Carbon sequestration in kiwifruit soils of New Zealand

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Abstract
Soil is a major component which sequesters huge amounts of carbon. In different locations and over time soil may exhibit a complex degree of variability in organic carbon content. Changes in soil organic carbon (SOC) levels have not been monitored for kiwifruit grown under different management practices. To evaluate the sequestration of organic carbon in Andisols used for kiwifruit production we analysed three management systems from three growing regions in the Bay of Plenty of New Zealand. Replicated soil samples were collected from three kiwifruit orchards per region. Within each orchard samples were taken from the grass alleyways, the wheel tracks and plant rows in three depths for two consecutive years. For comparison, soil was also collected from nearby pastoral and arable land as paired samples. In kiwifruit orchards of two regions, soil under organic management sequestered more carbon than under conventional management while the opposite was the case in the third region. We recorded higher SOC concentrations in the wheel tracks followed by the alleyway and then the plant row. In the top 0.15 m SOC significantly decreased over 5 cm increments. Kiwifruit orchards in the Katikati region sequestered more SOC than pastoral land and the reverse was true for the Te Puke orchard region. SOC stocks in kiwifruit orchards were significantly higher than under arable land use in all three regions. Our results indicated that soils of kiwifruit orchard can be a good carbon sink.

Key Words
Andisol, carbon footprints, climate change, southern hemisphere

Introduction
Increased greenhouse gases in the atmosphere are becoming a world wide concern. Scientists predict that current relative annual increase in tropospheric CO_2 is almost 0.5% and future levels are projected to double during the next century due to human activities. Resolving this problem requires decreasing CO_2 from the troposphere by either reducing or avoiding emissions, or increasing the amount of carbon sink activity. Depending on management and environment, soil organic carbon can either be a source or sink for carbon. It is estimated that about 40 x 10^3 to 80 x 10^3 million t C can be sequestered in soils over next 50 to 100 years through sustainable management. The magnitude of CO_2 emission from agricultural and deforestation activities is estimated at about 1.6 x 10^3 million t C y^{-1} and SOC sequestration potential could offset about 15% of global CO_2 emission (Lal 2007). A widespread loss of soil carbon has been reported under some dairy and dry stock pastoral land uses in New Zealand (Schipper *et al.* 2007). Australian research has shown that SOC declines after the conversion of land to arable cropping and the rate of decline was between 19 and 45% in major soils of cereal belt of southern Queensland after 20-70 years of cropping (Dalal and Mayer 1986, Skjemstad *et al.* 2001). On the other hand, conversion of cropland to pasture or forest is likely to lead to an increase in soil carbon (Vesterdal *et al.,* 2002). It is therefore predictable that agricultural management systems as well as climate and soil inherent properties determine whether soils will be a net carbon sink or source. Kiwifruit of the genus *Actinidia* (Actinidiaceae) is very widespread in both the northern hemisphere and southern hemisphere. In the southern hemisphere, New Zealand is the largest kiwifruit producer. The total acreage of kiwifruit planted in New Zealand now exceeds 12,177 ha with different management practices and species. New Zealand climate, soils and agricultural management practices are different from than those of other countries, and will have an important impact on soil carbon stocks in New Zealand compared with other regions. To our knowledge there is a scarcity of detailed research on carbon sequestration in kiwifruit systems. Investigating carbon sequestration also requires the ability to understand the spatio-temporal distribution of organic carbon in the soil system. We hypothesized that soil properties of kiwifruit orchard alter due to management practices over time, which leads to changes in soil organic carbon levels. The aim of the present study was to determine the effects of different management practices on carbon sequestration of Andisol used for kiwifruit production in the Bay of Plenty in New Zealand.

Materials and methods
In this study three management practices (organic, biological and conventional) were selected from three agro-ecological zones (Katikati: 37°36S 175°56E; Tauranga: 37°43S 176°06E and Te Puke: 37°47S

176°23E), located in the Bay of Plenty, North Island of New Zealand. The Katikati sites are approximately 19 km north-west of the Tauranga sites, with the Te Puke sites 28 km to the east of the Tauranga sites. Katikati sites ranged from 15 to 20 m, Tauranga sites ranged from 20 to 48 m and Te Puke sites ranged from 7 to 12 m above sea level. The biological, conventional and organic sites are all within a kilometre of each other in each region. Sites were also included from nearby pastoral and arable land to use as pair samples. Soils of all experimental sites are classified as Allophanic Orthic Pumice soils (Vitrads/Vitricryands Andisol, USDA; Mollic Andosol, FAO) formed predominantly from ryolitic tephra between ~ 4000 and 40,000 years ago during the region's geographic history of periodic volcanic eruptions. Three sampling plots (bays) of 500 cm x 400 cm were randomly selected within each site for soil collection at 0-5cm, 5-10cm and 10-15cm depth. In kiwifruit orchards, soil samples were collected from between the plants along the row (plant row); in the middle of the sward between the rows (grass alleyway) and from the area that machinery travels along between the rows (wheel tracks) using Daiki Soil Sampler with 100cc core (Daiki Rika Kogyo Co., Ltd., Japan) in August 2008 and 2009. The plant row is often sprayed with an herbicide to control weeds, and also some banded application of fertiliser is used. This region of the orchard is also not compacted by any machinery operations. The wheel tracks are compacted by vehicle traffic, and the alleyway has a certain cover of various plant species that may affect the soil properties. Three phase distribution of soil and different forms of soil water were measured from undisturbed soil samples and particle size distribution and chemical properties were measured from disturbed and sieved (<2mm) soil sample. Soil properties were measured following standard methods (data not shown). All experimental sites were sandy loam soils. Soil organic carbon was measured using three recognised methods: wet chemistry (Walkley and Black 1934), dry chemistry (TruSpec® CHN Determinators, LECO Corp., St Joseph, MI, USA) and loss-on-ignition (Kalra and Maynard 1994) for the 81 soil samples, collected from different kiwifruit orchards at various depths including a wide range of soil types. Based on the results, a regional regression equation was developed to estimate SOC from loss-on-ignition (LOI) with optimum heating temperature and duration, as LOI is popular as a rapid, easy and inexpensive method. Carbon storage was estimated as: Carbon stock (t ha^{-1}) per soil layer = carbon (%) x bulk density (Mg m^{-3}) x layer depth (m) x 10, 000 (m^2 ha^{-1}). The relative proportion of carbon in the kiwifruit orchard and pastoral land to the 10-15cm deep sample from the arable land was calculated. All statistical analyses were performed by JMP 4.0 (SAS Institute, Cary, North Carolina, USA).

Results and discussion

Overall effect of management practice, depth, position, and regions on soil organic carbon was significant (MANOVA results are not shown). Various researchers have noted that soil organic carbon is influenced by management, climate, soil mineral composition, soil biota, and position in the landscape. Due to the interactions that occur between these factors it is difficult to determine the absolute importance of any single factor on soil organic carbon. However, management is arguably the most important, followed by climate (Lal 2007, Baldock and Skjemstad, 1999) and soil type. In Japanese apple orchard production systems on Andisol Rahman and Sugiyama (2008) observed that sampling time of year had a more predominant effect on soil organic carbon than management. In the present study, results revealed that the region is the most dominant factor in soil organic carbon sequestration. The minimum, maximum, mean, standard deviation, coefficient of variation, skewness and kurtosis for soil organic carbon kiwifruit orchard for depths, positions, managements and regions are depicted in Table 1.

Table 1. Comparisons of summary statistics for soil organic carbon in kiwifruit orchard of Bay of Plenty.

	Management[1] (n = 162)			Depth, cm (n = 162)			Position[2] (n = 162)			Zone[3] (n = 81)		
	Org	Bio	Con	0-5	5-10	10-15	AW	WT	PR	KK	TR	TP
Minimum, %	1.59	1.60	1.79	2.01	2.02	1.65	1.89	1.59	1.65	2.47	1.59	1.65
Maximum, %	7.39	8.72	7.52	8.72	7.15	7.51	6.97	7.52	7.51	8.72	7.31	7.61
Mean, %	3.96	4.11	3.93	4.82	3.82	3.36	3.98	4.29	3.72	5.14	3.66	3.19
SD	1.35	1.49	1.28	1.33	1.14	1.23	1.38	1.42	1.27	1.10	1.18	0.99
CV, %	34.1	36.2	32.7	27.7	29.8	36.5	34.7	33.0	34.2	21.5	32.3	31.0
Skewness	0.43	0.44	0.70	0.26	0.56	0.88	0.51	0.50	0.51	0.53	0.62	1.07
Kurtosis	-0.50	-0.38	0.40	-0.34	-0.30	0.77	-0.40	-0.09	-0.28	-0.14	0.15	2.02

[1]Org: Organic; Bio: Biological; Con: Conventional; AW[2]: Alleyway; WT: Wheel track; PR: Plant row; KK[3]: Katikati; TR: Tauranga; TP: Te Puke.

The present study showed a considerably larger variability at a smaller scale (CV: 21.5 to 36.2 %) which is comparable to the results of Goderya (1998). Biological and/or organic kiwifruit management systems stored more SOC than other systems. The highest SOC was recorded in the 0-5 cm layer, and decreased linearly with increased depth. Organic carbon content in soil depends on several factors, amongst which microbial community plays a significant role. In Andisol used for apple cultivation, recent research showed that

organic carbon content positively correlated with fungi population, but negatively correlated with bacteria and actinomycetes (Rahman and Sugiyama 208). The highest SOC was found under wheel track, followed by alleyway then plant row. Previous research in kiwifruit orchards has shown that more litter accumulation is associated with higher numbers of earthworms in wheel tracks than alleyway or plant row (M H Rahman *et al*. unpublished data 2008). Such accumulations in association with earthworm activities are most likely to contribute more SOC in wheel track. Baldock and Skejemstad (1999) pointed out that the activity of soil decomposers and fauna may be important for soil organic carbon.
The values of total organic carbon stocks in soils for different management systems averaged over two years are presented in Table 2. Soil organic carbon stocks varied significantly across regions with the highest in

Table 2. Organic carbon stock (t ha^{-1}) in soils (average for two years) with different management practices of Bay of Plenty.

Soil management	Depth, cm	Katikati	Tauranga	Te Puke	Average
Organic kiwifruit	0-5	24.41 (1.80)[1]	20.42 (1.94)	18.16 (3.27)	21.00 (2.09)
	5-10	19.12 (1.41)	14.01 (1.32)	14.51 (2.62)	15.88 (1.58)
	10-15	16.63 (1.23)	11.61 (1.10)	11.32 (2.04)	13.19 (1.31)
	LSD[2]	1.62	1.13	1.61	*1.57*
Biological kiwifruit	0-5	24.92 (1.84)	21.79 (2.07)	18.34 (3.21)	21.68 (2.16)
	5-10	19.17 (1.42)	15.81 (1.49)	13.13 (2.32)	16.04 (1.60)
	10-15	17.36 (1.28)	12.92 (1.22)	9.46 (1.68)	13.25 (1.32)
	LSD	1.31	1.11	1.14	*1.70*
Conventional kiwifruit	0-5	22.83 (1.69)	22.72 (2.16)	16.05 (2.88)	20.53 (2.04)
	5-10	17.15 (1.27)	16.26 (1.53)	12.71 (2.22)	15.37 (1.53)
	10-15	14.66 (1.08)	12.81 (1.20)	10.69 (1.87)	12.72 (1.26)
	LSD	1.21	1.03	1.12	*1.57*
Pastoral	0-5	21.95 (1.62)	20.84 (1.98)	20.11 (3.66)	20.97 (2.09)
	5-10	19.12 (1.41)	16.31 (1.54)	17.85 (3.21)	17.76 (1.77)
	10-15	15.12 (1.12)	12.68 (1.19)	7.65 (1.31)	11.82 (1.17)
	LSD	1.18	1.18	1.29	*1.83*
Arable	0-5	16.76 (1.24)	16.18 (1.54)	13.09 (2.35)	15.34 (1.53)
	5-10	16.01 (1.18)	13.59 (1.29)	11.30 (2.01)	13.63 (1.36)
	10-15	13.53 (1.00)	10.63 (1.00)	5.91 (1.00)	10.02 (1.00)
	LSD	1.10	1.05	1.17	*1.07*
Organic kiwifruit	0-15	60.15 (1.30)	46.04 (1.14)	43.99 (1.45)	50.06 (1.28)
Biological kiwifruit	0-15	61.45 (1.33)	50.52 (1.25)	40.93 (1.35)	50.96 (1.31)
Conventional kiwifruit	0-15	54.64 (1.18)	51.79 (1.28)	39.45 (1.30)	48.62 (1.24)
Pastoral	0-15	56.19 (1.21)	49.82 (1.23)	45.61 (1.51)	50.54 (1.30)
Arable	0-15	46.30 (1.00)	40.40 (1.00)	30.31 (1.00)	39.00 (1.00)
	LSD	3.05	2.52	2.27	*2.44*
Kiwifruit	0-15	58.75 (1.27)	49.45 (1.22)	41.46 (1.37)	49.89 (1.28)
Pastoral	0-15	56.19 (1.21)	49.82 (1.23)	45.61 (1.51)	50.54 (1.29)
Arable	0-15	46.30 (1.00)	40.40 (1.00)	30.31 (1.00)	39.00 (1.00)
	LSD	2.78	2.90	3.39	*2.56*

[1]Data within parenthesis are relative proportion in the kiwifruit orchard and arable land to 10-15 cm deep.

[2]LSD: Least significant difference at $p < 0.05$ among the values within columns.

Katikati and the lowest recorded in Te Puke. This may reflect climatic differences of the areas studied, the time that a given site has been under the present land use relative to the initial soil carbon content or a systematic difference in orchard management. The relative proportion of SOC was significantly higher in kiwifruit orchards than that of arable land (Table 2). Our results indicate that kiwifruit soil stored 49.9 t SOC ha^{-1} in top 0-15 cm layer, which is ~5 times higher than those of cotton soils in northern New South Wales of Australia (Knowles and Singh, 2003). Additionally, kiwifruit tend to have a deeper rooting system than shallow rooted plants and may sequester higher SOC at depth in kiwifruit orchards than in pastoral or arable systems. This study found that organic carbon storage capacity of kiwifruit orchard soils was ~1.3 times higher than arable soil at 0-15 cm layer. The SOC stocks in kiwifruit orchards averaged across the three regions and different management systems showed a decrease of about 40% in the top 15 cm of the soil. We intend to analyze the SOC stocks below a depth of 15 cm in kiwifruit orchards in the future.

In kiwifruit, there may be some more potential for increasing carbon stocks by adopting new land use and soil amelioration including bioenergy herbaceous perennial grasses, recycling organic products such as biochar and introducing soil microfauna. However the information on these aspects with special reference to carbon budgets is lacking in kiwifruit orchards. The information is also lacking related to climatic conditions and biological activity versus carbon sequestration in kiwifruit management systems which need to be elucidated.

Conclusions and considerations

This is a baseline study on carbon stocks in kiwifruit soils in the Bay of Plenty of New Zealand. Our preliminary study showed that organic management leads to significantly higher soil carbon storage than conventional kiwifruit management in two out of three regions. To maintain potentially high SOC in soils, higher C:N ratio (more lignin and less carbohydrate and protein) and/or lower N:C ratio plant or plant material should be established in the sward or introduced as compost or mulch. The following should to be considered in future research on carbon storage in kiwifruit orchards to mitigate and adapt to climate change: (i) soil process and profile (ii) plant species and management practices (iii) landscape and climate (iv) surveillance site and baseline benchmarks (vi) regional and temporal scale (vii) related and effective soil sampling technique and (viii) cost-effective and rapid SOC estimation method which will help to develop and disseminate guidelines for kiwifruit growers economically and environmentally sustainable carbon storage. Since undertaking this work, PlusGroup is now managing the Sustainable Farming Fund funded Carbon in Orchard Soils Team, investigating the role of different kiwifruit management systems on SOC; and the effect of SOC on kiwifruit production, carbon sequestration and carbon footprints.

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