Carbon storage in kiwifruit orchards to mitigate and adapt to climate change

SFF Project C09/20 Final Report

Allister Holmes, PlusGroup, 37A Newnham Road, RD 4, Tauranga 3174.

Dr Karin Müller, Plant & Food Research, Private Bag 3230, Hamilton 3240.

Dr Brent Clothier, Plant & Food Research, PO Box 11-600, Palmerston North 4442.

Executive summary

Soil organic carbon (SOC) is critical natural capital for primary producers. Higher levels of SOC give a natural advantage to growers, providing storage of water and nutrients, encouraging microbial activity, and imparting resilience to the soil in periods of climatic extremes such as drought or high rainfall events.

This project was undertaken because a key group of industry stakeholders identifying the need to assess the soil carbon stock of New Zealand kiwifruit orchards. In order to assess the SOC stock, it was necessary to develop a practical methodology that would meet the requirements of international guidelines such as PAS 2050: "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services". The methodology that we developed to meet this requirement also allowed for the rapid collection of soil samples at various depths in orchards with minimal soil surface disturbance. Development of this practical collection methodology allowed us to record extensive measurements from 64 orchards throughout NZ.

Using this methodology, we were able to assess the SOC stock of sites under different management regimes, with different kiwifruit cultivars and in different growing regions of NZ. SOC stocks varied between 42.46 t ha^{-1} and 600.84 t ha^{-1}, with the highest average regional SOC stock recorded in Northland and the lowest in Hawkes Bay.

Work comparing two blocks of kiwifruit side-by-side on the same property that had been established 10 and 25 years ago found that the "old" block had 6 t ha^{-1} more carbon sequestered than the "young" block, equating to an annual carbon sequestration rate of 400 kg C ha^{-1} $year^{-1}$, in the top 1 metre of soil. On a different orchard location, we measured SOC stocks to 9 metres deep under 30 year old kiwifruit and adjacent long-term pasture. This kiwifruit orchard sequestered 6.3 tonnes C per hectare per year more than the pasture soil in the top 9 metres of soil. These are significant amounts of C sequestration.

The implication of this finding is that the SOC sequestered each year within the top 1 m of soil equates to about 4% of the emissions of Hayward kiwifruit grown in New Zealand and

consumed in the United Kingdom when a conversion factor of 3.67 is used to convert SOC to CO_2 equivalents. If the top 9 m of soil are included in this calculation then the amount of SOC sequestered equates to about 42% of the emissions associated with growing fruit in New Zealand for consumption in the United Kingdom. Practically, it is likely to be difficult to develop a robust and cost effective methodology based on this depth of sampling. Currently carbon accreditation organizations are undertaking due diligence on this methodology and our findings in regards to the potential for growers to receive carbon credits.

This increase in SOC also gives many production benefits as well as imparting resilience to the effects of both extreme wet and dry periods, which are more likely given predictions of climate changes. Any increase in SOC will improve drainage, root penetration and help reduce compaction, especially critical in regions that have low levels of natural SOC, such as Gisborne, Hawkes Bay and Motueka.

The COST team has provided reports to the owners of the 64 orchards in this study showing the profile of SOC in their orchard vs. the district average, and this reporting has resulted in constructive dialogue around the presence of and ways to increase SOC.

Several of the growers studied are now in the process of implementing practices such as sub-soiling and establishment of deep-rooted sward species to increase SOC based on the findings of this work.

Hayward kiwifruit caused significantly less GHG emissions per kg of fruit in the orchard phase than Hort16A. This is mainly a result of the significantly higher amounts of nitrogen fertilizers applied in Hort16A compared with Hayward. The emissions associated with fertilizers and composts were the most important hot-spots for both varieties. Taking the economic aspect of production into consideration, a NZ$ of profit from Hayward or Hort16A production caused similar GHG emissions. In other words, the eco-efficiency of Hayward Green was comparable with that of Hort16A Gold. Comparing the GHG emissions of the two management systems, integrated and organically grown kiwifruit production, we found that the carbon footprint of organic production was only slightly lower than that of integrated production. However, this environmental advantage was not reflected in the eco-

efficiency. On the contrary, integrated kiwifruit production was slightly more eco-efficient than organic production due to the higher yields of integrated production. .

If SOC were measured to the depth of 30 cm, as required under the Kyoto Protocol, only 34.5% of the SOC in the top 9 metres of kiwifruit soils would be measured, as opposed to 60.6% of the SOC in pasture.

The kiwifruit industry has used the presence of this project and its findings in its annual sustainability report. This has proved valuable as retail customers have wanted to better understand the ability of the New Zealand kiwifruit industry to continue to supply in the future without being constrained by a loss in soil productivity or increased vulnerability to climatic events.

During the course of this work, we have worked with various regional councils to confirm the pedology of the study sites, and this engagement has been beneficial to all parties.

This work has attracted the interests of other perennial tree crop industries, as the methodology developed is readily transferrable to other crops.

We have communicated the findings of this work at a number of conferences, and in publications, as well as on the www.plusgroup.co.nz website.

Now that we have completed this report, we plan to present our findings at a range of conferences, as well as through a range of popular and scientific publications.

By extrapolating the findings of our study, we estimate that the New Zealand kiwifruit industry sequesters about 90,000 tonnes of carbon annually on orchard to 9 metres deep.

Acknowledgements

Without the help and cooperation of all the growers we visited, interviewed and took soil samples from their orchards, this work would not have been possible. We thank them for the generosity with their time, access to their orchards and interest in the project.

Tim Oliver and Brian Cantlon as grower representatives on the project team

Helen Percy and Janine Alfeld as Senior Project Advisors, SFF

Dani Guinto and the Bay of Plenty Regional Council

Alistair Mowat, Jayson Benge, Richard Pentreath and ZESPRI Limited

Dr Markus Deurer, formerly of Plant & Food Research

Hawkes Bay Regional Council

Tasman District Council

Waikato Regional Council

Northland Regional Council

Steve Saunders, Managing Director PlusGroup Limited for his vision to instigate this project

Alan McCurran and other PlusGroup staff

Dr Hasinur Rahman formerly employed by PlusGroup

Funded by:

Sustainable Farming Fund

Ministry of Agriculture and Forestry

Te Manatū Ahuwhenua, Ngāherehere

Zespri® Kiwifruit

Contents

List of tables

List of figures

1. Introduction

Kiwifruit is the fruit of a perennial woody vine. The largest population of kiwifruit worldwide is the *Actinidia deliciosa* cultivar Hayward, a green-fleshed fruit. Kiwifruit is one of the New Zealand's highest earning horticultural exports. Export earnings for New Zealand grown kiwifruit were $1.122 billion over the 2011-12 year. The major kiwifruit growing areas in New Zealand are Te Puke, Tauranga, Katikati, Eastern BOP, Gisborne, Hawkes Bay, South Auckland, Northland, Waikato and Motueka. In New Zealand, 9,336 hectares of *Actinidia deliciosa* Hayward is under integrated management, and 576 hectares grown according to BIO-GRO organic standards. For *Actinidia chinensis* Hort16A, a gold-fleshed fruit, the areas total 2,590 hectares (Zespri Group Limited Annual Review, 2012).

Management practices designed for carbon storage in kiwifruit orchards, and other perennial tree crops, are potential tools for New Zealand growers to mitigate and adapt to the consequences of climate change. In particular, growers in existing growing regions will need to be more resilient to climate related impacts associated with warmer temperatures, scarcer water resources and a greater risk of extreme storm events. National and international initiatives to reduce rising atmospheric concentrations of greenhouse gases (GHG) include encouraging growers and other value chain stakeholders to reduce the GHG emissions associated with the production of their products and services. Changes in management methods could enable growers to meet eco-verification market demands for products with a low carbon footprint, and potentially exploit the emerging business opportunity in carbon storage.

The estimation of carbon (C) storage is very important in the context of greenhouse gas balance assessment, and how soil C dynamics exerts its influence on the global C cycle (Tremblay et al., 2006, Ouimet et al., 2009). The potential of using soil organic carbon (SOC) as an indicator of soil quality and functioning and a broader indicator of ecosystem services responses to environmental changes has reinforced the importance of having appropriate techniques to measure accurately SOC concentrations and to predict adequately the C storage in soils. The choice of methodology for C assessment is critical to the accurate quantification of SOC concentration, content and change over time (Perie and Ouimet, 2008). The 2011 version of the PAS 2050: "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services" still does not account for soil C, but the

proposed ISO 14067 protocol for carbon foot-printing will address soil carbon change, carbon storage and carbon sequestration.

SOC stock is the biggest ecosystem carbon reservoir in the world. Estimates for this stock in the top 1 metre of soil range between 1500 and 2000 Pg C (Batjes, 1996; IPCC, 2007). It has been suggested that a good estimation of carbon pools in the soils, and how they can be maintained, or better enhanced, could help mitigate atmospheric CO_2 increases and anticipated changes in climate (Batjes et al., 1997; Lal et al., 1998). Regional and global estimates of soil C stocks can be determined by extrapolating the means of soil carbon content for broad categories of soil types or vegetation across the areas occupied by those categories (Batjes, 1996; Bernoux et al., 2002). To calculate the total amount of carbon per hectare of land, it is important that the soil bulk density of the soil profiles has been used (Fang et al., 1996). In New Zealand, our multi-institute research programme called the Sustainable Land Use Research Initiative (SLURI) has calculated that 17% of our nation's GDP is reliant on the top 150 mm of soil (Kirkham et al., 2007). This natural capital stock underpins our economic future.

Most kiwifruit grown in New Zealand is grown on Andisols, soils mainly derived during the weathering of tephra and other parent materials with a significant amount of volcanic glass (Lowe & Palmer, 2005). These have many distinctive properties that are rarely found in soils from other parent materials under similar conditions, including high contents of organic matter, high porosity, low bulk density and a high water holding capacity. Allophane and imogolite are key minerals of the Andisols in the Bay of Plenty, with allophane being an extremely reactive sphere and therefore, the soils have high P-retention and the tendency to bind organic carbon. Also, the turnover of soil organic material is slower than in non-allophanic soils (Parfitt, 1990 & 2009). The allophanic Andisols are very important for agriculture and for studies investigating carbon sequestration as they occur predominantly in the North Island volcanic ash in New Zealand and over 32,100 km^2 comprising about 12.5% of NZ soils (Lowe et al., 2005).

a. Problem

Globally, concern about food security is high due to growing demand from population growth, rising energy related costs, vulnerability to extreme events as well as degradation of soil and water resources. In offshore markets, there is also growing concern that many existing land management practices for food production are releasing additional carbon into the atmosphere; thereby contributing to greenhouse gas emissions. At a global scale, past and current conversion of natural forests and grasslands to agriculture has resulted in an increase in carbon emission associated with oxidation of wood debris and soil carbon. Subsequent forest growth has largely balanced these emissions in temperate regions (Houghton, 1999). However, ongoing energy intensive food production on agricultural land does result in a net increase in carbon emissions through this land use. By demonstrating that in New Zealand the production of perennial fruit crops, such as kiwifruit, can enhance or maintain carbon storage and reduce overall carbon emissions associated with the land use then greater differentiation of our products in environmentally concerned markets such as Europe, and increasingly in Asia, may be possible. The New Zealand government and regional councils are also under ever-increasing pressure from international treaties and taxpayers to improve their environmental stewardship.

Carbon storage within orchard systems could be recognised as a progressive step in environment management. Furthermore, it may play a role in lowering the risks of more environmental legislation that could result in increased compliance costs and less entrepreneurial flexibility. The project quantifies how much the environment benefits from carbon storage in kiwifruit orchards, thereby providing stewardship for the environment and public good. Higher soil carbon content increases the soil's functioning to filter excessive amounts of nutrients and contaminants. It can also reduce the run-off of nutrients and erosion, as well as acting as a net sink for greenhouse gases, and can reduce the need for precious water resources for irrigation during droughts. Regional councils (e.g. Waikato Regional Council) are monitoring soil carbon contents to monitor trends in soil health and its public good role of offering environmental benefits and valuable ecosystem services. Currently, there is no standard methodology to verify any claims of carbon storage in kiwifruit orchards that might be needed in future stewardship initiatives, or to participate in carbon trading schemes.

b. Mitigation

This project calculates the rate of carbon sequestration and the carbon footprint of the orchard phase of the life cycle in both Hayward and Hort 16A orchards, and orchards with different soil types and management practices. More soil carbon increases the storage of water and supply of nutrients, and in turn this would reduce the energy-related carbon footprint of irrigation and fertilizers, increase the water use efficiency of the production, and reduce the application of nitrogen fertilizer that causes direct and indirect emissions of nitrous oxide. All of these functions would help New Zealand kiwifruit producers to manage input costs while reducing environmental and climatic related risks as well as continuing to be considered as a leading supplier of sustainably produced food.

c. Adaptation

Supermarkets, consumers and governments are increasingly starting to value financially environment-related impacts of production. In many cases, these measures provide a means to assess the overall sustainability of a given food supply chain. This is becoming more important in a competitive environment where food supply occurs under a range of constraints. Under these conditions, retailers want to ensure that they can secure reliable sources of food at reasonable prices ahead of their competitors. Carbon storage management could help New Zealand growers to adapt to new market requirements, grow existing market segments or contribute to a price eco-premium. Findings from this project will assist growers in the development of their environmental stewardship as well as demonstrate proactive leadership in the primary industry as it adapts to climate change. This could help avoid additional environmental legislation, including the resulting compliance costs, and enable them to take advantage of any carbon trading schemes that might become commonplace.

d. Opportunities

Generally, higher soil carbon contents increase the soil's ability to filter excessive amounts of nutrients and contaminants, to mineralize nutrients, to reduce the run-off of nutrients and erosion, to act as a net sink for greenhouse gases, and to reduce the need for precious water resources (Deurer et al., 2011). We expect that higher soil carbon contents will

reduce production costs for New Zealand kiwifruit growers. Soils with higher carbon contents have more macro-pores that lead to a better aeration of wet or irrigated soils, and are consequently a safeguard against the occurrence of root diseases such as *Armillaria*, and possibly the conditions that make kiwifruit vines more vulnerable to *Pseudomonas syringae* pv. *actinidiae* (Psa). This is particularly important in the case of kiwifruit as the vine has a low tolerance to root anoxia associated with water logging and inundation by floodwaters.

The project quantified the carbon footprint of the orchard phase of kiwifruit production. An ability to lower the carbon footprint of a given product such as kiwifruit may become a means to enter specific markets or to maintain price premiums. Therefore, New Zealand kiwifruit growers could adapt a specific set of carbon-storage management practices as one of several possible strategies to achieve a lower carbon footprint and ensure “shelf access” in premium supermarkets. By incorporating this quantification into international and national certification standards, the risk of “green-wash” associated with weak environmental claims will be eliminated. In future, with markets that trade carbon, New Zealand kiwifruit growers may well profit directly from carbon sequestered in their soils.

2. Main objectives

We set out to quantify above- and below ground carbon storage, including its environmental and economic implications in kiwifruit orchards. We hypothesized that carbon storage offers mitigation for climate change and enhances water and nutrient use efficiency; thereby providing adaptation to climate change. Better knowledge of carbon storage will contribute to the eco-verification of New Zealand's image of "clean-green" kiwifruit. The objectives of this work were to:

1. Design a methodology to sample carbon storage in kiwifruit orchards
2. Quantify the carbon storage in kiwifruit orchards with different management, cultivars and soil texture
3. Quantify the rate of carbon sequestration over time
4. Quantify the carbon storage in kiwifruit orchards with the same management and cultivar in different regions
5. Quantify the carbon footprint of the orchard phase of kiwifruit production
6. Survey two different cultivars (Hayward, Hort 16A), two soil textures (coarse and fine), and two different types of orchard management (BIO-GRO certified organic, integrated) in the Bay of Plenty
7. Survey three orchards with a single factor combination of either integrated or Hayward in Northland, South Auckland, Waikato, Eastern Bay of Plenty, Gisborne, Hawke's Bay and Motueka
8. Develop and disseminate guidelines for growers on economically and environmentally sustainable carbon storage

3. Identify a robust sampling framework for characterising carbon storage in kiwifruit orchards

As there is no standard methodology to verify any claims of carbon storage in kiwifruit orchards, one of our initial objectives was to develop a robust sampling protocol to quantify soil carbon stocks in kiwifruit orchards. Our hypothesis for this preliminary work was that the depth distribution of soil carbon stocks will be different in “young” and “old” kiwifruit orchards and that the vine row and grass alleyway need to be sampled separately. We identified two blocks that were representative for many kiwifruit orchards in the Bay of Plenty (BOP) on an orchard located in Te Puke. The soil is a Typic Orthic Allophanic Soil (Hewitt 1998) with a loamy texture. One of the blocks was established 10 years (young) and the other 25 years (old) ago. These adjacent blocks have received the same management practices and have the same soil type and climate. We sampled the SCS of each block from the soil surface to 1 m depth in six depth increments. Results were presented in Deurer et al. (2010), with the key results and preliminary conclusions being:

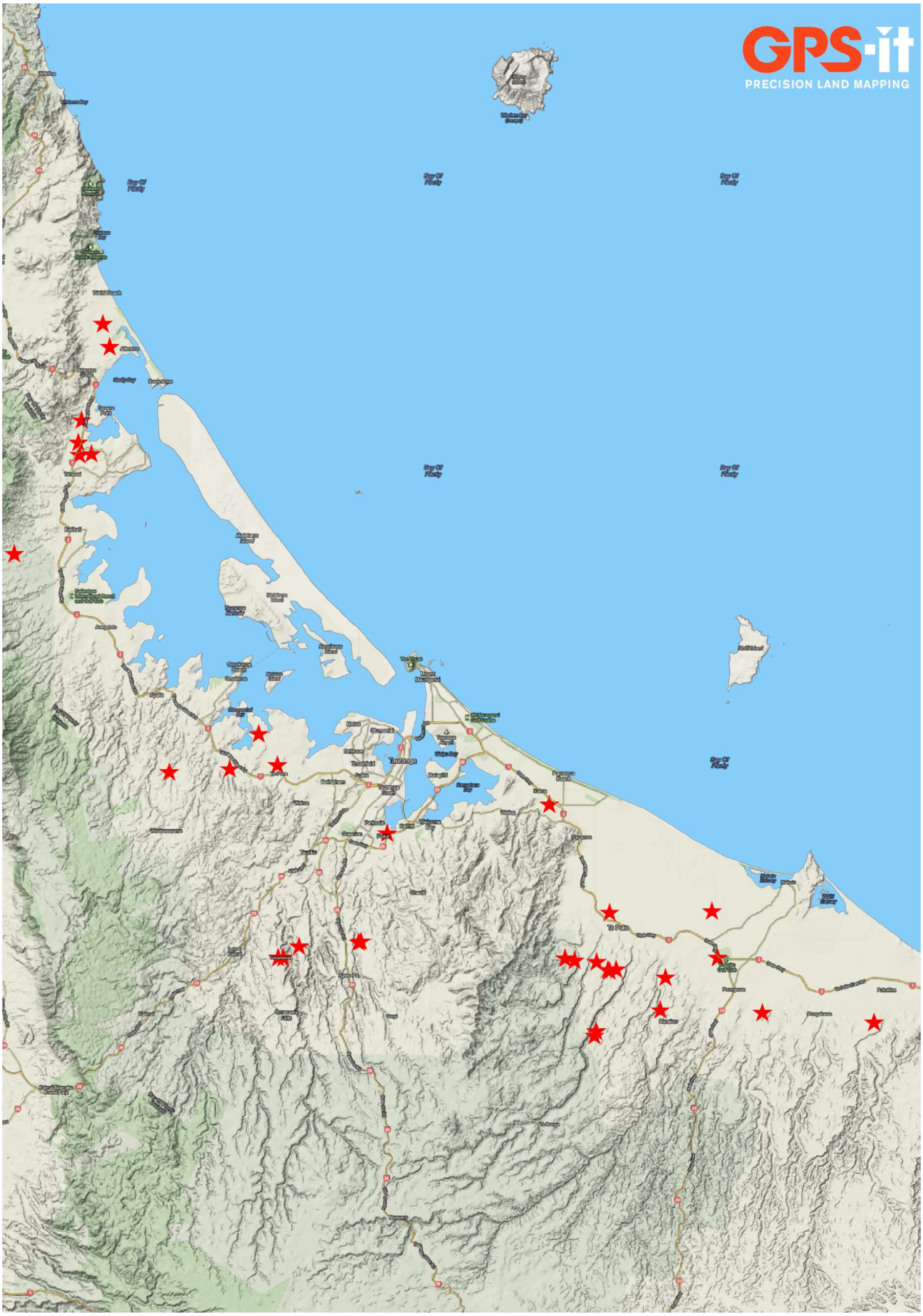
1. The “young” kiwifruit block stored 139 t C ha^{-1} and the “old” block 145 t C ha^{-1} to 1 m depth. For both the young and old block, 80-90% of the soil carbon stock was stored in the top 0.5 m and 89-95% in the top 0.7 m. A maximum depth to 0.5 m is sufficient for a general soil carbon stock inventory and 1 m if temporal or spatial soil carbon stock dynamics are of interest.
2. With a maximum sampling depth of 0.5 m, there was no significant difference between the soil carbon stock in row and alley. In orchard blocks without herbicide used in the rows, the vine row and grass alleyway need not be separately sampled.
3. We found a CV of 5-15% and, therefore 4-10 cores are needed to have at least 80% confidence in the estimated SCS.
4. We recommend separating each core from the top to the bottom into 0-0.1, 0.1-0.3, and 0.3-0.5 m depths for a general inventory. If the dynamics of the soil carbon stock are of interest, we recommend adding another increment 0.5-1 m depth.
5. We could detect a weak spatial pattern of the soil carbon stock only for the “old” kiwifruit block. The pattern had a size (= range) of about three metres. Additionally, the pattern periodically recurred every 5.5 m, which is about the distance between

kiwifruit vines in the row. We recommend that a sampling bay along a vine-row should have a maximum length of 3 m.

4. Quantify carbon storage in kiwifruit orchard systems with different carbon management

Before selecting the 40 orchards on which to undertake the extensive soils research and grower survey, we visited more than 200 kiwifruit orchards across the Western Bay of Plenty region and recorded the history including plant species, cover crops, shelterbelts, herbicide strip etc. We extensively surveyed the carbon storage in 40 different kiwifruit orchards in the Western Bay of Plenty according to our methodology.

Figure 1. Map showing locations of the kiwifruit orchards included in the Western Bay of Plenty study.



The technical specification for selecting sampling areas in a chosen orchard was based on the European Commission EUR 21576 EN/2 Protocol. Orchards of less than five hectares had three sampling sites established, and orchards of 5-10 hectares had four sampling sites established. No orchards in the forty-orchard group were greater than 10 hectares. Where an orchard contained more than one variety of kiwifruit, the area of the kiwifruit variety to be sampled determined the number of samples drawn.

Three vines were selected in the orchards not immediately adjacent to shelterbelts, roadways or other atypical features; and a 3 m by 3 m grid was laid out. The 3-metre grids were used, as in our preliminary work we found a weak spatial pattern repeating every 3.1 metres in older (25 year plus) kiwifruit orchards. Recording the GPS coordinates of this grid allowed us to return to the same grid for later sampling.

Non-destructive soil samples were taken immediately outside the grid in the centre of the grass alleyway. These samples were not taken in the grid in order to minimize disturbance of the soil inside the grid as this may later be sampled.

Tables 1 to 3 summarize the descriptive statistics of the SOC stocks in the different soil depths and for the three chosen impact factors, i.e. kiwifruit variety, orchard management and soil texture.

Table 1. Soil organic carbon stocks in kiwifruit orchards in three depths, 0-0.3, 0.3-0.5 and 0.5-1 m and integrated to 1 m depth separated into orchards growing Hayward or Hort16A. Averages followed by a different letter are significantly different at a confidence level of 95%.

		Kiwifruit Variety	
Depth (m)	**Summary of Statistics**	**Hayward**	**Hort16A**
0-0.3	Mean (t ha^{-1})	120.74a	121.98a
	Minimum (t ha^{-1})	73.08	76.37
	Maximum (t ha^{-1})	163.81	168.20
	Standard deviation (t ha^{-1})	24.86	20.37
	Coefficient of Variation (%)	20.59	16.70
0.3-0.5	Mean (t ha^{-1})	38.75a	37.79a
	Minimum (t ha^{-1})	17.77	24.54
	Maximum (t ha^{-1})	54.55	58.62
	Standard deviation (t ha^{-1})	10.07	9.40
	Coefficient of Variation (%)	25.98	24.87
0.5-1	Mean (t ha^{-1})	40.42a	41.73a
	Minimum (t ha^{-1})	10.79	22.22
	Maximum (t ha^{-1})	65.17	96.41
	Standard deviation (t ha^{-1})	14.17	16.94
	Coefficient of Variation (%)	35.05	40.59
0-100	**Mean (t ha^{-1})**	**199.29a**	**200.98a**
	Minimum (t ha^{-1})	**113.95**	**127.46**
	Maximum (t ha^{-1})	**273.28**	**321.99**
	Standard deviation (t ha^{-1})	**44.06**	**40.66**
	Coefficient of Variation (%)	**22.28**	**20.23**

Table 2. Soil organic carbon stocks in kiwifruit orchards in three depths, 0-0.3, 0.3-0.5 and 0.5-1 m and integrated to 1 m depth separated into orchards managed as integrated or organic orchards. Averages followed by a different letter are significantly different at a confidence level of 95%.

		Management System	
Depth (m)	**Summary of Statistics**	**Integrated**	**Organic**
0-0.3	Mean (t ha^{-1})	120.23a	122.49a
	Minimum (t ha^{-1})	73.08	97.56
	Maximum (t ha^{-1})	168.2	163.81
	Standard deviation (t ha^{-1})	25.59	19.50
	Coefficient of Variation (%)	21.28	15.92
0.3-0.5	Mean (t ha^{-1})	38.75a	37.79a
	Minimum (t ha^{-1})	17.77	24.54
	Maximum (t ha^{-1})	54.55	58.62
	Standard deviation (t ha^{-1})	10.07	9.4
	Coefficient of Variation (%)	25.98	24.87
0.5-1	Mean (t ha^{-1})	40.81a	41.33a
	Minimum (t ha^{-1})	10.79	25.34
	Maximum (t ha^{-1})	96.41	65.17
	Standard deviation (t ha^{-1})	18.79	11.56
	Coefficient of Variation (%)	46.05	27.97
0-100	**Mean (t ha^{-1})**	**198.92a**	**201.35a**
	Minimum (t ha^{-1})	**113.95**	**158.37**
	Maximum (t ha^{-1})	**321.98**	**272.48**
	Standard deviation (t ha^{-1})	**51.24**	**31.59**
	Coefficient of Variation (%)	**25.76**	**15.69**

Table 3. Soil organic carbon stocks in kiwifruit orchards in three depths, 0-0.3, 0.3-0.5 and 0.5-1 m and integrated to 1 m depth separated into orchards with fine or coarse texture. Averages followed by a different letter are significantly different at a confidence level of 95%.

		Soil texture	
Depth (m)	**Summary of Statistics**	**Coarse**	**Fine**
0-0.3	Mean (t ha^{-1})	121.68a	121.06a
	Minimum (t ha^{-1})	73.08	88.47
	Maximum (t ha^{-1})	168.2	160.69
	Standard deviation (t ha^{-1})	28.31	15.71
	Coefficient of Variation (%)	23.26	12.98
0.3-0.5	Mean (t ha^{-1})	37.32a	39.56a
	Minimum (t ha^{-1})	18.82	17.77
	Maximum (t ha^{-1})	55.04	58.62
	Standard deviation (t ha^{-1})	9.55	9.59
	Coefficient of Variation (%)	25.60	24.23
0.5-1	Mean (t ha^{-1})	43.04a	38.66a
	Minimum (t ha^{-1})	17.48	10.79
	Maximum (t ha^{-1})	96.41	62.2
	Standard deviation (t ha^{-1})	17.48	12.39
	Coefficient of Variation (%)	40.60	32.03
0-100	**Mean (t ha^{-1})**	**198.76a**	**201.81a**
	Minimum (t ha^{-1})	**113.95**	**116.90**
	Maximum (t ha^{-1})	**321.95**	**269.60**
	Standard deviation (t ha^{-1})	**50.28**	**30.81**
	Coefficient of Variation (%)	**25.29**	**15.27**

While the SOC stocks tended to be slightly higher in the Hort16A orchards than in the Hayward orchards, with the exception of the depth 0.3-0.5 m, these differences were not significant (P<0.05) in any of the three soil depths analyzed (Table 1). Bulk density tended to be higher in the Hort16A kiwifruit orchard soils than the Hayward orchard soils, while SOC concentrations showed the opposite pattern. Both parameters, SOC concentrations and bulk density, were not significantly (P<0.05) different in the soils of different kiwifruit varieties at any of the depths investigated. The variability of SOC stocks was highest in the lower subsoil (Table 1). This related to the higher variability of the SOC concentrations at this depth. As expected, the orchards under organic management generally had slightly higher SOC stocks than the orchards under integrated management practice. Again the differences were not significant (P<0.05; Table 2) in any of the three depths. While SOC concentrations tended to be slightly lower in the organic orchards than the integrated orchards, bulk density showed the opposite trend. None of the differences was significant at the 95% confidence level. This supports the results of Benge et al. (2007), who similarly found no impact of orchard management on carbon concentrations in the top 30 cm of kiwifruit orchard soils in New Zealand. With regard to the impact of soil texture on carbon stocks, we found no pattern and no significant difference between the SOC stocks of soils with different textures (Table 3).

We hypothesized that SOC stocks would be higher under Hort16A than under Hayward kiwifruit orchards because Hort16A vines have a more vigorous growth than Hayward vines, and therefore produce more litter. Leaves and canopy that are mulched after pruning was thought to increase SOC concentrations in the soils. However, this was not found in this study, which supports the findings of Kong et al. (2010), who found residue-derived carbon was generally respired rather than sequestered. In addition, it is possible that the vigorous growth of Hort16A, which can lead to more shaded sward conditions, will result in more competition for water and nutrients for the understory plants compared to Hayward orchards, so that the overall combined carbon input of kiwifruit and understory plants is comparable in both kiwifruit varieties.

Carbon concentrations in soils are the result of carbon inputs driven by plant productivity and carbon management practices, such as compost and manure applications and tillage practices, as well as the process of carbon decomposition. Soil carbon management is a key success factor for organic orchards. Soil organic matter is the main source of the major plant nutrients, and for nitrogen, it is the only supply. Because of this, external carbon inputs into soils are generally higher in organic than integrated production systems (Fliessbach, Oberholzer, Gunst, & Mader, 2007). Usually organically managed orchards are not only reliant on the cycling of nutrients within the system, but also on regularly applied external organic matter, for example, in the form of large amounts of compost or manure. An organic management system generally also relies on less frequent mowing than in an integrated orchard and does not use herbicide for weed control. This may lead to deeper rooting of the understory vegetation in organic compared to integrated orchards. We assumed that these higher carbon inputs through the understory vegetation and organic matter applications would also result in higher SOC concentrations, however, this was not found in this study. This could again be a consequence of the residue-root exudates findings of Kong et al. (2010). In addition, it takes time before changes to different management systems can be noticed in soil carbon stocks, especially at deeper depths (Schipper et al., 2007). We do not have information on the time of conversion for the 20 organic orchards included in our study. Moreover, the differentiation between organic and integrated management practices is not very clear: Many of the integrated growers included in this study also applied compost to their orchards. All orchards included in this study had grassed alley areas. On the other hand, integrated orchardists apply synthetic nitrogen, which is not allowed in certified organic management systems. This will not only increase aboveground productivity but also affect the belowground productivity contributing to carbon stocks, especially at larger depths.

5. Carbon sequestration over time

Specific work undertaken to develop the sampling strategy for this work (Deurer et al., 2010) compared two blocks of kiwifruit side-by-side on the same property that had been established 10 and 25 years. This analysis is called a “space-for-time” method. They found that the “old” block had 6 t ha^{-1} more carbon sequestered than the “young” block. This then equates to an annual carbon sequestration rate of 400 kg C ha^{-1} $year^{-1}$, in the top 1 metre of soil. This is a significant amount of C sequestration.

At a different orchard location, outlined in detail later in this report, we measured SOC stocks to 9 metres deep under 30 year old kiwifruit and adjacent long-term pasture. This work indicates that the kiwifruit orchard had sequestered 6.3 tonnes C per hectare per year more than the pasture soil in the top 9 metres of soil.

Based on these results we selected a group of 40 orchards that had been established from between 1 to 49 years to obtain a temporal continuum of orchards to estimate the rate of sequestration of carbon in kiwifruit orchard soils. However, no correlation was found between the levels of SOC in the top 1 metre of soil and the years that the orchard had been established, as opposed to the findings of Deurer et al. (2010). The affects of differences in soil, climate and management practices may have over-ridden the factor of age of the orchard. It is possible, however, that if the SOC was sampled to a deeper depth, a correlation may be present, because SOC in the surface soil is constantly recycling and supplying the microbial processes that maintain soil health.

This work is just one case study, but it provides a baseline result of SOC stocks in kiwifruit orchards throughout the growing regions of New Zealand. By returning to these 40 orchards in as little as five years (in 2015), we should be able to measure whether there has been significant changes in SOC stocks. These findings will validate the rate of carbon sequestration calculated from the two exploratory studies above.

6. Quantify the carbon storage in kiwifruit orchards with the same management and cultivar in different regions.

Soil organic carbon (SOC) concentrations and stocks were measured to a depth of 1 m in kiwifruit orchards in New Zealand's eight major kiwifruit growing regions, viz. Western Bay of Plenty, Eastern BOP, Gisborne, Hawkes Bay, South Auckland, Northland, Waikato and Motueka. The sites were all producing Hayward kiwifruit using an integrated management system.

The results showed that SOC stocks varied between 42.5 t ha^{-1} and 601 t ha^{-1}. The highest average regional SOC stock was recorded in Northland and the lowest in Hawkes Bay. They regionally ranked as Northland > South Auckland > Western Bay of Plenty > Waikato > Eastern BOP > Gisborne > Motueka > Hawkes Bay. From this work, the total carbon stock in the top 1 metre of kiwifruit orchard soils in New Zealand was estimated to be 2,240,760 tonnes. This is a natural capital stock that must be maintained and, better still, enhanced.

Figure 2. Map showing location of NZ regional study orchards.

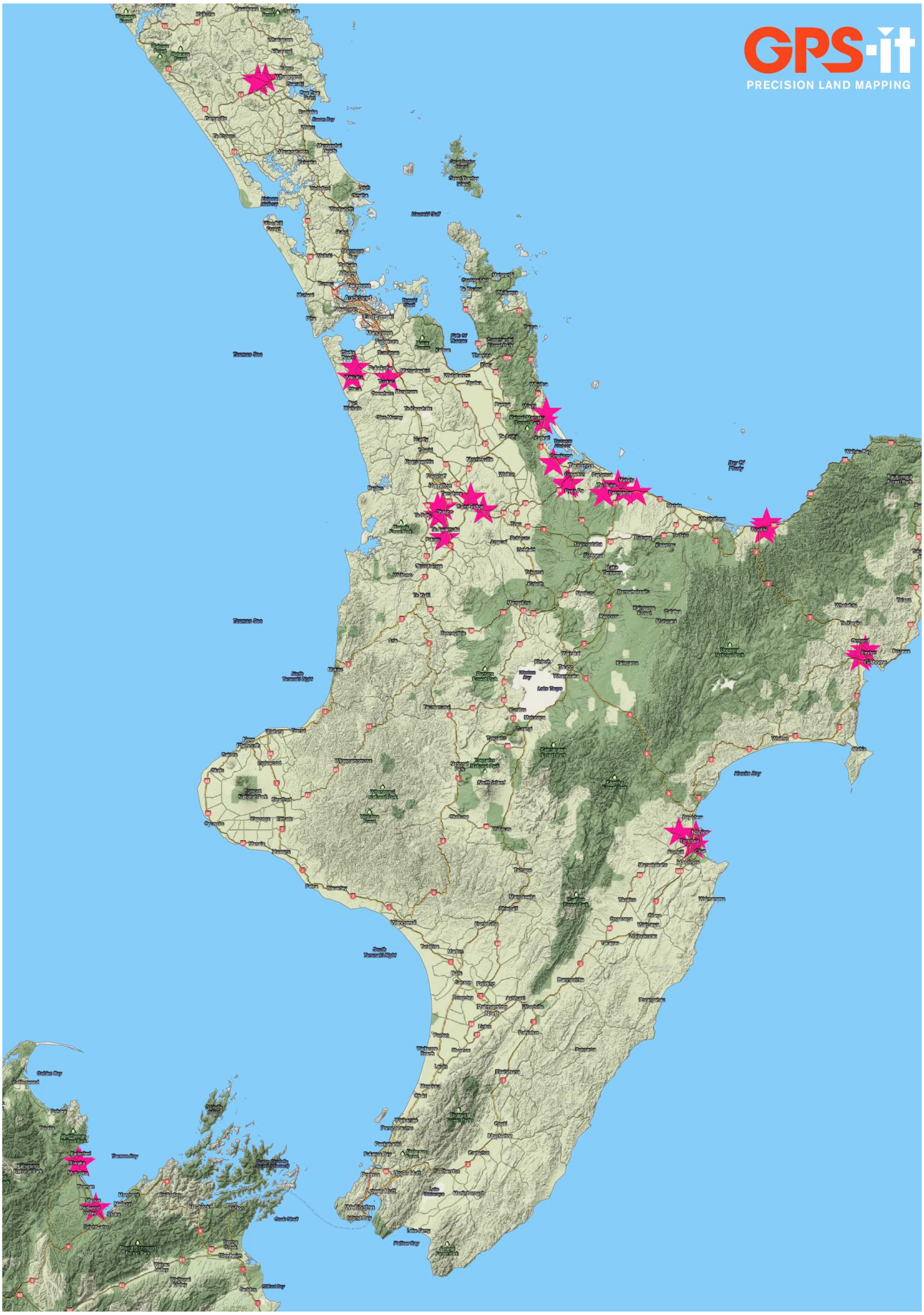


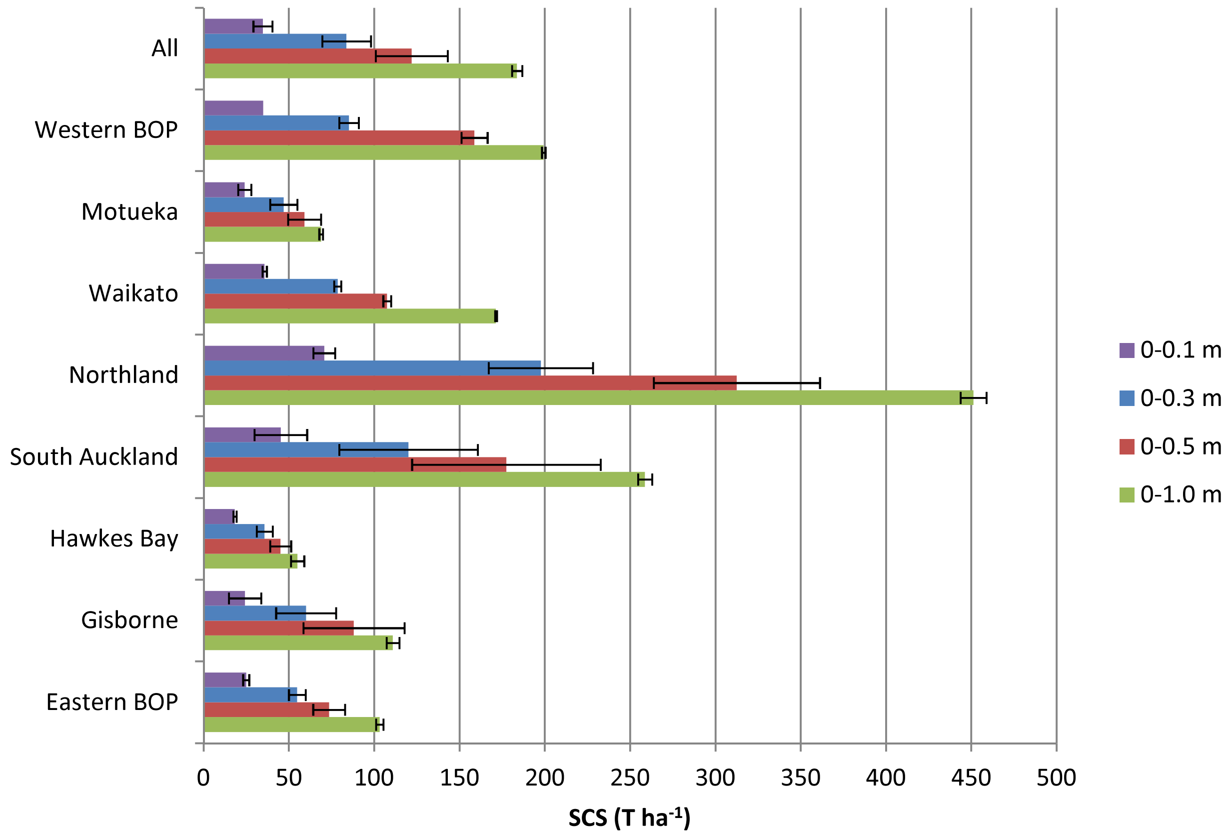
Table 4. Soil organic carbon to 1 metre deep in kiwifruit orchards by region.

Region	Area (ha)	C (t ha^{-1})	C (t in region)
Western BOP	8288	188.03	1558393
Eastern BOP	1756	103.17	181167
Gisborne	255	102.83	26222
Hawkes Bay	191	55.07	10518
Motueka	511	68.86	35187
Waikato	469	171.30	80340
South Auckland	500	258.69	129345
Northland	456	451.29	205788
Other	77	179.22	13800
TOTAL	**12503**	**179.22**	**2240760**

A Hayward kiwifruit orchard under integrated management practice in New Zealand stored on average 174.9 t C ha^{-1} (standard error, ± 3 t C ha^{-1}) to a depth of 1 m. On average, 50.8% of the carbon stocks down to a depth of 1 m were stored in the top 30 cm, which is the standard depth according to the requirements of the Kyoto protocol. About 72.4% of the carbon stocks down to a depth of 1 m were captured when increasing the sampling depth to 0.5 m. These results underscore the necessity to analyze soil carbon stocks in an orchard to a depth of at least 0.5 m.

The SOC stocks were calculated with SOC concentrations and bulk density. Significant ($P<0.05$) differences were observed in SOC concentrations between agro-ecological zones (Figure 3). The highest average SOC concentrations were found in Northland in all depths, generally followed by South Auckland with the exception of the second depth interval, where the average SOC concentrations in the BOP were slightly higher than those in South Auckland. The maximum average SOC concentration was 9.17% measured in the top 0.1 m of an orchard soil in Northland. The minimum average SOC concentration of 0.08% was measured in the depth interval 0.5 – 1 m in orchards located in Eastern BOP and Motueka. This information provides new and interesting baseline data that will be increasingly important in a carbon emission constrained world.

Figure 3. Soil carbon stocks (SCS) integrated to four different depths (0-0.1, 0-0.3, 0-0.5, 0-1 m depth) in Hayward kiwifruit orchards under integrated management located in the eight most important kiwifruit growing regions in New Zealand. In every region, three representative orchards were sampled with six samples taken per depth (0-0.1, 0.1-0.3, 0.3-0.5, and 0.5-1 m depth). Exceptions were Waikato and Gisborne, where we sampled six and two kiwifruit orchards respectively, and the Bay of Plenty where we sampled 10 kiwifruit orchards. The bars represent the standard error of the measurements.



The highest stocks in the top 1 metre of soil were recorded in the orchard soils in Northland (451 ± 10.7 (one standard error of the means) t C ha^{-1}). The lowest were in the orchard soils in Hawkes Bay (55.1 ± 0.9 t C ha^{-1}). Carbon stocks in orchards located in Eastern BOP, Gisborne, Hawkes Bay and Motueka were significantly ($P<0.05$) lower than those recorded in the soils in the Western Bay of Plenty, South Auckland and Waikato, as shown in Figure 3.

The differences observed may reflect differences in the soil types dominating in the regions, plus climatic differences between the regions, as well as the time that a given site has been under the present land use, and the systematic management differences (e.g. irrigation practices) between regions. The impact of climate variables on carbon stocks results from their effects on plant productivity on the one hand, and soil carbon decomposition on the other hand (Martin et al., 2011). We found a positive significant ($P<0.01$) relationship between soil carbon stocks (SCS) to a depth of 1 m and regional annual precipitation (RAP). This explained 16% of the variability observed: SCS = -.69 x 0.1498 RAP. We found a significant ($P<0.01$) positive correlation between clay content and SOC concentrations, as did Jobbagy & Jackson (2000). Bulk density and SOC concentrations were significantly ($P<0.01$) negatively correlated in all soil depths, which was also a trend observed by Curtis et al. (1964), Avnimelech et al. (2001) and Prevost (2004). It is also likely that soils with different texture and bulk density will respond differently to climate variations (Jobbagy & Jackson, 2000).

7. Quantify the sustainability of kiwifruit production with different approaches

Assessing the sustainability of orchards generally focuses on quantifying environmental impacts and resource consumption. The Life Cycle Assessments of carbon, or water, footprints of New Zealand kiwifruit are such examples. However, the sustainability evaluation of an orchard needs to consider more than only its environmental impact. A sustainable orchard must also be profitable, maintain natural capital and sustain the flow of ecosystem services, and be socially responsible in the longer term. Eco-efficiency is a metric that links environmental performance directly with profitability and is, in our opinion, an improved measure of sustainability. The objective of this part of the study was to identify a sustainable kiwifruit production system in the Bay of Plenty, New Zealand, considering the environmental and economic performance of different production systems.

Firstly, we calculated the carbon footprint for two varieties and two production systems. The carbon footprint of kiwifruit production is defined as the sum of all greenhouse gases (GHG) emitted during the life cycle or part of the life cycle of kiwifruit production, expressed as CO_2 equivalents (CO_{2e}). Carbon dioxide equivalent (CO_{2e}) is defined as a measure used to compare the emissions from various greenhouse gases based upon their global warming potential (OECD, 2001). In this study, we focused on the orchard phase. Our estimation of the carbon footprint of kiwifruit production followed the PAS 2050 methodology (BSI 2011). The methodology is summarised in the report of Deurer et al. (2008). We related the GHG emissions to both the land area (one hectare) and the product (one kg of kiwifruit). When the focus of an analysis is on the environmental impact in a local area, then the per hectare unit production is more appropriate than a mass-related functional unit is. For the consumer and supermarket chains, the environmental footprint expressed per kg of product is the metric of interest and as such, it might become part of a carbon footprint label.

Secondly, we assessed the eco-efficiency of two varieties and two management systems. For the eco-efficiency analysis, we combined the carbon footprint per area with the profitability of a kiwifruit production system. Eco-efficiency quantifies the environmental impact per unit of profit. In this study we defined it as kg CO_{2e} ha^{-1} per \$ profit ha^{-1}. This should provide a metric of the value of the provisioning ecosystem services that come from carbon.

The sustainability analysis was based on the same 40 orchards in the BOP that we had chosen for the carbon stock analysis of our study. For this part of the study it is important to note that all orchards were mature and in their productive phase. The experimental design of the orchards included was a completely randomized block design with two factors. The primary factor was the management system (integrated, organic BIO-GRO), and the kiwifruit variety (*Actinidia deliciosa* cv. Hayward, *Actinidia chinensis* cv. Hort16A) was the secondary factor. The confidence level of the analysis was set to 80%. Data on orchard production practices were gathered through a comprehensive questionnaire completed with the orchardists in 2010. The questionnaire covered several topics including general orchard information (fuel and electricity use) and variety specific management practices and the various inputs related to those activities (organic and inorganic fertilizers, pesticides, lime etc.). The growers also provided information on production costs, yields and the economic value of the produce per area. Our survey and analysis of carbon storage in kiwifruit orchards built on existing data from the studies of Rahman et al. (2010) and Benge et al. (2007).

8. Quantify the carbon footprint for the orchard phase of kiwifruit production (greenhouse gas emissions) per area of production

Greenhouse gas emissions associated with the production, packaging, storage and transportation of fertilizers were the highest emissions for all kiwifruit orchards, independent of kiwifruit variety and management system, followed by GHG emissions associated with the on-farm nitrogen cycle, fuel use and pesticide production and import (Figures 4 & 5). Table 6 provides an overview of the total GHG emissions for the two kiwifruit varieties and the two management systems as well as an allocation of the total GHG emissions to the different management operation in an orchard.

a. Variety

The more vigorous Hort16A is more demanding on soil fertility and thus, requires higher fertilizer inputs to maintain the more vigorous growth. These features of the new variety are directly reflected in a comparison of the GHG emissions of the two varieties: Hayward clearly holds a more favourable position to reduce GHG emissions from kiwifruit production.

The total GHG emissions per area of Hayward orchards were significantly ($P=0.12$) lower than those per hectare of Hort16A orchards for the orchard phase (Figure 4 & Table 6). Analyzing the different processes that cause GHG emissions in kiwifruit orchards revealed that Hort16A had significantly ($P \leq 0.2$) higher GHG emissions with respect to fertilizer inputs and N-associated emissions than the variety Hayward. This resulted mainly from higher inputs of N-fertilizers. N-fertilizer has high GHG emissions in the production phase and additionally, leads to considerable emissions of N_2O from soil after its application in the orchard, according to IPCC protocols for GHG emissions. The GHG emissions of total fuel consumption for the two varieties were comparable. We note that similar to the analysis of GHG emissions for the management systems (see below), the emissions associated with fertilizers and composts were the most important hot-spots for both varieties. This finding is supported by the work of Hillier et al. (2011), who found a similar trend across all crops. While this study did not assess any of the new ZESPRI varieties (Gold3 “SunGold”, Gold9 and Green14), it is important to undertake the same footprint analysis for them. It will be necessary to wait until plantings of these reach maturity (approximately 2014) to calculate accurately their footprint on an equivalent basis.

b. Management

The total GHG emissions of the organic and integrated management were very similar (P>0.2). The largest differences between the two management systems resulted from the GHG emissions associated with the total fuel use (Table 6). The emissions related to fuel use in the integrated orchards were significantly (P=0.011) higher than those in the organic orchards. In integrated kiwifruit orchards, fuel use accounted for 21% of the total GHG emissions, whereas in the organic kiwifruit orchards it accounted for 15%. The significantly higher GHG emissions from fuel use in the integrated orchards reflect the significantly higher GHG emissions of mowing, spraying and fertilization activities, as shown in Table 6. Integrated orchardists mowed their properties significantly more often than organic orchardists did. In general, organic orchardists are not allowed to use synthetic fertilizers but rely on natural fertilizers. According to our survey, the organic kiwifruit orchardists in the Bay of Plenty applied a range of organic soil amendments including compost, vermicast, poultry manure, fishmeal, and chicken manure mixed with compost at a ratio of 50:50. They also used lime, gypsum and phosphate rock. The fertilization practices of the organic growers led to considerable GHG emissions due to the production, packaging, storage and transportation of these fertilizers. These were comparable to those from the integrated orchards related to synthetic fertilizers (Figure 4). In fact, the GHG-emissions related to N-fertilizers and composts were the most important hot-spots for both management systems, with 78% and 85% of the total GHG emissions in the integrated and organic kiwifruit orchards, respectively (Figure 5; Table 6). As expected, the GHG emissions related to the production and import of pesticides were significantly (P<0.2) lower in the organic orchards than in the integrated orchards.

Table 5. Amount of fertilizer needed to add one kilogram of nitrogen.

Fertilizer	kg fert kg^{-1} Nitrogen	Reference
50% chicken manure / 50% compost	47.34[1]	www.ecochem.com/t_manure_fert.html
CAN	3.77	Zonderland-Thomassen, Boyes, & Ledgard, 2011
DAP	5.56	Kongshaug, 1998
Fishmeal	76.92[1]	www.ecochem.com/t_manure_fert.html
Vermicast	76.92[1]	www.ecochem.com/t_manure_fert.html

[1] assuming a dry matter content of the fertilizer of 65% (Barber and Rothmann, 2008 – unpublished data)

Table 6. Average greenhouse gas (GHG) emissions by area (one hectare) for kiwifruit production in New Zealand for different varieties (Hayward and Hort16A) and management systems (integrated, organic BIO GRO). Data is based on a survey with 40 orchards in a completely randomized block design. The numbers in brackets represent one standard deviation.

GHG emissions ($kg\ CO_{2e}\ ha^{-1}$)	**Hort16A**	**Hayward**	**Integrated**	**Organic**
Total fuel use	943 (±106)a[1]	867 (±101)a	1043 (±112)b	720 (±86)c
Fuel use - mowing	182 (±39)a	171 (±37)a	238 (±45)b	106 (±17)c
spraying	283 (±34)a	356 (±37)b	396 (±33)c	228 (±31)d
mulching	23 (±6)a	22 (±5)a	29 (±5)b	14 (±4)c
fert spreading	455 (±59)a	318 (±54)b	379 (±66)c	371 (±52)c
Fertilizers	3201 (±569)a	2110 (±196)b	2646 (±302)c	2636 (±547)c
Pesticide use	20 (±3)a	32 (±7)b	39 (±7)c	14 (±3)d
N-associated emissions	1582 (±280)a	1043(±108)b	1332 (±116)c	1293 (±290)c

[1]Figures in the same row followed by different letters are significantly different at the 80% significance level ($P \leq 0.2$).

Figure 4. Average greenhouse gas emissions for fuel consumption, fertilizer production, pesticide production and N-associated emissions for the two varieties (Hayward and Hort16A) by area (one hectare). The bars denote one standard deviation.

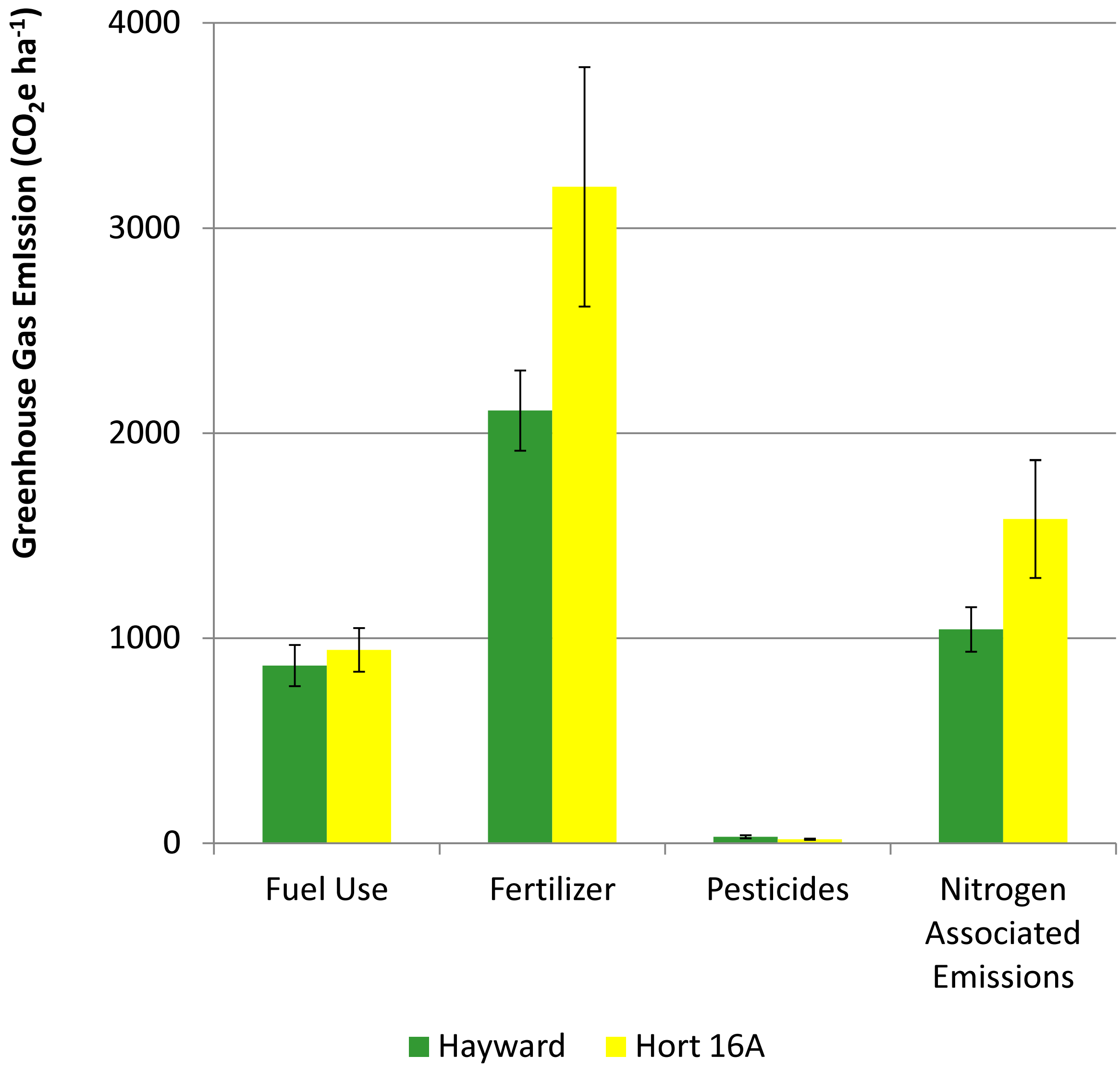
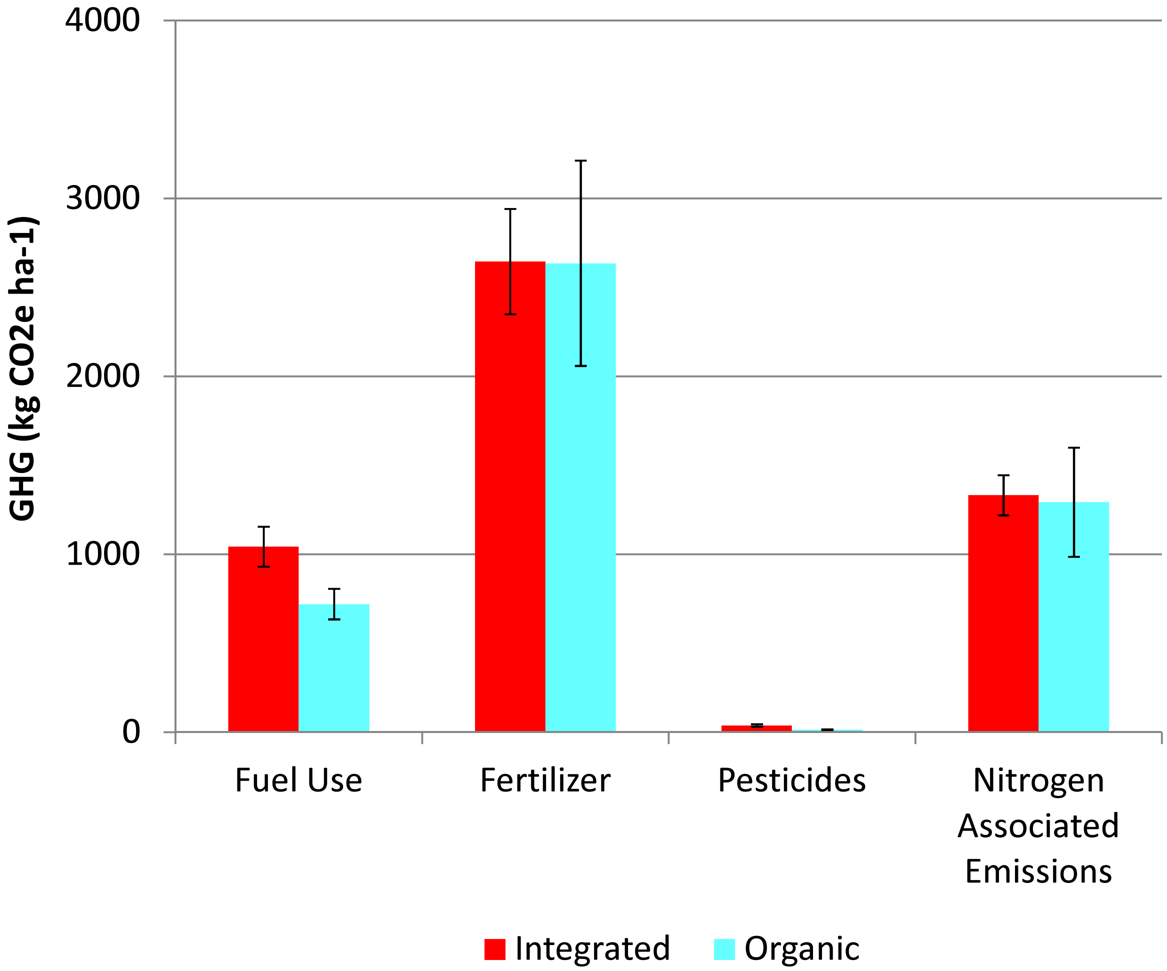


Figure 5. Average greenhouse gas (GHG) emissions for fuel consumption, fertilizer production, pesticide production and N-associated emissions for the management practices in integrated and organic kiwifruit production systems by area (one hectare). The bars denote one standard deviation.



9. Quantify the carbon footprint for the orchard phase of kiwifruit production (greenhouse gas emissions) per unit of production

Including yield data in the questionnaire enabled us to extend the analysis, and estimate GHG emissions per kg of kiwifruit production.

a. Variety

The average yield of the Hort16A kiwifruit was 30 (± 1.5) t ha^{-1}, while Hayward kiwifruit yield averaged 31.5 (± 2.9) t ha^{-1}. The yields were comparable ($P \geq 0.2$). Taking into account these yields, the GHG emissions can then be referred to a mass-based functional unit (1 kg of kiwifruit). The GHG emissions per kg of Hort16A kiwifruit were significantly ($P<0.2$) higher than those of a kg of Hayward kiwifruit (Figure 6). This reflects the significantly higher GHG emissions of Hort16A kiwifruit per area of production, while the yields per area of both varieties were comparable. This is the metric that the consumer and supermarket chains are interested in, and therefore may become part of a carbon footprint label.

In this study, however, changing the functional unit did not change the overall result for the comparison of the two kiwifruit varieties, primarily because of the similar yields of the varieties in the year of the survey. Hort16A kiwifruit production was associated with significantly higher GHG emissions than the production of Hayward kiwifruit, regardless of the functional unit. The GHG emissions were governed by the fertilizer inputs. To reduce the environmental impact, especially of kiwifruit production, growers need to optimize nutrient use efficiency. This would also have other multiple benefits such as cost reductions and reduced leachate loadings on groundwater.

b. Management

The average yield of the integrated orchards was 36 (± 2.3) t ha^{-1}, while the organic orchards' yield averaged 25 (± 1.7) t ha^{-1}. The GHG emissions per kg of organically produced kiwifruit were similar ($P>0.2$) to those of a kilogram of kiwifruit produced using an integrated management system (Figure 7) in spite of the significantly lower yield of the organic production systems.

Thus, the choice of the functional unit for the analysis did not affect the comparison of the two management systems. Organic production only had a slightly more favourable position than integrated production if the analysis was area-based. The GHG emission associated with a kilogram of organic fruit was similar to that of integrated fruit. It is likely that consumers would expect higher GHG emissions associated with integrated kiwifruit production. However, our study did not show this.

Since 2009, there have been new plantings, and grafting of old varieties into the new ZESPRI varieties Gold3 "SunGold", Gold9 and Green14. In June 2012, ZESPRI announced that over 2000 hectares of Gold3 "SunGold" license would be released, predominantly to replace the Hort16A that had been destroyed by Psa. While establishing the new variety, growers will continue to use pesticides, fertiliser and fuel, but yields will be very low per hectare during this establishment phase. This will in turn result in a high carbon footprint per kg of fruit produced.

10. Quantify the eco-efficiency of kiwifruit production

a. Variety:

Hort16A Gold kiwifruit yielded significantly ($P \leq 0.2$) higher prices in the market than Hayward Green kiwifruit. This is reflected in the significantly larger profit per area of Hort16A Gold kiwifruit production than per area of Hayward Green kiwifruit production despite the fact that it is more expensive to grow Hort16A Gold than Hayward Green kiwifruit because of higher agrichemical input levels. Finally, the estimated eco-efficiency expressed as GHG emissions per NZ$ profit was not significantly ($P \geq 0.2$) different between the two varieties (Figure 6). However, there was a tendency that a NZ$ of profit led to less GHG emissions for Hort16A Gold then for Hayward Green – but this was not statistically significant.

b. Management:

Fruit produced under organic management yield higher prices in the market: usually growers can sell 1 kg of organically grown kiwifruit for a significantly higher price than 1 kg of kiwifruit from an integrated orchard. This is reflected in the fact that per area the profit was larger in an organic than in an integrated orchard in spite of higher yields in the integrated orchards. However, the variability in costs and yielded prices in the market was large and, therefore, this difference was not significant ($P \geq 0.2$). Finally, the estimated eco-efficiency expressed as GHG emissions per NZ$ profit was not significantly ($P \geq 0.2$) different between the two management systems (Figure 7). However, integrated management systems tended to be more eco-efficient than organic management systems.

Our analysis demonstrated that eco-efficiency can enhance product differentiation for customers and can assist orchardists in decision-making with regard to selecting a kiwifruit variety and management system. One of the major drivers of the carbon footprint per unit of production, and hence eco-efficiency, is the yield per hectare of the crop in question. This stresses the need to reference foot-printing results to the yield and its inter-annual yield variation and consequently creates a problem for eco-labelling and consumer choices.

Figure 6. Average greenhouse gas (GHG) emissions per kg and eco-efficiency (GHG emissions per NZ$ profit) of Hayward and Hort16A. The bars denote one standard deviation.

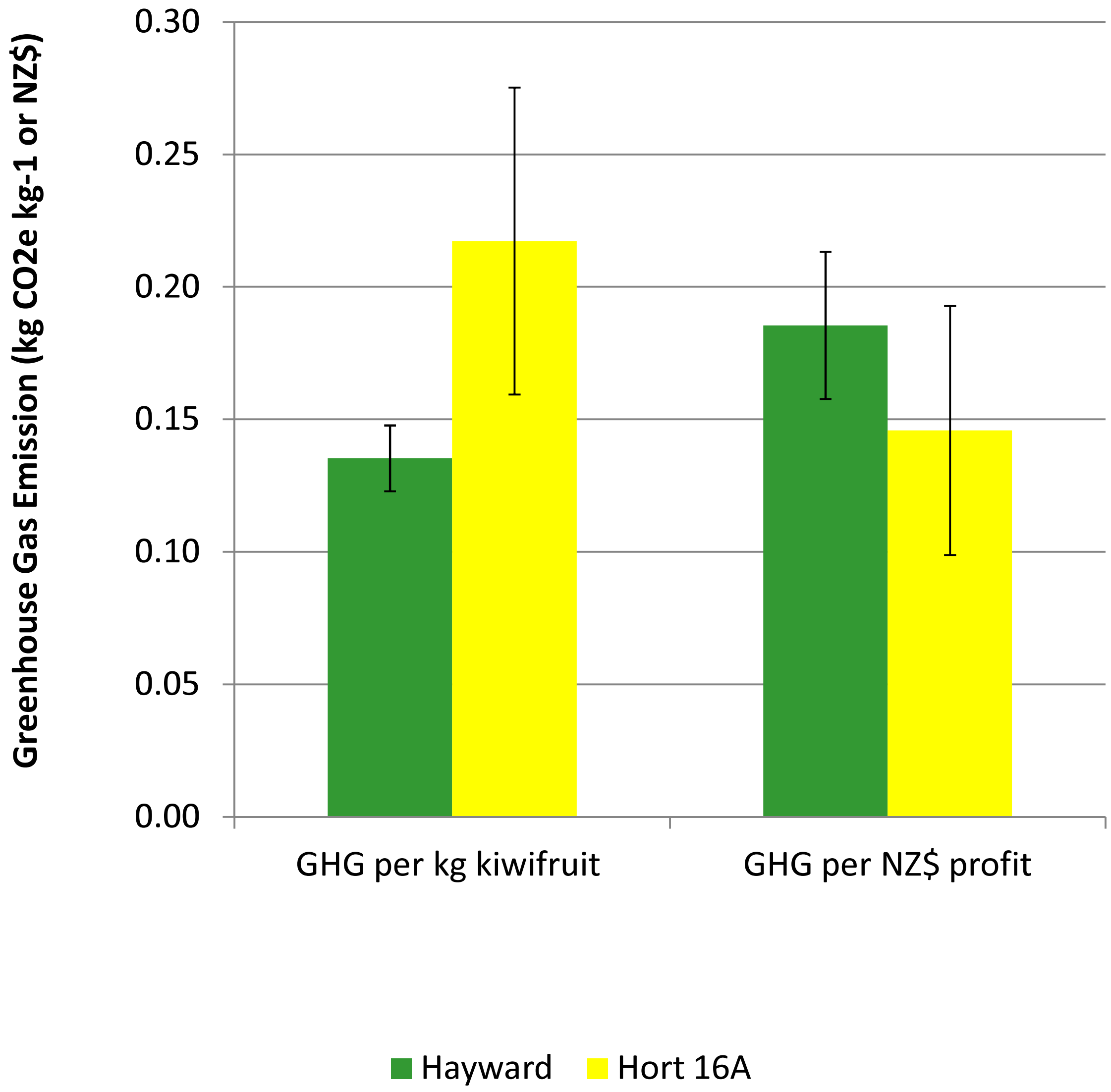
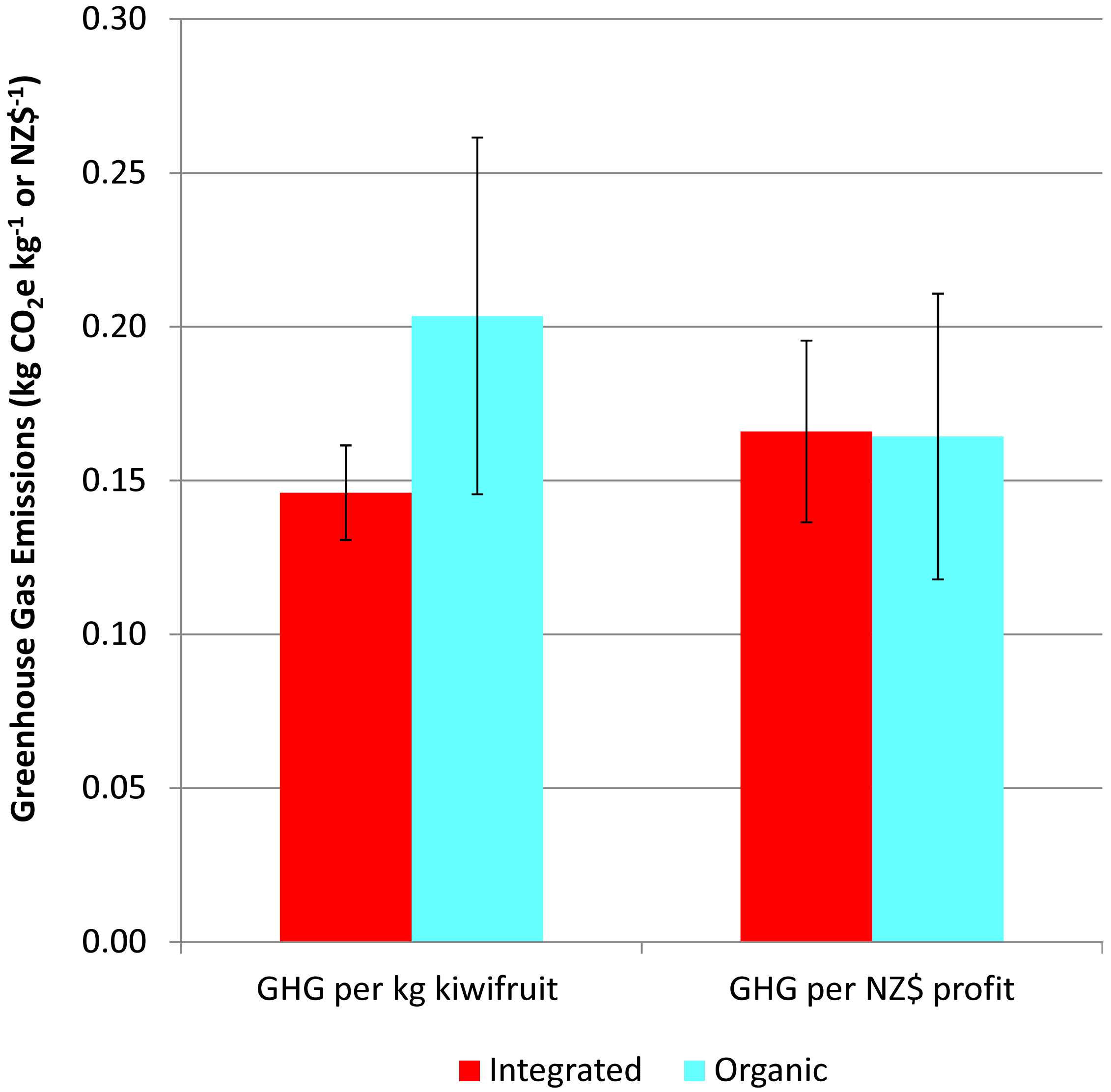


Figure 7. Average greenhouse gas (GHG) emissions per kg and eco-efficiency (GHG emissions per NZ$ profit) of kiwifruit grown under organic and integrated management systems. The bars denote one standard deviation.



11. Develop grower guidelines on economically and environmentally sustainable carbon storage

Continuing investment is needed into soils to ensure maintenance of their natural capital stocks and the continuation of the value of the ecosystem services they provide (Clothier et al., 2012). Furthermore, it is of similar benefit to the soil, plus of value to the atmosphere, to maintain, hoard, and sequester carbon in the soil to ensure continuing soil functioning and protect the atmosphere from a build-up in carbon dioxide, the product of soil respiration. The value of ecosystem services is often taken for granted as a service provided by natural systems, including agricultural production systems. Events such as the Great Dust Bowl drought and loss of topsoil in the mid-West United States in 1934 caused, in part, by extensive cultivation of fragile native grasslands led to the displacement of over 2.5 million people (Cooper, 2004).

Clothier et al. (2012) also noted that plant residues and mulches, along with plant roots, are important sources of carbon inputs into the soils. The value of mulches and residues is that they provide sources of carbon that can improve soil functioning and health. An improvement in soil health leads to greater plant productivity and healthier root growth, which in turn will maintain or enhance soil carbon stock. There is therefore a virtuous circle between the inputs of carbon in residues and mulches, soil health, plant productivity and carbon sequestration.

Soil organic carbon (SOC) is a key indicator of soil health because it plays a role in a number of key functions. These functions can be divided into three types:

- Biological functions of SOC:
    1. provides nutrients and habitat for organisms living in the soil
    2. provides energy for biological processes
    3. contributes to soil resilience, which is the ability of soil to return to its initial state after a disturbance, for example, after tillage

- Chemical functions of SOC:
    1. enhances nutrient retention capacity
    2. enhances the mineralization of key nutrients from the soil itself
    3. provides resilience against pH change
    4. acts as a main store of many key nutrients especially nitrogen and potassium
- Physical functions of SOC:
    1. binds soil particles into aggregates improving soil structural stability
    2. enhances the water holding capacity of soil
    3. moderates changes in soil temperature

The impact of soil carbon on soil-water retention

Soil organic matter is a key component of soil that affects its chemical, biological and physical properties and functioning. Through its role in affecting soil structure and adsorption processes, soil carbon would be expected to alter the soils ability to retain water. The two main descriptors of the soil's ability to retain water are its water content at the so-called 'field capacity' at a pressure potential of -33 kPa, and the water content at the 'wilting point' of -1500 kPa.

There have been many studies aimed at determining the impact of soil carbon on these properties, and contradictory findings have been reported. Rawls et al. (2003) listed a selection of these, as shown in their Table 7 overleaf.

Table 7. Observed effect of organic matter content on soil water retention at two water potentials. Full references can be found in Rawls et al. (2003).

Authors	-33 kPa	-1500 kPa
Bauer and Black (1981)	Yes	Yes
Bell and van Keulen (1995)	No	Yes
Beke and McCormick (1985)	No	Yes
Petersen et al. (1968)	No	Yes
Calhoun et al. (1973)	Yes	No
Lal (1979)	No	No
Danalatos et al. (1994)	No	No
De Jong (1983)	Yes	Yes
Jamison and Kroth (1958)	Yes	Yes
Riley (1979)	Yes	Yes
McBride and MacIntosh (1984)	Not determined	Yes
Salter and Haworth (1961)	No	No

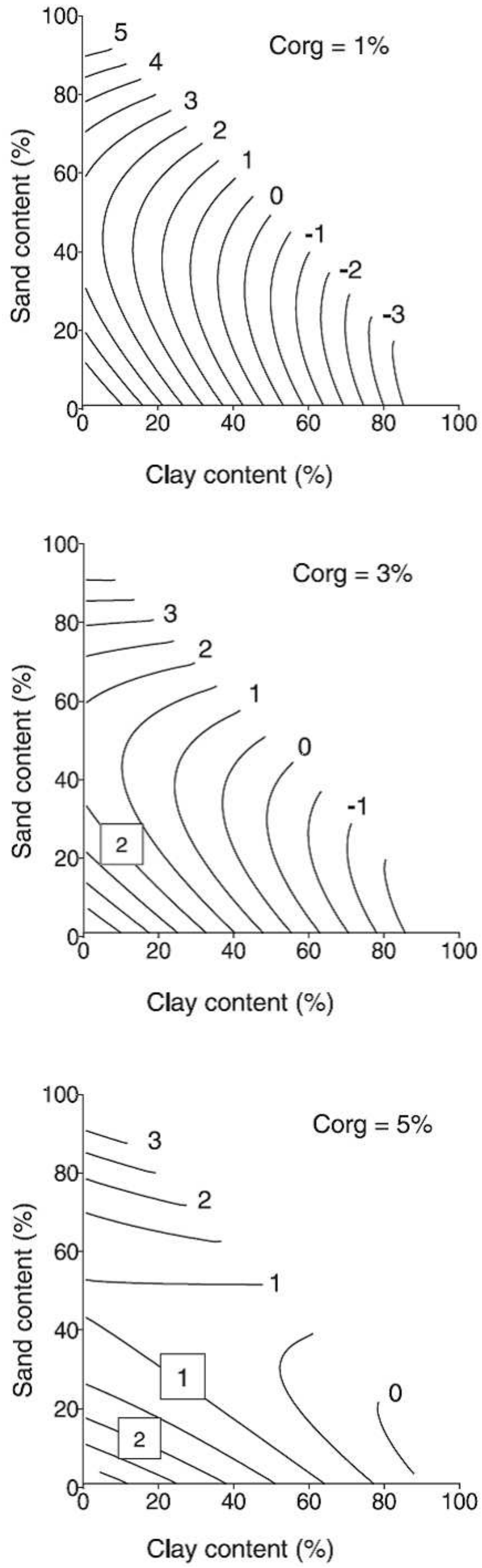
Faced with these contradictions, Rawls et al. (2003) hypothesised that the effect of soil carbon on water retention would depend on both the textural make-up of the soil, and the level of soil organic matter itself. To test this they used the massive U.S. National Soil Characterization Database and they used regressions trees and the group method of data handling to unravel the relationships.

Indeed, they did find that the proportion of textural components affected the relationship of water retention to organic carbon content.

For the wilting point measure at -1500 kPa, they found a substantial increase in water retention correlating with soil organic carbon in soils with low clay contents, and in fact, they saw the opposite trend in soils with high clay contents. Thus, carbon seems to have a positive impact on water retention at wilting point in sandy soils.

Soil water retention at field capacity (-33 kPa) was found to be more strongly affected by organic carbon than that at the wilting point of -1500 kPa. The relationship they found is reproduced in Figure 8 overleaf.

Figure 8. Changes in the soil water content at -33 kPa (percentage volume) per 1% change in organic carbon content, for three initial levels of organic carbon (C_{org}) (Rawls et al. 2003).



For soils with low initial soil carbon (C_{org}) the impact of a change in organic carbon is greatest, with large and positive increases at low clay contents, and negative changes in soils with high clay contents (top figure). In soils with high organic matter contents, the changes were always positive, although of a lesser order (bottom figure).

Therefore, the effect of changes in organic carbon on soil-water retention depends on the textural component and the level of soil carbon. At low carbon levels, an increase in organic carbon leads to greater water retention in coarse soils, and a decrease in fine-textured soils. At high levels of carbon, an increase in soil organic matter results in an increase in soil water retention for all soils, albeit with a muted response.

Growers can help maintain and improve their SOC by:

- **Deep rooted inter-row species.** Deep rooting sward species such as Chicory, Plantain and Clover species can create explorative root channels in the soil at depth, and when these roots die, they create carbon rich channels that are explored by earthworms that draw carbon to a depth where it can be sequestered.
- **Natural shelterbelts.** Fast-growing tree species produce a large amount of biomass and grow large explorative root systems. They also grow stem and leaf biomass suitable for mulching back into the soil because of shelter trimming.
- **Maintaining vegetation cover.** Photosynthesising plants are the link between the atmosphere and the soil and provide the way into the ground for organic carbon (ISHS, 2012). It is important to have large volumes of fibrous roots deep in the ground at all times of the year, as permanent ground cover also buffers soil temperature, inhibits weeds, slows soil evaporation, increases transpiration and reduces erosion.
- **Minimising tillage and mowing.** Excessive soil tillage increases exposure of organic carbon to the air and sunlight, all of which enhance the processes by which it is broken down and converted to CO_2. Maintaining a thick sward protects soil biota and encourages recycling of organic thatch material. Table 6 shows that organic growers are already carrying out less mowing passes per annum than integrated growers.
- **Retention of crop residues.** Crop residues such as vine prunings and shelter trimmings reduce the possibility of erosion and are an important initial building block

of soil organic carbon. Furthermore, the supply of carbon-rich resides to the surface soil enhances soil health by improving soil microbial and biophysical functioning.

- **Use of carbon-rich amendments.** The application of fertilisers and soil conditioners such as organic fertilisers, green manure crops, inoculants that promote the growth of soil microbes will enhance soil health and the build up of soil carbon. However, one orchard in the study has been adding 50 tonnes per hectare per year of composted pine shavings and pig manure to the orchard for at least ten years and there was no significant increase measured in SOC.

Identify opportunities related to SOC stocks: Carbon trading

There are possible carbon trading opportunities for individual growers, and this is a rapidly changing area of investment and payments. A kiwifruit grower with a four-hectare orchard is storing 1,436 tonnes of carbon on the orchard to nine metres deep. Converting this to CO_2 equivalents gives 5,265 tonnes (by multiplying by 3.67), and based on the current market price of CO_2 equivalents at NZ$6 per tonne, this then represents a potential value to the grower of $31,592. Agricultural and horticultural producers are already paying increased costs for inputs such as fuel, fertilisers and pesticide because of ETS schemes of carbon taxes. If perennial horticultural crops become included in the ETS Scheme, landholders would need to:

- estimate and report changes in the amount of carbon sequestered in their orchards;
- receive permits for net increases in orchard carbon sequestration;
- surrender permits for net emissions from the orchard.

PlusGroup has recently made an application to the ETS for a large mixed kiwifruit grower to gain carbon credits for the shelterbelts, vines and the soil on the property. Carbon trading is likely to be an area of growth and rapid change. Prudence would suggest that a good inventory of carbon stocks and changing inventory values would be valuable.

Green (2009) outlined that certain characteristics of soil carbon make it difficult to incorporate it into carbon trading. Soil organic carbon is present in different forms and pools of different cycling rates and with varying stability or longevity. Depending on the lifespan of the carbon trade, only a proportion of soil carbon is sufficiently stable to be considered in carbon trading. Increasing the amount of carbon in the stable fraction is generally a long-term process. Consequently, it is possible, but difficult for soil carbon to be bundled into units tradable by land managers for the defined terms and times necessary for trading in carbon. Any carbon market will require that carbon credits are technically credible, measurable and able to be verified by a third party.

Carbon is generally present at reasonably low concentration in soils, being generally less than 5% soil mass, but the total stock down to depth is large. Small changes in the concentration over time can be important but strain the limits of measurement within the relatively short timeframes desirable for carbon trading. The large variations in the content of soil carbon across the landscape and down the soil profile challenge the reliability of sampling methods. On a worldwide scale, other large perennial horticultural industries such as South African fruit and wine grape producers are aware of the potential to sequester carbon in soils and biomass on orchards and vineyards. The South Africa Fruit & Wine Initiative, 2012, is using this as part of their efforts to mitigate the effects of climate change and ultimately secure the long-term viability of their businesses.

Information needed to decide on whether farmers may use soil carbon to participate in carbon trading includes:

- reliable methods to account for relatively small amounts of carbon to be stored on individual farms in relatively short timeframes;
- tools to help farmers decide on the processes, benefits, costs, risks and responsibilities of trading in soil carbon; and
- relatively cheap and simple methods for directly measuring the stable pool of organic soil carbon and its residence times at different depths in soils.

12. Benefits of our findings to different stakeholders in the kiwifruit industry

a. Zespri International

Primary industry land-based companies such as Zespri, have collaborated with government agencies and other sectors to measure, and understand the risks and benefits associated with the environmental footprint of its products. This information is needed to provide information to customers and consumers on the impacts of consumption as well as identifying any significant environmental risks that the industry is vulnerable to that may affect its longer-term viability. Ecosystem services such as soil provisioning, assimilate capacity, and regulatory services such as water and nutrient cycling are essentially provided free. There is no market for the valuable ecosystem services that soil, water and carbon provide, other than the provisioning service of kiwifruit yield. Nonetheless, the regulating and cultural services provided by kiwifruit orchards are valuable, but yet unpaid for. Over time, degradation of these services can lead to higher cost and/or reduced crop productivity, or landscape-wide deleterious impacts. This degradation could eventually lower overall profitability and competitiveness of the industry. Increasingly, value chain stakeholders such as retailers and the banking sector are seeking more information from primary producers on better understanding the current state of the ecosystem services that producers depend on to provide products for customers. They are also interested in the value of the ecosystem services that growers provide to the wider community and ecology. These industry stakeholders want to ensure that their investment in finance lending and long-term supply contracts is secure. To this end, Zespri has been investing in partnership with Government agencies to:

- Measure its environmental footprint
- Identify any risks or opportunities associated with any given component of the environmental footprint
- Develop or seek out solutions to mitigate the risks and exploit the opportunities
- Transfer and implement efficient and effective solutions
- Measure the impact of these solutions on its subsequent environmental footprint, and track its continuous improvement over time.

A presentation given in 2011 titled "Sustainability Insights from Zespri" noted that their brand value is critically dependent upon metrics of sustainability.

Figure 9. ZESPRI sustainability supports core brand value.

Therefore, understanding the amount of SOC in soils and being aware of the size of the production footprints associated with environmental impacts contributes to the value of the ZESPRI brand.

The largest amount of emissions associated with the lifecycle of a New Zealand kiwifruit is the sea-freight from New Zealand to a Northern Hemisphere port. A Zespri study found that kiwifruit shipped from New Zealand and consumed in Europe contributes 1.74 kg of carbon equivalents per kilogram of kiwifruit across its lifecycle from orchard to consumer. Some 35% of this emission is related to the shipping of the fruit. As we have found that kiwifruit orchards sequester 6.3 t Carbon per hectare per year more than pasture, this figure would well offset some of the emissions associated with the production and shipping of kiwifruit. Furthermore, the focus of the consumer is often the production phase of product, rather than the transport or use phase. As the late Professor Gareth Edwards-Jones said, the consumer is "... more focussed on the grower rather the sea captain or truck driver".

b. The environment

SOC is a measure of the soil's natural capital. Higher SOC levels equate to greater levels of ecosystem services provided by those soils. Daily (1997) outlined the range of ecosystem services that can be offered by biological systems as:

- Purification of air and water
- Mitigation of floods and droughts
- Detoxification and decomposition of wastes
- Generation and renewal of soil and soil fertility
- Pollination of crops and natural vegetation
- Control of the vast majority of potential agricultural pests
- Dispersal of seeds and translocation of nutrients
- Maintenance of biodiversity, from which humanity has derived key elements of its agricultural, medicinal and industrial enterprise
- Partial stabilization of the climate
- Moderation of temperature extremes and the force of winds and waves
- Support of diverse human cultures

- Providing the aesthetic beauty and intellectual stimulation that lift the human spirit

While kiwifruit growers obviously gain immense financial benefits from their own provisioning ecosystem services, there is currently no external value to the grower of other ecosystem services such as the supporting, regulatory and cultural services. Schemes such as EBEX21, which provides the mechanism for primary producers to obtain carbon credits through the regeneration of native bush, and the MAF Forestry Allocation Plan, allocating carbon credits to producers of forest species, provide external value to primary producers increasing the ecosystem services they provide. However, there is currently no mechanism in New Zealand to value ecosystem services provided by the soil. If the land use is to change from perennial orchards to arable cropping, or even pastoral systems, the direct removal of shelterbelt trees and kiwifruit vines will reduce the carbon stored on the property. The change in land use will also result in a loss of SOC from the topsoil. This change will be similar to that experienced by the removal of forest and establishment of pasture, as seen in a large scale on the Central Plateau near to Reporoa.

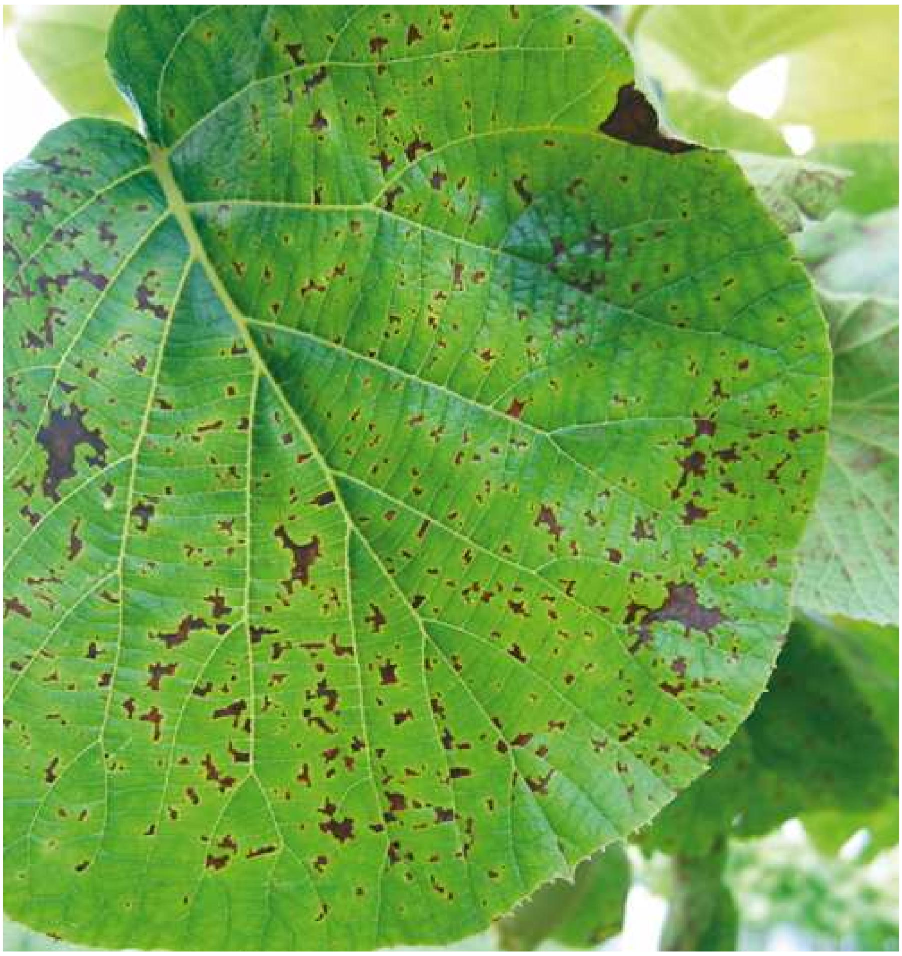
c. Research scientist

There was only one scientific publication in 1972 relating to “Soil Organic Carbon”. This figure has increased to over 200 articles each year since 2006. Soil and SOC have received intense interest in recent years because of the role they can play in mitigating the effects of elevated atmospheric CO_2 and therefore climate change. Lal, 2004, estimated that with appropriate use and management soils have the potential to sequester ~ 0.9 Pg C per year.

13. *Pseudomonas syringae* pv. *actinidiae*

It would be remiss to report on any sustainability issues in the New Zealand kiwifruit industry without addressing the possible affect of the Psa infection currently spreading. Best practice for the removal of existing plant material prior to the grafting of new varieties involves ideally burying the vine material (KVH, 2012). However, a large number of growers are burning the plant material due to the difficulty in creating a hole large enough to bury it all in. This combustion is resulting in the loss of the plant-stored carbon as CO_2. Removal of canopy is also exposing the normally protected topsoil to harsh summer conditions that will resulting in the loss of soil carbon through oxidation.

Figure 10. Symptoms of *Pseudomonas syringae actinidiae* pv. *actinidia* (Psa) on Hort 16A kiwifruit leaf.



14. Grower survey results

The main reason to undertake the survey was to ascertain the carbon footprint of the orchard and therefore of each unit of kiwifruit. Growers were open and candid with the information they gave to us, and they gave the COST team permission to access their spray records and crop payment records directly from ZESPRI. Access to this data was invaluable as it allowed us to compare all nutrient inputs and property financial income on the same basis. Establishing the exact weight of fruit harvested from the orchard was harder to determine, but this was calculated from the pack house “Net Submit” figures.

The project was fortunate that soil sampling and surveying was completed before Psa was discovered in the Te Puke region in November 2010. Growers then became more resistant to people accessing their orchards following this discovery.

The most common change during the survey period was the grafting of new varieties (Gold3 “SunGold”, Gold9 or Green14) into the orchard. This will become an increasing trend in the near future, with over 2000 hectares to be grafted to the Gold3 “SunGold” new variety after the devastation of Hort 16A orchards by Psa. Yet we do not know the carbon footprint of these new varieties. Cutting established canopies out in order to graft in new varieties, whether instigated by Psa infection or not, exposes the topsoil to hot summer weather without any canopy cover, and there are likely to be significant changes in the soil properties.

Figure 11. Orchard after removal of leaders due to Psa Infection.

a. Machinery

There was large variation in the horsepower and age of tractors and other machinery. Many of the tractors and machinery items were of an unknown, old vintage, and they had limited value, but the growers had no plans for their replacement or upgrading. The higher carbon emissions of older tractors (due to their poorer fuel economy) are likely to be offset by the extended period that the emissions from the production of the new machine are associated with. However, one large orchard, which is owned by a group of investors as part of a portfolio of orchards, replaced all four of their tractors on a seven-year rollover period.

Table 8. Summary of findings of grower survey.

Orchard Information	Average	Range
Distance from pack house (km)	18.9	0-60
Age of vines (years)	25.2	1-49
Altitude (m)	68.1	6-185
Machinery Information	**Average**	**Range**
Mowing (pass $year^{-1}$)	5.0	2-17
Mowing tractor (hp)	57.2	21-95
Spraying (pass $year^{-1}$)	8.2	3-18
Sprayer (hp)	80.1	35-115
Mulching (pass $year^{-1}$)	2.0	2
Mulching tractor (hp)	66.2	35-95
Contractor fert spreader (pass $year^{-1}$)	1.1	0-2
Own fert spread (pass $year^{-1}$)	2.8	0-6
Fertiliser spreading tractor (hp)	62.2	27-95

Most orchardists undertook regular soil tests every year or second year and their fertiliser programmes were calculated and applied according to these results. Amongst the 40 subject orchards there were groups of orchards that had soil testing and fertiliser recommendations carried out by the same soil agronomist. In these cases, the fertiliser recommendations were often identical, with distinct “mixes” applied. Leaf tests were more uncommon.

b. Cultivation

There was very little soil cultivation carried out in the subject orchards. Two orchardists used a forced air aerator through contoured blocks, and three orchardists used "Ground Hog" surface cultivators after harvest. It is likely that undertaking surface cultivation using a "Ground Hog" would help incorporate plant residues into the soil.

Figure 12. Ground Hog aerator / cultivator.

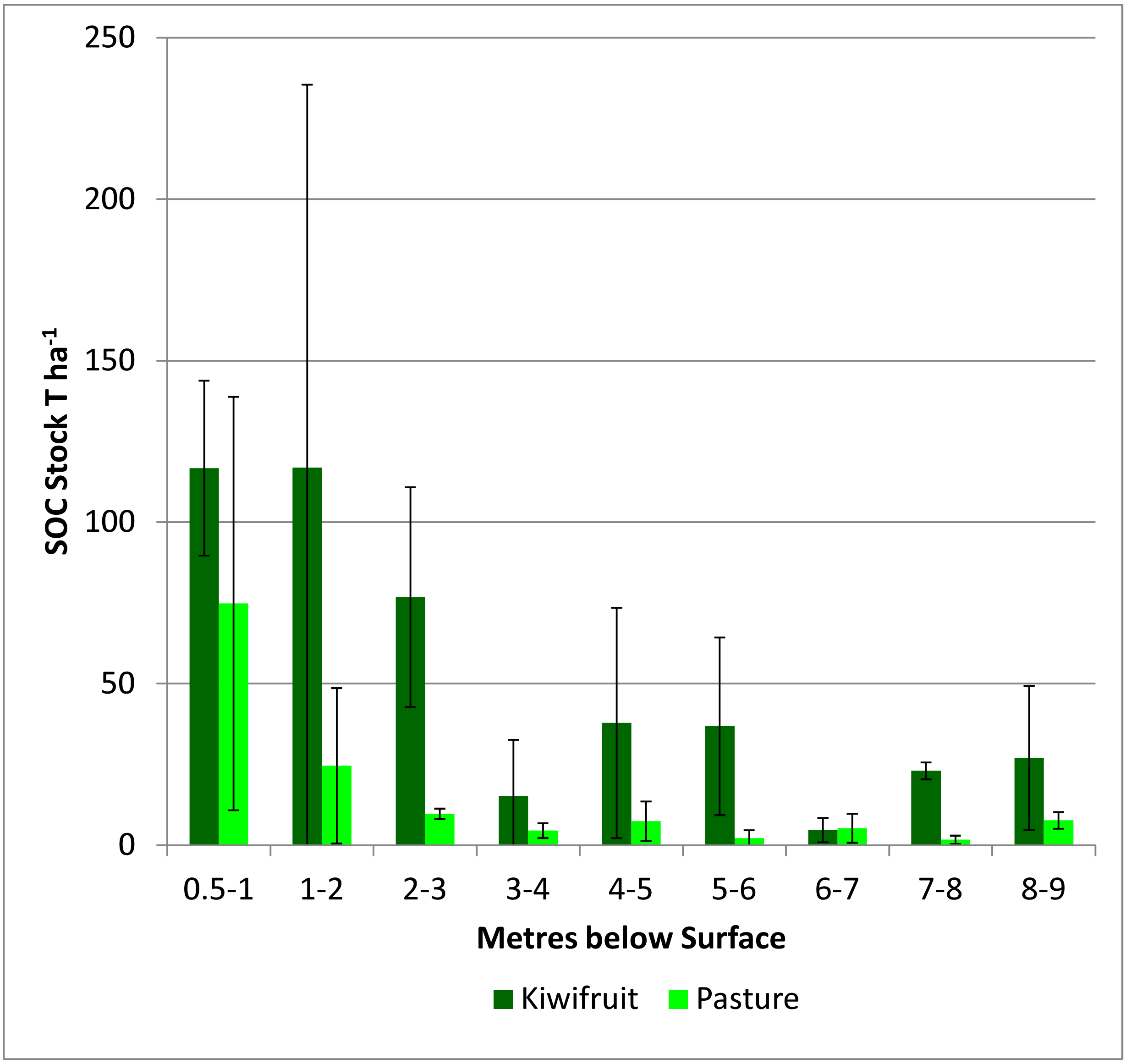
15. Nine metre deep soil organic carbon sampling and analysis from adjacent pasture and kiwifruit crops

Given our findings that kiwifruit orchards had significantly higher SOC stocks at depths of 0.5 – 1 metre confirmed the findings of Deurer et al. (2010) that carbon was sequestered by kiwifruit orchards below the level of 50 cm. These findings raised the question of how deep the increased levels of soil carbon would be present in kiwifruit orchards, compared to pasture sites. Observations from soil excavations have found kiwifruit roots seven or more metres below the soil surface. It is therefore logical to assume that these roots increase SOC at these depths. To measure vertical SOC, we collected soil samples at depths to 9 m from kiwifruit orchard and adjacent pastureland in June 2011.

Figure 13. Soil core sample obtained by use of geotechnical probe. Topsoil at top left of photo, to approximately 3 metres deep at bottom right of photo.

We measured SOC and bulk density in different soil depth intervals (0-0.3, 0.3-0.5, 0.5-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8 and 8-9 metres). The total carbon stock was significantly higher in the kiwifruit profile than in the pasture profile.

Figure 14. Soil organic carbon (SOC) stock to 9 metres deep in adjacent long-term kiwifruit and pasture blocks. The bars denote one standard deviation



These findings show that if the SOC were measured to the depth of 30 cm, as required under the Kyoto Protocol, only 34.5% of the SOC in the top 9 metres of kiwifruit soils would be measured, as opposed to 60.6% of the SOC in pasture.

By extrapolating the findings described above, we estimate that the total carbon stock in the top nine metres of kiwifruit orchard soils in New Zealand is 3,779,540 tonnes. This compares to 2,240,760 tonnes in the top metre of soils. This result requires more study into carbon sequestration at depth.

16. Microbial community structure in New Zealand andisols under kiwifruit cultivation

The impact of management practices on soil microbiology is of great importance as microorganisms drive nutrient generation and turnover in soil. We investigated soil microbial community structure using phospholipid-derived fatty acid (PLFA) profiles analysis according to the methodology of Frostegard et al. (1993). Soils were collected from three agro-ecological zones (Katikati, Tauranga and Te Puke) with two management systems (organic and integrated) and two soil types (coarse and fine textured) under two kiwifruit species (Hayward and Hort16A) at two orchard positions (vine row & alleyway). Surface (0-10 cm) soil samples were collected, as the microbial population is generally much higher in surface soils. Total PLFA content was higher in organic than integrated management systems. Significantly higher values for total PLFA were recorded in fine textured soils compared to coarse textured soils. The lowest total PLFA content was detected in the vine row. Our results indicate that the management system, location/position in the orchard and soil texture play a significant role in total microbial community structure in the allophanic soils of kiwifruit orchards. It is well established that the aboveground plant community is influenced by the diversity and abundance of belowground biological communities through nutrient cycling. Therefore, we intend to clarify the linkage between biological communities in the soil and aboveground vegetation, nutrient cycles and Psa infection. Our pilot study indicates that the belowground biological communities influence the aboveground kiwifruit vine.

17. Kiwifruit orchard biomass

Work undertaken and published by PlusGroup (Rahman et al. 2010) has calculated that the standing biomass of kiwifruit vines and roots to a depth of 1 metre contains 19.74 t carbon per hectare. As we have shown in our soil sampling to 9 metres deep, the value for roots would be even higher.

Almost all kiwifruit orchards in New Zealand have substantial shelterbelts made up of exotic tree species. The 40 orchards in the COST trial were surveyed to estimate the amount of carbon stored in living shelterbelts on NZ kiwifruit orchards. Four species (Japanese Cedar (*Cryptomeria japonica*); Sheoak (*Casuarina cunninghamiana*); Radiata Pine (*Pinus radiata*) and Poplar (*Populus* sp.) were found to comprise over 95% of all shelterbelts.

On average, 223.5 T ha^{-1} carbon is stored in the top 1 metre of kiwifruit soils in the Western Bay of Plenty. Another 43.5 T ha^{-1} of carbon was found to be stored in the shelterbelts. This represents a significant 19.5% of the value of the soil stock to 1 metre deep, and therefore shelterbelts should be included in any future estimations of carbon in perennial horticulture systems.

In addition, the SOC was found to be higher under the shelterbelts than under the kiwifruit pergola. This finding is supported by the work of Sivakumaran et al. (2011), who found a steady decrease in SOC as distance from an isolated tree increases in a silvo-pastoral setting.

Table 9. Carbon stock in New Zealand kiwifruit industry based on different soil sampling depths.

	T ha^{-1}	Industry (million t)
Soil to 1 metre deep	179.2	2.2
Vines	19.7	0.2
Shelterbelts	43.5	0.5
Total (1 metre deep)	**242.5**	**3.0**
Soil to 9 metre deep	295.8	3.7
Vines	19.7	0.2
Shelterbelts	43.5	0.5
Total (9 metres deep)	**359.1**	**4.5**

18. Scope for further work

1. As part of this project, we have also installed 42 fluxmeters in seven different orchards across the Western Bay of Plenty. This enables determination of the subsoil hydrology, soil-water dynamics, plus the nutrient and dissolved organic carbon leaching. We have obtained an extension to this funding from the SFF to allow us to continue collecting leachate from these DFM's until June 2013. We will report on the amounts of nitrate and ammonium leaching from the soil profiles. We will also report on the fractions of stable and labile carbon found in the drainage samples.
2. Initial measurements undertaken as part of this study have identified that it is likely that it will be possible to measure changes in SOC in some of the orchards after only five years (in 2015) to confirm the rates of sequestration claimed in this report.
3. Given one of the hot spots for carbon emissions is the use of nitrogenous fertilisers, a study to maximize the nitrogen use efficiency (NUE) of kiwifruit could drastically reduce the footprint associated with N use. In-season root-zone nitrogen management has been used in other crops to achieve higher yields and high NUE, while resulting in lower N losses to ground water (Meng et al., 2012).
4. Estimations of GHG emissions related to the application of organic soil amendments are highly uncertain. Experiments are necessary to better quantify effects of different organic amendments including, for example, compost, vermicast, manure and fishmeal on carbon stocks, biodiversity and microbiological activities, and soil health, as well as related GHG emissions.
5. As new varieties become more widespread in the near future, it will be necessary to repeat the carbon footprint analysis for each new variety.
6. Undertake a larger scale nine-metre deep soil-sampling project to confirm the findings of our preliminary sampling at this depth.

19. References

Avnimelech, Y., Ritvo, G., Meijer, L., & Kochba, M. (2001). Water content, organic carbon and dry bulk density in flooded sediments. *Aquacultural Engineering, 25*, 25-33.

Batjes, N. (1996). Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science, 47*(2), 151-163.

Batjes, N., & Sombroek, W. (1997). Possibilities for carbon sequestration in tropical and subtropical soils. *Global Change Biology, 3*(2), 161-173.

Benge, J., Manhire, J., Pearson, A., Reid, J., & Moller, H. (2007). Differences in soil quality between and within organic and integrated management kiwifruit orchards in New Zealand. *Acta Hort., 753*, 599-608.

Bernoux, M., Carvalho, M. D., Volkhoff, B., & Carri, C. (2002). Brazil’s soil carbon stocks. *Soil Science of America Journal, 66*(3), 888-896.

Clothier, B., Gentile, R., McIvor, I., & Simpson, R. (2012). *Sustainable land and soil management: mulches and trees.* Auckland: The New Zealand Institute for Plant & Food Research Limited.

Cooper, M. (2004). *Dust to Eat - Drought and Depression in the 1930s.* New York: Clarion Books.

Curtis, R., & Post, B. (1964). Estimating bulk density from organic matter content in some Vermont forest soils. *Soil Sci.Soc.Am.Proc, 28*, 285-286.

Daily, G. (1997). *Nature's Services: Societal Dependence on Natural Ecosystems.* Island Press.

Deurer, M., & Rahman, M. (2010). Quantifying soil carbon sequestration in kiwifruit orchards. Development of a sampling strategy. *Proceedings of the Workshop - Farming’s Future: Minimising footprints and maximising margins.*, 445-469.

Deurer, M., Clothier, B., & Pickering, A. (2008). *Carbon Foot printing for the Kiwifruit Supply Chain - Report on Reduction Opportunities.* Palmerston North: Landcare Research.

Deurer, M., Grinev, D., Young, I., Clothier, B., & Mueller, K. (2011). Is it desirable to have high levels of organic matter in vineyard soils? *Romeo Bragato Conference.* Auckland.

Fang, J., Liu, G., & Xu, S. (1996). Soil carbon pool in China and its global significance. *Journal of Environmental Sciences, 8*(2), 249-254.

Fisher, E. (2011, January 7). Cicadas a growing problem for kiwifruit orchardists. *Bay of Plenty Times*.

Fliessbach, A., Oberholzer, H.-R., Gunst, L., & Mader, P. (2007). Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. *Agric. Ecosystem. Environ., 118*, 273-284.

Frostegård, A., Baath, E., & Tunlid, A. (1993). Shifts in the structure of soil microbial communities in limed forests as revealed by phospholipid fatty acid analysis. *Soil Biology & Biochemistry, 25*, 723-730.

Green, G. (2009). *Carbon trading for farmers - a summary of the Carbon Pollution Reduction Scheme and the potential carbon trading options.* Southern Midlands Council.

Hillier, J., Hawes, C., Squire, G., Hilton, A., Wale, S., & Smith, P. (2011). The carbon footprints of food crop production. *International Journal of Agricultural Sustainability, 7*(2), 107-118.

Houghton R.A. (1999). The annual net flux of carbon to the atmosphere from changes in land use 1850–1990. *Tellus*, 51B:2198-313.

International Panel on Climate Change. (2007). *The Physical Science Basis.* IPCC.

International Society for Horticultural Science. (2012). *Harvesting the sun - A profile of world horticulture.* (A. Aitken, Ed.) Leuven: ISHS.

Jobbagy, E., & Jackson, R. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecol. Appl., 10*, 423-436.

Kirkham, M., & Clothier, B. (2007). Loss and recovery of research investment for applied sciences: A salutary lesson from New Zealand. *Horttechnology, 17*(1), 9-13.

Kiwifruit Vine Health. (2012, July). *www.kvh.org.nz.*

Kong, A., & Six, J. (2010). Tracing root vs. residue carbon into soils from conventional and alternative cropping systems. *Soil Science Society America Journal, 74*, 1201-1210.

Kongshaug, G. 1998. Energy Consumption and Greenhouse Gas Emissions in Fertilizer Production. IFA Technical Conference, Marrakech, Morocco, 28 September - 1 October, 1998, 18pp.

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma, 123*, 1.

Lal, R., Kimble, J., & Follett, R. (1998). Land use and soil C pools in terrestrial ecosystems. In *Management of carbon sequestration in soil* (pp. 1-10).

Lowe, D., & Palmer, D. (2005). Andisols of New Zealand and Australia. *Journal of Integrated Field Science, 2*, 39-65.

Martin, M., Wattenbach, M., Meersmans, P. S., Jolivet, C., Boulonne, L., & Arrouays, D. (2011). Spatial distribution of soil organic carbon stocks in France. *Bio geosciences, 8*, 1053-1065.

Meng, Q.-F., Chen, X.-P., Zhang, F.-S., Cao, M.-H., Cui, Z.-L., Bai, J.-S., Müller, T. (2012). In-season root-zone nitrogen management strategies for improving nitrogen use efficiency in high-yielding maize production in China. *Pedosphere, 22*(3), 294-303.

Mithraratne, N., Barber, A., & McLaren, S. (2010). *Carbon Foot printing for the Kiwifruit Supply Chain - Report on Methodology and Scoping Study.* Landcare Research.

OECD. (2001). *Environmental Indicators for Agriculture.*

Ouimet, R., Tremblay, S., Perie, C., & Pregent, G. (2009). Ecosystem carbon accumulation fallow farmland afforestation with Red Pine in Southern Quebec. *Can. J. For. Res., 37*, 1118-1133.

Parfitt, R. (1990). Allophane in New Zealand - A Review. *Australian Journal of Soil Research, 28*, 343-360.

Parfitt, R. (2009). Allophane and imogolite: role in soil biogeochemical processes. *Clay Minerals, 44*, 135-155.

Perie, C., & Ouimet, R. (2008). Organic carbon, organic matter and bulk density relationships in boreal forest soils. *Can. J. Soil. Sci., 88*, 315-325.

Prevost, M. (2004). Predicting soil properties from organic matter content following mechanical site preparation of forest soils. *Soil Sci. Soc Am J., 68*, 943-949.

Rahman, M., & Holmes, A. (2010). Carbon Sequestration in kiwifruit soils of New Zealand. *Proceedings of the 19th World Congress of Soil Science*, 66-69.

Rawls, W.J., Y.A. Pachepsky, J.C. Ritchie, T.M. Sobecki and H. Bloodworth 2003. Effect of soil organic matter on soil water retention. *Geoderma* 116:61-76.

Schipper, L., Baisden, W., Parfitt, R., Ross, C., Claydon, J., & Greg, A. (2007). Large losses of soil C and N from soil profiles under pasture in New Zealand during the past 20 years. *Global Change Biology, 13*, 1138-1144.

Sivakumaran, S., McIvor, I., Deurer, M., Gillum, A., Sloan, S., Jeyakumar, P., & Hedderley, D. (2011). Soil functions of pastoral hill country influenced by the presence of *Salix matsudana* x *alba* trees. In Plant & Food Research, *Poplar and Willow Breeding.*

South Africa Fruit & Wine Initiative. (2012). *Top 10 mitigation options through the supply change.* Retrieved from South Africa Fruit & Wine Initiative: http://www.climatefruitandwine.co.za/download/Growers'%20Information%20Resource%20-%20Mitigation%20Options.pdf

Tremblay, D., Perie, C., & Ouimet, R. (2006). Changes in organic C storage in a 50 year White Spruce chronosequence established on fallow land in Quebec. *Can. J. For. Res., 36*, 2713-2723.

Zonderland-Thomassen, M., Boyes, M., & Ledgard, S. (2011). *An ILCD database of three fertilisers for the kiwifruit industry.* Hamilton: AgResearch Limited.