

Carbon sequestration in kiwifruit soils of New Zealand

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Introduction

The magnitude of CO₂ emissions from agricultural and deforestation activities is estimated at about 1.6×10^3 million t C y⁻¹ and SOC sequestration potential could offset about 15% of global CO₂ emission (Lal 2007). 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 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. We hypothesized that soil properties of kiwifruit orchards 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.



Figure 1: Kiwifruit orchards with different management. Left: Conventional kiwifruit orchard. Right: Organic kiwifruit orchard.

Materials and methods

In this study three management practices (organic, biological and conventional; Figure 1) 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 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 paired samples. Soils of all experimental sites are classified as Allophanic Orthic Pumice soils (Vitradis/Vitricryands Andisol, USDA; Mollic Andosol, FAO; Figure 2).

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) in August 2008 and 2009. The plant row is often sprayed with a 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. 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 (%) \times bulk density ($Mg\ m^{-3}$) \times layer depth (m) \times 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).



Figure 2: Left: A typical soil (Allophanic Orthic Pumice) profile in a kiwifruit orchard in Te Puke. The topsoil has a depth of 22 cm. Right: Two large earthworms at about 50 cm soil depth exiting from channels created by decayed roots.

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 given 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

¹Org: 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 the 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 2008). 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 (Figure 2) 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)
	<i>LSD</i> 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)
	<i>LSD</i>	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)
	<i>LSD</i>	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)
	<i>LSD</i>	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)
	<i>LSD</i>	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)
	<i>LSD</i>	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)
	<i>LSD</i>	2.78	2.90	3.39	2.56

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

²LSD: 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 the 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 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 (v) regional and temporal scale (vi) 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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