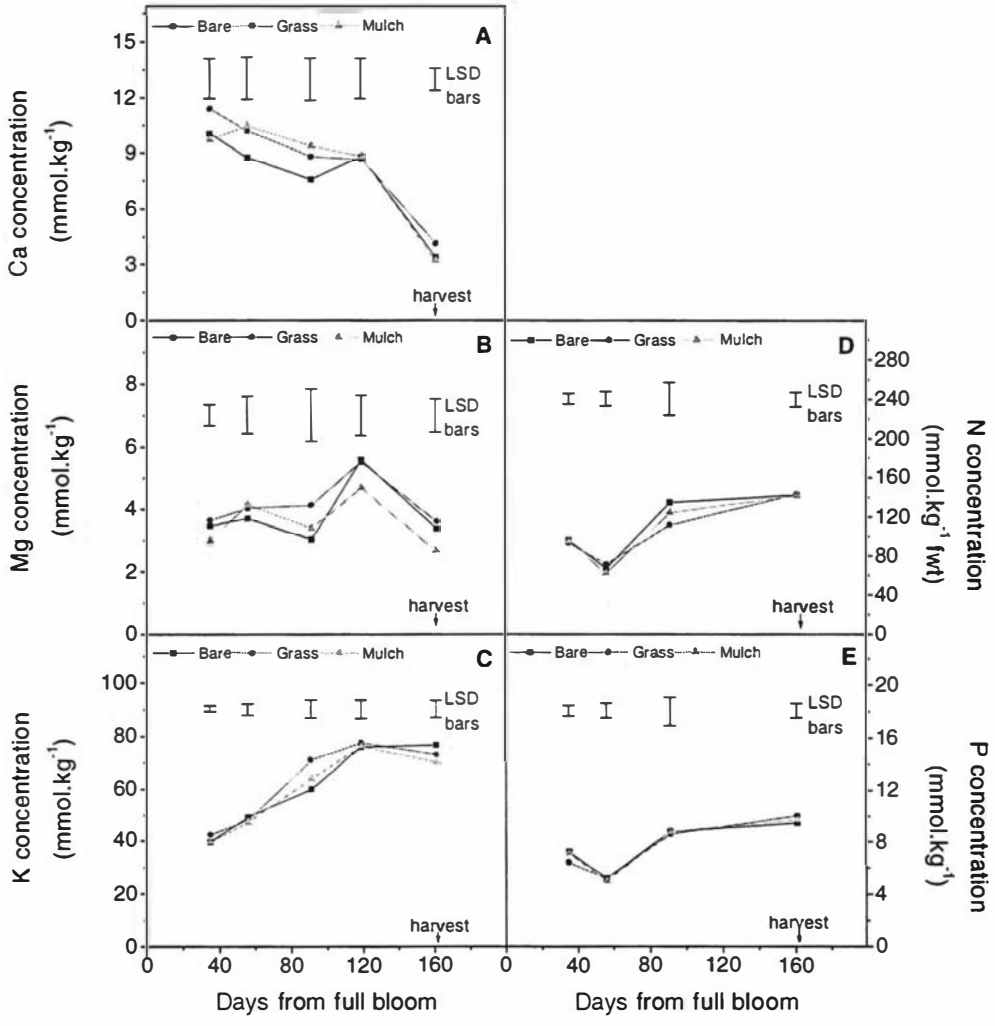

Figure 3.26 Seasonal variation in the average concentrations, on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from bare, grass and mulch plots at the Massey site during the 1997 / 98 growing season. Each LSD was estimated at the 5 % significance level ($n = 9$).

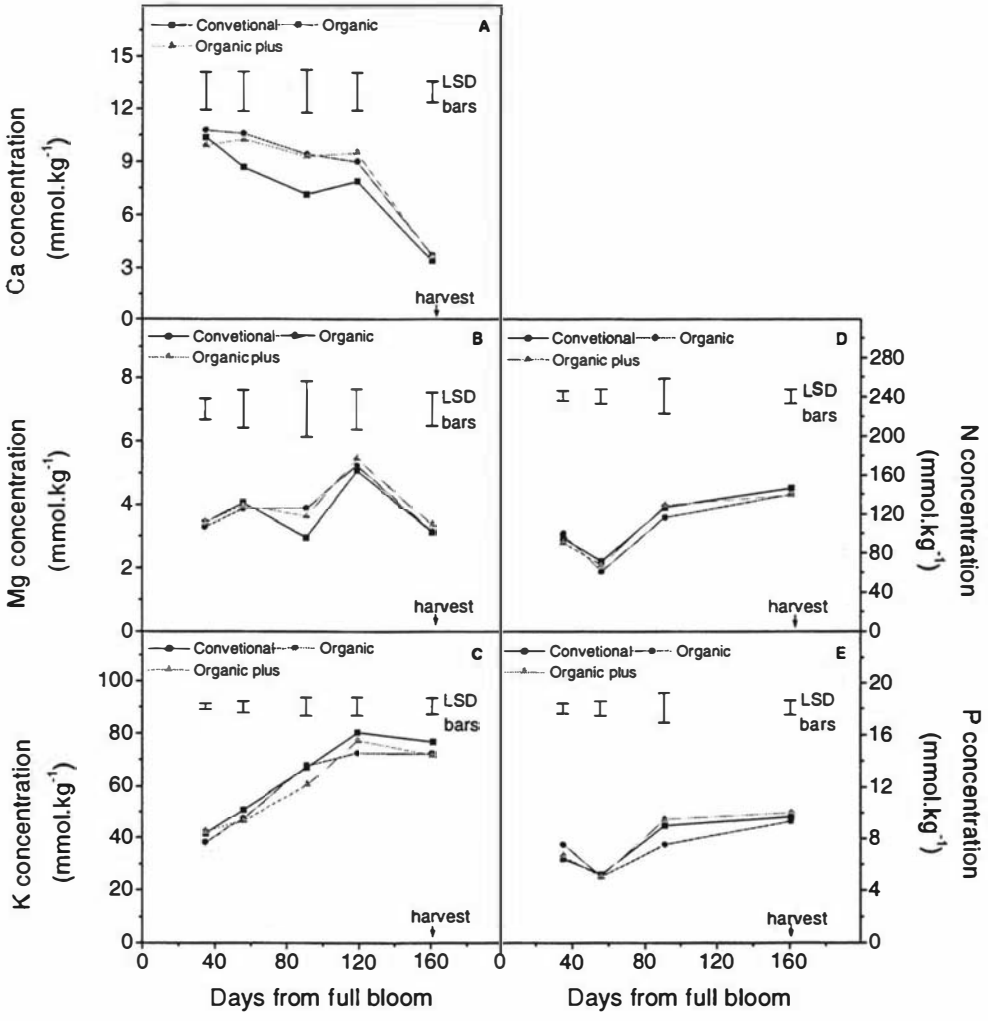

Figure 3.27 Seasonal variation in the average concentrations, on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from conventional, organic and organic plus plots at the Massey site during the 1997 / 98 growing season. Each LSD was estimated at the 5 % significance level ($n = 9$).

Table 3.39 Concentrations (mmol.kg^{-1}), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from bare, grass and mulch plots at the Massey site, averaged across the 1997 / 98 season. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
Bare	7.69 a	3.83 a	60.08 a	126.62 a	9.04 a
Grass	8.71 a	4.20 a	62.12 a	113.34 b	8.78 a
Mulch	8.35 a	3.60 a	59.83 a	125.19 a	9.02 a
SED	0.53	0.24	1.02	4.43	0.32

Table 3.40 Concentrations (mmol.kg^{-1}), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from conventional, organic and organic plus plots at the Massey site, averaged across the 1997 / 98 season. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
Conventional	7.46 a	3.75 a	63.12 a	129.98 a	9.20 a
Organic	8.81 b	3.86 a	59.17 b	117.14 b	8.77 a
Organic plus	8.48 b	4.02 a	59.74 b	118.03 b	8.87 a
SED	0.48	0.24	1.02	4.43	0.32

At the HortResearch site, in both the 1996 / 97 and 1997 / 98 seasons, the concentrations of minerals in fruit did not differ significantly with ground cover, fertiliser regime or the interaction of the two on the two occasions that sampling occurred (data not shown). Nor were there any consistent differences across the two seasons. In both seasons, the concentrations of Ca in fruit decreased from 8 weeks after full bloom until harvest while the concentrations of Mg, K, P increased. The concentration of N in fruit also increased in the 1996 / 97 season but not in the 1997 / 98 season. At harvest, the average concentrations of Ca and Mg in fruit were greater in the 1997 / 98 season (Table 3.41) while the concentrations of K, N and P in fruit were greater in the 1996 / 97 season (Table 3.42).

Table 3.41 Average (± SE) concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit at the HortResearch site during the 1996 / 97 growing season. Sampling occurred 8 weeks after full bloom and at harvest ($n = 54$).

	8 weeks	Harvest
Ca	14.79 ± 0.60	5.62 ± 0.13
Mg	4.02 ± 0.13	4.34 ± 0.11
K	44.87 ± 0.39	70.86 ± 1.21
N	79.79 ± 1.69	136.56 ± 2.68
P	5.48 ± 0.17	11.96 ± 0.25

Table 3.42 Average (± SE) concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit at the HortResearch site during the 1997 / 98 growing season. Sampling occurred 8 weeks after full bloom and at harvest (n = 54).

	8 weeks	Harvest
Ca	11.47 ± 0.30	8.10 ± 0.26
Mg	3.83 ± 0.17	5.10 ± 0.07
K	53.90 ± 0.57	63.60 ± 0.63
N	115.21 ± 3.03	114.00 ± 5.87
P	7.89 ± 0.22	8.98 ± 0.44

Soil Vs. vine mineral concentrations

Throughout each season, the concentrations of Ca, Mg and K in the sap, foliage and fruit of vines at both sites did not appear to be linked to their concentrations in the soil solution (data not shown). For example, 4 and 8 weeks after full bloom, in the 1997 / 98 season, there were considerable differences in the concentrations of Ca in the soil solution at the Massey site but the concentrations in the vines were relatively stable, especially in the foliage (Figs. 3.28 and 3.29).

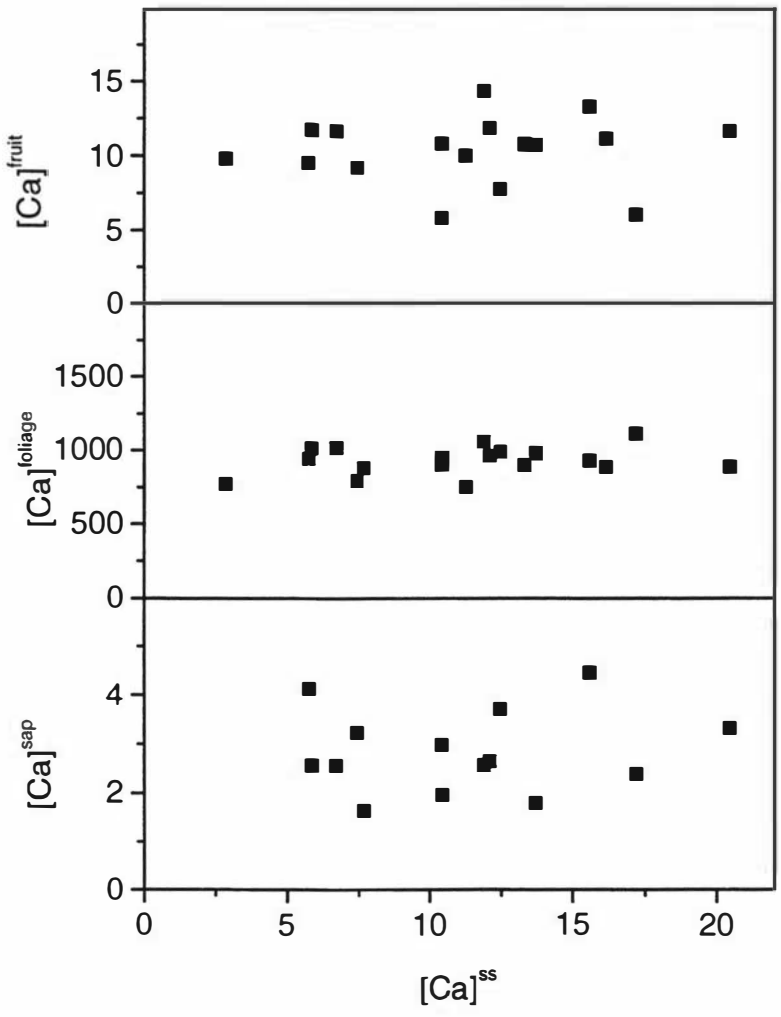

Figure 3.28 Relationships between the concentrations (mmol.kg^{-1}) of Ca in the soil solution ([Ca]^{ss}) of plots at the Massey site, 4 weeks after full bloom in the 1997 / 98 season, and the concentrations (mmol.kg^{-1}) of Ca in the xylem sap ([Ca]^{sap}), foliage ([Ca]^{foliage}) and fruit ([Ca]^{fruit}) of the vines from those plots. Each data point represents the average of a plot. Concentrations for the soil solution, xylem sap and fruit are expressed on a fresh weight basis while concentrations for foliage are expressed on a dry weight basis. The relationships are not significant at the 5 % level.

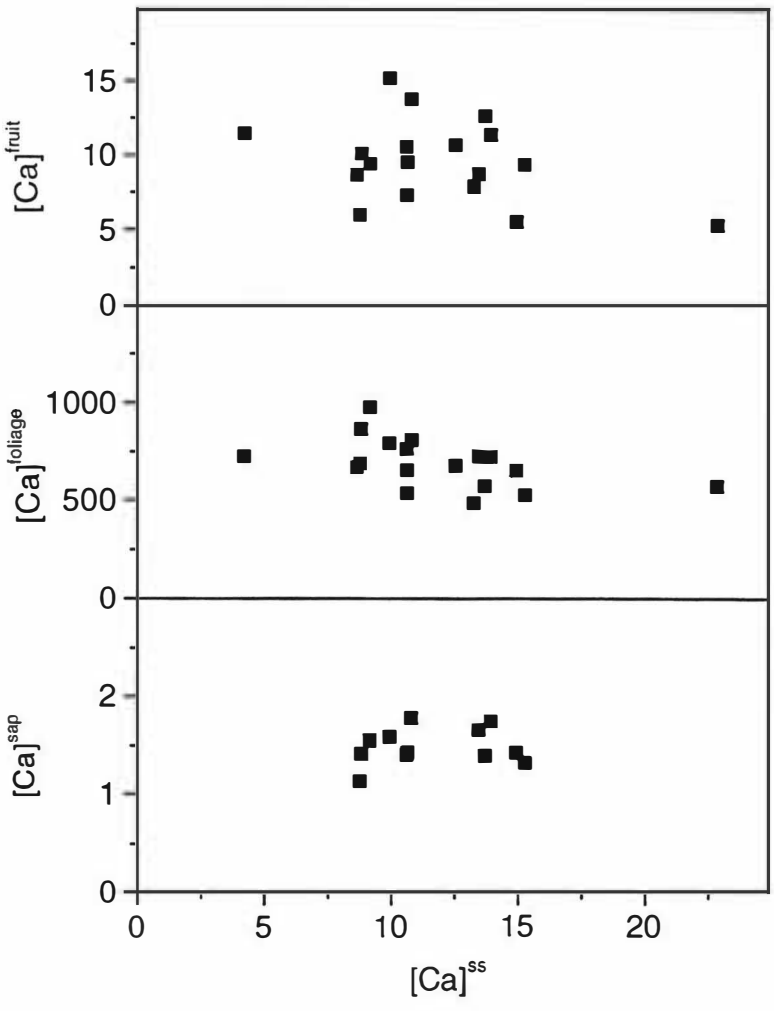

Figure 3.29 Relationships between the concentrations (mmol.kg^{-1}) of Ca in the soil solution ([Ca]^{ss}) of plots at the Massey site, 8 weeks after full bloom in the 1997 / 98 season, and the concentrations (mmol.kg^{-1}) of Ca in the xylem sap ([Ca]^{sap}), foliage ([Ca]^{foliage}) and fruit ([Ca]^{fruit}) of the vines from those plots. Each data point represents the average of a plot. Concentrations for the soil solution, xylem sap and fruit are expressed on a fresh weight basis while concentrations for foliage are expressed on a dry weight basis. The relationships are not significant at the 5 % level.

Fruit growth

At the Massey site, fruit volume throughout the 1996 / 97 and 1997 / 98 seasons increased steadily from anthesis to harvest, reaching final average volumes of close to 90 mL (Figure 3.30) and 100 mL (Figure 3.31), respectively. In both seasons, fruit growth consisted of 2 approximately linear phases: a phase of rapid growth in the first 2 months after full bloom and a phase of less rapid growth thereafter until harvest. Fruit growth did not differ significantly with ground cover, fertiliser regime or the interaction of the two throughout either season (data not shown).

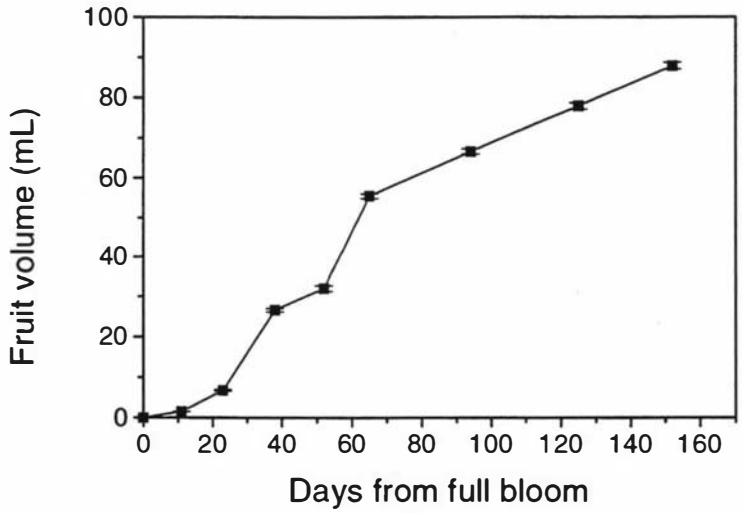

Figure 3.30 Seasonal variation in the average size of fruit at the Massey site in the 1996 / 97 season. Vertical bars represent standard errors (n = 27).

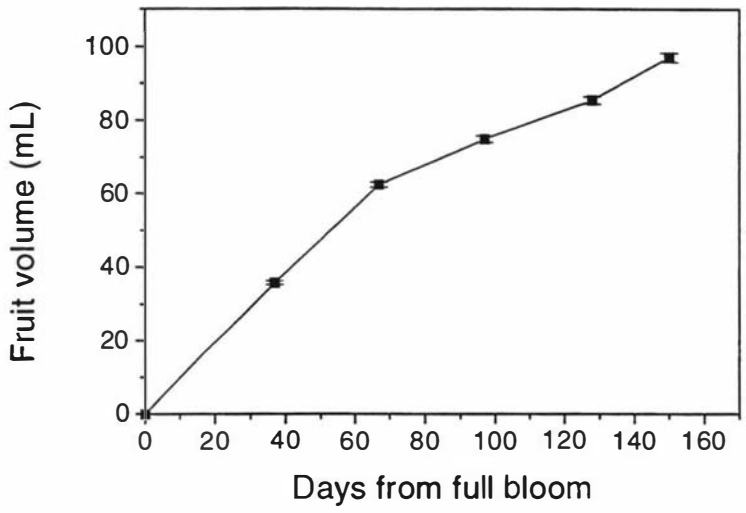

Figure 3.31 Seasonal variation in the average size of fruit at the Massey site in the 1997 / 98 season. Vertical Bars represent standard errors (n = 27).

At the HortResearch site, in both the 1996 / 97 and 1997 / 98 seasons, fruit volume did not differ significantly with ground cover, fertiliser regime or the interaction of the two on the two occasions that sampling occurred (data not shown). In the 1997 / 98 season, fruit were larger both 8 weeks after full bloom and at harvest, than in the previous season (Table 3.43)

Table 3.43 Average (± SE) size (mL) of fruit at the HortResearch site in the 1996 / 97 and 1997 / 98 seasons, 8 weeks after full bloom and at harvest.

	8 weeks	Harvest
1996 / 97 (n = 216)	53.32 ± 0.41	80.57 ± 0.60
1997 / 98 (n = 108)	65.38 ± 0.53	100.91 ± 0.92

Root length density

At both sites, 8 weeks after full bloom in the 1996 / 97 season, there were twice as many roots deeper in the soil than near the soil surface (Figs. 3.32 - 3.34). Also, twice as many roots were present in the soil at the Massey site than at the HortResearch site. At the Massey site, the RLD of vines differed significantly with ground cover, fertiliser regime and the interaction of the two at a depth of 0 - 30 mm, with significantly more roots found in mulch and organic plus plots. Also, the difference between the conventional and organic plus regime was greater for the mulch cover than for the bare soil. No significant differences occurred at 30 - 75 mm although mulch plots generally contained fewer roots than bare plots.

At the HortResearch site, RLD did not differ significantly with ground cover, fertiliser regime or the interaction of the two at either depth (data not shown). Average RLDs of 4.33 ± 0.324 (n = 12) and 11.39 ± 0.489 (n = 12) $m.L^{-1}$ were measured at depths of 0 – 30 mm and 30 – 75 mm, respectively.

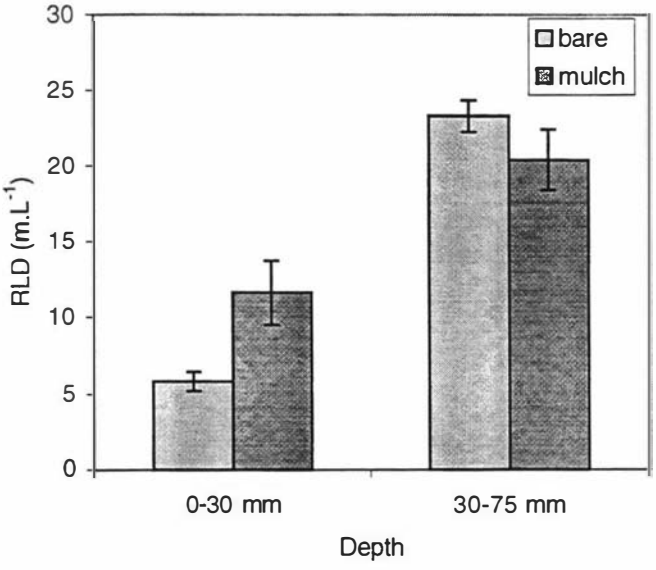

Figure 3.32 Average root length densities (RLDs) of vines from bare and mulch plots at the Massey site in the 1996 / 97 season, 8 weeks after full bloom. Sampling occurred at two depths: 0 - 30 mm and 30 - 75 mm. Vertical bars represent standard errors (n = 6).

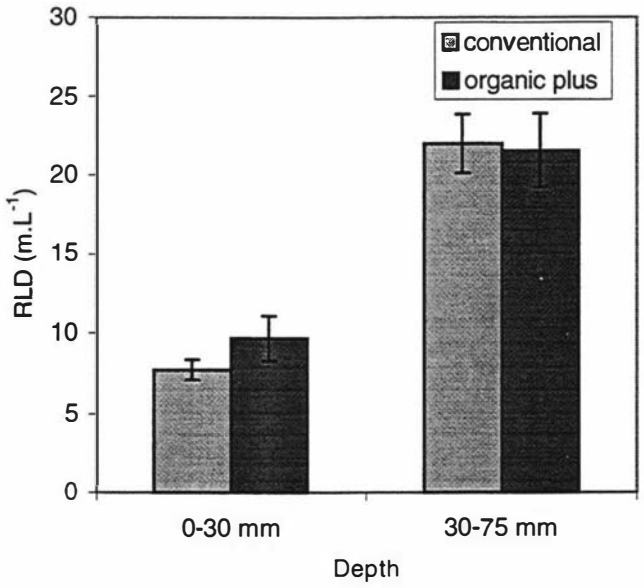

Figure 3.33 Average root length densities (RLDs) of vines from conventional and organic plus plots at the Massey site in the 1996 / 97 season, 8 weeks after full bloom. Sampling occurred at two depths: 0 – 30 mm and 30 - 75 mm. Vertical bars represent standard errors (n = 6).

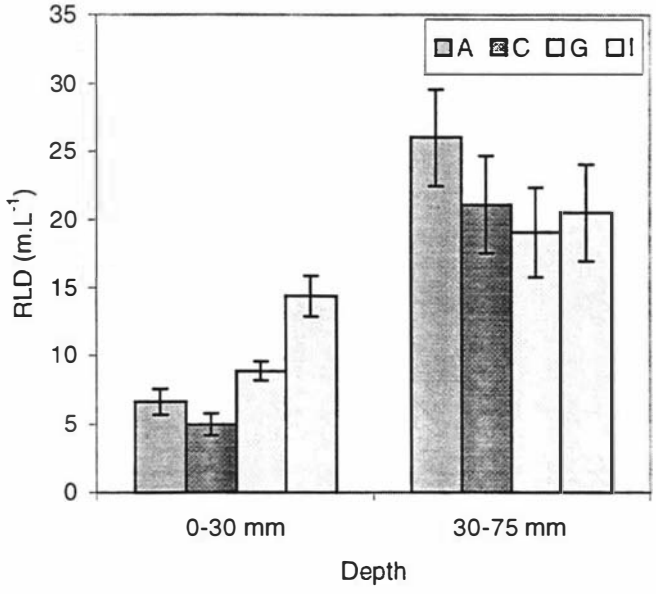

Figure 3.34 Average root length densities (RLDs) of vines from treatment A (bare and conventional), C (bare and organic plus), G (mulch and conventional) and I (mulch and organic plus) plots at the Massey site in the 1996 / 97 season, 8 weeks after full bloom. Sampling occurred at two depths: 0 - 30 mm and 30 - 75 mm. Vertical bars represent standard errors (n = 3).

3.4.2 Attributes at harvest

3.4.2.1 Crop load and fruit size

The number, average size and yield of fruit harvested from each site varied considerably across the three years. In all three years, the average number (Table 3.44) and yield (Table 3.46) of fruit harvested from the HortResearch site was much greater than that of fruit harvested from the Massey site. In 1996, fruit harvested from the HortResearch site were, on average, much larger than fruit harvested from the Massey site but smaller in 1997 (Table 3.46). Average fruit size did not differ substantially between the two sites in 1998.

In all three years, the average number and yield of fruit harvested from both sites did not differ significantly with ground cover, fertiliser regime or the interaction of the two (data not shown). Similarly, there were generally no significant differences in the average weight of fruit harvested from either site. However, in 1997, fruit from grass plots at the Massey site were significantly larger than those from bare and mulch plots (Table 3.47). At the same time, considerably fewer fruit were harvested from grass plots, a feature that may have been mediated through competition by the grass for available nitrogen, as has been reported in other fruit crops such as peach (Hogue and Neilsen, 1987). In 1998, fruit from conventional plots at the HortResearch site were significantly larger than fruit from organic and organic plus plots (Table 3.48) presumably because the N added to those plots promoted fruit growth.

Table 3.44 Average (± SE) numbers (000's / ha) of fruit harvested from the Massey and HortResearch sites in 1996, 1997 and 1998 (n = 27). Yields are based on vine spacings of 5 m x 2.5 m and 6 m x 5 m for the Massey and HortResearch sites respectively.

Site	1996	1997	1998
Massey	234 ± 9	145 ± 10	154 ± 7
HortResearch	266 ± 8	471 ± 12	337 ± 8

Table 3.45 Average (± SE) yields (tonnes / ha) of fruit harvested from the Massey and HortResearch sites in 1996, 1997 and 1998 (n = 27). Yields are based on vine spacings of 5 m x 2.5 m and 6 m x 5 m for the Massey and HortResearch sites respectively.

	1996	1997	1998
Massey	24.53 ± 0.74	15.5 ± 1.0	17.29 ± 0.79
HortResearch	30.32 ± 0.82	41.8 ± 0.9	37.84 ± 0.87

Table 3.46 Average (± SE) sizes (g) of fruit harvested from the Massey and HortResearch sites in 1996, 1997 and 1998 (n = 27).

Site	1996	1997	1998
Massey	101.08 ± 0.95	106.57 ± 1.17	112.49 ± 1.21
HortResearch	112.88 ± 0.72	89.10 ± 0.65	112.27 ± 0.64

Table 3.47 Average number (000's / ha), yield (tonnes / ha) and individual weight (g) of fruit harvested from bare, grass and mulch plots at the Massey site in 1997. Yields are based on a vine spacing of 5 m x 2.5 m. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Average number	Average weight	Average yield
Bare	161 a	104.11 a	16.73 a
Grass	114 a	111.38 b	12.78 a
Mulch	159 a	104.78 a	16.62 a
SED	25.9	2.71	2.66

Table 3.48 Average number (000's / ha), yield (tonnes / ha) and individual weight (g) of fruit harvested from conventional, organic and organic plus plots at the HortResearch site in 1998. Yields are based on a vine spacing of 6 m x 5 m. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	Average number	Average weight	Average yield
Conventional	328 a	114.77 a	37.6 a
Organic	340 a	111.41 b	37.9 a
Organic plus	344 a	110.63 b	38.0 a
SED	23	1.46	2.4

3.4.2.2 Fruit maturity

In all three years, fruit from the HortResearch site was harvested in the first week of May while fruit from the Massey site was harvested in the third week of May. Massey fruit were always harvested with greater SSC than HortResearch fruit (Table 3.49), especially in 1998. Despite fruit being harvested at comparable times within sites in all three years, there was considerable variation in SSC between years at both sites; across the three years, the ranges in average maturity of Massey and HortResearch fruit were 2.2 and 0.62 °Brix, respectively.

The SSC of fruit harvested from both sites generally did not differ significantly with ground cover, fertiliser regime or the interaction of the two in any of the three years. However, at the HortResearch site in 1998, the SSC of fruit from bare and conventional plots was significantly greater than that of fruit from grass and organic plus plots, respectively (Tables 3.50 and 3.51).

Table 3.49 Average (± SE) SSC (°Brix) of fruit harvested from the Massey and HortResearch sites in 1996, 1997 and 1998. In all three years, fruit from the Massey site were harvested in the third week of May while fruit from the HortResearch site were harvested in the first week of May.

	Massey	HortResearch
1996	7.94 ± 0.05 (n = 500)	6.01 ± 0.03 (n = 540)
1997	6.43 ± 0.04 (n = 324)	6.20 ± 0.03 (n = 324)
1998	8.63 ± 0.09 (n = 216)	6.63 ± 0.04 (n = 216)

Table 3.50 Average SSC (°Brix) of fruit harvested from bare, grass and mulch plots at the HortResearch site in 1998. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	SSC (°Brix)
Bare	6.73 a
Grass	6.48 b
Mulch	6.66 a b
SED	0.09

Table 3.51 Average SSC (°Brix) of fruit harvested from conventional, organic and organic plus plots at the HortResearch site in 1998. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	SSC (°Brix)
Conventional	6.79 a
Organic	6.57 a b
Organic plus	6.50 b
SED	0.09

3.4.2.3 Fruit mineral concentrations

The concentrations of Ca, Mg, K, N and P in fruit harvested from each of the sites varied considerably across the three years (Tables 3.52 and 3.53). In all three years at both sites, the concentrations did not differ significantly with ground cover, fertiliser regime or the interaction of the two (data not shown). However, fruit harvested from grass plots often contained more Ca and Mg as well as less N than fruit from bare and

mulch plots while fruit from conventional plots often contained more N and K than fruit from organic and organic plus plots.

Table 3.52 Average (± SE) concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorus (P) in fruit harvested from the Massey site in 1996, 1997 and 1998.

	1996 (n = 108)	1997 (n = 54)	1998 (n = 54)
Ca	5.95 ± 0.32	6.35 ± 0.17	3.57 ± 0.20
Mg	4.14 ± 0.19	5.76 ± 0.14	3.22 ± 0.177
K	52.09 ± 1.13	117.38 ± 1.77	73.23 ± 1.09
N	88.97 ± 2.39	140.67 ± 2.94	142.08 ± 2.55
P	6.54 ± 0.20	12.29 ± 0.24	9.71 ± 0.19

Table 3.53 Average (± SE) concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorus (P) in fruit harvested from the HortResearch site in 1996, 1997 and 1998.

	1996 (n = 108)	1997 (n = 54)	1998 (n = 54)
Ca	5.03 ± 0.30	5.62 ± 0.13	8.10 ± 0.26
Mg	5.57 ± 0.26	4.34 ± 0.11	5.10 ± 0.07
K	65.19 ± 1.21	70.86 ± 1.21	63.60 ± 0.63
N	100.68 ± 1.79	136.56 ± 2.68	114.00 ± 5.87
P	7.80 ± 0.18	11.96 ± 0.25	8.98 ± 0.44

At both sites in 1996, and at the Massey site in 1998, there appeared to be considerable variation in fruit Ca concentrations, which resulted in large LSDs, relative to the means (Table 3.54). In all years at both sites, the variation in Ca concentrations was due mostly to between-experimental unit variation (i.e. variation between analytical samples of different plots) rather than within-sample variation[6] (i.e. analytical error between duplicate measurements). In 1997, smaller experimental error and analytical error resulted in smaller LSDs.

Table 3.54 Average Ca concentrations in fruit from the Massey and HortResearch (HR) sites, and the experimental (DF = 16) and analytical (DF = 27) error variances associated with them.

Estimate	Massey 1996	HR 1996	Massey 1997	HR 1997	Massey 1998	HR 1998
Mean Ca concentration	5.95	5.03	6.35	5.62	3.57	8.1
LSD (Main effects, $P = 0.05$)	1.84	2.58	0.95	0.58	1.21	1.82
Experimental error variance	9.53	8.11	0.84	0.45	1.86	2.11
Analytical error variance	0.59	1.01	0.25	0.13	0.27	0.49

[6] Within-sample variation was able to be determined because duplicates of each sample were analysed for Ca.

3.4.2.4 Fruit firmness

Across the three years, there was no consistent difference in the average firmness of fruit between sites despite the consistent differences in SSC (Table 3.55). In 1996, the average firmness of fruit harvested from the HortResearch site was 20 N greater than that of fruit harvested from the Massey site while in 1997 and 1998, fruit from the Massey site were slightly firmer than fruit from the HortResearch site.

The firmness of fruit harvested from both sites in 1996 and 1997 did not differ significantly with ground cover, fertiliser regime or the interaction of the two (data not shown). In 1998, fruit harvested from grass plots at the Massey site were significantly firmer than fruit harvested from bare and mulch plots (Table 3.56). Similarly, fruit harvested from organic and organic plus plots were significantly firmer than fruit harvested from conventional plots (Table 3.57). The firmness of fruit harvested from the HortResearch site in 1998 did not differ significantly with ground cover (data not shown) but fruit from organic and organic plus plots were significantly firmer than those harvested from conventional plots, (Table 3.58). The firmness of fruit harvested from both sites in 1998 did not differ significantly with the interaction of ground cover and fertiliser regime (data not shown).

Across all plots, the firmness of fruit harvested from both sites in each season tended to be negatively correlated with the SSC of fruit i.e. the more mature the fruit at harvest, the softer they tended to be (Figure 3.35). In addition to being more mature, softer fruit at harvest also tended to contain more nitrogen.

Table 3.55 Average (± SE) flesh firmnesses of fruit (N) harvested from the Massey and HortResearch sites in 1996, 1997 and 1998. In all three years, fruit from the Massey site were harvested in the third week of May while fruit from the HortResearch site were harvested in the first week of May.

	Massey	HortResearch
1996	54.57 ± 0.37 (n = 500)	75.12 ± 0.29 (n = 540)
1997	69.55 ± 0.40 (n = 324)	64.26 ± 0.29 (n = 324)
1998	65.04 ± 0.67 (n = 216)	62.39 ± 0.39 (n = 216)

Table 3.56 Average flesh firmnesses (f) of fruit harvested from bare, grass and mulch plots at the Massey site in 1998. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	f (N)
Bare	63.24 a
Grass	68.92 b
Mulch	62.99 a
SED	1.79

Table 3.57 Average flesh firmnesses (*f*) of fruit harvested from conventional, organic and organic plus plots at the Massey site in 1998. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	f (N)
Conventional	61.78 a
Organic	66.57 b
Organic plus	66.81 b
SED	1.79

Table 3.58 Average flesh firmnesses (*f*) of fruit harvested from conventional, organic and organic plus plots at the HortResearch site in 1998. Separation of means is based on Tukey's test ($P = 0.05$). Means with the same letter do not differ significantly.

	f (N)
Conventional	59.92 a
Organic	63.96 b
Organic plus	63.31 b
SED	1.27

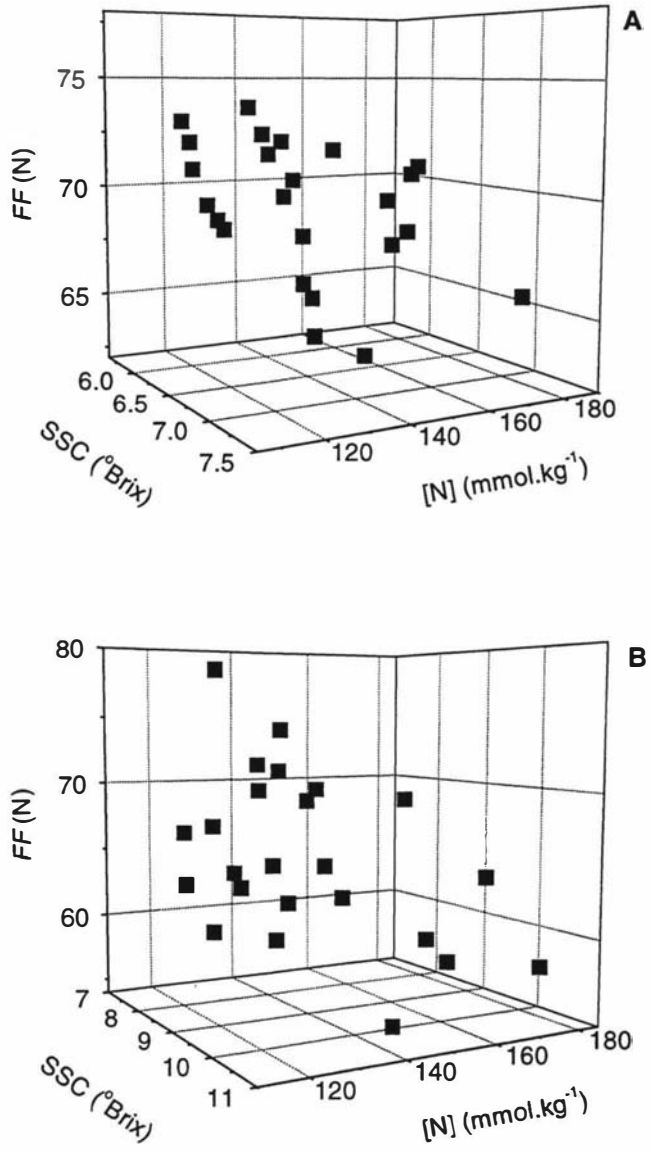

Figure 3.35 Relationships between the firmness (*FF*), soluble solids content (SSC) and nitrogen concentration ([N]) of fruit harvested from the Massey site in 1997 (A) and 1998 (B). Each data point represents the average for a plot. Nitrogen concentrations are expressed on a fresh weight basis.

3.4.3 Postharvest attributes

3.4.3.1 *Botrytis*

In all three years, the incidence of *Botrytis* in fruit from both sites at condition checking was very low with the total incidence never being greater than 0.3 %. Furthermore, the incidence of *Botrytis* in fruit from either site did not differ significantly with ground cover, fertiliser regime or the interaction of the two across the three years (data not shown).

3.4.3.2 Softening behaviour

In 1996, fruit from the Massey site softened rapidly during storage in a hyperbolic manner with the average firmness dropping below the export threshold level of 10 N in less than 60 days (Figure 3.36). In contrast, fruit from the HortResearch site in 1996 softened much less rapidly (Figure 3.37). After approximately 7.5 months storage, the average firmness of fruit was still 17.3 N. The manner in which the HortResearch fruit softened in 1996 also differed to that of the Massey fruit, especially during the middle and latter stages. During the first two months of storage, the firmness of fruit declined rapidly in a hyperbolic manner but in the ensuing 3 - 4 months there was very little change in firmness, resulting in a plateau phase. During the final few months of storage, the firmness of fruit declined rapidly again.

In 1997, fruit harvested from the Massey site softened rapidly in a hyperbolic manner during the first 3 - 4 months of storage. Thereafter, the rate of softening declined until approximately 6 months after storage when softening accelerated again with the firmness dropping below the export threshold of 10 N after approximately 7 months of storage (Figure 3.38). Similarly, fruit harvested from the HortResearch site in 1997 softened rapidly in a hyperbolic manner during the first 3 - 4 months of storage. Thereafter, very little softening occurred until approximately 7 months after storage when softening began to accelerate again. HortResearch fruit were stored for

approximately 8.5 months but even after that amount of time, the firmness of fruit did not drop below the export threshold level of 10 N (Fig. 3.39).

In 1998, Massey fruit softened rapidly in a hyperbolic manner during the first 2 months of storage. Thereafter, the rate of softening declined until approximately 5 months after storage when the rate of softening accelerated again. The average firmness of fruit reached the export threshold of 10 N after approximately 7 months of storage (Figure 3.40).

Initially, several softening models were used to describe the softening behaviour of fruit from the HortResearch and Massey sites in 1996, 1997 and 1998. These included basic Complementary Michaelis-Menten and Gompertz types as well as more complex 'segmented' types, which consisted of two or more equations joined to describe different regions of the x-space. However, these models tended to be over or insensitive to changes in firmness. Subsequently, polynomial models (described hereinafter) were generally found to accurately describe the softening behaviour of fruit although the following Complementary Michaelis-Menten equation best characterised the rapid and hyperbolic softening behaviour of fruit from the Massey site in 1996:

$$f = a[1 - \frac{t}{t+b}] \qquad (3.1)$$

In the above model, f represents firmness (in Newtons) and t represents time (in days). The parameter a represents the initial firmness of fruit while b is the half time parameter (i.e. time taken to reach half the initial firmness). The parameter values obtained by fitting Eq. 3.1 to the firmness data did not differ significantly with ground cover, fertiliser regime or the interaction of the two. The softening behaviour of fruit from the Massey site in 1997, and from the HortResearch site in 1996 and 1997, was best described using the following quartic polynomial equation, where the parameters a and b respectively represent the firmness of fruit and the rate at which firmness is changing at time 0, while the parameters c, d, e define the inflexion points of the curves generated by the equation:

$$f = a + bt + ct^2 + dt^3 + et^4 \qquad (3.2)$$

An attempt was made to describe the softening behaviour of fruit from the Massey site in 1998 with Eq. 3.2 but it was found to be over-sensitive to initial and final changes in firmness and poorly described the data. Instead the following polynomial better described the softening behaviour of this fruit:

$$f = a + bt + ct^{1.5} + dt^3 + et^{0.5} \qquad (3.3)$$

The parameters obtained from fitting Eq. 3.2 to the Massey firmness data from 1997, and the HortResearch data from 1996 and 1997, did not differ significantly with ground cover, fertiliser regime or the interaction of the two on any occasion. However, after fitting Eq. 3.3 to the Massey firmness data from 1998, parameter *a* (representing the firmness of fruit at time 0) was found to differ significantly with ground cover (Table 3.59) and fertiliser regime (Table 3.60). In particular, fruit from grass plots were initially firmer than fruit from bare and mulch plots which is consistent with the data presented in Table 3.53. Furthermore, fruit from organic and organic plus plots were initially firmer than fruit from conventional plots which is consistent with the data in Table 3.54. The remaining 4 parameters (i.e. *b*, *c*, *d* and *e*) did not differ significantly with ground cover, fertiliser regime or the interaction of the two indicating no significant differences in the remaining softening behaviour of fruit during storage.

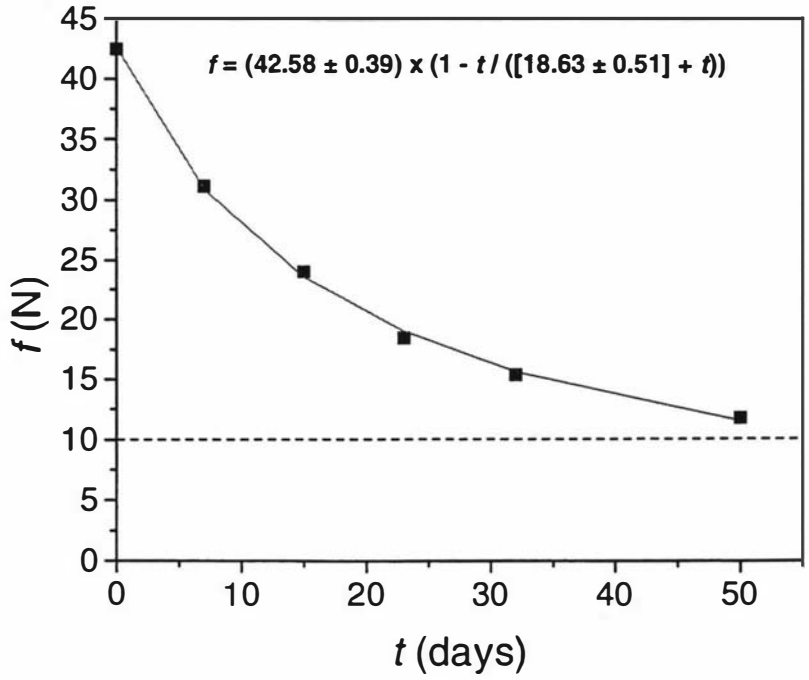

Figure 3.36 Average softening behaviour of fruit harvested from the Massey site in 1996. The solid line represents the line of best fit obtained by fitting the inset equation to the data while the dashed line represents the minimum threshold level of firmness for export.

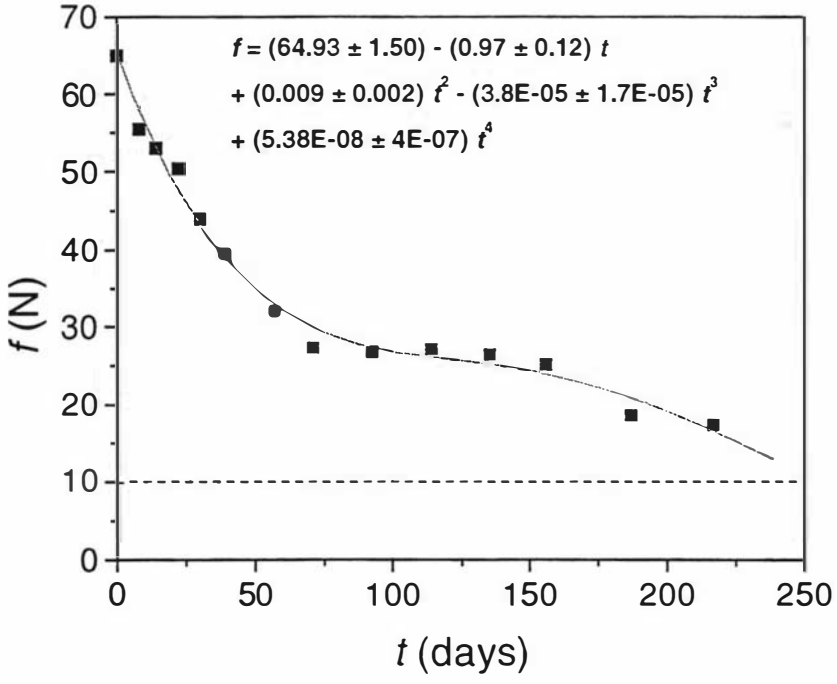

Figure 3.37 Average softening behaviour of fruit harvested from the HortResearch site in 1996. The solid line represents the line of best fit obtained by fitting the inset equation to the data while the dashed line represents the minimum threshold level of firmness for export.

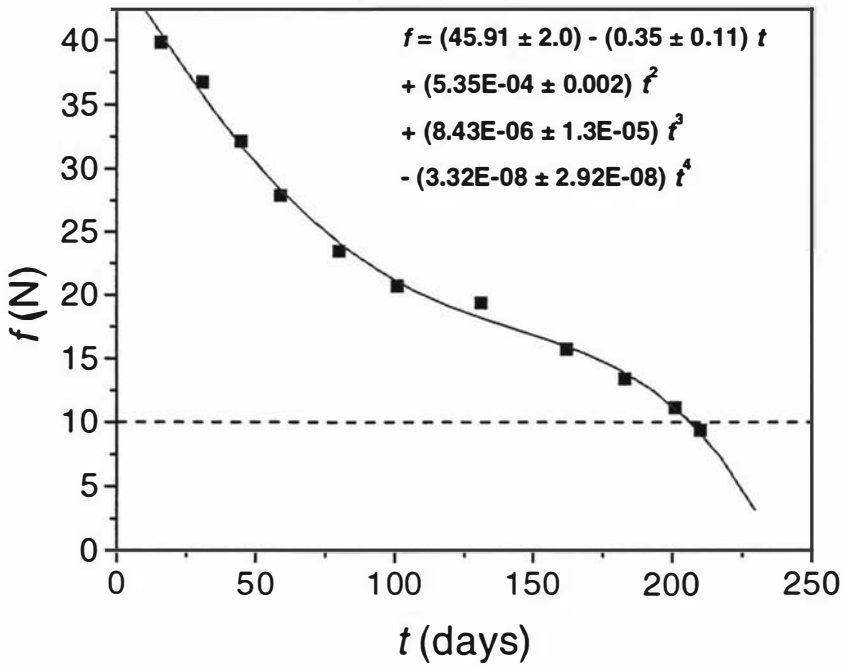

Figure 3.38 Average softening behaviour of fruit harvested from the Massey site in 1997. The solid line represents the line of best fit obtained by fitting the inset equation to the data while the dashed line represents the minimum threshold level of firmness for export.

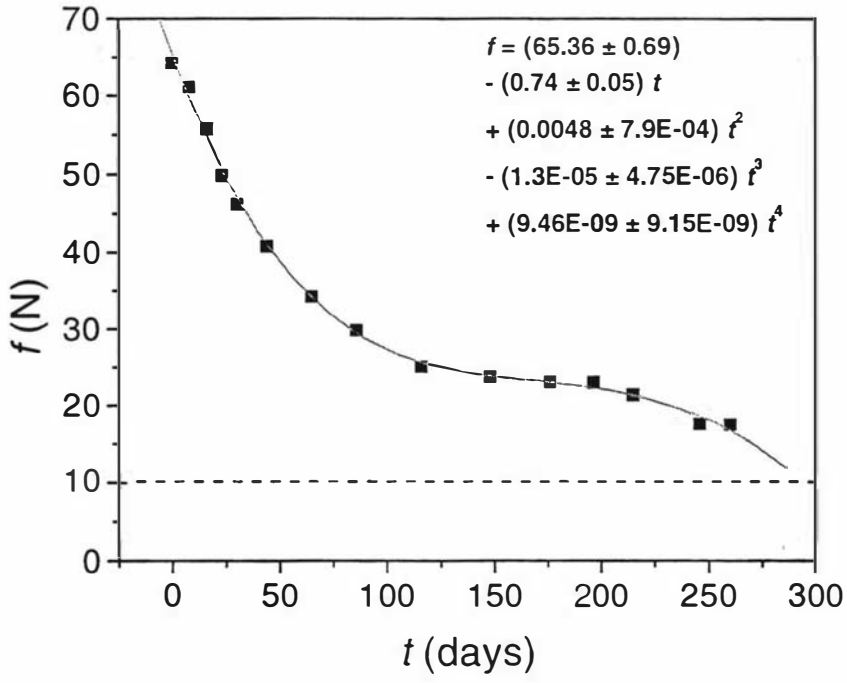

Figure 3.39 Average softening behaviour of fruit harvested from the HortResearch site in 1997. The solid line represents the line of best fit obtained by fitting the inset equation to the data while the dashed line represents the minimum threshold level of firmness for export.

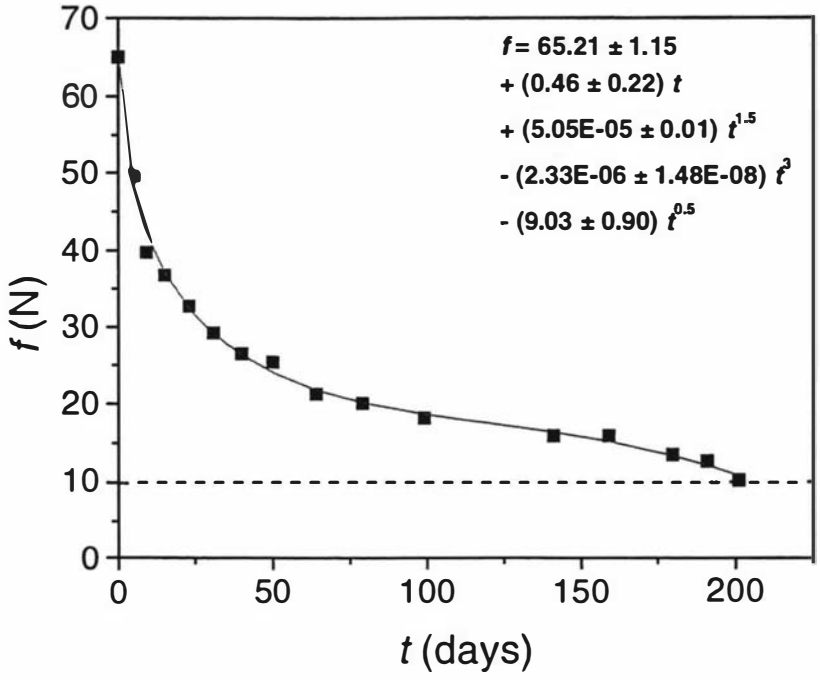

Figure 3.40 Average softening behaviour of fruit harvested from the Massey site in 1998. The solid line represents the line of best fit obtained by fitting the inset equation to the data while the dashed line represents the minimum threshold level of firmness for export.

Table 3.59 Estimates of the parameter *a* for the quartic polynomial model used to describe the average softening behaviour of fruit from bare, grass and mulch plots at the Massey site in 1998. This parameter represents the average firmness of fruit at time 0. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	a
Grass	68.99 a
Bare	63.56 b
Mulch	63.27 b
SED	1.75

Table 3.60 Estimates of the parameter *a* for the quartic polynomial model used to describe the average softening behaviour of fruit from conventional, organic and organic plus plots at the Massey site in 1998. This parameter represents the average firmness of fruit at time 0. Separation of means is based on Tukey's test ($P = 0.05$, $n = 9$). Means with the same letter do not differ significantly.

	a
Conventional	62.13 a
Organic	66.78 b
Organic plus	66.91 b
SED	1.75

Despite the lack of significant differences in the statistics describing softening behaviour of fruit from the Massey site in 1997 and 1998, fruit from grass plots were consistently firmer than fruit from the bare and mulch plots in both seasons (Figs. 3.41 and 3.42). Also, fruit from organic and organic plus plots were consistently firmer than fruit from conventional plots (Figs. 3.43 and 3.44). Fruit harvested from grass plots at the HortResearch site in 1997 were also consistently firmer than fruit from mulch plots (Figure 3.45) while fruit from organic and organic plus plots were consistently firmer than fruit from conventional plots (Figure 3.46). However, these differences were very small. Averaged across time in 1997 and 1998, fruit from grass plots at both sites were consistently firmer than those from bare and mulch plots (Table 3.61). Also, fruit from conventional plots at both sites were less firm than fruit from organic and / or organic plus plots (Table 3.62). No consistent differences were apparent in the softening behaviour of fruit from either site in 1996 (data not shown).

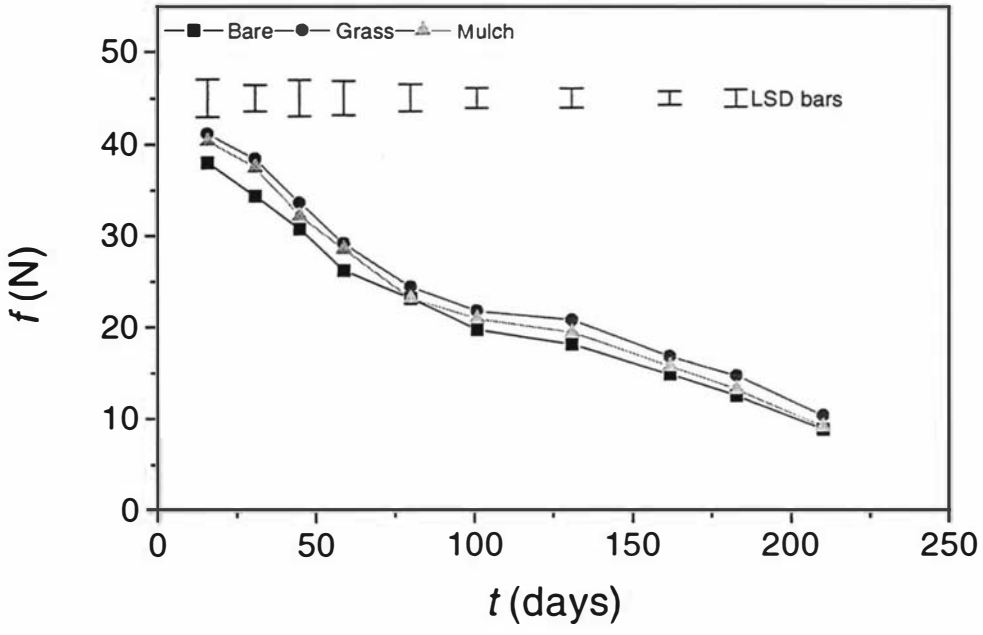

Figure 3.41 Average softening behaviour of fruit harvested from bare, grass and mulch plots at the Massey site in 1997. Each LSD was estimated at the 5 % significance level (n = 9).

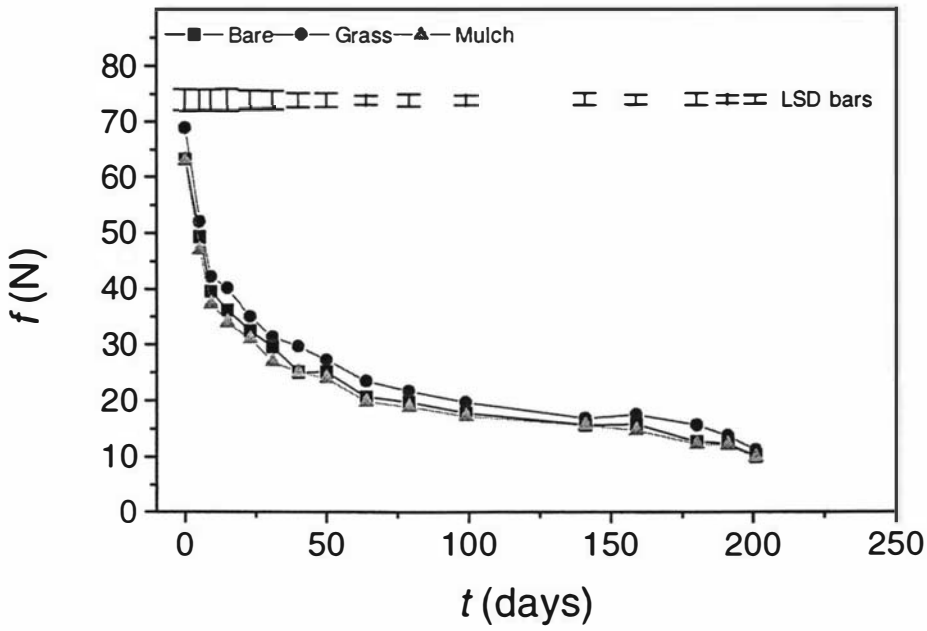

Figure 3.42 Average softening behaviour of fruit harvested from bare, grass and mulch plots at the Massey site in 1998. Each LSD was estimated at the 5 % significance level (n = 9).

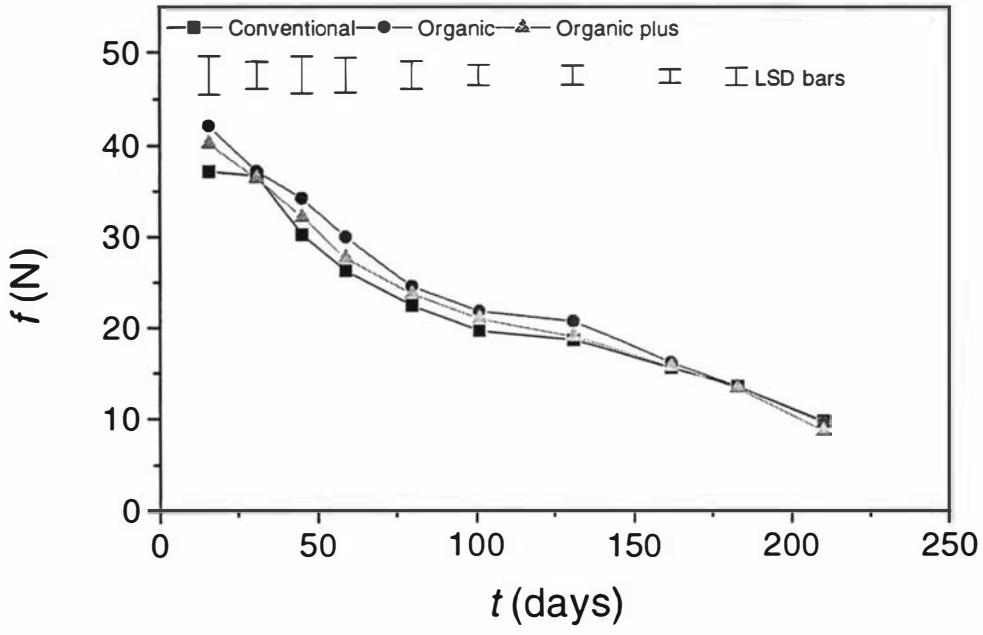

Figure 3.43 Average softening behaviour of fruit harvested from conventional, organic and organic plus plots at the Massey site in 1997. Each LSD was estimated at the 5 % significance level ($n = 9$).

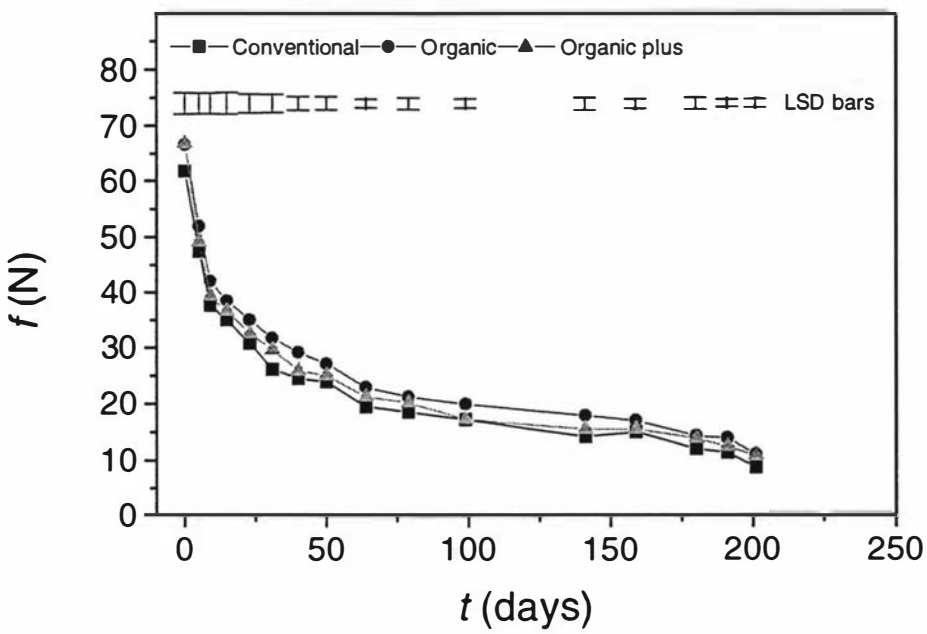

Figure 3.44 Average softening behaviour of fruit harvested from conventional, organic and organic plus plots at the Massey site in 1998. Each LSD was estimated at the 5 % significance level (n = 9).

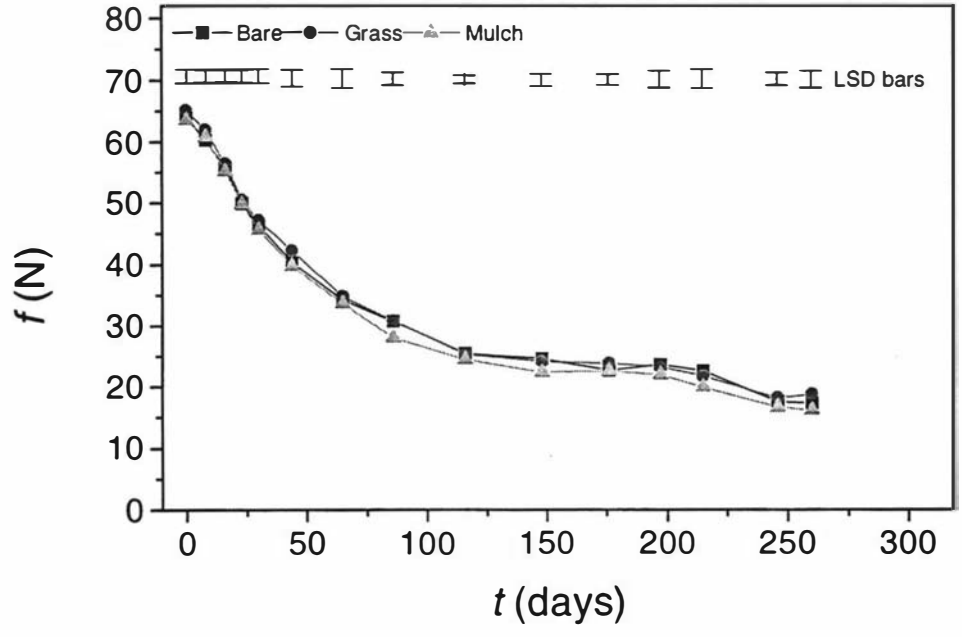

Figure 3.45 Average softening behaviour of fruit harvested from bare, grass and mulch plots at the HortResearch site in 1997. Each LSD was estimated at the 5 % significance level ($n = 9$).

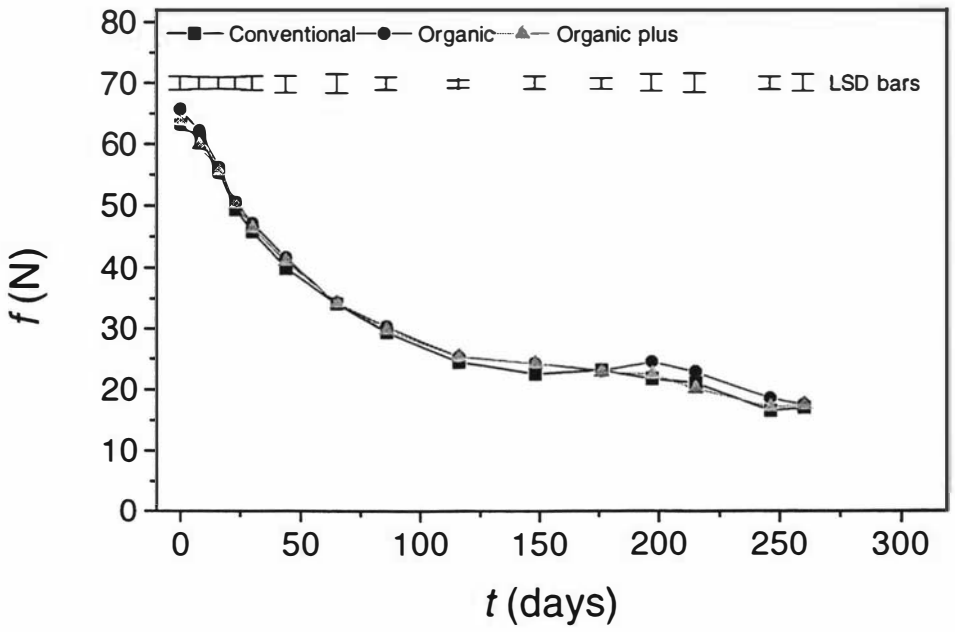

Figure 3.46 Average softening behaviour of fruit harvested from conventional, organic and organic plus plots at the HortResearch site in 1997. Each LSD was estimated at the 5 % significance level (n = 9).

Table 3.61 Firmnesses (N) of fruit from bare, grass and mulch plots at the Massey site in 1997 and 1998 and from the HortResearch site in 1997, averaged across their entire storage durations. Firmness was measured at 0°C. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	Massey 1997	HortResearch 1997	Massey 1998
Bare	21.24 a	34.53 a b	25.24 a
Grass	23.17 b	35.05 a	28.24 b
Mulch	22.45 a b	33.44 b	24.69 a
SED	0.83	0.57	0.78

Table 3.62 Firmnesses (N) of fruit from conventional, organic and organic plus plots at the Massey site in 1997 and 1998 and from the HortResearch site in 1997, averaged across their entire storage durations. Firmness was measured at 0°C. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

	Massey 1997	HortResearch 1997	Massey 1998
Conventional	21.49 a	33.80 a	24.49 a
Organic	23.05 a	35.06 b	27.99 b
Organic plus	22.31 a	34.16 a b	26.18 c
SED	0.83	0.57	0.78

3.4.3.3 Soft patches

Incidences

Respectively, 1.3 % and 2.2 % of fruit from the Massey and HortResearch sites developed soft patches during storage in 1996. In 1997, 8.1 % and 11.8 % of fruit from the Massey and HortResearch sites, respectively, developed soft patches during storage, while in 1998, 31 % of fruit from the Massey site developed soft patches during storage.

In 1996, the incidence of soft patches in fruit from both sites did not differ significantly with ground cover, fertiliser regime or the interaction of the two (data not shown). However, in 1997, the incidence of soft patches for fruit from grass plots at both sites was about half as much as that for fruit from bare plots (Table 3.63); at the HortResearch site, the incidence of soft patches also differed significantly with the interaction of ground cover and fertiliser regime with the difference in the effects of the fertiliser regimes being smaller for the grass cover than the bare and particularly the mulch cover (Table 3.64). In 1998, the incidence of soft patches for fruit from grass plots at the Massey site was again about as half as much as that for fruit from bare plots (Table 3.65); again; the incidence of soft patches differed significantly with the interaction of ground cover and fertiliser regime with the difference in the effects of the fertiliser regimes again being smaller for the grass cover than the bare and mulch covers (Table 3.66). While in all three seasons the incidence of soft patches did not differ significantly with fertiliser regime at either site, fruit from conventional plots did tend to develop more soft patches than fruit from organic and organic plus plots (data not shown).

Table 3.63 Average proportions (%) of fruit from bare, grass and mulch plots at the Massey and HortResearch sites in 1997 that developed soft patches during storage. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

Ground cover	Massey	HortResearch
Bare	10.29 a	10.93 a
Grass	5.38 b	4.47 b
Mulch	8.40 a b	13.42 a
SED	1.59	2.60

Table 3.64 Average proportions (%) of fruit from treatment A - I plots at the HortResearch site in 1997 that developed soft patches (SP) during storage. Separation of means is based on Tukey's test (P = 0.05, n = 3). Means with the same letter do not differ significantly.

Treatment	Factor A	Factor B	% SP
A	Bare	Conventional	12.48 a b
B	Bare	Organic	10.62 a b
C	Bare	Organic plus	9.72 a b
D	Grass	Conventional	5.38 a b
E	Grass	Organic	3.91 b
F	Grass	Organic plus	4.10 b
G	Mulch	Conventional	19.39 a
H	Mulch	Organic	8.23 a b
I	Mulch	Organic plus	13.62 a b
SED			4.50

Table 3.65 Average proportions (%) of fruit harvested from bare, grass and mulch plots at the Massey site in 1998 that developed soft patches (SP) during storage. Separation of means is based on Tukey's test (P = 0.05, n = 9). Means with the same letter do not differ significantly.

Ground cover	% SP
Bare	35.65 a
Grass	20.73 b
Mulch	37.65 a
SED	4.36

Table 3.66 Average proportions (%) of fruit harvested from treatment A - I plots at the Massey site in 1998 that developed soft patches (SP) during storage. Means do not differ significantly at the 5 % significance level (n = 3).

Treatment	Ground cover	Fertiliser regime	% SP
A	Bare	Conventional	38.63
B	Bare	Organic	29.95
C	Bare	Organic plus	38.36
D	Grass	Conventional	23.14
E	Grass	Organic	17.72
F	Grass	Organic plus	21.32
G	Mulch	Conventional	39.24
H	Mulch	Organic	41.63
I	Mulch	Organic plus	32.07
SED			7.55

Mineral associations

In both 1996 and 1997, fruit from both sites which developed soft patches contained significantly less Ca than those which did not (Tables 3.67 – 3.70), especially in 1996 when HortResearch fruit that developed soft patches contained half as much Ca as fruit that did not. Soft patch fruit from the Massey site in both years also contained significantly less K than healthy fruit while soft patch fruit from the HortResearch site contained significantly less Mg than healthy fruit. In 1996, soft patch fruit from the HortResearch site also contained significantly more N than healthy fruit. The concentration of P did not differ in fruit with and without soft patches. In nearly all instances, the ratios of Mg, K and N to Ca were significantly greater for fruit with soft patches (Tables 3.71 – 3.74). The mineral content of fruit with and without soft patches was not determined in 1998.

Table 3.67 Average concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from the Massey site in 1996 which did (+ SP) or did not develop (- SP) soft patches during storage. Separation of means is based on Tukey's test ($P = 0.05$, $n = 24$). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
+ SP	5.38 a	3.99 a	49.73 a	83.63 a	6.35 a
- SP	6.47 b	4.27 a	54.14 b	93.88 a	6.71 a
SED	0.34	0.30	1.93	4.91	0.41

Table 3.68 Average concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from the HortResearch site in 1996 which did (+ SP) or did not develop (- SP) soft patches during storage. Separation of means is based on Tukey's test ($P = 0.05$, $n = 24$). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
+ SP	3.02 a	4.87 a	63.79 a	106.56 a	8.12 a
- SP	6.81 b	6.20 b	66.44 a	95.45 b	7.52 a
SED	0.34	0.33	1.73	2.42	0.29

Table 3.69 Average concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from the Massey site in 1997 which did (+ SP) or did not develop (- SP) soft patches during storage. Separation of means is based on Tukey's test ($P = 0.05$, $n = 24$). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
+SP	6.02 a	5.62 a	114.85 a	141.62 a	12.28 a
- SP	6.73 b	5.97 a	120.85 b	140.98 a	12.45 a
SED	0.31	0.27	3.08	4.50	0.49

Table 3.70 Average concentrations (mmol.kg^{-1}), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from the HortResearch site in 1997 which did (+ SP) or did not develop (- SP) soft patches during storage. Separation of means is based on Tukey's test (P = 0.05, n = 27). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
+SP	4.74 a	4.18 a	69.68 a	136.13 a	11.13 a
- SP	6.47 b	4.51 b	72.77 a	137.03 a	12.13 a
SED	0.28	0.16	1.96	5.96	0.44

Table 3.71 Average ratios of the concentrations (mmol.kg^{-1}), on a fresh weight basis, of magnesium (Mg), potassium (K) and nitrogen (N) to calcium (Ca), in whole kiwifruit from the Massey site in 1996 which did (+ SP) or did not develop (- SP) soft patches during storage. Separation of means is based on Tukey's test (P = 0.05, n = 27). Means with the same letter do not differ significantly.

	Mg : Ca	K : Ca	N : Ca
+ SP	0.89 a	13.74 a	27.22 a
- SP	0.75 b	9.83 b	17.69 b
SED	0.07	1.72	4.03

Table 3.72 Average ratios of the concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of magnesium (Mg), potassium (K) and nitrogen (N) to calcium (Ca), in whole kiwifruit from the Massey site in 1997 which did (+ SP) or did not develop (- SP) soft patches during storage. Separation of means is based on Tukey's test (P = 0.05, n = 27). Means with the same letter do not differ significantly.

	Mg : Ca	K : Ca	N : Ca
+ SP	0.97 a	20.45 a	25.18 a
- SP	0.89 a	18.27 a	22.05 b
SED	0.04	1.09	1.11

Table 3.73 Average ratios of the concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of magnesium (Mg), potassium (K) and nitrogen (N) to calcium (Ca), in whole kiwifruit from the HortResearch site in 1996 which did (+ SP) or did not develop (- SP) soft patches during storage. Separation of means is based on Tukey's test (P = 0.05, n = 27). Means with the same letter do not differ significantly.

	Mg : Ca	K : Ca	N : Ca
+ SP	2.05 a	33.08 a	23.16 a
- SP	0.91 b	10.95 b	15.81 b
SED	0.19	4.06	2.03

Table 3.74 Average ratios of the concentrations ($mmol.kg^{-1}$) on a fresh weight basis of magnesium (Mg), potassium (K) and nitrogen (N) to calcium (Ca), in whole kiwifruit from the HortResearch site in 1997 which did (+ SP) or did not develop (- SP) soft patches during storage. Separation of means is based on Tukey's test ($P = 0.05$, $n = 27$). Means with the same letter do not differ significantly.

	Mg : Ca	K : Ca	N : Ca
+ SP	0.90 a	15.45 a	31.13 a
- SP	0.70 b	11.49 b	21.50 b
SED	0.03	0.78	2.07

3.5 Discussion

3.5.1 Preharvest attributes

3.5.1.1 Soil attributes

Soil temperature

Presumably, the similar soil temperatures experienced across seasons at each site, especially the Massey site, can be attributed to similar air temperatures and amounts of solar radiation across seasons, although these were not measured. The experimental blocks and vines were managed in the same way across seasons, which would have further reduced variation in soil temperatures across seasons.

Within each season, variation in soil temperatures may have been due to changes in the level of solar radiation and air temperature, soil moisture content and canopy area. Increases in temperature probably resulted from drying out of the soil and an increase in incident radiation while wetting of the soil and canopy growth probably lowered soil temperatures. Wind may have also lowered soil temperatures by enhancing the cooling

process of evaporation (McLaren and Cameron, 1996). Later in the season, towards harvest, a decrease in air temperature and the amounts of solar and incident radiation are likely to have contributed to the generally lower soil temperatures recorded then.

Variation in soil temperature associated with the ground covers can be attributed to their functions as barriers to heat transfer. The lower 6.00 am and higher 2.00 pm soil temperatures associated with bare plots are likely to have resulted from higher solar heat input during the day, followed by higher rates of heat escape through the evening and night. Ground covers insulate and moderate soil temperature by reducing solar heat input during the day and heat escape at night (Section 2.3.1.5). This is likely to explain the less extreme cycling of soil temperatures associated with the grass and mulch covers. The lessening of differences between ground covers towards harvest in the current study can be attributed to the decrease in the general level of the soil temperature of plots later in the season.

Soil temperature is strongly influenced by the amount of energy that it receives from the sun as well as the physical properties of the soil. The lack of variation in soil temperature associated with the fertiliser amendments in this study was consistent with the expectation that their major effects would be on the chemical properties of the soil rather than the amount of radiation falling upon the soil or the physical properties of the soil.

Soil moisture content

Variation in the soil moisture content of the soil between seasons was presumably consistent with the levels of rainfall at each site, although this was not monitored. For example, the greater amount of moisture in the soil at the Massey site early in the 1996 / 97 season, relative to the same time in the 1997 / 98 season, may have been due to greater amounts of rainfall then. Within each season, variation in soil moisture content can be attributed to variation in rainfall, irrigation, air temperature and incident radiation. Dry, hot and sunny conditions would have been responsible for low soil

moisture content while rain and irrigation would have replenished the amount of moisture in the soil.

Like temperature, variation in the moisture content of the soil associated with the ground covers can be attributed to their functions as barriers, in this case to both heat and water transfer. The greater rates of solar input during the day associated with bare soil would have resulted in greater loss of water though evaporation. The mulch on the other hand would have reduced solar input and water loss by evaporation during the day thereby improving moisture conservation of the soil (Section 2.3.1.5). The general improvement in the moisture content of mulch plots may have also be a consequence of improved water infiltration (Greenham, 1953). Grass plots would be expected to contain less water than both bare and mulch plots as the grass would be expected to remove substantial amounts of water to support its own growth. However, grass can improve soil physical properties such as porosity, which may subsequently increase the water holding capacity of the soil (Section 2.3.1.5) and therefore the amount of water in the soil.

In this study, the smaller differences in soil moisture content between ground covers towards harvest at the Massey site may have resulted from lower air temperatures and amounts of solar radiation then and therefore less water loss (by evaporation) from plots, especially bare plots. High levels of rainfall would be expected to saturate the soil thereby reducing the magnitude of differences in soil moisture content. However, the moisture content of the soil generally declined towards harvest, especially at the Massey site in the 1996 / 97 season, eliminating this possibility.

The lack of variation in soil moisture content associated with the fertiliser amendments was again consistent with the expectation that their major effects would be on the chemical properties rather than the physical properties of the soil. It has been observed that fertilisers such as gypsum (i.e. calcium sulphate) can alter soil structure (McLaren and Cameron, 1996), which may impact on physical properties of the soil and

subsequently, the infiltration and movement of water in the soil. However, this did not appear to occur in the current study.

Soil inorganic nitrogen content

Variation in the ammonium and nitrate contents of the soil between seasons, especially at the Massey site around the time of full bloom, can be mainly attributed to differences in the amount of fertiliser applied; twice as much N was added to conventional plots in the 1997 / 98 season. Differences in nitrogen-related soil processes (Section 2.4.6.2) may have also explained some variation between seasons.

Within each season, increases in both the ammonium (NH_4^+) and nitrate (NO_3^-) contents of conventional plots can mainly be attributed to the application of urea immediately prior to those increases. Mineralisation (Section 2.4.6.2) probably contributed significant amounts of inorganic N to the soil too (Tillman, 1999 - personal communication). Subsequent decreases in the amount of ammonium would have been mainly due to plant uptake and the conversion to nitrate (NO_3^-) by nitrification (Section 2.4.6.2). Increases in nitrate contents coincided with decreases in ammonium contents which is consistent with the proposition that nitrification was occurring. Subsequent decreases in the nitrate contents would have resulted from processes such as immobilisation, denitrification and leaching (Section 2.4.6.2).

In the 1997 / 98 season at the Massey site, the amount of ammonium in the soil from about a month after full bloom did not increase despite applications of urea indicating that at that time, the amount of ammonium removed from the soil was greater than the amount added. The amount of nitrate in the soil increased considerably at the same time indicating that a high rate of nitrification contributed to the decrease in the ammonium concentration.

The amount of ammonium in the soil generally did not differ significantly with ground cover. However, considerably less nitrate was frequently measured in mulch and grass plots. If the rate of nitrification was lower in covered plots then they would have

contained greater amounts of ammonium but this was not the case. It would seem that the rate of nitrification, and therefore the amount of nitrate produced, was similar in the bare, grass and mulch plots. Hence, considerably more nitrate must have been removed from the grass and mulch plots due to either greater rates of plant uptake, immobilization, denitrification and / or leaching. However, given that the nitrogen status of the vines was largely unaffected by ground cover (if anything, vines from grass plots contained less N), it seems that the uptake by vines did not contribute much to the differences in the nitrate content of the soil. Grass plots consistently contained more nitrate than mulch plots indicating that some of the processes above were occurring at much greater rates in mulch plots.

The inorganic N content of non-conventional plots generally did not change substantially within each season as a result of the relatively low amounts of N added to and in those plots. The relatively high amounts of inorganic N observed in organic and organic plus plots at the Massey site, early in the 1996 / 97, suggests that the fishmeal added to those plots in that season contained significant amounts of N although this was not measured.

It was anticipated that in the present study, applying high rates of urea to the conventional plots would considerably increase the inorganic N content of the soil beyond that of the non-conventional plots. However, in both the 1996 / 97 and 1997 / 98 seasons, considerable amounts of inorganic N appeared to be removed from the soil system presumably through leaching, plant uptake and volatilisation. Small amounts of inorganic N may have also been removed through immobilization, denitrification and fixation (Section 2.4.6.2). The loss of inorganic N from conventional plots may have minimised differences in the inorganic N content of conventional, organic and organic plus plots, especially at the Massey site in the 1996 / 97 season. It would seem that maintaining the amount of inorganic N in soil at the Massey site at a level that impacts significantly on plant growth could be limited by the removal of substantial amounts of applied N.

Greater differences in the inorganic N content of soil in the 1997 / 98 season can be attributed to twice as much urea being added to conventional plots and no fishmeal (a potential source of N) being added to organic and organic plus plots. Decreases in ammonium and nitrate differences between ground covers and fertiliser regimes towards harvest can be attributed to decreases in the overall concentrations of inorganic N in the soil.

Soil solution cation concentrations

Between seasons, considerable variation occurred in the pattern of accumulation of cations in soil solution with the concentrations decreasing from a much earlier point in the 1996 / 97 season. This may have resulted from differences in the rates of plant uptake and movement through the soil profile (McLaren and Cameron, 1996), both of which may have been much greater early in the 1996 / 97 season, relative to the same time in the 1997 / 98 season. Nitrification enhances leaching of cations from the soil (McLaren and Cameron, 1996) and differences in the timing and rates of this process may have contributed to the variation in the patterns of cation accumulation between seasons. In the 1996 / 97 season, nitrification occurred earlier in the season, as indicated by the respective decreases and increases in the concentrations of ammonium and nitrate at that time. This is consistent with the observation that the concentrations of cations in the soil solution decreased earlier in the 1996 / 97 season, relative to the 1997 / 98 season. Differences in pH can influence the cation status of the soil with the amounts of basic cations decreasing as the soil becomes more acidic (i.e. the pH drops; McLaren and Cameron, 1996). However, soil pH did not differ substantially between seasons and so differences in the accumulation of cations in the soil cannot be confidently attributed to differences in soil pH.

Within each season, increases in the concentrations of cations in the soil solution can be attributed to the application of fertilisers immediately prior to those increases. At those times exchange processes in the soil are important as the addition of cations such as Ca will displace other cations (e.g. Mg and K) from soil exchange complexes thereby increasing their concentrations in the soil solution. Subsequent decreases in the

concentrations of cations would have resulted from plant uptake as well as soil processes such as leaching and fixation (McLaren and Cameron, 1996). The general decline in soil pH each season can be attributed to a number of factors including a decrease in the amount of cations in the soil, the formation of soluble acids, the release of hydrogen ions by plant roots, dissociation of functional groups on soil colloids, and the hydrolysis of aluminium (McLaren and Cameron, 1996).

Variation in the concentrations of cations in the soil solution associated with ground covers may be attributed to differences in the amounts removed from the soil. Soil solution from bare plots generally contained more cations than that from grass plots, which was probably due to less moisture in those plots and therefore greater concentration of the cations; a reduction in the water status of the soil does not force cations to return to exchange complexes in the soil because those complexes are often already saturated with cations (Tillman, 1999 – personal communication).

Variation in the pH and concentrations of cations in the soil solution associated with the fertiliser regimes can be attributed to differences in the amounts and types of cations contained in the fertilisers added to the plots. In particular, organic plus plots contained more Ca than conventional plots because gypsum ($CaSO_4.2H_2O$) and dolomite ($CaCO_3.MgCO_3$) were added to those plots; both contain approximately 24 % Ca (McLaren and Cameron, 1996). At times, organic plus plots tended to contain more Mg than conventional plots probably as a result of the dolomite (approx. 10 % Mg) added to those plots (McLaren and Cameron, 1996). However, at other times, conventional plots contained more Mg than organic plus plots, which may have arisen from the significant displacement of Mg^{2+} ions from soil colloids into the soil solution by K^+ ions (supplied by the potassium fertilisers). The lower pH of conventional plots may be attributed to greater amounts of inorganic N and rates of nitrification as well as the displacement of H^+ ions from the surfaces of soil colloids and plant roots by K^+ ions (McLaren and Cameron, 1996).

Throughout each season in this study, the general decline in the magnitude of differences in the concentrations of cations in the soil solution, associated with the soil amendments, may be attributed to a decline in the overall concentrations of minerals in the soil solution.

3.5.1.2 Vine and fruit attributes

Xylem sap mineral concentrations

Late in each season, there was very little sap flowing in vines at the Massey site, which made it impossible to extract sap using just a syringe. Presumably, high negative pressures (i.e. tension) in the xylem tissues due to high rates of transpiration and low root or hydrostatic pressures may have contributed to the difficulties in extracting sap. The reduction in the moisture content of the soil throughout the season may have led to a reduction in the mass flow of water from the soil through the plant and therefore a reduction in sap flow.

The concentrations of minerals in the xylem sap generally decreased throughout each season. However, there were occasions where the mineral concentrations appeared to increase. It is difficult to explain with any certainty the discrepancies in the trends of the concentrations of minerals in the xylem sap that occurred between sites and years. However, differences may have arisen because of differences in factors such as environmental conditions, age of vines (i.e. young vs. mature) and training system (i.e. T-bar vs. pergola).

In the 1996 / 97 season, the pattern of change in the concentrations of Ca and Mg in the xylem sap of vines at the Massey site was similar to that reported elsewhere (Ferguson, 1980c). Concentrations of both were greatest early in the season with decreases thereafter. Furthermore, the concentrations of minerals in the xylem sap throughout the season were similar in magnitude to those observed in other work (Ferguson, 1980c; Peterlunger et al., 1990). Variation in the composition of xylem sap of kiwifruit between the current work and other work may be attributed to differences in the method

of collection (Ferguson, 1980a), the season and time of day that sap was collected, the age and nutritional status of plants (Huguet, 1973; Pate, 1976; Peterlunger et al., 1990) the site of collection, and the time taken to collect the sap (Ferguson, 1980a).

The lack of substantial differences in the mineral and particularly the Ca concentration of the xylem sap, associated with the fertiliser regimes, is consistent with other work that found Ca fertilisation had only minor effects on the Ca nutrition of crops (Boon et al., 1966; Wilton, 1991; Wooldridge, 1994). It would appear that the uptake of minerals, especially Ca, is limited at the root level and that some sort of barrier or antagonist to mineral uptake operates at the soil / root interface.

Soil cation balance may influence Ca uptake. In particular, excessive amounts of Mg and K in the soil are known to suppress Ca uptake (Wilton, 1991). In this study, conventional plots contained more K than organic plus plots and yet the uptake of Ca from these plots was not obviously different. The Mg added to organic plus plots (in the form of dolomite) could have suppressed the uptake of Ca but given that conventional plots often contained similar amounts of Mg, this is unlikely.

There is evidence to indicate that soil N influences the uptake of minerals. In particular, N in the form of ammonium inhibits the uptake of cations presumably as a result of cationic competition (Section 2.4.6.2). In this study, organic plus plots generally contained less ammonium than conventional plots and therefore the uptake of cations should have been less inhibited. However, the lack of differences in the concentrations of cations in the xylem sap would indicate that this did not happen.

The competitive mechanisms mentioned above could have resulted in differences in the mineral composition of the xylem sap of kiwifruit in this study. However, there was no evidence to suggest that any of them occurred at great enough levels to influence the uptake of minerals; perhaps other mechanisms limited the uptake of minerals from the soil. Aluminum and other polycovalent cations (e.g. scandium and iron) have been found to inhibit the uptake of Ca in crops (Clarkson and Sanderson, 1971). However,

this is unlikely to have happened in the current study given that the fertiliser regimes, especially the organic plus regime, did not contain large amounts of polyvalent minerals.

It is possible that, in the current study, the amounts of roots near the soil surface of plots were not sufficient to achieve significant differences in the uptake of minerals from there. In particular, there may not have been enough roots near the soil surface of organic plus plots to absorb the significant amounts of Ca there. That said, roots often proliferate in regions of high fertility (Drew and Saker, 1975) although the amount of roots near the soil surface of conventional and organic plus did not differ significantly despite the considerable differences in fertility. It is possible that mineral uptake may be enhanced by incorporating fertilisers deeper in the soil where roots may be more abundant - in this study more roots were found at 30 – 75 mm than at 0 – 30 mm. However, it is important to bear in mind that the type of roots influence the uptake of minerals e.g. the uptake of Ca is much greater by younger, unsuberised roots (Ferguson, 1980c). Therefore, the addition of fertilisers deeper in the soil may only be effective in enhancing Ca uptake if there are considerably more young roots there. The proportions of young roots at different depths were not measured in this study.

Leaf mineral concentrations

The patterns of mineral nutrient accumulation by kiwifruit leaves were similar in the 1996 / 97 and 1997 / 98 seasons, especially at the Massey site, and were generally similar to those found for other deciduous fruiting trees and vines (Leece and Gilmour, 1974; Marschner, 1995; Smith, 1962). In particular, the concentrations of N and P decreased while the concentrations of Ca and Mg increased during the season, especially in the first few months after full bloom, which is consistent with other research (Smith et al., 1987; Smith et al., 1988). This research has also reported a decrease in the concentration of K in kiwifruit leaves after fruit set. The absolute concentrations throughout each season were also quite similar although there was some variation that can be attributed to differences in a number of factors influencing the accumulation of minerals in plants. These are discussed below.

In the case of Ca, the relatively high transpiration rate of kiwifruit (Judd and McAneney, 1984) may partly account for the increases in the concentrations of this element early in each season of the current study. It has been shown that Ca uptake by roots and subsequent transport to shoots is closely related to the rate at which plants transpire (Barber, 1974; Stebbins and Dewey, 1972). There was very little change in the concentration of Ca in leaves from about 8 – 10 weeks after full bloom presumably because of a decrease in transpiration (Section 2.4.4). In kiwifruit leaves, dry matter accumulation typically ceases about 10 weeks after full bloom (Smith et al., 1987), which may explain why the concentration of Ca did not decrease later in each season.
Mg and K are highly mobile in the phloem of plants unlike Ca which is transported almost exclusively in the xylem of plants (Marschner, 1995). The increase in the concentrations of these elements in leaves at the Massey site, especially later in each season when leaves were fully expanded, may have been due to continued import of those elements into the leaves via the phloem. Furthermore, the amounts of Mg and K retranslocated or exported from the leaves must have been less than the amounts that were imported.

Developing fruit can significantly influence the nutrient status of leaves. Strong competition of fruit for N (Smith et al., 1987) may have accounted for the decreases in the concentrations of this element in the current study (Smith et al., 1988). Losses of other nutrients (e.g. P) from leaves may have also occurred in the current study but were probably less pronounced given the lower mobility of those nutrients in the plant, and in some cases the small demand of developing fruit for these elements (Smith et al., 1988). Ca in particular often becomes highly immobile once it is deposited in the leaves and fruit of plants (Addiscott, 1974; Bollard, 1960; Himelrick and McDuffie, 1983; Millikan and Hanger, 1965; Rinnie and Langston, 1960; Shear and Faust, 1970; Simon, 1978).

The general lack of significant differences in the concentrations of Ca, Mg and K in leaves associated with the ground covers and fertiliser regimes was consistent with the lack of differences in the concentrations of these minerals in the xylem sap of vines. On the other hand, leaves from grass plots did often contain less N than leaves from bare

and mulch plots which is consistent with other work that has found living ground covers to reduce the amount of N in leaves (Merwin and Stiles, 1994; Welker and Glenn, 1988) and fruit (Hulme, 1956; Johnson and Samuelson, 1990). Leaves from grass plots also tended to contain less Ca than leaves from bare plots, which was consistent with the lower concentrations of Ca in the soil solution. However, soil solution from mulch plots, if anything, contained less Ca than that from grass plots yet the leaves from mulch plots tended to contain more Ca than leaves from grass plots. Therefore, it would seem that the reduction in the Ca content of leaves from grass plots was due to a reduction in the processes driving the translocation of Ca into leaves (e.g. transpiration) rather than a reduction in the amount of Ca available in the soil solution. Mechanisms by which grass may affect transpiration are proposed in the general discussion.

Leaves from conventional plots often contained more N than leaves from organic and organic plus plots presumably because significantly more N fertiliser (i.e. urea) was added to those plots. Leaves from conventional plots often contained more K too, which may be attributed to the application of the potassic superphosphate to those plots. In the third season, leaves from organic plus plots at both sites consistently contained more Ca and Mg than leaves from conventional plots which was presumably the result of adding gypsum and dolomite to those plots. At the Massey site, leaves from organic plots also contained more Ca and Mg than those from conventional plots which may have been due to greater amounts of those minerals in those plots (not measured) and / or lower levels of antagonism (e.g. from ammonium ions, the concentrations of which were lowest in organic plots).

Fruit mineral concentrations

The patterns of mineral nutrient accumulation by fruit were similar in the 1996 / 97 and 1997 / 98 seasons. The majority of both Ca and Mg accumulated in fruit within 8 weeks of flowering while the majority of K did not accumulate in fruit until much later in the season. This is consistent with previous work that has reported the rate at which nutrients accumulate in kiwifruit differs among the elements (Smith et al., 1988). Approximately 70 % of the maximum quantity of Ca in kiwifruit has been

shown to accumulate within 8 weeks of flowering (coinciding with the rapid cell division phase of fruit development; Ferguson, 1984) whereas only 37 % of the total K content has been shown to accumulate by the same stage of growth (Smith et al., 1988). The rapid uptake of Ca during the early stages of fruit development can be attributed to greater rates of transpiration then. The decline in the accumulation of Ca in fruit during the later stages of growth is probably due to a reduction in the transpiration rate of fruit resulting from a number of changes accompanying fruit growth. A shift from xylem to phloem as the major supply route of assimilates to fruit as well as xylem dysfunction may also contribute to a reduction in Ca accumulation (Section 2.4.5). Fruit dry matter content and volume both increase steadily throughout the season (Davison, 1990) so that there is considerable dilution of Ca in fruit later in the season; subsequent changes are small. This results in a rapid decrease in Ca concentration later in the season, relative to the first 4 – 8 weeks after full bloom when considerable uptake of Ca is occurring.

Unlike for Ca, the major supply route to fruit for N, K, and P throughout the entire growing season, and for Mg mid-season, is the phloem. The net accumulation of Mg, P and K in fruit reportedly slows or possibly ceases shortly before harvest (Ferguson, 1980b) whereas N appears to accumulate at a steady rate throughout the season (Clark and Smith, 1988). In the current study, increases in the fruit concentrations of N, P, K, and Mg, later in the season, indicated import of those minerals into fruit throughout the season.

Much of the N and K translocated in the phloem is supplied from leaves on fruiting laterals, where significant remobilisation commences approximately eight weeks after pollination (Smith et al., 1987). In this study, the concentration of N in leaves declined during the season, which may be attributed to an export to developing fruit. However, the concentrations of elements such as K in leaves did not change dramatically during the season at the same time that they increased in fruit suggesting remobilisation of these elements from other reserves within the plant and / or a continuous uptake from the soil. For elements such as Ca where remobilisation from leaves is limited, or where

the timing of remobilisation does not coincide with the fruit's requirements, fruit demands must be met continuously from reserves within the plant and / or via uptake from the soil (Clark and Smith, 1988).

The concentrations of minerals in fruit from both sites in the 1996 / 97 and 1997 / 98 seasons were not significantly affected by ground cover, fertiliser regime or interactions of the two. This was consistent with the lack of significant differences in the concentrations of minerals in the xylem sap and leaves. Nevertheless, fruit from grass plots consistently contained less N than leaves from bare and mulch plots which is consistent with what was observed in the leaves and the proposition that grass may compete with vines for the uptake of minerals, especially nitrogen. Fruit from grass plots also tended to contain more Ca than those from bare plots, which is inconsistent with the lower concentrations of Ca measured in the leaves of those plots. The reasons for this apparent discrepancy are unclear although it is possible that a reduction in transpiration reduced the concentrations of Ca in leaves, without being detrimental to the Ca content of fruit, while at the same time, some other factor enhanced the translocation of Ca into fruit e.g. a decrease in the ratio of leaves to fruit, increase in fruit size and therefore water loss from fruit. It seems that ground covers may affect the distribution of minerals throughout kiwifruit vines but further research is required to confirm this and identify the mechanisms involved.

In the 1997 / 98 season, significant differences in the concentrations of N and K in Massey fruit associated with the fertiliser regimes, averaged across the entire season, can be attributed to differences in the N and K contents of those regimes with the conventional regime containing substantially more of both. At the same time, the greater amounts of Ca in fruit from organic and organic plus plots was consistent with the greater amounts of Ca in leaves from those plots, further indicating uptake of some of the extra Ca added to those plots and / or less antagonism of Ca uptake.

Soil Vs. vine mineral concentrations

The concentrations of cations in soil solution vary considerably due to differences in the moisture content of the soil and / or the amount of minerals in the soil. In this study for example, bare plots contained greater concentrations of minerals presumably as a result of the lower amounts of water in those plots and therefore a greater concentrating effect. Similarly, organic plus plots contained more Ca than conventional plots due to the greater amounts of Ca added to those plots; those plots contained similar amounts of water and so the difference in Ca concentration can not be attributed to differences in the water status. The lack of relationships found in this study, between the concentrations of cations in the soil solution and their concentrations in the vines, indicates that there is limited potential to change the mineral status of kiwifruit vines by either manipulating the water or mineral status of the soil.

Fruit growth

The bi-linear patterns of fruit growth observed at the Massey site in the 1996 / 97 and 1997 / 98 seasons were similar and consistent with other work that has measured the growth of kiwifruit (Hall et al., 1996; Judd and McAneney, 1987; Snelgar et al., 1992; Tombesi et al., 1994). The growth of kiwifruit has also been described as double-sigmoidal in form (Buwalda and Smith, 1990; Davison, 1990) and in a number of instances this is a very noticeable characteristic (Hopping, 1976; Lai et al., 1989; Van Oostrom, 1985). In one instance, the pattern of fruit growth was even described as being triple-sigmoidal (Pratt and Reid, 1974). Variation in the patterns of fruit growth can presumably be attributed to differences in environmental conditions during the season. Factors such as temperature and water uptake are likely to have marked effects on cell division and cell expansion, both of which have been linked to the different phases of fruit growth, although there is little quantitative evidence to support this. In the current study, rapid increases in volume during the early stages of fruit development were probably due mostly to rapid rates of cell division and water uptake during those periods, both of which probably slowed later in fruit development. Increases later in fruit development were probably due to continued cell expansion, particularly in the inner pericarp tissue (Hopping, 1976; Woolley et al., 1992).

Differences in soil attributes, especially moisture and mineral contents, did not appear to be large enough to induce differences in fruit growth. Fruit from conventional plots in particular were expected to be larger than fruit from organic and organic plus plots given the considerable amount of N added to those plots and that N applications have previously resulted in the production of larger fruit (Costa et al., 1997). Presumably, the N was not translocated into fruit in sufficient enough quantities to achieve substantive changes in fruit growth.

Root length density

Mean root length densities (RLDs) at both sites in 1997 were consistent with what has previously been reported; typically, the RLD of kiwifruit vines over the entire rooting volume range from 0 to 8 $cm.mL^{-1}$ (i.e. 0 – 80 $m.L^{-1}$) (Costa et al., 1997; Gandar and Hughes, 1988; Hughes et al., 1986). Variation in mean RLD between sites may be attributed to differences in age. Vines at the HortResearch site were grafted in 1982 and therefore their root systems are likely to have been fully developed and to have occupied greater volumes of soil deeper in the profile. In contrast, vines at the Massey site were grafted in 1991 and so the extent of root exploration is likely to have been considerably less with substantially more roots still occupying the upper horizons of the soil. Other factors may have also contributed to the variation between sites particularly soil factors such as bulk density (Hughes and Wilde, 1988). Differences in rootstocks may have also contributed to the variation in RLD between sites.

At the Massey site, mulching improved the surface rooting of vines which is consistent with other work (Atkinson and Wilson, 1980; Baker, 1943; Faust, 1989; Hogue and Neilsen, 1987; Knavel and Mohr, 1967; Kotze and Joubert, 1992; White and Holloway, 1967). The mulch influenced a number of soil attributes throughout the growing season and in particular had a moderating effect on soil temperature and increased soil moisture content, both of which have been associated with increased root growth under organic mulches (Greenham, 1953). Roots tend to proliferate in regions of high fertility (Drew and Saker, 1975) which could explain the greater mean RLD measured near the soil surface of organic plus plots, compared to conventional plots.

Despite an increase in the RLD of mulch plots near the soil surface at the Massey site, the uptake of Ca from those plots was apparently not enhanced as indicated by lack of differences in the concentrations of Ca contents in the xylem sap and leaves. In other words, the uptake of Ca appeared to be constrained at the root level by factors which have yet to be identified but may have included the amounts of antagonistic cations such as ammonium. It is possible that this constraint could partly be overcome by appropriate fertiliser practices. For example, in this study, the organic plus regime slightly enhanced the Ca status of the vines at the Massey site in the 1997 / 98 season.

Although mean RLD at the HortResearch site did not appear to differ significantly with ground cover, fertiliser regime or the interaction of the two, considerable variation in the distribution of roots through the soil may have masked any differences. Uneven distribution of major structural roots, which determines the distribution of fine roots (Hughes and Gandar, 1989), is likely to have contributed to the variation. Also, small-scale variations in soil properties and patterns of root turnover may have resulted in some variation (Hughes and Wilde, 1988). Considerable sampling is required to compensate for this variability in root distribution. In this study, a reasonable amount of variation was anticipated given that the amount of time and resources available for the sampling of roots was limited by the large number of soil, vine and fruit attributes measured.

3.5.1.3 Conclusions

This study and other work (Section 2.3.1.5) has demonstrated that soil amendments can significantly affect a number of soil properties particularly moisture content, temperature and mineral content. However, these effects may not always result in large changes in vine and fruit attributes before harvest for reasons that are unclear.

In the current study, leaves and fruit from organic plus plots consistently contained more Ca and less N than those from conventional plots which was consistent with more Ca and less N added to and measured in those plots. Also, leaves and fruit from grass

plots consistently contained less N than those from bare and mulch plots indicating a competitive effect of the grass for N; there was also some indication that grass affected the Ca status of vines and in particular the leaves. These effects were often not statistically significant so while it appears that soil amendments have the potential to influence the mineral status of kiwifruit vines, under some conditions, their effects may be constrained at the root level, possibly due to unfavourable cation balances in the soil. Further research is required to determine the factors that influence the uptake of nutrients from the soil, especially those that are important to fruit quality.

3.5.2 Attributes at harvest

3.5.2.1 Crop load and fruit size

Considerable variation in yield and fruit size occurred between sites and years with no apparent trends. Such variation could be attributed to differences in a number of factors including shading (Snelgar and Hopkirk, 1988), water status, vine vigour (Chouliaris et al., 1995), pollination (Richardson and McAneney, 1990), thinning (Lahav et al., 1989), age of vines (Sale and Lyford, 1990) and fertilisation (Tagliavini et al., 1995). Vines at the HortResearch site were much older (10 years) and larger than those at the Massey site which presumably explains the greater yields from that site.

Within sites, it was evident that on occasions when the yield was high, the number of fruit was also high but the average size of fruit was low presumably because each fruit received a smaller proportion of the total amount of assimilates intended for fruit (i.e. a dilution effect). That said, in 1998 the average size of fruit did not differ much between sites despite twice as many fruit being harvested from the HortResearch site. Therefore, it appears that other factors in addition to crop load influence the final size of fruit. Such factors include nutrition (Tagliavini et al., 1995), water deficits (Judd et al., 1989; McAneney et al., 1991; Prendergast et al., 1990), leaf area (Cooper and Marshall, 1991; Tombesi et al., 1994), and light levels (Grant and Ryugo, 1984; Snelgar and Hopkirk, 1988; Snelgar et al., 1992; Morgan et al., 1985).

The general lack of variation in crop load, fruit size and yield associated with the soil amendments at both sites was consistent with the lack of differences in vine and fruit attributes before harvest. In 1997, fruit from grass plots at the Massey site were significantly larger than fruit from bare and mulch plots which is inconsistent with the proposition that grass competes with vines for the uptake of mineral nutrients (especially N) and moisture, and would therefore be expected to retard fruit growth. This anomaly may be attributed to considerably less fruit being harvested from grass plots and therefore less dilution of fruit size (Section 3.4.2.1). In 1998, larger fruit were also harvested from conventional plots, which may have been due to the considerable amounts of N added to those plots; N fertilisation has increased the size of kiwifruit in other work (Costa et al., 1997). However, considerably fewer fruit were also harvested from conventional plots which may again have meant less dilution of fruit size.

3.5.2.2 Fruit maturity

The considerable variation in the SSC of fruit that occurred between sites and years can be predominantly attributed to differences in harvest date, with fruit from the Massey site being harvested later and more mature in all three seasons than fruit from the HortResearch site. Differences in vine age and crop load may have also contributed to differences in maturity between sites given that fruit from young vines or those with a light crop load, such as those at the Massey site, tend to have higher soluble solids concentrations than fruit from more mature vines or those with a heavier crop load (Beever and Hopkirk, 1990). Furthermore, differences in soil type may have also contributed to differences in maturity between sites. Within each site, differences in environmental conditions would have been a likely candidate for the differences in maturity that were observed between seasons. Variation in temperature between seasons would have also been an important factor (Section 2.3.1.3).

The general lack of variation in the maturity of fruit associated with the soil amendments in this study was consistent with the lack of variation in other fruit and vine attributes measured before and at harvest. Aerial factors known to influence

maturity such as air temperature (Section 2.3.1.9) were consistent across plots at both sites and were therefore expected to contribute little to the variation in fruit maturity.

3.5.2.3 Fruit mineral concentrations

At harvest, the concentrations of minerals in kiwifruit, on a fresh weight basis, typically range from 4 - 13 mmol.kg^{-1} for Ca, 4 - 13 mmol.kg^{-1} for Mg, 47 - 147 mmol.kg^{-1} for K, 66 - 116 mmol.kg^{-1} for N and 7 - 22 mmol.kg^{-1} for P (Beever and Hopkirk, 1990). In this study, the concentrations of minerals in fruit harvested from both sites in all years were consistent with these values with the notable exception of N, which tended to be higher than has generally been reported.

The lack of significant main factor or interaction differences in the mineral status of fruit harvested throughout this study is consistent with the lack of significant differences that were observed in the mineral status of the xylem sap and foliage. However, fruit from grass plots often contained less N than fruit from bare and mulch plots indicating again that the grass may have competed with vines for the uptake of N thereby reducing the amount taken up and translocated into the fruit. Also, fruit from conventional plots tended to contain more N than fruit from organic and organic plus plots, which can probably be attributed to differences in the types and quantity of fertilisers added i.e. considerably more N was added to conventional plots.

It was anticipated in this study that the organic plus regime would significantly enhance the concentrations of Ca in harvested fruit given the considerable amounts of gypsum in that regime. However, this did not always occur indicating that at times, some sort of barrier or antagonist to Ca uptake was operating at the root level; alternatively, the leaves may have provided stronger sinks for any extra Ca that was taken up thereby minimising differences in the Ca status of fruit.

The relatively small analytical error in fruit Ca concentrations throughout the current work indicates that the procedure used to measure fruit Ca concentrations was

reasonably accurate and provided a reasonably robust means to investigate treatment effects. Despite this, it is possible that significant differences in the average concentrations of Ca, Mg, K, N and P in fruit were present between treatments at harvest but were not detected due to inherently large differences between experimental units (vines), as indicated by the estimates of error variance in Table 3.54. In 1996 and 1998, these resulted in large LSD values, as much as 50 % of the overall mean, for comparison between treatments. In 1997, however, the experimental errors at both sites were relatively small yet no significant differences were detected in fruit Ca concentrations indicating that at least in that year, the soil amendments had only minor effects. The experimental error differed noticeably across the 3 years indicating that in some years, the vines were more variable than in others.

3.5.2.4 Fruit firmness

The firmness of fruit harvested throughout this study was typical of commercially harvested fruit (Beever and Hopkirk, 1990; MacRae et al., 1990). However, considerable variation occurred between sites and years, which can be predominantly attributed to variation in maturity; generally, firmer fruit contained less soluble solids and vice-versa. There were instances within sites where firmer fruit apparently contained more soluble solids than softer fruit. Therefore, the firmness of fruit at harvest may also be influenced by factors other than SSC e.g. amounts of dry matter in cell walls, the mineral status of fruit, the 3D structure of fruit, and cell turgor pressure (Section 2.2.5.6).

Generally, firmness at harvest did not vary noticeably with soil amendment, which is consistent with the lack of variation in other attributes measured at harvest, especially the SSC of fruit. However, there were occasions where the grass cover resulted in firmer fruit and the conventional regime resulted in softer fruit. These differences could be attributed to the effect of these amendments on the mineral status of fruit. In particular, fruit from grass plots tended to contain less N than fruit from bare and mulch plots while fruit from the conventional plots tended to contain more N than fruit from

organic and organic plus regimes. Variation in the N status of fruit has previously been linked to the variation in firmness and storage behaviour of fruit (Section 2.3.1.8) and in the current study, across all plots, fruit containing more N at harvest tended be softer at harvest, and vice versa (Section 3.4.2.4). Fruit from conventional plots also tended to be more mature than fruit from organic and organic plus plots which may have also contributed to them being softer. The current study demonstrated that across plots, more mature fruit tended to be softer (and contain more N) at harvest, and vice versa (Section 3.4.2.4).

3.5.2.5 Conclusions

Generally, fruit attributes at harvest did not differ substantially with soil amendment. The organic plus regime especially had relatively minor effects on the quality of fruit at harvest considering the large amounts of Ca that it contained. However, grass appeared to consistently reduce the concentrations of N in fruit, which may have contributed to the fruit being consistently (though not significantly) firmer at harvest. These findings are consistent with the lack of variation in vine and fruit attributes before harvest and support the proposition that the effects of the soil amendments, under some conditions, may be constrained at the root level.

3.5.3 Postharvest attributes

3.5.3.1 *Botrytis*

The development of very little *Botrytis* in fruit from both sites in all 3 years can be attributed to low amounts of inoculation throughout the growing season and / or the strong development of resistance in fruit. The ability to identify the effects of the soil amendments on the incidence of *Botrytis* was limited by the very low incidences of the disease.

3.5.3.2 Softening behaviour

Characterisation

The softening behaviour of fruit in this study was often tri-phasic in nature beginning with a rapid phase of softening followed by a period where very little change in firmness occurred and ending with a phase of accelerated softening. Originally, a number of models, both simple and complex, were used to characterise this softening behaviour. Most were found to be unsuitable because of a gross lack of fit. In the end, empirically derived quartic polynomial models (Eqs. 3.2 and 3.3) were found to best describe this softening behaviour based on their 'goodness of fit' (determined visually). While these models accurately characterised the softening behaviour of fruit, they contain a number of parameters that have only tenuous links to biological meaning. Therefore, they offer little explanation of the underlying processes involved in the softening phenomenon. Furthermore, these models contain a relatively large number of parameters, the estimates of which have large uncertainties (i.e. large errors). Consequently, the predictive capacities of these models are also limited as are their abilities to segregate lines of fruit based on rates of softening.

In 1996, Massey fruit softened very rapidly in a bi-phasic manner. This was probably a consequence of accelerated ripening due to ethylene contamination (0.12 $\mu L.\ L^{-1}$ or 12.2 mPa, measured at 80 days) of the coolstore. Under ethylene-free conditions, it is possible that these fruit may have softened in a similar fashion to other fruit in the study. With that in mind, the bi-phasic softening behaviour was best described, based on the 'goodness of fit' (determined visually), using a Complementary Michaelis-Menten model. The same model has been used previously to accurately characterise the softening behaviour of kiwifruit (Benge et al., 1995 – unpublished; Davie et al. 1991 - unpublished). This model can be described as quasi-physiological and empirical rather than mechanistic as it really doesn't describe the underlying processes (e.g. cell wall degradation) involved in fruit softening. Nevertheless the two parameters in this model are relatively independent and can be estimated accurately. Such a model could be used to accurately predict the softening behaviour of some lines of fruit and could provide

the industry with a valuable tool for segregating lines of fruit based on their rates of softening.

The Complementary Michaelis-Menten model poorly described the tri-phasic softening behaviour of other fruit in the study. Similarly, the quartic polynomial models poorly described the softening behaviour of fruit that was bi-phasic. This indicates that it may be difficult to identify a global model that can be used to predict the softening behaviour of fruit from different sources, based on just firmness measurements.

Fruit storage potential must be a function of fruit compositional attributes at harvest. Therefore, it may be possible to develop a predictor of fruit storage behaviour based on these attributes using a multivariate approach. This may provide the industry with a tool for segregating fruit, which is free of the difficulties associated with the modelling of changes in fruit firmness. Previously, considerable effort has been made to predict the incidence of bitter pit in apple, using fruit and tree attributes measured at harvest, especially fruit mineral contents (Boon, 1980; Johnson and Ridout, 1998; Tomala, 1997). This work has only been moderately successful, and at best, it has provided some evidence that the storage behaviour of fruit is linked to its composition at harvest although the physiological basis for these relationships remains unclear. Ideally, a predictor of kiwifruit storage behaviour would be based on attributes measured non-destructively at harvest so that individual fruit could be segregated. This is more powerful than segregation based upon batches or lines of fruit, which is all that is possible with destructive measurements.

Soil amendment differences

In all three years the lack of variation in the softening behaviour of fruit was consistent with the general lack of significant differences in vine and fruit attributes measured before and at harvest, particularly the concentrations of minerals and soluble solids in fruit. Differences in fruit softening behaviour have previously been attributed to variation in both these attributes (Sections 2.3.1.8 and 2.3.1.9). Although no significant differences were detected, the grass appeared to improve the retention of firmness in

fruit as did the organic and organic plus regimes, especially at the Massey site. These effects may have been mediated through differences in the concentrations of minerals in fruit i.e. on average, fruit from bare and mulch plots often contained slightly more N and less Ca than those from grass plots. Similarly, fruit from conventional plots often contained slightly more N and less Ca than those from organic and organic plus plots. N has previously been shown to be detrimental to the storage life of kiwifruit (Cheah, 1989; Costa et al., 1997; Johnson et al., 1997; King et al., 1987; Mowatt et al., 1993; Prasad et al., 1988; Prasad and Spiers, 1991) while Ca appears beneficial (Section 2.4).

3.5.3.3 Soft patches

The considerable variation in the incidence of soft patches in fruit between years and sites may have been due to differences in the composition of fruit at harvest; the storage potential of fruit must be mediated though fruit composition and the structure or levels of infection with pathogens at harvest. Also, differences in harvest dates may have contributed to differences in the incidence of disorder while differences in the period of storage may have also been a contributory factor. In 1996, fruit from the Massey site underwent rapid softening and were only stored for approx. two months. Therefore the opportunity for senescence related disorders to develop was limited. In contrast, fruit from the Massey site in 1998 remained firm enough to be stored for an extended period (approx. 8 months) and therefore soft patches were given a greater opportunity to develop.

Like softening behaviour, the lack of variation in the incidence of soft patches in fruit from both sites in 1996 associated with the soil amendments was anticipated given that they were established in the same growing season. In the two subsequent seasons, fruit from grass plots at both sites developed significantly less soft patches. Fruit from bare and mulch plots often contained slightly more N and less Ca than those from grass plots, a feature that may have contributed significantly to the differences in the level of soft patches. Similarly, fruit from conventional plots often contained slightly more N

and less Ca than those from organic and organic plus plots, which may explain why that fruit tended to develop more soft patches, though not significantly more.

Averaged across all plots, fruit from both sites that developed soft patches consistently contained less Ca than fruit that did not. This is consistent with the findings from the pairwise comparison of production systems (Section 4.3.2.2) as well as other work (Banks et al., 1995). Therefore, it appears that the development of soft patches is strongly linked to the Ca content of fruit. That said, there were no significant or consistent differences in the concentrations of Ca in fruit associated with each of the ground covers despite the significant differences in the incidence of soft patches. It may be that the ratio of Ca to some other fruit component is more important in the development of disorders rather than the concentration of Ca *per se*. For example, at the HortResearch site in 1997 and at the Massey site in 1998, the Mg : Ca ratios of fruit from grass plots were significantly lower than those of fruit from bare and mulch plots (data not shown) which may have contributed to the lower incidence of soft patches from grass plots.

Mg and K are both renowned as antagonists of Ca effects in plant tissue and therefore fruit high in both these minerals would be expected to be more susceptible to storage disorders (Section 2.4.6.2). However, this was not the case in the present study as fruit that developed soft patches consistently and on occasions contained significantly less K and Mg than fruit that did not. However, in all instances the ratios of Mg and K to Ca were greater for fruit that developed soft patches suggesting that it maybe the ratios of these elements to other fruit components, especially Ca, that are important in the development of disorders rather than their absolute concentrations *per se*.

Throughout this study, the N : Ca ratios of fruit with soft patches were significantly greater than those without soft patches which is consistent with other work that has found high concentrations of N to be detrimental to the storage life of kiwifruit (Cheah, 1989; Costa et al., 1997; Johnson et al., 1997; King et al., 1987; Mowatt et al., 1993;

Prasad et al., 1988; Prasad and Spiers, 1991). Therefore, it appears that, like Mg and K, N may also be important in the development of disorders in kiwifruit.

Previously, firmer kiwifruit have been found to contain less P than softer kiwifruit (Mowatt et al., 1993). However, in this study, the concentration of P in fruit with and without soft patches did not differ consistently or significantly indicating that the concentration of this element alone is not critical in the development of disorders in kiwifruit.

3.6 Conclusions

In this study, ground covers and fertiliser regimes considerably modified the soil environment and consistently affected a number of fruit and vine attributes. In particular, the organic and organic plus regimes often enhanced the Ca status of vines while at the same time decreased the amount of N in vines. Also, the grass cover consistently reduced the amount of N in vines. However, these effects were usually not significant indicating that while soil amendments have some potential to influence the mineral status of kiwifruit vines, their effects may be constrained at the root level by factors which have yet to be clearly identified. Identifying such factors could lead to the development of strategies that may allow the composition of vines to be manipulated in a way that would enhance the storage behaviour of fruit.

Of all the soil amendments, only the grass significantly influenced the storage behaviour of fruit. Although the mechanism(s) by which grass may influence storage behaviour is unclear, there are indications that changes in the mineral nutrition, particularly the N status of the vine and fruit, are involved. If the improvement in the storage behaviour of fruit from grass plots was due simply to a reduction in the uptake of N, then reducing the amount of N added to the soil would be expected to have a similar effect. However, considerably less N was added to and measured in organic and organic plus plots but yet the fruit from those plots did not store significantly better than fruit from conventional plots. Therefore, it seems that the improvement in the storage behaviour of fruit from

grass plots involved mechanisms other than or in addition to those associated with the nitrogen nutrition of vines. These mechanisms have yet to be identified.

Fertiliser regime had only minor effects on the storage behaviour of kiwifruit, which was consistent with the minor effects on fruit and vine attributes before and at harvest. It therefore seems that manipulating the storage potential of kiwifruit may not always be possible by applying or withholding fertilisers. Instead, the establishment of a grass sward in orchards may have more potential for reliably enhancing the storage potential of kiwifruit.

At the industry level, there is anecdotal evidence indicating that fruit from organic properties store better than fruit from their conventional counterparts. The work described here indicates that this difference could be related to differences in orchard floor management as organic orchards typically have overall cover while conventional orchards have herbicide strips. However, further work needs to be carried out on a larger-scale to confirm the benefits of the grass observed in this study, especially to fruit storage potential. The current work has also indicated that differences in fertiliser practices may also contribute to differences in the storage behaviour of fruit, although less strongly than differences in orchard floor management.

3.7 References

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Chapter 4

Pairwise Comparison of the Storage Potential of Organically and Conventionally Grown Kiwifruit

4.1 Introduction

This chapter outlines work carried out in 1996 alongside the work described in the previous chapter. The major objective of the study was to compare the responses of fruit from paired organic and conventional production systems to typical postharvest handling and storage regimes given that fruit from organic properties were reputed to store better than fruit from conventional properties (Section 2.3.1.4). Although reasons for this difference are unclear, they must be linked to one or more orchard factors prior to the fruit being harvested e.g. soil characteristics. Whatever the reasons for the difference in fruit storage potential, they must be mediated by differences in fruit composition at harvest. Therefore, the composition of organic and conventional fruit was also compared in this study, to quantify inherent differences that may have been built into the fruit by the time they were harvested. Mechanical damage during the handling of kiwifruit has exacerbated the incidence of soft patches (Davie, 1997). Handling might also be expected to increase the spread of disease spores. Therefore, this study also set out to examine the effects of handling on the softening behaviour of fruit as well as the incidence of *Botrytis*.

Recently, strong associations have been found between a combination of fruit attributes measured at harvest and the incidence of soft patches in kiwifruit (Banks et al., 1994 – unpublished). The validation and expansion of such associations could provide the industry with a tool that would allow it to segregate lines of fruit at harvest with differences in storage potentials. Consequently, this study attempted to identify similar associations between various fruit attributes measured at harvest and the incidence of disorders in fruit after long-term storage.

4.2 Materials and methods

4.2.1 Orchard survey

In 1996, ten pairs of 'organic' and 'Kiwigreen' orchards were identified in the Bay of Plenty region, NZ[7]. Within pairs, the altitude, climate and soil type of each orchard were similar. However, altitude, climate and soil type differed between pairs due to their geographical separation. Subsequently, 30 trays of count 36 sized fruit (plus 20 additional fruit, count 36 size) were harvested from each of the growers as soon as the average soluble solids concentrations (SSC) of their fruit was as close to 6.2 % as practically possible. The position of sampled fruit was standardised as the second fruit (from the basal end of the shoot) on a fruiting lateral, taken only if it had a subtending leaf. Fruit were sampled from several vines evenly spaced throughout a single block at each orchard. Within each pair, fruit were harvested on the same day within hours of each other (to minimise differences in fruit attributes such as maturity) but pairs of growers were harvested on different days. Fruit were harvested over a period of 10 days in May. For each grower, 10 trays of fruit were picked directly into polylined single layered tray while the remaining 20 trays of fruit were harvested into picking aprons / bags then transferred into wooden bins. After harvesting, fruit from each of the orchards were transported to the HortResearch Research Orchard packhouse in Te Puke. Those fruit harvested into wooden bins were then run across a conventional grader (Treeways) and of those 20 trays, 10 were subsequently treated with Rovral in an attempt to prevent *Botrytis* infections (by dipping the stem ends of each fruit into the Rovral). During grading, the 20 trays of fruit per grower were packed into polylined single layered trays. By the end of grading and treatment with fungicide, the following 3 handling treatments had been established per grower:

[7] Organic growers in pairs 8, 9 and 10 were paired against the same Kiwigreen grower as their properties were all next to each other. Hence, the Kiwigreen data presented here for these pairs are all the same.

No.	Treatment	No. of trays of fruit
1.	Not handled, no fungicide dip (CONTROL)	10
2.	Handled, no fungicide dip	10
3.	Handled, fungicide dip	10
		30

At the same time that fruit were being graded, the flesh firmness and soluble solids content (SSC) of the 20 additional fruit sampled from each grower were determined as described in the previous chapter.

After grading, all 30 trays of fruit from each of the growers were transported to the Plant Growth Unit coolstore at Massey University where they were stored at 0°C. Throughout storage, the flesh firmness of fruit from each of the 3 treatments per grower was regularly measured as described in the previous chapter. The firmness of 10 fruit per treatment per grower was measured on each occasion i.e. 1 fruit was sampled from each of the 10 trays per treatment per grower to account for any variation between trays.

After 10 weeks of storage, fruit from all treatments and growers were condition checked and scored for *Botrytis*; infected fruit were removed. At the end of storage, all remaining fruit were inspected and scored for the presence or absence of soft patches as described in the previous chapter. The concentrations of Ca, Mg, K, N and P in fruit with and without soft patches were also determined as described in the previous chapter.

4.2.2 Data analysis

Fruit data collected at harvest (i.e. average maturity, flesh firmness, and mineral concentrations) were subjected to an analysis of variance (ANOVA) using the general linear models (GLM) procedure of SAS (Little et al., 1991).

Treatment differences in the softening behaviour of fruit were determined by identifying non-linear models that best characterised the data and then by comparing the parameters obtained from fitting those models to each set of treatment data. Models were fitted to the data using the non-linear (NLIN) procedure of SAS while the parameters were compared by subjecting them to an ANOVA using the GLM procedure of SAS (Little et al., 1991). A split-plot model was used in the ANOVA with location as blocks, grower as the main plot factor and handling treatment as the sub-plot factor.

The soft patch and *Botrytis* count data were subjected to an ANOVA using the GLM procedure of SAS (Little et al., 1991) and the same split-plot model described above. Data that appeared to be non-normally distributed were appropriately transformed. In cases where transformations did not improve the error structure, the data were subjected to the Genmod procedure of SAS (Little et al., 1991), which assumes a binomial error structure. Differences in the concentrations of minerals in fruit with and without soft patches were also elucidated by subjecting the data to an ANOVA. A split-split-plot model was used with location as the blocks, grower as the main plot, handling treatment as the sub-plot factor, and soft patches (plus or minus) as the sub-sub-plot factor.

Across all grower lines, fruit attributes measured at harvest that were significant in explaining the variation in the incidence of soft patches were identified firstly by natural log transformation and standardisation of the original variables and then by regressing the new variables against the natural log of levels of soft patches. The GLM procedure of SAS (Little et al., 1991) was used to perform the analyses. Plots of the relationships between raw data (i.e. non-transformed averages) for the important variables and disorder levels are presented.

4.3 Results

4.3.1 Fruit attributes at harvest

4.3.1.1 Maturity

During the harvest period, fruit harvested early were generally less mature than fruit harvested later. However, the maturity of fruit did not differ significantly between locations (Table 4.1). Within pairs (i.e. locations), fruit from the organic production systems were consistently and significantly less mature at harvest than fruit from the Kiwigreen production systems (Tables 4.2 and 4.3).

4.3.1.2 Flesh firmness

The flesh firmness of fruit from each of the locations was also similar at harvest although there were significant differences between some locations (Table 4.4). Within pairs (i.e. locations), fruit firmness at harvest did not differ consistently or significantly between the organic and Kiwigreen production systems (Tables 4.5 and 4.5).

Table 4.1 Average soluble solids concentrations (SSC) of fruit harvested from each of the locations surveyed in the 1996 pairwise comparison of fruit storage potential. Means do not differ significantly at the 5 % significance level ($n = 2$).

Location	Date of harvest	SSC (°Brix)
1	2-May-98	5.50
2	3-May-98	5.77
3	3-May-98	6.02
4	6-May-98	5.94
5	6-May-98	5.63
6	7-May- 96	6.42
7	7-May-98	6.27
8	13-May-96	6.30
9	13-May-98	6.24
10	13-May-98	6.19
SED		0.32

Table 4.2 Average (± SE) soluble solids concentrations (SSC, °Brix) of fruit harvested from each of the Kiwigreen and organic production systems at each location surveyed in the 1996 pairwise comparison of fruit storage potential (n = 20).

Location	Organic	Kiwigreen	Difference
1	5.20 ± 0.07	5.81 ± 0.08	-0.61
2	5.51 ± 0.11	6.04 ± 0.17	-0.53
3	5.20 ± 0.08	6.84 ± 0.39	-1.64
4	5.47 ± 0.07	6.41 ± 0.23	-0.94
5	5.51 ± 0.15	5.75 ± 0.12	-0.24
6	6.04 ± 0.16	6.80 ± 0.15	-0.76
7	6.07 ± 0.10	6.48 ± 0.16	-0.41
8	6.24 ± 0.10	6.36 ± 0.17	-0.12
9	6.13 ± 0.08	6.36 ± 0.17	-0.23
10	6.03 ± 0.09	6.36 ± 0.17	-0.33

Table 4.3 Average soluble solids concentrations (SSC) of fruit harvested from Kiwigreen and organic production systems in the 1996 pairwise comparison of fruit storage potential, averaged across all growers. Separation of means is based on Tukey's test (P = 0.05, n = 10). Means with the same letter do not differ significantly.

	SSC (°Brix)
Kiwigreen	6.32 a
Organic	5.74 b
SED	0.14

Table 4.4 Average flesh firmness (*f*) of fruit harvested from each of the locations surveyed in the 1996 pairwise comparison of fruit storage potential. Separation of means is based on Tukey's test ($P = 0.05$, $n = 2$). Means with the same letter do not differ significantly.

Location	*f* (N)
1	72.1 a b
2	69.4 a b
3	62.5 b
4	65.0 a b
5	61.9 b
6	70.0 a b
7	69.0 a b
8	76.8 a b
9	80.8 a
10	80.3 a
SED	3.93

Table 4.5 Average (± SE) flesh firmness (N) of fruit harvested from each of the Kiwigreen and organic production systems at each location surveyed in the 1996 pairwise comparison of fruit storage potential (n = 20).

Location	Organic	Kiwigreen	Difference
1	69.7 ± 1.66	74.0 ± 1.35	-4.3
2	70.3 ± 1.04	68.5 ± 1.68	1.8
3	62.2 ± 2.73	62.8 ± 3.69	-0.6
4	67.3 ± 1.31	62.8 ± 4.15	4.5
5	57.8 ± 2.34	65.9 ± 1.56	-8.1
6	68.1 ± 1.78	71.8 ± 0.92	-3.7
7	64.8 ± 1.52	73.1 ± 1.54	-8.3
8	76.5 ± 1.11	77.2 ± 1.55	-0.7
9	84.5 ± 1.18	77.2 ± 1.55	7.3
10	83.4 ± 1.63	77.2 ± 1.55	6.2

Table 4.6 Average flesh firmness (f) of fruit harvested from organic and Kiwigreen production systems in the 1996 pairwise comparison of fruit storage potential, averaged across all growers. Means do not differ significantly at the 5 % significance level (n = 10).

Production system	f (N)
Kiwigreen	71.0
Organic	70.4
SED	1.76

4.3.1.3 Mineral concentrations

The concentrations of Ca, Mg, K, N and P in fruit did not differ consistently (Tables 4.7 and 4.8) or significantly (Table 4.9) with production system at harvest. However, within 8 of the 10 pairs surveyed, the concentration of Ca in fruit from the organic systems was greater than that in fruit from their conventional counterparts. Furthermore, the P-value for a significant difference in the Ca concentration of fruit from the two systems, obtained from an analysis of variance, was 0.06 (tested at a significance level of 5 %). Therefore, it appears that fruit from organic orchards contained marginally more Ca than fruit from Kiwigreen orchards.

Table 4.7 Average (± SE) concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg) and potassium (K) in fruit from each of the Kiwigreen and organic production systems at each location surveyed in the 1996 pairwise comparison of fruit storage potential ($n = 2$).

	Ca		Mg		K	
Location	Organic	Kiwigreen	Organic	Kiwigreen	Organic	Kiwigreen
1	3.56 ± 0.41	4.64 ± 0.61	3.99 ± 0.37	4.54 ± 0.29	72.5 ± 2.82	63.4 ± 3.97
2	5.06 ± 0.94	3.08 ± 0.34	3.69 ± 0.37	4.29 ± 0.27	73.3 ± 3.34	76.8 ± 3.27
3	4.17 ± 0.50	3.28 ± 0.41	4.16 ± 0.27	4.21 ± 0.31	75.9 ± 5.25	70.6 ± 2.45
4	4.96 ± 0.63	3.56 ± 0.59	4.15 ± 0.27	3.69 ± 0.32	64.1 ± 1.67	72.8 ± 0.73
5	5.89 ± 0.62	4.43 ± 0.58	4.78 ± 0.38	3.92 ± 0.24	96.8 ± 9.28	76.0 ± 2.61
6	3.82 ± 0.39	5.37 ± 0.34	3.69 ±0.23	5.29 ± 0.33	62.3 ± 3.76	63.6 ± 2.12
7	5.02 ± 0.55	3.95 ± 0.56	3.25 ± 0.26	3.88 ± 0.32	56.2 ± 3.37	69.9 ± 2.78
8	5.95 ± 0.77	4.09 ± 0.36	3.62 ± 0.45	3.78 ± 0.42	61.2 ± 4.11	53.2 ± 3.18
9	5.70 ± 0.69	4.09 ± 0.36	3.54 ± 0.50	3.78 ± 0.42	46.7 ± 5.72	53.2 ± 3.18
10	4.44 ± 0.48	4.09 ± 0.36	3.12 ± 0.39	3.78 ± 0.42	57.2 ± 7.16	53.2 ± 3.18

Table 4.8 Average (± SE) concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of nitrogen (N) and phosphorous (P), in fruit from each of the Kiwigreen and organic production systems at each location surveyed in the 1996 pairwise comparison of fruit storage potential ($n = 2$).

	N		P	
Location	Organic	Kiwigreen	Organic	Kiwigreen
1	95.6 ± 5.57	87.8 ± 3.82	7.73 ± 0.61	6.95 ± 0.38
2	87.7 ± 6.74	118.2 ± 4.86	8.11 ± 0.73	9.46 ± 0.93
3	89.8 ± 5.86	97.7 ± 3.34	8.76 ± 0.50	9.16 ± 0.39
4	91.2 ± 6.17	112.5 ± 4.86	7.84 ± 0.56	8.56 ± 0.43
5	97.6 ± 6.47	90.6 ± 4.08	9.64 ± 0.51	8.61 ± 0.32
6	103.9 ± 8.36	78.5 ± 3.05	8.02 ± 0.39	6.75 ± 0.90
7	90.6 ± 7.34	103.9 ± 4.20	9.41 ± 1.29	9.97 ± 0.42
8	82.5 ± 4.18	86.9 ± 3.67	8.40 ± 0.46	8.34 ± 0.44
9	105.1 ± 4.78	86.9 ± 3.67	10.39 ± 0.75	8.34 ± 0.44
10	103.3 ± 10.18	86.9 ± 3.67	9.54 ± 1.19	8.34 ± 0.44

Table 4.9 Average concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in fruit from organic and Kiwigreen production systems in the 1996 pairwise comparison of fruit storage potential, averaged across all growers. Means do not differ significantly at the 5 % significance level ($n = 10$).

	Ca	Mg	K	N	P
Organic	4.85	3.80	65.3	95.0	8.45
Kiwigreen	4.06	4.12	66.6	94.7	8.78
SED	0.39	0.21	3.20	5.78	0.34

4.3.2 Postharvest attributes

4.3.2.1 Fruit softening behaviour

The softening behaviour of fruit from each of the surveyed growers was similar during storage, consisting of three distinct phases i.e. an initial rapid phase during the first 2 months, a plateau phase in the ensuing 3 - 4 months and finally, another rapid phase during the final months (Figure 4.1). This behaviour was described using the following empirical quartic polynomial model:

$$f = a + bt + ct^2 + dt^3 + et^4 \qquad (4.1)$$

In the above equation, the parameters a and b respectively represent the firmness of fruit and the rate at which firmness is changing at time 0. The parameters c, d, e on the other hand define the inflexion points of the curves generated by the equation.

After fitting Eq. 4.1 to data from each pair of growers, the parameters that were obtained did not differ between the organic and Kiwigreen production systems. In other words, whole fruit softening behaviour throughout storage did not differ with production system. Values for the 5 parameters describing the average softening behaviour of fruit from all locations and growers are presented in Table 4.10. The softening behaviour typical of fruit surveyed in this pairwise comparison is illustrated in Figure 4.1. Given that fruit softening did not differ with production system or location, the average softening behaviour of fruit from only one location is presented.

Table 4.10 Average estimates (± SE) of the parameters *a*, *b*, *c*, *d* and *e* for the quartic polynomial model used to characterise the softening behaviour of all fruit surveyed in the 1996 pairwise comparison of fruit storage potential (n = 60).

a	*b*	*c*	*d*	*e*
57.92	-0.71	3.89E-03	5.38E-06	-6.15E-08
± 0.59	± 2.56E-02	± 5.39E-04	± 4.39E-06	± 1.18E-08

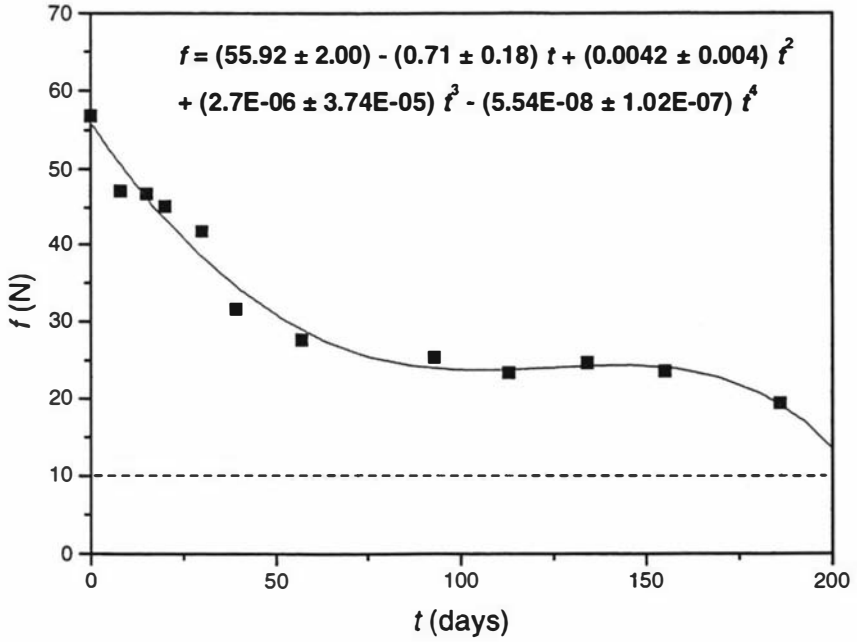

Figure 4.1 Average softening behaviour of fruit from both growers at location 1 in the 1996 pairwise comparison of fruit storage potential. The solid line represents the line of best fit obtained by fitting the inset equation to the data. The dashed line represents the minimum threshold level of firmness for export.

Fruit from all growers surveyed in the pairwise comparison softened so slowly during storage that none reached the minimum export threshold level of 10 N even after 180 days of storage. Therefore, it was not possible to compare the time taken for fruit from each of the production systems to reach 10 N. Instead, the time taken for fruit from each of the systems to soften to an arbitrary minimum of 30 N was compared, but no significantly differences were found (data not shown).

Significant differences were detected in two of the parameters (*c* and *d*) that described the softening behaviour of fruit associated with each of the three handling treatments applied at harvest (Table 4.11). It appeared that handled fruit remained firmer than control fruit throughout storage, although the differences were marginal (Figure 4.2).

Table 4.11 Estimates (± SE) of the parameters *a*, *b*, *c*, *d* and *e* for the quartic polynomial model used to characterise the average softening behaviour of fruit from each of the 3 handling treatments applied at harvest to fruit surveyed in the 1996 pairwise comparison of fruit storage potential. Separation of means is based on Tukey's test ($P = 0.05$, $n = 20$). Means with the same letter do not differ significantly.

Treatment	*a*	*b*	*c*	*d*	*e*
1	58.71 a	-0.79 a	5.35E-03 a	-5E-06 a	-3.70E-08 a
2	57.97 a	-0.67 b	3.72E-03 a b	4.37E-06 a	-5.58E-08 a
3	57.08 a	-0.66 b	2.60E-03 b	1.67E-05 a	-9.21E-08 a
SED	0.77	0.04	1.05E-03	8.88E-06	2.49E-15

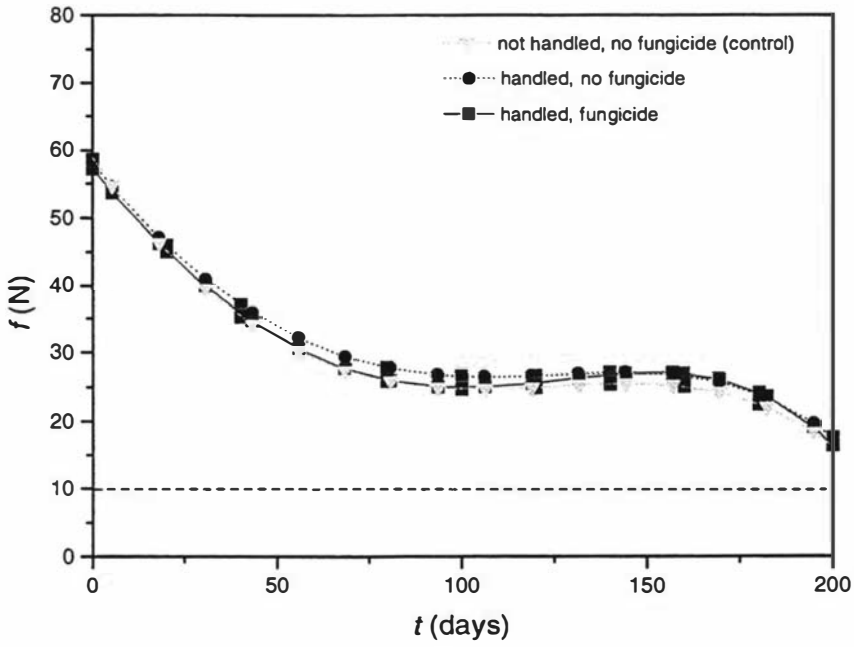

Figure 4.2 Softening behaviour of fruit associated with each of the three handling treatments applied at harvest in the 1996 pairwise comparison of fruit storage potential, averaged across all locations and growers. The curves represent the lines of best fit obtained by fitting Eq. 4.1 to the data. The dashed line represents the minimum threshold level of firmness for export.

4.3.2.2 Soft patches

Within the majority of pairs (8 of 10), the incidence of soft patches that developed during storage tended to be higher in fruit from the Kiwigreen production system than from the organic system (Table 4.12). The average difference was just statistically significant ($P \approx 0.04$). The incidence of soft patches differed significantly between the three handling treatments imposed on fruit at harvest with control fruit developing more soft patches than handled fruit treated with or without fungicide (Table 3.13).

Table 4.12 Proportions (%) of fruit from each of the organic and Kiwigreen production systems at each of the locations surveyed in the 1996 pairwise comparison of fruit storage potential which developed soft patches during storage.

Location	Organic	Kiwigreen	Difference
1	2.62	1.90	0.72
2	0.46	6.41	-5.95
3	3.85	5.37	-1.52
4	1.16	4.40	-3.24
5	1.01	1.46	-0.45
6	1.31	0.29	1.02
7	0.15	2.03	-1.89
8	0	0.58	-0.58
9	0.29	0.58	-0.29
10	0	0.58	-0.58
		$\bar{x}$	-1.28
		SE	0.69

Table 4.13 Average proportions (%) of fruit from each of 3 handling treatments imposed at harvest in the 1996 pairwise comparison of fruit storage potential, which developed soft patches (SP) during storage, averaged across all locations and growers. Separation of means is based on Tukey's test ($P = 0.05$, $n = 20$). Means with the same letter do not differ significantly.

Treatment	% SP
1 (no handling, no fungicide - control)	2.18 a
2 (handling, no fungicide)	1.61 b
3 (handling, fungicide)	1.38 b
SED	0.029

The concentrations of minerals in fruit did not differ with postharvest handling treatments (data not shown). Averaged across all growers and treatments, fruit that developed soft patches contained significantly less Ca and Mg and significantly more N and P than healthy fruit (Table 4.14). Fruit without soft patches contained almost twice as much Ca as fruit with soft patches.

Table 4.14 Average concentrations ($mmol.kg^{-1}$), on a fresh weight basis, of calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N) and phosphorous (P) in whole kiwifruit from the 1996 pairwise comparison of fruit storage potential which did (+ SP) or did not develop (- SP) soft patches during storage, averaged across all locations and growers. Separation of means is based on Tukey's test ($P = 0.05$, $n = 100$). Means with the same letter do not differ significantly.

	Ca	Mg	K	N	P
- SP	5.40 a	4.33 a	66.86 a	91.48 a	8.34 a
+ SP	2.81 b	3.46 b	65.77 a	101.21 b	9.00 b
SED	0.20	0.10	1.72	2.69	0.23

4.3.2.3 *Botrytis*

After 10 weeks of storage, the incidence of *Botrytis* was low in fruit from all surveyed growers (Table 4.15) with the total incidence across all growers being less than 0.5 %. The incidence of *Botrytis* did not differ significantly ($P < 0.01$) with production system though organic fruit did tend to be less affected than conventional fruit. Similarly, the incidence of *Botrytis* in fruit did not differ significantly between the three handling treatments imposed at harvest though the control fruit were more affected than handled fruit treated with or without fungicide (Table 4.16). Fungicide appeared to cut *Botrytis* levels in handled fruit by 50 %.

Table 4.15 Proportions (%) of fruit harvested from each of the organic and Kiwigreen production systems at each of the locations in the 1996 pairwise comparison of fruit storage potential which were detected with *Botrytis* after 10 weeks of storage.

Location	Organic	Kiwigreen	Difference
1	0.46	0	0.46
2	0	0	0
3	0	2.87	-2.87
4	0.11	0.7	-0.59
5	0.11	0.23	-0.12
6	0	0	0
7	0.23	0.11	0.12
8	0	0.11	-0.11
9	0	0.11	-0.11
10	0	0.11	-0.11
		$\bar{x}$	-0.33
		SE	0.29

Table 4.16 Proportions (%) of fruit from each of three handling treatments imposed at harvest in the 1996 pairwise comparison of fruit storage potential, which were detected with *Botrytis* after 10 weeks of storage, averaged across all locations and growers. Means do not differ significantly at the 5 % significance level (n = 20).

Treatment	% *Botrytis*
1 (no handling, no fungicide – control)	0.50
2 (handling, no fungicide)	0.19
3 (handling, fungicide)	0.09
SED	0.21

4.3.3 Indicators of fruit storage potential

The model obtained from the regression of fruit attributes measured at harvest against the proportion of fruit with soft patches (% SP) for individual grower lines was as follows:

$$\begin{aligned}\text{Ln (\% SP)} = \; & (0.047 \pm 0.148) - (0.837 \pm 0.203 \times [\text{Ca}]) \\ & + (0.065 \pm 0.319 \times [\text{K}]) + (0.463 \pm 0.253 \times [\text{Mg}]) \\ & + (0.260 \pm 0.237 \times [\text{N}]) + (0.069 \pm 0.218 \times [\text{P}]) \\ & - (0.262 \pm 0.177 \times \text{SSC}) - (0.093 \pm 0.264 \times \text{initial firmness}), \end{aligned} \quad (4.2)$$

where the regressor variables are natural log transformed and standardised. The 'goodness of fit' of this model is illustrated in Figure 4.3 by a plot of the predicted vs. observed natural logs of incidences of soft patches. Of the seven variables in the model, only [Ca] was identified as being significant at the 5 % level (P = 0.003).

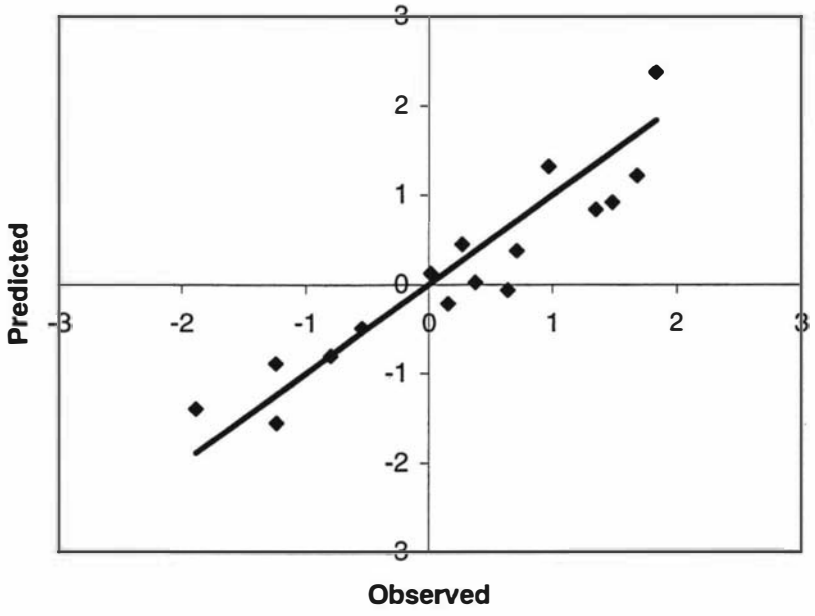

Figure 4.3 Predicted vs. observed natural logs of incidences of soft patches (%). Predicted values are based on Eq. 4.2. Each data point represents a single grower line.

Generally, the incidence of soft patches increased as the concentration of Ca in fruit (Indicator 1) decreased (Figure 4.4). With the exception of one source, lines of fruit with greater than 2 % soft patches were segregated well from those with less than 2 % by the use of an arbitrary threshold for Ca of about 3.7 units. However, for lines of fruit with less than 2 % soft patches, some with different Ca concentrations developed similar levels of soft patches. Similarly, lines of fruit with the same Ca concentrations developed different levels of soft patches.

According to the regression analysis, fruit attributes other than Ca measured at harvest were not significant in describing the variation in the incidence of soft patches. Yet, combinations of some of these variables with Ca produced indicators that were strongly associated with the incidence of soft patches, particularly the combination of [Ca], SSC, initial firmness, [N], and [Mg] (Indicator 2; Figure 4.5). This indicator discriminated very well between lines of fruit with high, moderate and low incidences of soft patches.

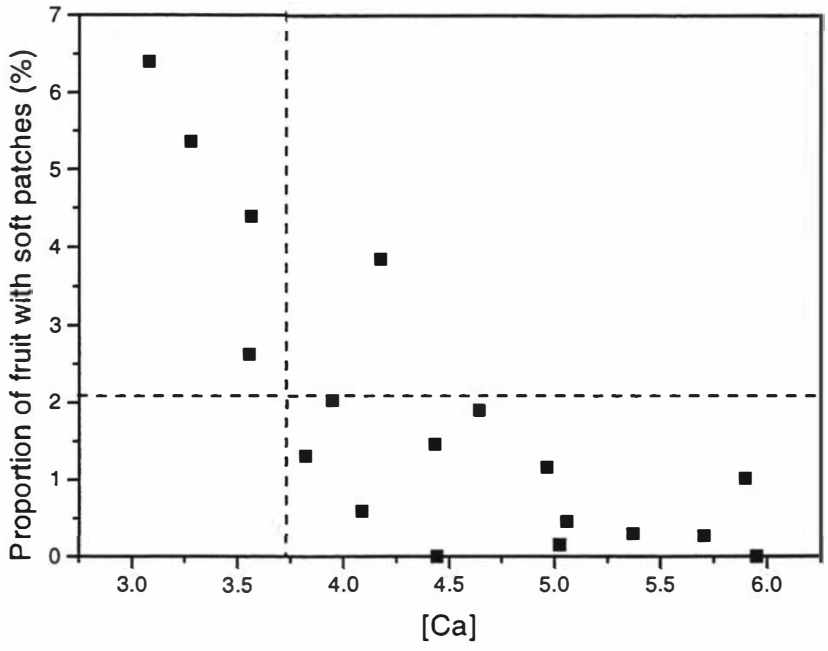

Figure 4.4 Relationship between the average concentration of Ca ([Ca]) in fruit at harvest (Indicator 1) and the incidence of soft patches after long term storage. Each data point represents a single grower line. The dashed lines represent examples of possible arbitrary points for segregating lines of fruit with high and low incidences of disorder.

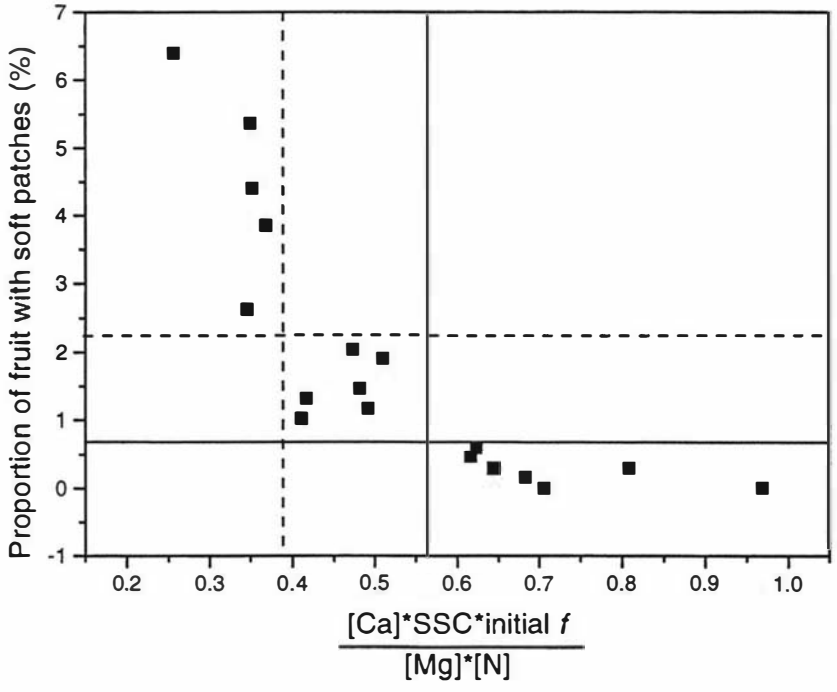

Figure 4.5 Relationship between the ratio of the product of average calcium concentration ([Ca]), soluble solids concentration (SSC) and initial firmness (*f*) to the product of average magnesium concentration ([Mg]) and nitrogen concentration ([N]) of fruit at harvest (Indicator 2), and the incidence of storage disorders after long term storage. Each data point represents a single grower line. The solid and dashed lines represent examples of possible arbitrary points for segregating fruit with high, moderate and low incidences of disorder.

4.4 Discussion

4.4.1 Fruit attributes at harvest

Variation in the maturity of fruit at harvest associated with location can mainly be attributed to differences in harvest date with fruit harvested later in the season being more mature than those harvested earlier in the season. Differences between locations may also have arisen from differences in soil type, microclimate and altitude. Fruit from properties at higher altitudes probably matured later given that flowering is later at higher altitudes and that the fruit are on the vine for the same number of days (although there is some speculation that fruit at higher altitudes have a longer growing season; Bruce Stowell, 1999 - personal communication). Temperatures experienced during autumn may have also contributed to the variation in maturity between locations, in that fruit grown under higher temperatures between mid-March and mid-May would have accumulated less soluble solids (Hopkirk et al., 1989). Furthermore, minimum temperatures during the growing season may have contributed to variation in fruit maturation between locations. Cooler nights would have favoured the accumulation of soluble solids in fruit (Seager et al., 1996). The amount of rainfall during autumn may have also influenced fruit maturity. High rainfall presumably would have had a negative effect on the rate of increase in soluble solids although this would have depended on many factors including the level and duration of rainfall, soil texture and soil porosity (Pailly et al., 1995). For pairs of lines harvested at similar times but at different locations, differences in fruit maturity between the pairs are likely to have arisen from differences in such factors as rainfall and temperature especially during fruit maturation.

In this survey, organic fruit were consistently and significantly less mature than conventional fruit at harvest though the reasons for this difference are unclear. Differences in canopy management (and therefore the exposure of fruit to light) between the two production systems may have contributed to differences in the maturity of fruit. However, organic canopies tend to be less dense than conventional canopies (Stowell, 1999 - personal communication). Therefore, organic fruit would be expected

to be more mature than their conventional counterparts given that shaded kiwifruit tend to have lower soluble solids concentrations (Antognozzi et al., 1995; Snelgar et al., 1991; Tombesi et al., 1993).

Like SSC, the firmness of fruit at harvest differed significantly between some locations. Typically, early harvested fruit tend to be firmer than late harvested fruit. However, in this survey, there was no consistent relationship between harvest date and firmness though later harvested fruit were generally more mature. Despite conventional fruit being more mature than organic fruit at harvest, the firmness of organic and conventional fruit at harvest did not differ significantly. This is surprising given that the more advanced maturity of conventional fruit would be expected to be linked to advanced ripening and softening in that fruit. It seems that factors that contribute to the firmness of fruit at harvest are not necessarily reflected in SSC, the industry's chosen indicator of maturity.

Given the anecdotal evidence for differences in the storage behaviour of organic and conventional fruit, and the associations that have been found between fruit mineral content and subsequent storage behaviour, it was anticipated that differences would be observed in the mineral contents of fruit from the two production systems in this survey. Although, the concentrations of Mg, K, N and P in fruit did not differ consistently or significantly with production system, the concentration of Ca did tend to be greater in fruit from organic properties. The statistical significance of this difference was on the borderline of significance making it difficult to be absolutely confident that the concentration of Ca in fruit differed with production system but also making it difficult to be confident that there was no difference. Differences in the nutritional practices of organic and conventional production systems would be expected to affect the mineral nutrition and quality of fruit; typically, there is a greater use of synthetic fertilisers that supply greater amounts of more readily available nutrients in conventional systems. That said, the effects of different types and quantity of fertilisers added in each system may be confounded by other practices (e.g. canopy and ground cover management) which may affect the mineral nutrition of fruit. Generally, fruit from organic production

systems tend to be smaller than fruit from their conventional counterparts (presumably as a result of the lower quantities of N that are added). Therefore, differences in the fruit size distribution of organic and conventional production systems could further influence the final concentrations of minerals in fruit. However, in the case of this study, the selection of evenly sized fruit for all treatments eliminated this possibility.

4.4.2 Postharvest attributes

Whole fruit softening behaviour during storage did not differ with production system in this survey. This was surprising given that organic fruit were less mature at harvest and that less mature fruit tend to be firmer at harvest but soften more rapidly towards the end of storage (Section 2.2.2). It is possible that differences in fruit softening behaviour might have been identified if the fruit had been stored longer and allowed to soften to below 10 N. On the other hand, differences in softening behaviour may have never occurred during storage.

It was anticipated that differences in whole fruit softening might have arisen given the difference (albeit marginal) in the Ca status of organic and conventional fruit at harvest and the known associations between Ca concentrations in kiwifruit and subsequent storage behaviour (Banks et al., 1995; Davie and Banks, 1994; Mowatt and Banks, 1992; Prasad et al., 1990; Prasad and Spiers, 1991; Resnizky and Sive, 1993; Tagliavini et al., 1995). However, this did not occur, indicating that the difference in the Ca status of fruit was not large enough to produce differences in whole fruit softening. Alternatively, fruit attributes other than or in addition to Ca concentration may be important to the softening behaviour of kiwifruit.

In the current study, there was some indication that the softening behaviour of fruit differed with handling treatment despite previous findings reporting little or no effects of handling on whole fruit softening behaviour (Banks et al., 1993; Davie, 1997). However, there was some inconsistency, in that control fruit appeared to soften slightly more rapidly than handled fruit without fungicide but those handled and treated with

fungicide softened in a similar fashion to the control fruit. It may be that fungicide promoted softening but it seems more likely that fruit from all treatments would have softened similarly and that the apparent difference relates to sampling variation.

Organically grown fruit developed significantly less soft patches than conventionally grown fruit, even though they were generally less mature. This observation contrasts with earlier work indicating that less mature fruit develop more soft patches (Davie et al., 1996). It would therefore seem that factors other than or in addition to SSC are important in the development of soft patches. Differences in the Ca status of fruit may have contributed to differences in the incidences of soft patches.

Averaged across all growers in this survey, fruit that developed soft patches contained significantly less Ca than healthy fruit which is consistent with other work (Davie et al., 1994). Furthermore, soft patch fruit on average contained more N and P which is consistent with other work that has found these elements to be detrimental to the storage behaviour of fruit (Section 2.3.1.8). Healthy fruit, on average, also contained more Mg than healthy fruit, which was not expected given that Mg purportedly antagonises the uptake and effects of Ca in fruit (Section 2.4.6.2). It is possible that the high concentrations of Ca in those fruit countered any deleterious effects of the Mg.

The mineral nutrition of kiwifruit, especially Ca nutrition, appears to be important to fruit quality and in particular the development of soft patches. Therefore, orchard factors that impact on the mineral nutrition of fruit would be expected to significantly affect the incidence of soft patches during storage.

The incidence of *Botrytis* in fruit was low across all growers presumably due to either low levels of inoculation with the pathogen or high levels of resistance to infection. The incidence of *Botrytis* did not differ significantly with production system or handling treatment. However, the incidence of *Botrytis* in organic fruit tended to be lower than that in conventional fruit for reasons that are unclear. One possibility is that the amounts of antagonists to pathogens such as *Botrytis* were higher in organic orchards due to

lower concentrations of chemical residues. Organic growers may also have had better hygiene practices that contributed to low amounts of pathogens in their orchards. Differences in fruit composition, especially Ca content, may have also contributed to the difference in the incidence of *Botrytis*. Apples with more Ca have been found to be less susceptible to *Botrytis* (Conway et al., 1993) which may also be true for kiwifruit.

Handled fruit were less affected with *Botrytis* than non-handled fruit despite the expectation that handling would increase the spread of spores and the incidence of *Botrytis*. A lack of curing of the non-handled fruit, which were harvested directly into trays with polyliners, may have contributed to the greater incidence of *Botrytis* in that fruit. Curing has previously been found to dramatically reduce the incidence of *Botrytis* in kiwifruit (Lallu et al., 1997). As anticipated, treatment of handled fruit with Rovral fungicide reduced the incidence of soft patches.

Previously, grading has increased the incidence of soft patches in kiwifruit (Banks et al., 1993), presumably as a result of mechanical damage. However, in the current study, handling decreased the incidence of soft patches in growers' fruit. Reasons for this are unclear although differences in the curing of fruit may have been involved.

4.4.3 Indicators of fruit storage potential

The storage behaviour of fruit must be mediated by the composition of fruit at harvest. Given the complexity of the changes that occur during fruit maturation and ripening, it is likely that a number of fruit attributes at harvest are linked to the subsequent storage behaviour of fruit. However, there is evidence to indicate that fruit storage behaviour may be driven by just a few attributes at harvest.

In this work, the concentration of Ca in fruit at harvest was strongly associated with the incidence of soft patches after long-term storage. In particular, lines of fruit high in Ca at harvest tended to develop less soft patches than lines of fruit with less Ca which is consistent with other research that has found Ca beneficial to fruit storage (Section

2.4.1). The combination of Ca concentration with other fruit attributes at harvest produced even better associations with the incidence of soft patches. There was some evidence that Mg was involved in the development of soft patches. For lines of fruit with the same average Ca concentration, those that had more Mg at harvest appeared to be more susceptible to the development of soft patches. This is consistent with reports that Mg antagonises Ca effects in plants and could therefore be detrimental to fruit quality (Section 2.4.6.2). There was also some evidence that firmer fruit at harvest developed less soft patches. Based on evidence presented in Section 2.2.2., fruit that are firmer at harvest would be expected to be less mature and therefore be softer at the end of long-term storage with a greater incidence of soft patches (Davie, 1997). Lines of fruit that were firmer in this work were not always less mature than softer lines, as indicated by SSC. Therefore, it seems that firmer lines of fruit are not always less mature at harvest and that SSC is not the only critical factor contributing to the initial firmness of fruit. Maturity was implicated in the development of soft patches i.e. fruit with higher SSC appeared to develop less soft patches. This is consistent with the proposition that more mature fruit are firmer after long term storage (Section 2.2.2.) and that firmer fruit at the end of storage develop less soft patches (Davie, 1997). Nitrogen was also implicated in the development of soft patches i.e. fruit high in N tended to develop more soft patches. This is consistent with other research that has found N to be detrimental to the storage behaviour of fruits including kiwifruit (Section 2.3.1.8). Given the apparent associations above, the best storing fruit at harvest would be expected to have high Ca concentrations, SSC and initial firmness with low Mg and N concentrations.

The associations identified in this work between combinations of fruit attributes at harvest and the incidence of soft patches appear to provide some real potential for segregating between good and poor storing lines of fruit. However, further research is required to confirm and determine more fully the nature of these relationships and to identify other factors that may strengthen them. Given that such relationships may be complex (e.g. involve components of non-linearity), biometrical approaches will need to be identified that will provide the best mathematical combinations of fruit attributes that

link to fruit storage behaviour. This will be a key issue in developing robust indicators of fruit storage behaviour.

4.5 Conclusions

The findings from this work are consistent with anecdotal evidence in the kiwifruit industry indicating that organically produced kiwifruit store better than their conventionally produced counterparts. The mechanisms for this difference are not clear although there was some indication that differences in the Ca nutrition of vines could be involved. However, given that the evidence for this was only just significant, further work is required to confirm this.

This work has also indicated that the storage behaviour of kiwifruit is linked strongly to fruit attributes at harvest, especially Ca. If the effects and interactions of those attributes are consistent then they could form the basis of a model that would allow the prediction of fruit softening behaviour. Subsequently, this would allow lines of fruit differing in storage potential to be segregated and marketed accordingly, close to harvest. There would therefore be considerable merit in confirming and developing the relationships that were identified in this work between fruit attributes at harvest and the quality of fruit at the end of long-term storage.

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Chapter 5

General Discussion

5.1 Introduction

Each year, the New Zealand Kiwifruit Industry suffers considerable financial losses due to poor storing fruit. Improving the storage potential of fruit, which was the major focus of this work, would considerably alleviate this problem. The prediction of storage potential at harvest would also reduce losses, as it would allow the segregation and niche marketing of fruit, improving the likelihood of gaining maximum returns on each sub-population.

The inherent storage potential of fruit derives from their composition, structure and physiology at harvest. Identification and manipulation of those attributes at harvest that strongly affect the storage behaviour of fruit, will provide means of improving the storage potential of kiwifruit. This chapter identifies fruit attributes at harvest (Figure 5.1 and 5.2) that are important to the storage behaviour of kiwifruit and the factors that may influence them before harvest. It also discusses the quantitative linkage of fruit attributes at harvest to final fruit quality that would facilitate the prediction of storage behaviour at harvest.

Several postharvest factors that can substantially affect the storage behaviour of kiwifruit are discussed in Section 2.3.2. Their effects are summarised in Figures 5.1 and 5.2. However, given that the focus of this work was on preharvest factors, they are considered only briefly in this discussion.

5.2 Fruit attributes important to the storage potential of kiwifruit

In the literature, only a few attributes have been consistently linked to the softening behaviour of kiwifruit. These include the concentrations of soluble solids (SSC) at harvest and minerals, particularly calcium (Ca; Sections 2.3.1.9 and 2.4). Whole fruit softening did not differ significantly between treatments in this work. This was consistent with the lack of differences in those attributes that have previously been reported to influence the softening behaviour of kiwifruit (Figure 5.1). Had larger differences occurred in some of those attributes, it seems likely that significant differences in softening behaviour may have occurred.

In the current work, Ca was implicated strongly in the storage behaviour of kiwifruit. In particular, fruit with higher concentrations developed less soft patches than fruit with lower concentrations, which is consistent with other work in this area (Davie, 1997). There was also some indication that the concentrations of Mg and N in fruit are important in the development of soft patches. However, the inconsistent relationships that were observed between the concentrations of these minerals and fruit quality suggests that it may be their ratios to other elements that are critical to fruit quality. Nevertheless, all other things being equal, high concentrations of either or both of these elements in fruit is likely to be detrimental to the storage potential of fruit.

Whole fruit softening of kiwifruit has been linked to fruit maturity (as indicated by SSC; Section 2.2.2). The lack of differences in the maturity of harvested fruit and subsequent whole fruit softening prevented this being tested or confirmed in the current work. However, the current work did indicate that SSC might be important in localised softening. In particular, more mature lines of fruit may develop less soft patches which is consistent with the proposition that more mature fruit are firmer after long term storage (Section 2.2.2) and that firmer fruit after long term storage tend to have less soft patches (Davie, 1997). The current work also indicated that the initial firmness of fruit

may be important in the subsequent development of soft patches i.e. firmer fruit may develop less soft patches. However, firmer fruit at harvest would be expected to be less mature and therefore softer after long term storage with a greater incidence of soft patches. It therefore seems that attributes other than SSC are critical to the firmness of harvested fruit. For example, the concentrations of minerals in fruit could be important to the initial firmness of fruit. The phosphate and dry matter contents of fruit have also been implicated in soft patch development (Davie, 1997). However, the contents of these in fruit with and without soft patches were not determined in this work and so their roles have yet to be confirmed.

The remainder of this discussion will focus on inherent factors that influence the storage behaviour of fruit, with particular attention being paid to those factors affecting fruit Ca status, which has consistently been linked to fruit storage behaviour. Other fruit attributes and the factors affecting them are briefly discussed.

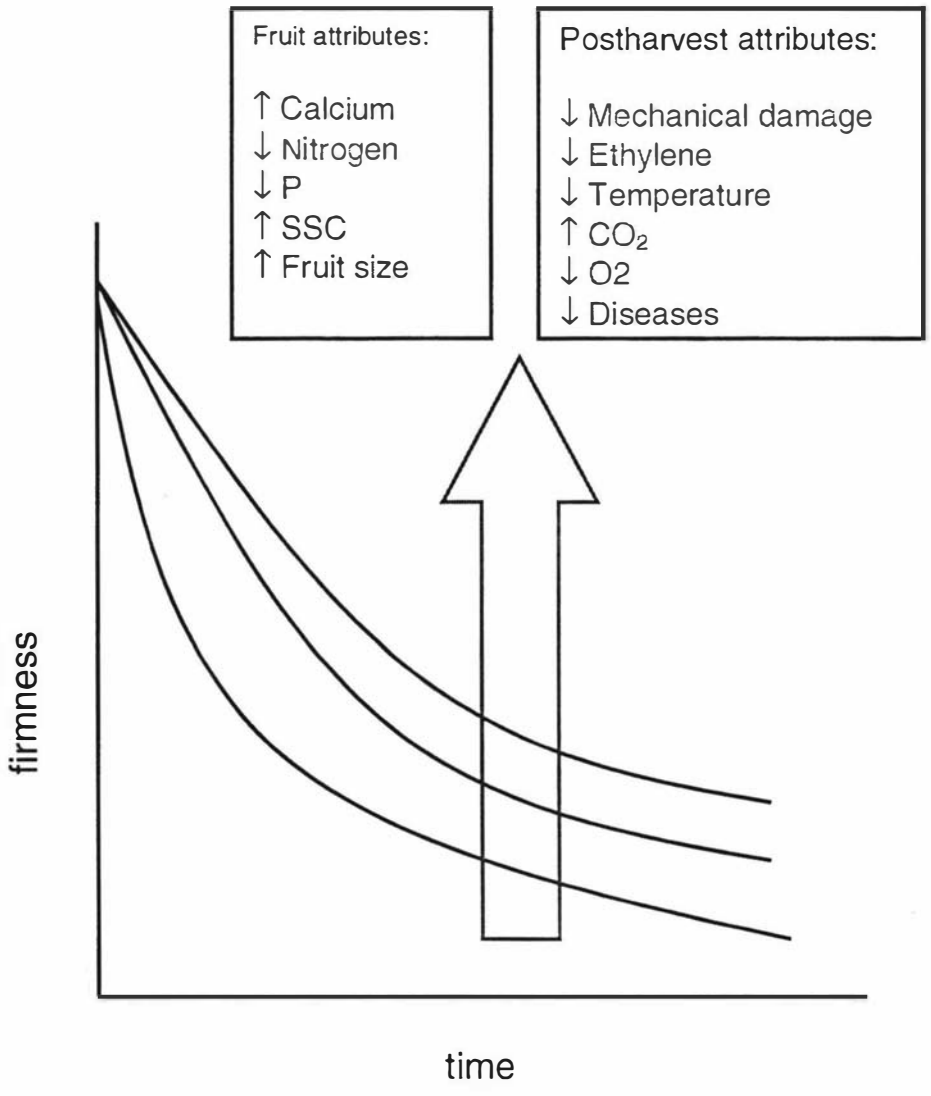

Figure 5.1 Conceptual model of the relationships between 'Hayward' kiwifruit attributes at harvest, postharvest factors and softening behaviour. A shift in the level of the factors in the direction of their associated arrows represents a shift of softening behaviour in the direction of the large arrow. These relationships have previously been reported but were not all explored in this work.

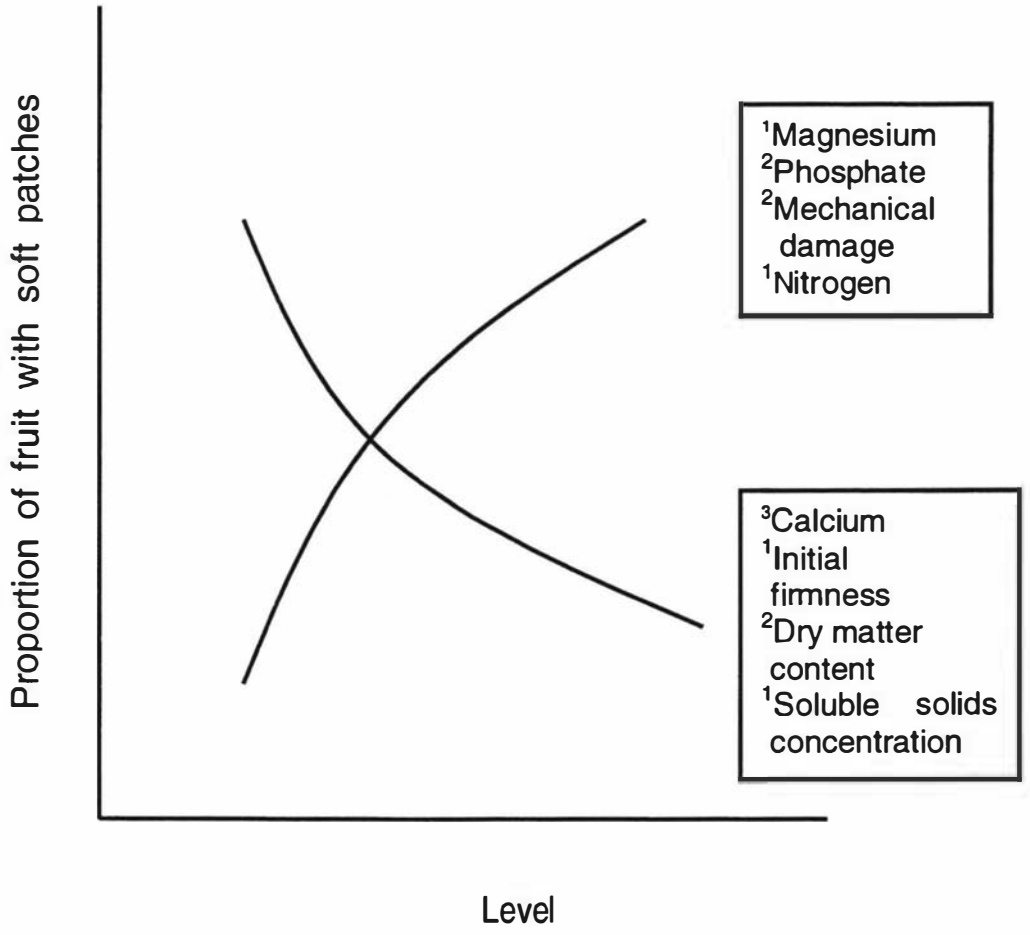

Figure 5.2 Conceptual model of the relationships between 'Hayward' kiwifruit attributes at harvest and the incidence of soft patches (1 = relationships demonstrated in this work; 2 = relationships that have been previously reported but not confirmed in this work; 3 = relationships demonstrated in this and other work).

5.3 Improving the storage potential of kiwifruit

Industry observations, the current work (Section 4.3.2.2) and other research (Hasey et al., 1996) indicate that organically produced kiwifruit store better than their conventionally produced counterparts. The mechanisms for this difference are not clear although they are presumably mediated, at least in part, by differences in one or more of the key attributes described above. Several aspects of the two production systems may contribute to the difference in storage behaviour. During the conception of this work, differences in soil properties were identified as being likely candidates for the difference in storage behaviour. Typically, organic orchards are completely grassed while conventional orchards have, at the very least, herbicide strips. Furthermore, unlike conventional orchards, organic orchards do not use synthetic fertilisers. Therefore, the major focus of the current work was on the effects of ground covers, in combination with organic and inorganic fertilisers, on the storage behaviour of kiwifruit.

The current work was carried out at two sites: the Fruit Crops Unit Orchard, Massey University and the HortResearch Research Orchard, Te Puke. The Te Puke site was used for industry relevance as the majority of kiwifruit are grown in the Bay of Plenty. However, fruit from that site have historically been very good storers and so it was anticipated that soil amendments might result in only minor improvements in storage behaviour. For that reason, the Massey site was also used as fruit from that site historically have generally not stored as well as those from the Bay of Plenty region. Therefore, the effects of the soil amendments on the storage behaviour of fruit were expected to be greater there. As it turned out, fruit from the Te Puke site stored very well. Generally, the Massey fruit also stored well although less well than the Te Puke fruit. The general lack of differences in the storage behaviour of fruit from both sites may have therefore occurred because the fruit from both sites were inherently good storers and so there was little scope for improving the storage potential of those fruit (Figure 5.3). If this were true, then differences in any effects of soil amendments would be expected to be greater for lines of fruit that are inherently poor storers. Hence, there

may be some merit in evaluating the effects of the soil amendments examined in this work at sites that typically produce poor storing fruit.

The effects of soil amendments on soil properties may not be consistent and could vary under different conditions. For example, the process of nitrification at the Massey site in the current work appeared to occur very rapidly. Thus, although a considerable amount of ammonium was added to conventional plots, it was quickly converted to nitrate. In this situation, any antagonistic effects of the ammonium on Ca uptake would have been limited. In situations where the rate of nitrification is slower, the addition of inorganic N to the soil would be expected to have greater antagonistic effects. Hence, while the soil amendments had only minor effects on the composition of vines and the storage behaviour of fruit in this work, their effects might be greater under different soil conditions. This is an important point to consider when explaining differences in the storage behaviour of fruit from different sites, especially sites with similar management practices.

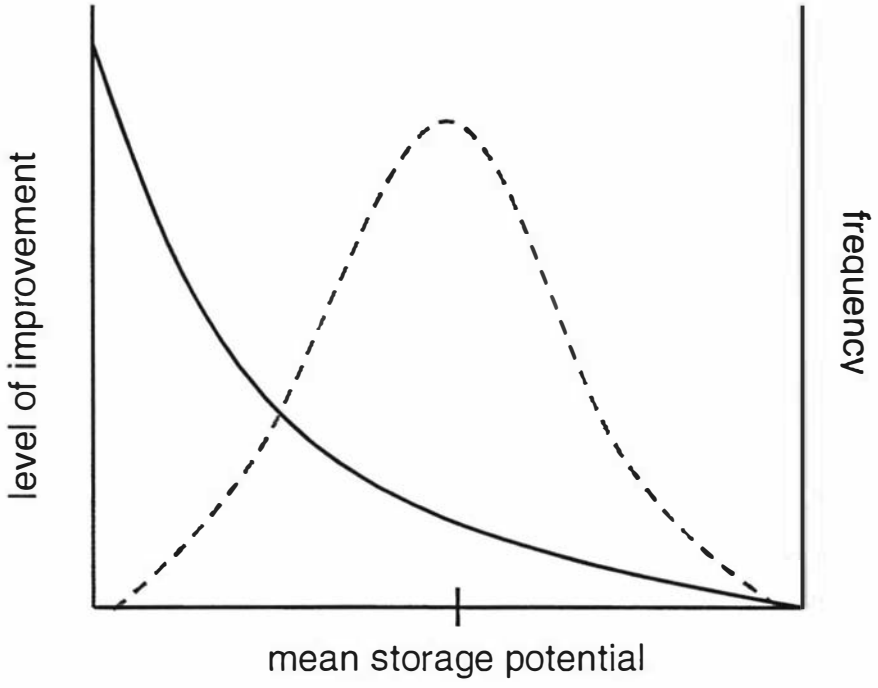

Figure 5.3 Conceptual model of the relationship between variation in the inherent storage potential of kiwifruit lines (dashed line) and the level of improvement that might be achieved in the storage potential of those lines (solid line). According to this model, there is little scope for improving the storage potential of lines to the far right of the mean but considerable scope for lines to the far left of the mean.

Although the storage potential of fruit in this work was largely unaffected by the soil amendments, the incidence of soft patches was significantly reduced by the grass cover. This is consistent with other research that has found that ground covers have generally improved the quality of fruits and in particular, have reduced the incidence of storage disorders (Section 2.3.1.5). The presence of grass in organic kiwifruit orchards may therefore be an important factor contributing to the better storage potential of fruit from those orchards. The grass did not significantly influence whole fruit softening in this work which indicates that localised and whole fruit softening may be driven by different processes.

The mechanism(s) by which grass may improve the storage behaviour of fruit is unclear. Grass may influence the storage potential of kiwifruit by regulating the mineral nutrition of vines and fruit, particularly Ca. However, the average Ca status of the fruit and vines in the current work was not significantly affected by the grass. On that basis it would seem that the mechanism involved in the effects of the grass did not involve Ca. On the other hand, in the pairwise comparison, fruit from organic orchards, which developed less soft patches, often contained more Ca than fruit from conventional orchards, with the average difference being on the borderline of statistical significance ($P \approx 0.06$; Section 4.3.1.3). Thus, Ca may have a role in the development of disorders although other factors may be more critical.

Although the average Ca status of fruit did not differ significantly with ground cover, it is possible that the grass may have reduced the within-vine variation of fruit calcium concentrations. If the existence of adequate calcium concentrations is required to avoid soft patch development, a reduction in variance in calcium contents of individual fruit in a population could substantially affect the incidence of soft patches without affecting mean calcium concentrations (Figure 5.4). However, the calcium contents of individual fruit associated with each of the ground covers were not determined in this work; only composite samples were analysed per plot. That said, the grass did reduce variation in other fruit attributes measured at harvest, particular SSC and initial firmness (data not shown). Therefore, it seems reasonable to speculate that the grass may have also

reduced the variation in the Ca contents of fruit. However, until the Ca contents of individual fruit are actually measured, it is difficult to be confident that differences in the storage behaviour of fruit were due to different levels of variation in the Ca contents of individual fruit. The same proposition could be made for fruit attributes other than Ca. For example, nitrogen has been linked to the development of soft patches and while the average concentrations of this element in fruit did not differ with ground cover, there may have been differences in the variability of nitrogen concentrations in fruit.

It is possible that grass may reduce the variation in the Ca contents of fruit by reducing variation in the rates of transpiration throughout the canopy. Transpiration is the main process driving the transport of Ca into fruit (Section 2.4.4) and is driven by differences in the partial pressures of water vapour between the fruit surface and the air in its immediate environment (Campbell, 1981).

Less heat is radiated from the soil of orchards with sod than from that of orchards that are bare, especially in spring (Hogue and Neilsen, 1987). This may contribute to differences in air temperatures within canopies and more importantly, fruit temperatures; an increase in fruit temperatures would result in an increase in transpiration and Ca accumulation, and vice versa. The amount of heat re-radiated from soils in an orchard depends on the amount of canopy (i.e. leaf area index) present and given that kiwifruit canopies are fully developed during fruit growth, there are likely to be only minor differences in the amount of re-radiated heat under the canopy of vines on bare and grass plots. Variation in the transpiration rates of vines, due to differences in the amount of re-radiated heat under canopies, would be expected to be correspondingly small.

Grass may also reduce variation in transpiration rates throughout a kiwifruit canopy by increasing the relative humidity (RH) of the air around fruit, especially those at the ends of canes nearer the ground; and this particularly applies to fruit grown on T-bar structures. Grass reduces air circulation near the soil surface thereby increasing the humidity – the longer and denser the grass the greater the effect (Geiger, 1965).

Presumably, grass also loses water itself to the surrounding air, which would be expected to further increase the RH of the air around fruit.

An increase in the RH around fruit lower in canopies coupled with a decrease in the surface temperature of those fruit, caused by grass, might result in a transpiration rate that was similar to that for fruit higher in the canopy (Figure 5.5). However, it is difficult to envisage why fruit at different heights in a fully developed canopy would be warmed differently. Further work is therefore needed to test the effects of grass on variation in the temperatures and transpiration rates of fruit throughout vines.

Throughout this work, the effects of mulch on soil properties were similar to those of the grass yet the mulch did not improve the storage potential of fruit. This further indicates that it was not soil properties *per se* but some other influence of the grass, such as those proposed above, that affected the storage behaviour of kiwifruit.

Although the grass consistently improved the storage potential of fruit throughout this work, the findings were based on relatively small experimental units of 2 – 4 vines. If these findings could be repeated on a larger scale then the savings to the industry could be considerable. Therefore, comparing the storage potential of fruit from larger blocks with and without grass (and all other things being equal) appears to have considerable merit.

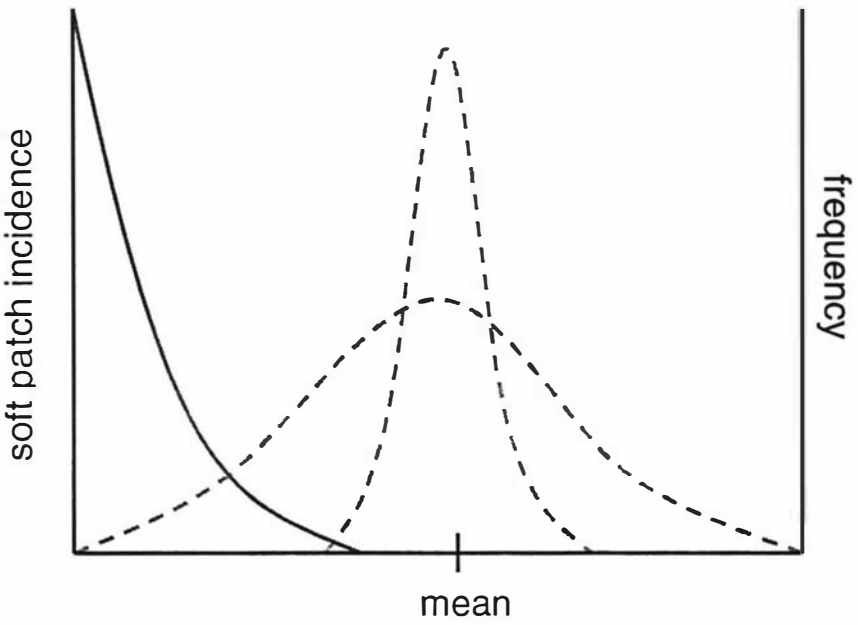

Figure 5.4 Conceptual model of the difference in variation (dashed curves) that may exist in the Ca contents of individual fruit from two populations with the same average. The population with the greatest variance would contain a larger proportion of individual fruit with low Ca concentrations and would therefore have a greater soft patch incidence (solid curve).

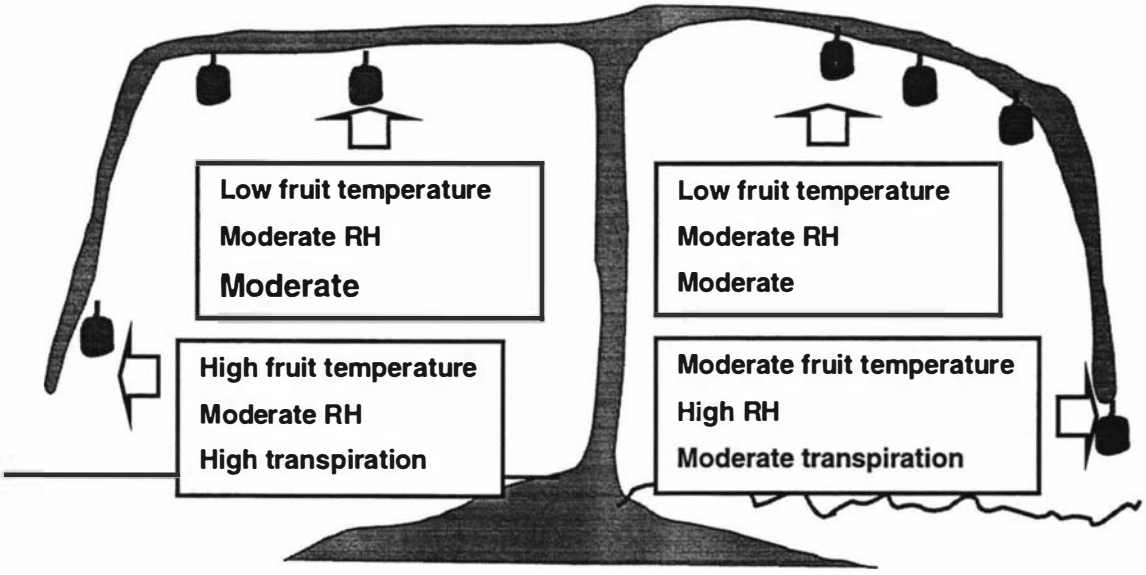

Figure 5.5 Model of proposed differences in the variation in fruit temperature (T) and the relative humidity (RH) of air within the canopies of vines from bare (left-hand side) and grass (right-hand side) plots.

5.4 Enhancing the Ca status of kiwifruit

From this and other research, it seems that enhancing the Ca status of kiwifruit would be beneficial to the storage behaviour of fruit. The next few pages discuss pre-harvest factors that may increase the uptake and concentrations of Ca in kiwifruit (Figure 5.6) and is based upon knowledge gained in the current work.

Firstly, inorganic cations in soils, especially ammonium ions, reportedly antagonise Ca uptake (Section 2.4.6.2). Therefore, minimising the amounts of these in the soil would be expected to favour the uptake of calcium. In this work however, considerable differences in the amount of some cations, including ammonium, in conventional and organic plots did not produce significant differences in the Ca status of vines or fruit, or the storage behaviour of fruit from those plots. It therefore appears that increasing the amounts of competing inorganic cations in the soil will not always be detrimental to the uptake of Ca by kiwifruit vines.

Adequate moisture in the soil is generally thought to assist in the uptake of Ca (Section 2.4.6.8). In this work, both the grass and mulch covers considerably improved the moisture content of the soil but without increasing the average Ca status of the vines from those plots. It would seem that increasing the moisture content of the soil does not necessarily guarantee improved uptake of Ca by kiwifruit vines.

Ca uptake is restricted to younger unsuberised parts of roots (Himelrick and McDuffie, 1983; Ferguson et al., 1987) and so the amounts and distribution of these in the soil would be expected to affect the amount of Ca that is taken up. In this study, the mulch increased the total length of roots near the soil surface but without affecting the Ca status of the vines. This can not have been the result of a lack of Ca near the soil surface in those plots because adding gypsum to those plots increased the amount of Ca near the soil surface but not the Ca status of the vines. It would seem that either not enough unsuberised root was present near the soil surface or that some other factor was limiting the effectiveness of Ca uptake by these roots.

Even though there were considerable differences in several soil factors, the average Ca status of vines and fruit in this work did not differ significantly, especially between conventional and organic plus plots. Adding considerable amounts of Ca to the soil (in the form of gypsum) had only minor effects on the Ca status of vines or fruit. This is consistent with other research that has indicated the difficulty of increasing the concentrations of Ca in trees and vines using Ca fertilisers (Section 2.4.6.2). It was anticipated that this constraint might be overcome by the use of a more soluble, and therefore more readily available, form of Ca than used in the previous work, though this strategy did not appear to be successful in the current work. The increased concentrations of Ca available in the soil solution indicated that increased amounts of Ca were available to the vine, both near the soil surface and to a lesser extent, deeper in the root zone. The current work has therefore indicated that, even when increases in Ca concentration in the soil solution were achieved, significant constraints to increasing Ca uptake remained. However, it has not excluded the possibility that supplemental manipulation of another soil attribute may overcome these constraints. It appears likely that the principal constraints to overall uptake of Ca by a kiwifruit vine operate at the root surface.

It may be possible to enhance the Ca status of kiwifruit vines and fruit by manipulating aerial factors. Transpiration is a key process facilitating the uptake of Ca in plants; increasing the rate of this process in fruit is likely to increase the amount of Ca that they accumulate during growth. Previously, transpirant drying oils applied to kiwifruit have successfully increased the Ca content of those fruit (Davie, 1997). However, applying such sprays to whole vines has decreased the Ca content of fruit, a result that was attributed to water stress induced by those sprays. Since promoting water loss from fruit appears to enhance the uptake of Ca, increasing airflow through an orchard by reducing the density of foliage in the lower parts of shelterbelts may be a practical means of increasing Ca uptake.

Excessive vegetative growth is likely to compete with fruit for assimilates including Ca. Therefore, the Ca status of fruit may be improved by pruning regimes that reduce

vegetative growth. Kiwifruit grown in direct sunlight have been found to contain more Ca than shaded fruit presumably due to differences in the transpiration rates (Antognozzi et al., 1995). Removing excessive vegetative growth is also likely to increase the exposure of fruit to sunlight and further enhance the accumulation of calcium. Removing excessive growth may also promote airflow through the canopy, which could enhance transpiration and Ca uptake.

Ca sprays appear to provide another means of enhancing the Ca status of kiwifruit prior to harvest (Gerasopoulos et al., 1996). However, further research is required to identify the most effective sprays and to optimise the concentrations and frequencies that these should be applied at in a range of growing situations and which are not toxic to the fruit.

At the onset of this work, it was proposed that differences in fertiliser practices contributed significantly to the differences in the storage potential of fruit from organic and conventional production systems. However, it seems that this may not necessarily be the case and that the storage potential of kiwifruit depends on other factors. Instead, differences in orchard floor management may contribute more to differences in the storage potential of organic and conventional fruit, although the mechanisms involved are not yet clear.

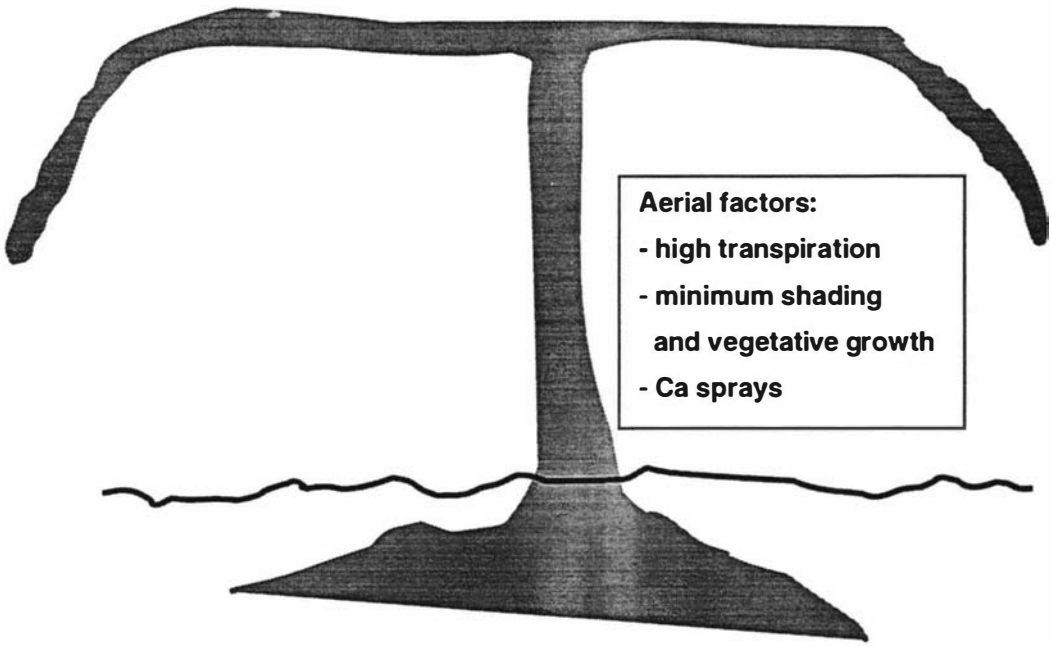

Figure 5.6 Pre-harvest factors thought to enhance the uptake and concentrations of Ca in kiwifruit.

5.5 Prediction of fruit storage potential

Although the general nature of softening in kiwifruit is well established (Section 2.2.2), there is a dearth of information on the modelling of kiwifruit softening behaviour during postharvest storage. This is surprising given the potential to provide the industry with a tool that would allow it to predict the firmness of kiwifruit at any point after harvest. Such a tool would allow lines of fruit that are likely to soften excessively to be identified and sent to market earlier thereby facilitating effective inventory management and reducing fruit losses.

Previously, several models have been used to characterise the softening behaviour of kiwifruit including Complementary Michaelis-Menten (CMM) and Gompertz functions (Davie, 1991 - unpublished). Generally however, these models did not accurately characterise the softening behaviour of fruit in the current work. Instead, quartic polynomial models provided better fits. The problem with these models is that they are largely empirical and do not explain the underlying processes involved in fruit softening. They also contain a relatively large number of parameters that generally have greater uncertainties associated with the estimation of their values, especially when the number of data points is limited. Therefore, while these models may accurately fit the softening behaviour of a given batch of fruit, their predictive capacity is limited. In contrast, parsimonious models, such as the CMM, contain fewer parameters whose values can generally be estimated with greater certainty. Therefore, they have greater predictive capacity and would be valuable in the industry for predicting fruit outturn. However, fruit from different sources appear to have inherently different softening patterns which cannot all be described by parsimonious models. Consequently, there appears to be little scope to identify a global and robust model that accurately predicts fruit softening behaviour, based on characterisation of initial trends in firmness values. However, the current work has indicated other approaches that could be used to predict the final outturn of fruit.

Fruit storage potential must be mediated by fruit compositional attributes at harvest. According to this and other work, Ca in particular is important to the storage potential of fruit and reasonable associations have been identified between the concentrations of Ca in fruit and softening behaviour. Previously, combinations of Ca with other fruit attributes have been linked to the incidence of disorders in kiwifruit (Banks et al., 1994 - unpublished). In the current work, strong associations were identified between combinations of fruit attributes measured at harvest (i.e. indicators), including Ca, and the incidences of soft patches (Section 4.4.3). If such relationships could be shown to be consistent in subsequent work, then they could form the basis of a model that will provide the industry with a tool that will allow it to better manage the variability in the storage behaviour of fruit.

The combinations of the fruit attributes identified in this work that were linked well to the incidence of soft patches were multiplicative and non-linear in nature e.g. $(A_1 \times A_2) / A_3$, where A_n ($n = 1, 2,\ldots$) is a fruit attribute. Identifying the attributes that are most important to storage potential and the best combinations of those attributes could be difficult given the possible complexity of the relationships between the various attributes. Therefore, appropriate biometrical approaches will need to be developed in order to identify the combinations of fruit attributes that will best predict the storage behaviour of fruit. This will be facilitated by a strong understanding of the mechanisms contributing to changes in fruit during storage, especially softening. In this work, multiple regression successfully identified fruit attributes that were strongly linked to the incidence of soft patches and is therefore likely to form the basis of more advanced biometrical approaches that will enable the best indicators of fruit storage potential to be identified.

At the moment, the indicators identified in this work are based on straight compositional attributes. However, it may be possible to build into those indicators attributes that are more representative of the physiological status of the fruit e.g. respiration rate, rate of ethylene production. Such attributes may provide some indication of the rate at which fruit quality is likely to deteriorate and therefore could

improve the ability of the current indicators to predict fruit quality. Relationships between "physiological" attributes and fruit outturn could easily be examined in work that attempts to confirm the relationships already established in this work.

At the moment, it seems that internal fruit attributes are likely to provide the greatest information regarding the storage potential of kiwifruit. Such attributes have traditionally been measured destructively although in recent times, advances in spectroscopy have meant that non-destructive measuring of some of these attributes (e.g. soluble solids concentrations) is now possible (McGlone and Kawano, 1998). The disadvantage with destructive measurements is that they can only be used for predictive purposes on a batch basis. Non-destructive (ND) measurements, on the other hand, allow fruit to be examined on an individual basis and repeatedly. ND measurements are often much more rapid too. Therefore, there is considerable merit in developing ND approaches for the measurement of attributes that are currently measured destructively. The measurement of Ca and other minerals in fruit, non-destructively, would be particularly valuable, especially considering the associations that have been found between mineral concentrations and the storage behaviour of fruit.

5.6 Conclusions

It appears that differences in the storage potential of conventional and organic kiwifruit could be related to differences in orchard floor management. Differences in fertiliser practices may also contribute to differences in storage behaviour, though not always. Grass cover particularly seems beneficial to fruit quality though the reasons for this are not clear. Given that Ca has been and was strongly implicated in the storage potential of kiwifruit, the effect of the grass may be mediated through changes in the Ca nutrition of fruit. In particular, the distribution of Ca to individual fruit within vines could be an important factor influencing outturn from fruit storage.

Enhancing the Ca status of fruit is likely to improve fruit storage behaviour. However, the potential to achieve this through manipulation of the soil environment may be

constrained at the root level under some conditions. Above ground approaches could therefore be more reliable and successful in enhancing the Ca status of fruit.

In addition to improving the storage potential of kiwifruit, losses in the kiwifruit industry could be considerably reduced by identifying and segregating lines of fruit at harvest with different storage potentials. Such an approach will rely upon the identification of fruit attributes that consistently influence the storage behaviour of fruit and the importance of any interactions between those attributes. A promising first step towards the development of such an approach has been made in this work. Given that the interactions between attributes could be complex, it will be essential to develop biometrical approaches that will be able to identify any important interactions that may exist.

5.7 References

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