Soil carbon stocks and their change in orchards and vineyards in New Zealand

Deurer M, Clothier BE, Greven M, Green S, Mills T

May 2008

Report to Landcare Research
HortResearch Client Report No. 25805
HortResearch Contract No. 22723

Deurer M, Clothier BE, Green S, Mills T
The Horticulture and Food Research Institute of New Zealand Ltd
HortResearch Palmerston North
Private Bag 11030
Manawatu Mail Centre
Palmerston North 4442
NEW ZEALAND
Tel: +64-6-356 8080
Fax: +64-6-354 6731

Greven M
The Horticulture and Food Research Institute of New Zealand Ltd
HortResearch Marlborough
PO Box 845
Blenheim 7240
NEW ZEALAND
Tel: +64 3 577 2370
Fax: +64 3 578 0153

DISCLAIMER

Unless agreed otherwise, HortResearch does not give any prediction, warranty or assurance in relation to the accuracy of or fitness for any particular use or application of, any information or scientific or other result contained in this report. Neither HortResearch nor any of its employees shall be liable for any cost (including legal costs), claim, liability, loss, damage, injury or the like, which may be suffered or incurred as a direct or indirect result of the reliance by any person on any information contained in this report.

This report has been prepared by The Horticulture and Food Research Institute of New Zealand Ltd (HortResearch), which has its Head Office at 120 Mt Albert Rd, Mt Albert, AUCKLAND. This report has been approved by:

Research Scientist	On behalf of Group Leader, Quality Systems
Date: 25 May 2008	Date: 25 May 2008

CONTENTS

Page

EXECUTIVE SUMMARY

Soil carbon stocks and their change in orchards and vineyards in New Zealand

Report to Landcare Research

Deurer M, Clothier BE, Greven M, Green S, Mills T May 2008

HortResearch was asked by Landcare to contribute an estimate of the typical dynamics of soil carbon stocks under horticultural land-use. Landcare was especially interested in the change of soil carbon stocks in orchards and vineyards in New Zealand when the soils are subjected to a land-use change (from permanent pasture) and to different orchard/vineyard management practices. Additionally, Landcare wanted HortResearch to advise on options to enhance soil carbon sequestration in orchard/vineyard systems.

There has been no systematic survey of the land areas of orchards/vineyards associated with specific soil orders. Consequently, it is currently not possible to estimate nationally the total carbon stocks in soils or their change under orchards/vineyards with a high degree of certainty. We estimated, therefore, the dynamics of soil carbon stocks in the topsoils of orchards/vineyards based on exemplary rather then representative measurements, and on modelling. These were our key findings:

- We compared an exemplary organic and an integrated apple orchard system in Hawke's Bay. The organic system with cover crops (permanent pasture) on the entire orchard floor and regular compost applications to the tree rows had 86.5 ± 16 t/ha of soil carbon in 0-0.3 m depth. The integrated system with cover crops (permanent pasture) in the alley and herbicided tree rows had 70 ± 6.5 t/ha of soil carbon in 0-0.3 m depth. We estimated (measurements) that, compared with a permanent pasture as a reference, the organic orchard lost 8.5 ± 15 t/ha soil carbon in 0-0.3 m depth in the last 12 years, while in the same time the integrated orchard lost 11 ± 7 t/ha soil carbon in 0-0.3 m depth.
- We estimated (measurements) that one exemplary integrated vineyard system in Marlborough lost 12 ± 5 t/ha soil carbon over the last 15 years in 0-0.15 m depth, compared with a permanent pasture as a reference.
- We estimated (modelling) that one exemplary kiwifruit orchard system in Te Puke lost between 19.9 t/ha (= no cover crop) and 7.6 t/ha (= 50% cover crop) soil carbon in 0-0.3 m depth over the last 17 years, compared with a permanent pasture as a reference.
- Our estimated losses of soil carbon stocks are slightly higher than those predicted by a recent study (Tate et al. 2005). This study estimated that in New Zealand, the conversion of grazing land to horticulture leads to a decline of the soil carbon stocks in 0-0.3 m depth of about 9 ± 7 t/ha. However, given the high uncertainties of our estimates and of the estimates in the cited study, the values of the estimated losses of both studies agree well.
- We identified from measurements, modelling and from a literature review three feasible options to enhance soil carbon sequestration in orchards/vineyards. Ranked according to carbon sequestration and cost efficiency, these are: (1) cover crops, (2) use of an organic system, and (3) subsoil carbon sequestration.

- We identified biochar as a promising option for soil carbon sequestration in orchards/vineyards. However, its practical feasibility for New Zealand soils, horticultural production systems, and climate is, due to a lack of applied research in this area, currently, unknown.

For further information, please contact:

Markus Deurer
The Horticulture and Food Research Institute of New Zealand Ltd
HortResearch Palmerston North
Private Bag 11030
Manawatu Mail Centre
Palmerston North 4442
NEW ZEALAND
Tel: +64-6-356 8080
Fax: +64-6-354 6731
Email: mdeurer@hortresearch.co.nz

INTRODUCTION

THE ROLE OF SOIL CARBON MANAGEMENT IN SOILS UNDER ORCHARD/VINEYARD LAND-USE

Soil carbon stocks are determined by the soil type, climate, type of land-use, and management. For soil carbon classification purposes, it is useful to distinguish among the impact of inherent soil properties, the soil genoform, and the anthropogenic influences - the soil phenoform (Droogers & Bouma 1997).

A recent document (Mackay et al. 2006) gives an overview of the typical range of soil carbon stocks associated with New Zealand's most prominent soil genoforms, the soil orders. The different New Zealand soil orders will have quite different soil carbon stocks (Figure 1). The variation in the soil carbon stocks in 0-0.15 m depth is about a factor of four. Therefore, independent of management or land-use history, orchards/vineyards located on different soil series will have different soil carbon stock levels.

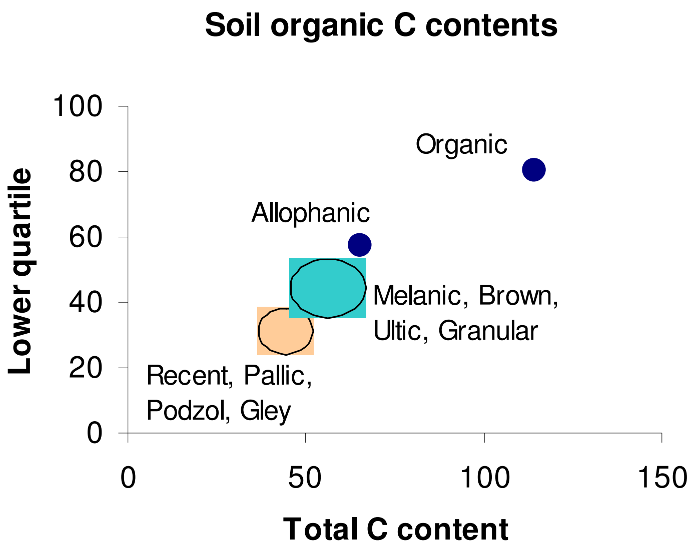

Figure 1. Mean total and lower quartile carbon (C) contents (Mg/ha) of soils in the 500 Soils Project data set (n=700; Mackay et al. 2006) in the top 0.15 m depth. Not all soil orders are represented**.**

Unfortunately, to our knowledge, there has been no systematic survey of the land areas of orchards/vineyards associated with specific soil orders.

We term the anthropogenic influence on the soil carbon stocks as "soil carbon management". Soil carbon management includes all "land management practices that maintain or increase soil C" (Kimble et al. 2007). The latter is very similar to the definition of "carbon sequestration management", namely "… any management practice that increases the photosynthetic input of carbon and/or slows the return of stored carbon to CO_2 via respiration, fire, or erosion will increase carbon reserves, thereby sequestering carbon or building carbon sinks" (Smith et al. 2007).

The various options for soil carbon management and their potential to increase soil carbon stocks under arable and forest land-use have been reviewed (Lal 2004; Smith et al. 2007). However, to our knowledge, no such review exists on options for soil carbon management in orchards and vineyards.

With respect to soil carbon management in orchard/vineyards, we suggest distinguishing between traditional/integrated systems and organic practices.

SOIL CARBON MANAGEMENT IN INTEGRATED ORCHARDS/VINEYARDS

Under traditional/integrated systems, no deliberate practices for soil carbon management exist. Soil carbon is not yet valued by such orchardists/winegrowers as providing additional value to their "natural capital" with respect to production and economic outcomes. Quite the opposite in fact, for in vineyards the nutrient source of mineralised nitrogen (N) from soils with high soil carbon stocks could lead to increased vegetative vigour, which could reduce grape yield and quality, and most certainly require more intensive practices such as pruning and hedging. Therefore, winegrowers prefer to use synthetic fertilizers, as their availability for the vines is much easier to predict and to manage than the nutrient supply from organic matter sources such as composts, or manures. Another example of a 'negative' soil carbon management practice is the avoidance of cover crops for the entire orchard/vineyard floor. Cover crops compete with the crops for water and nutrients (Tworkoski & Glenn 2001; Tesic et al. 2007). Economic incentives such as carbon credits (Sparling et al. 2006), or market access regulations that reward environmental stewardship such as the GlobalGAP protocols might in the future change the lack of consideration of 'positive' soil carbon management in traditional/integrated orchards/vineyards.

This is fundamentally different from the situation under an arable land-use, where a positive effect of soil carbon on the productivity has been reported for New Zealand by the Sustainable Land Use Research Initiative (Mackay et al. 2006).

SOIL CARBON MANAGEMENT UNDER ORGANIC ORCHARDS/VINEYARDS

Soil carbon management is the key for success in organic orchards/vineyards. In organic orchards/vineyards, soil organic matter is the main source of the major plant nutrients, and for nitrogen it is the only means of supply. Because of the soil-ecosystem service of nutrient supply, organic orchardists/winegrowers value soil organic matter highly. Better soil carbon management in organic orchards/vineyards than in traditional/integrated ones should, therefore, be provide a 'positive' outcome. Indeed, for arable systems it was found that carbon inputs into the soil are generally higher in organic than in integrated or conventional production systems (Gunapala & Scow 1998; Fliessbach et al. 2007).

However, the sequestration objective of soil carbon management somewhat contradicts the nutrition objective, using controlled and continuous soil carbon turnover as a nutrient source in organic orchard/vineyard systems. This dilemma was recently discussed in the scientific literature under the title: The soil carbon dilemma – should we hoard it or should we use it? (Janzen 2006).

CURRENTLY AVAILABLE DATA SETS TO ESTIMATE SOIL CARBON STOCKS AND THEIR CHANGE OVER TIME IN SOILS UNDER HORTICULTURAL LAND-USE

To the best of our knowledge, there are no large data sets under horticultural land-use available, either in New Zealand or internationally, that are explicitly dedicated to the monitoring of soil carbon stocks, and their change over time due to a change in land-use, and/or management practices.

We have identified two data sets of ours that we can use (Data sets 1 and 2) to provide a preliminary estimate for the dynamics of soil carbon stocks under horticultural land-use. Two other data sets of ours (Data sets 3 and 4) could be extended in the future to serve that purpose also. Our data sets are:

Data set 1: Soil carbon management of apple orchard systems (organic/integrated) in Hawke's Bay
Data set 2: Soil carbon status and management of vineyard systems in Marlborough
Data set 3: Soil carbon status of vineyards in Hawke's Bay
Data set 4: Soil carbon status of kiwifruit orchards in the Bay of Plenty, Nelson, and Northland.

KEY CHARACTERISTICS OF THE DATA SETS

The data sets are described in detail in the Appendix. Here, we focus only on the four key characteristics of the data sets that are relevant for the analysis of the soil carbon stocks, and their change over time under orchard/vineyard practices. These characteristics are:

1. *How representative is the data set*? The total number of soil samples, the number of locations/sites, the soil order and/or the number of soil orders sampled
2. *Is it possible to derive the soil carbon stocks from the data set?* The sampling depth(s) and bulk densities
3. *Is it possible to derive the change of soil carbon stocks over time?* The land-use before horticulture and its associated soil carbon stock. The number/dates of times on which the soil carbon stocks were sampled
4. *What impact has/had a specific soil carbon management on the rate of change of soil carbon stocks?* Detailed information on the soil carbon stocks (see 2), their change over time (see 3), and the soil carbon management over at least the last 10 years.

Additionally, we give a short description of the primary objective of the study that resulted in the data set, and we list the publications where these results can be found.

Data set 1

The primary objective of the work that led to this data set was to investigate the impact of soil carbon management on soil quality. The major results have just been published (Deurer et al. 2008a).

How representative is the data set?
Six soil samples were taken in 2006 from each of the tree row, and the alley between the tree rows, of an organic and an adjacent integrated apple orchard in Hawke's Bay.

Both sites have the same soil order (Recent). Therefore, because of the small number of samples and the single soil order sampled, the data set is not representative of the soil carbon stocks of apple orchards in other parts of Hawke's Bay, or New Zealand. However, given the need for well-drained soils for apple production, Recent soils are probably over-represented in the inventory of orchard soils.

Is it possible to derive the soil carbon stocks?
Yes, soil carbon stocks and bulk densities were measured in three incremental depths (0-0.1, 0.1-0.2, 0.2-0.3 m) down to 0.3 m.

Is it possible to derive the change of soil carbon stocks over time?
Yes, but in a limited way. The land-use before horticulture was (arable) commercial vegetable production in both systems, but the soil carbon stocks at the point of land-use change are unknown. However, at the same time that the apple trees were planted about 12 years ago, the alleys between the apple trees were sown into pasture. We assume that 12 years is long enough for the soil carbon in the pasture system to reach equilibrium in the top 0.3 m. Therefore, the difference of soil carbon between the tree rows and the alleys can be used to estimate the annual change of soil carbon stocks when a pasture is turned into an apple orchard.

What impact has/had a specific soil carbon management on the rate of change of soil carbon stocks?
The information on soil carbon stocks, their change over time, and the soil carbon management practices over the last 12 years is known.

Data set 2

The primary objective of the work leading to this data set was to investigate the potential of different soil carbon management practices to change the soil carbon stocks in the vine rows. The major results were presented at a wine workshop.

How representative is the data set?
Three soil samples were taken in 2007 from each of 2-4 sites in the vine-row and inter-row of five different vineyards in Marlborough. The sites were all of the same soil order (Recent). Therefore, because of the small number of samples and the single soil order sampled, the data set is not representative of the soil carbon stocks of vineyards in the whole of the Marlborough region, or New Zealand. Vineyards, because of their requirement for free-draining conditions do, however, tend to be on Recent soils.

Is it possible to derive the soil carbon stocks?
Yes, but only for 0-0.15 m and only for one vineyard. The soil carbon stocks and bulk densities were measured in a mixed sample from 0-0.15 m depth.

Is it possible to derive the change of soil carbon stocks over time?
Yes, but in a limited way. The land-use before horticulture was extensive sheep and beef pasture, although the soil carbon stocks at that point in time were unknown. However, the inter-rows and headlands in the vineyard remained as pasture. Therefore, the difference of soil carbon between the tree rows and the inter-rows/headlands can be used to estimate the yearly change of soil carbon stocks from extensive sheep and beef pasture to vineyard.

What impact has/had a specific soil carbon management on the rate of change of soil carbon stocks?
The information on soil carbon stocks, their change over time, and the soil carbon management over the last 10-15 years is known.

Data set 3

The primary objective of the work leading to the data set was to begin to investigate the components of terroir, and the soil carbon status was included as part of this study in Hawke's Bay. The data set has not been presented or published.

How representative is the data set?
Three soil samples were taken in 2007 from the vine-row of five different vineyards. The soil order, or soil type of the sites are unknown. Therefore, because of the small number of samples the data set is not representative of the soil carbon stocks of vineyards in either Hawke's Bay, or New Zealand.

Is it possible to derive the soil carbon stocks?
Yes, but only for 0-0.2 m. The soil carbon stocks and bulk densities were measured in a mixed sample from 0-0.2 m depth.

Is it possible to derive the change of soil carbon stocks over time?
No.

What impact has/had a specific soil carbon management on the rate of change of soil carbon stocks?
The data set contains too little information to answer this question.

Data set 4

The primary objective of the work leading to the data set was to analyse the soil carbon status in different kiwifruit orchards as part of a study on vine nutrition. The data set has not been presented or published.

How representative is the data set?
Three soil samples were taken in 2006 and 2007 from the vine row of each of five different kiwifruit orchards. Four of these orchards were in the Bay of Plenty, one was in Nelson, and one in Northland. The soil order of the sites is not known. Therefore, because of the small number of samples the data set is not representative of the soil carbon stocks of kiwifruit orchards in New Zealand.

Is it possible to derive the soil carbon stocks?
Only for the samples from the Bay of Plenty, and only for 0-0.2 m. For the other samples, no bulk densities were measured.

Is it possible to derive the change of soil carbon stocks over time?
No.

What impact has/had a specific soil carbon management on the rate of change of soil carbon stocks?
The data set contains too little information to answer this question.

LIMITATIONS OF THE DATA SETS TO ESTIMATE SOIL CARBON STOCKS AND THEIR CHANGE OVER TIME

The impact of land-use change and management options are the focus of this report. Consequently, we will limit our analysis to the data sets 1 and 2.

From both data sets the change of soil carbon stocks due to land-use change can be estimated, but not directly. A space-for-time substitution has to be applied. This certainly increases the uncertainty of the estimate.

The data sets are extremely limited, both with respect to the number of samples and to the number of soil orders covered. Therefore, the data sets and the analysis based on them are provisional, and not representative.

We use the terms "traditional/integrated" and "organic" to label different soil carbon management practices. However, soil carbon management is not yet an explicit objective of either system. There is no standard or set of rules around what exactly "soil carbon management" is.

IDENTIFICATION OF KNOWLEDGE GAPS

There is no representative and comprehensive data set for soil carbon stocks and their change under horticulture (Tate et al. 2005). Therefore, any analysis of the current soil carbon stocks and of their future development under horticultural land-use is uncertain.

As a consequence, predictions of the change of soil carbon stocks following a change from other land-uses to horticulture, or of a particular horticultural management practice, are currently based on limited and un-representative data, and/or modelling.

INTERNATIONAL INFORMATION ON THE BEHAVIOUR OF SOIL CARBON STOCKS UNDER ORCHARD/VINEYARD MANAGEMENT PRACTICES

There are very few studies associated with the change in soil carbon stocks in horticulture.

The study of Deurer et al. (2008) compared the soil carbon stocks under integrated and organic apple orchards in New Zealand (same land-use history for >10 years, soil order, type, texture, and climate), with the soil carbon stocks under their grassed alleys as a permanent pasture reference. They found that the integrated apple orchard management led to significantly lower soil carbon stocks in 0-0.1 and 0.2-0.3 m depth of the tree row than did the organic orchard management. In this case, the tree row of the integrated orchard was herbicided, drip-irrigated, and received no external organic matter inputs. The tree row of the organic orchard was grassed, not irrigated, and regularly received compost.

In another study, four pairs of conventional/organic vineyard soils (0-0.1 m) in Germany and France on different soil types were compared (Probst et al. 2008). No significant differences of soil organic carbon stocks were found. However, the vine-rows in this organic system were not covered by grass or other crops. Organic management (>= 10 years) only meant waiving synthetic pesticides, combined with the use of organic fertilizers, green manure, and shallow or reduced tillage.

From another study, only the conference abstract is available (Montanaro et al. 2008). They measured the net gain of carbon (entire system: above and below ground) in peach and kiwifruit orchards. They found that sustainable soil management (namely, cover crop, no-tillage, compost application, mulching of pruning residues, regulated deficit irrigation) led to a net carbon gain of 17 t/ha/year, while the comparable conventionally managed orchards lost 6 t/ha/year.

From yet another study, only the conference abstract is available (McGourthy & Reganold 2004). They state they have found that cover crops in the inter-rows of vineyards increased soil organic carbon stocks.

"BEST AVAILABLE" CURRENT ESTIMATE OF LIKELY CHANGE IN SOIL CARBON STOCKS AS A RESULT OF ORCHARD/VINEYARD LAND-USE AND OF MANAGEMENT PRACTICES

CALCULATION OF THE "BEST AVAILABLE" CURRENT ESTIMATE AND ITS UNCERTAINTY

"Best available" current estimate of a change of soil carbon stocks as a result of land-use change (conversion to horticulture) based on modelling

A recent study (Tate et al. 2005) estimated the land use effect (LUE) of a conversion of grazing land to horticulture on soil organic carbon stocks for the 0-0.3 m depth. They estimated a total change of -9±7 t C/ha. The LUE estimate came from a model with no land use-soil-climate interactions, and, therefore, they applied it across all soil-climate categories and slope-rainfall combinations (Tate et al. 2005). In New Zealand, some measurements exist for soil carbon (C) changes with conversion to and from pastures for some grain crops, but not for horticultural conversion (Tate et al. 2005).

The uncertainty of these estimates is noted to be high.

We also used the HortResearch SPASMO (Soil Plant Atmosphere Model) model to estimate the change in soil carbon stocks in 0-0.3 m depth over time (1990-2008) when a permanent pasture was turned into a kiwifruit orchard (Figure 2). We used a soil and climate record representative of the main kiwifruit production area in New Zealand around Te Puke. Under a "bare orchard floor scenario", the decline was 1.98 kg/m^2 equalling 19.8 t/h soil carbon in 0-0.3 m depth over 17 years. If pasture were used as a cover crop in the alleys ("50% cover crop scenario"), the decline was 0.76 kg/m^2, equalling 7.6 t/ha soil carbon in 0-0.3 m depth over 17 years. If the entire orchard floor were covered by pasture ("100% cover crop scenario"), we found a carbon increase of about 0.47 kg/m^2 equalling 4.7 t/ha soil carbon in 0-0.3 m depth over 17 years. The SPASMO model, if guided by sound measurements from field studies of biochar incorporation, could be used to model this carbon-change sequence with, and without the addition of biochar. Futhermore, if these experiments measured the impact on the performance of the vines and trees, and the environmental services that biochar establishes, we could asses through modelling the benefits, or deleterious consequences of biochar additions to vineyards and orchards.

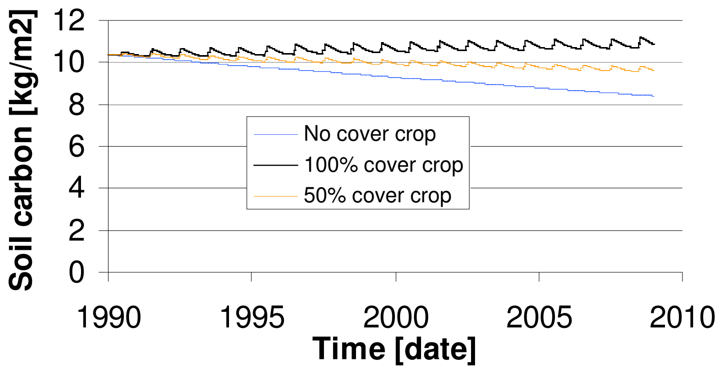

Figure 2. Modelled change of soil carbon stocks in the soil of an exemplary kiwifruit orchard with different orchard floor management practices. We used existing records of the climate and soils around Te Puke. The previous land-use (before 1990) was permanent pasture. Note that we used permanent pasture as a cover crop.

The uncertainty of these estimates is noted to be high.

"Best available" current estimate of a change of soil carbon stocks as a result of land-use change (conversion to horticulture) based on exemplary measurements

N.B. In this, and all following sections, a number after a "±" sign denotes one standard deviation, rather than one standard error. However, for the -9 ± 7 t C/ha of Tate et al. (2005), then the number after the "±" sign denotes one standard error.

First, we estimated the change in soil carbon stocks in two comparable apple orchards in Hawke's Bay (integrated/organic) with respect to the permanent pasture reference (Data set 1). We used the soil under the permanent grass in the alley of each orchard as this reference. We considered the soil carbon stocks in 0-0.3 m depth. More details on the soils and orchard management are given elsewhere (Deurer et al. 2008a).

Over the 12 years (1994-2006), the row in the organic apple orchard system lost about 1.7 ± 3.1 kg C/m^2 (Table 1). Assuming that (at most) half the total area of the orchard is managed as a row, and the rest is permanent pasture, this equals a decline in the carbon stocks by 8.5 ± 15 t C/ha. This value corresponds closely to the estimated loss of 9 ± 7 t C/ha of Tate et al. (2005). We note also that because of the high standard deviation of the measurements, the change in soil carbon could be zero or positive.

Over the same time, the row in the integrated apple orchard system lost about 2.2 ± 1.3 kg C/m^2 (Table 1). Assuming again that only half the total area of the orchard is managed as a row and the rest remains as permanent pasture, this equals a decline in the carbon stocks by 11 ± 7 t C/ha. This value is somewhat higher than the estimated loss of 9 ± 7 t C/ha of Tate et al. (2005).

In orchards with no grass or cover crops in the alley, the soil carbon stock losses have to be multiplied by 2.

Table 1. Average carbon (C) stocks and their estimated change in two apple orchard soils (organic, integrated) in Hawke's Bay (Data set 1). The alley in both systems is permanently covered with grass and served as the reference.

Depth [m]	**Organic – row [kg C/m²]**	**Organic – alley [kg C/m²]**	**Integrated – row [kg C/m²]**	**Integrated – alley [kg C/m²]**
0-0.3	7.8±1.9	9.5±1.2	5.9±0.6	8.1±0.7
	Estimated change in soil organic stocks over 12 years [kg C/m² year]			
	-0.14±0.3	0	-0.18±0.1	0

Secondly, we estimated the change in soil carbon stocks in one vineyard in Marlborough with respect to a permanent pasture reference (Data set 2). We used the soil under the permanent grass in the headland of the vine-rows as this reference.

Over the last 15 years (1991-2006) the row in the integrated vineyard system lost about 2.4 ± 1 kg C/m^2 in 0-0.15 m depth (Figure 3). Assuming that (at most) half the total area of the vineyard is managed as a row, and the rest is permanent pasture, this equals a decline in the carbon stocks by 12 ± 5 t C/ha in 0-0.15 m depth. This value is somewhat higher than the estimated loss of 9 ± 7 t C/ha of Tate et al. (2005).

In vineyards with no grass or cover crops in the alley, the soil carbon stock losses have to be multiplied by 2.

However, it is not clear how much soil carbon was additionally lost in 0.15-0.3 m depth. Unfortunately, there are no data yet on the change of soil carbon stocks with time under different management systems (e.g. organic) in vineyards.

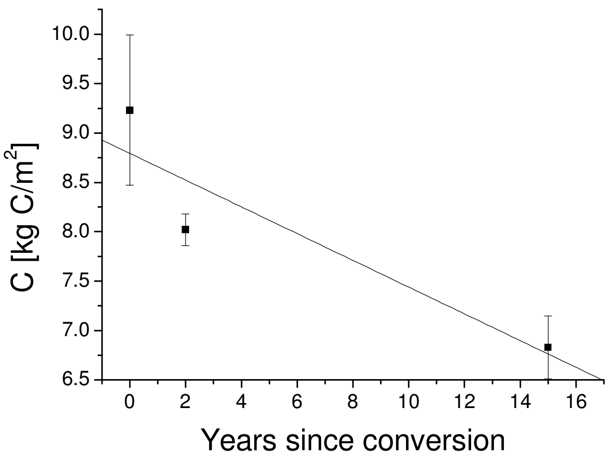

Figure 3. Average carbon stocks and their estimated change in one integrated vineyard in Marlborough (from Data set 2). The average rate of change of the soil carbon stocks (0-0.15 m depth) is -0.14 ± 0.06 kg C/m^2/year. The alley and the headland in the vineyard were permanently covered with grass and served as the reference ("Year 0").

"Best available" current estimate of a change of soil carbon stocks as a result of orchard/vineyard management based on some measurements and modelling

Organic system/cover crop

On average, the soil carbon stocks in 0-0.3 m depth were higher in the organic apple orchard in Hawke's Bay, at 86.5 ± 16 t C/ha, than the 70 ± 6.5 t C/ha in the comparable integrated apple orchard (Data set 1). However, the differences were statistically significant only at 0-0.1 m and in the 0.2-0.3 m depth, but not in the 0-0.3 m depth. It is not clear how much of the difference between the organic and integrated system can be attributed to the soil management option "cover crop", or to "organic" practices.

In the organic vineyard in Marlborough for the 0-0.15 m depth, the headland (= permanent pasture reference) had 7.6 ± 0.9 kg C/m^2 and the respective vine-row had 8.1 ± 0.6 kg C/m^2 (Data set 2). Therefore, in this one vineyard the soil carbon stocks under an organic management system were not significantly different from those in the permanent pasture reference. That is, there was no significant loss of soil carbon under this organic vineyard system.

In one kiwifruit orchard in Te Puke, we modelled the change of the soil carbon stocks in 0-0.3 m depth over 17 years. We used a soil and climate record representative for the main kiwifruit production area around Te Puke. Under a "bare orchard floor scenario", the decline was 1.98 kg/m^2, equalling 19.8 t/h soil carbon in 0-0.3 m depth over 17 years. If pasture were used as a cover crop in the alleys, the decline was 0.76 kg/m^2, equalling 7.6 t/ha soil carbon in 0-0.3 m depth over 17 years. If the entire orchard floor were covered by pasture, we found a carbon increase of about 0.47 kg/m^2, equalling 4.7 t/ha soil carbon in 0-0.3 m depth over 17 years (Figure 2).

Mulching of soil surface under vine-rows

In one integrated vineyard in Marlborough for the 0-0.15 m depth, the soil carbon stocks were 49.5 ± 3.5 t C/ha without mulching, and 63.5 ± 13.5 t C/ha with mulching (from Data set 2). Therefore, the use of mulch in this one vineyard led, on average, to higher soil carbon stocks, but this difference was not statistically significant.

In our opinion, all estimates given in this section are very uncertain.

NATIONAL AREA ASSOCIATED WITH THE "BEST AVAILABLE" ESTIMATE

National area of land use conversion from permanent pasture to orchards/vineyards

In a recent study, the area of land use conversion from permanent pasture to orchard/vineyards was estimated to be around 3000 ha/year (Tate et al. 2005). Overall, we think this number is still appropriate.

The total area of all "outdoor fruit crops" was 46,808 ha in 1990, and was 67,000 ha in 2007 (source: Statistics New Zealand). During this time, the total area of horticulture increased on average by about 1,188 ha per year. Over this time, there were relatively small changes for the two major horticultural crops, apples and kiwifruit (Figure 4).

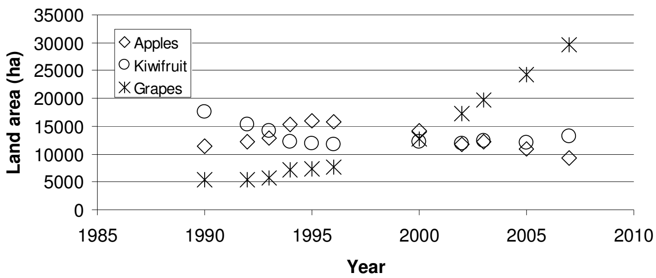

Figure 4. Land areas in New Zealand associated with the three largest horticultural crops (kiwifruit, apple, and winegrapes).

However, this might smooth over some of the recent and dynamic developments in the horticultural sector. For example, the area of wine-grapes has increased at a linear rate of about 2,400 ha per year since 2000 (Figure 4).

National area associated with specific soil carbon management in orchards/vineyards

At the moment, around 1500 ha of orchards/vineyards are classed as organic. This is about 2.5% of the total area. However, the organic sector is also highly dynamic and has increased by about 160% over the last decade.

There are no estimates available on the areas of orchards/vineyards associated with specific soil carbon management practices such as cover crops, application of compost, and mulching.

THE POTENTIAL FOR AN INCREASE OF SOIL CARBON STOCKS THROUGH IMPROVED SOIL CARBON MANAGEMENT IN ORCHARD/VINEYARD SYSTEMS

NON-BIOCHAR OPTIONS FOR SOIL CARBON MANAGEMENT IN ORCHARD/VINEYARD SYSTEMS

Cover crops

The introduction and/or efficient management of cover crops in the alleys and tree rows of orchards seems to be the most promising and cost-effective option for soil carbon management in orchard/vineyard systems.

We consider that the use of permanent grass as the cover crop in the tree row as the major reason why the organic apple orchard in Hawke's Bay had significantly higher soil carbon stocks than the comparable integrated system (Deurer et al. 2008a).

Vineyard floor management is already an integral component of integrated production in Europe, North America, South Africa, and New Zealand (Tesic et al. 2007). As well as its potential for increasing carbon stocks, orchardists and grapegrowers can use it as a powerful tool to control unwanted vegetative growth. However, under hot and dry conditions, and especially without additional irrigation, competition for water and nutrients (particularly at sensitive stages such as bloom and berry set for grapes) under such orchard-floor management can lead to a substantial decrease in yield (Tesic et al. 2007).

A further step might be to introduce purpose-bred grass species with higher productivity, and carbon allocation to deeper roots. For example, establishing deep-rooted grasses in savannahs has been reported to produce very high rates of soil carbon accrual (Fisher et al. 1994).

The grass species could be complemented by nitrogen-fixing plants such as legumes. Introducing legumes into grazing lands can promote soil carbon storage through enhanced productivity from the associated N inputs (Soussana et al. 2004).

Organic orchard/vineyard systems

Management of an orchard/vineyard as an organic system involves cover crops, along with other elements of soil carbon management such as the application of compost, mulches and/or manures. In the study comparing one organic and one integrated apple orchard in Hawke's Bay, the soil carbon stocks were significantly higher in the organic than in the integrated system (Deurer et al. 2008a).

However, to our knowledge, there are no systematic studies comparing a larger number of organic and integrated orchard/vineyard systems, which could confirm that organic systems have better soil carbon management.

Many studies have shown the increase of soil organic carbon stocks under arable farming. It is highly likely that those results showing an increase of soil carbon stocks in an arable situation would also apply for orchard/vineyards.

A regional soil survey in the Netherlands showed that land-use across a period of 63 years had a distinct effect on soil organic carbon stocks within one specific soil series. Soil organic carbon stocks significantly increased in soils under permanent pasture and arable crops that were organically managed (Pulleman et al. 2000). Carbon inputs into the soil were generally higher in organic than in integrated or conventional production systems (Gunapala & Scow 1998; Fliessbach et al. 2007).

However, the seemingly better carbon sequestration under "organic" management might have hidden carbon costs. For example, no net sink for carbon is likely to accompany the use of animal manure/compost on agricultural lands, as this in most cases requires 'mining' carbon somewhere else (Schlesinger 2000).

Carbon sequestration in subsoil horizons

Routine soil carbon stock inventories estimate the soil organic carbon pool down to a soil depth of about 1 m. Deeper soil horizons, however, may have a high capacity to sequester soil organic carbon, as the turnover time and chemical recalcitrance of soil organic matter increases with depth. The subsoil carbon sequestration may be achieved by higher inputs of fairly stable organic matter to deeper soil horizons. The subsoil below 1 m may have the potential to sequester globally between 760-1520 Pg of soil carbon (Lorenz & Lal 2005). These authors suggest that using breeding and genetic engineering will result in better efficiencies. This can be achieved directly by selecting plants and cultivars with deeper and thicker root systems that are high in chemically recalcitrant compounds like suberin. Furthermore, recalcitrant compounds could be a target for plant breeding and biotechnology to promote soil carbon sequestration.

Another way to achieve subsoil carbon sequestration is to promote a high surface input of organic matter. That would promote the production of dissolved organic carbon DOC that can be transported to deeper soil horizons.

Estimated increase of soil carbon stocks due to the different non-biochar options for soil carbon management in orchard/vineyard systems

To our knowledge, there are no data sets larger than ours that are available from which to derive the potentials of different soil carbon management options under horticulture. We know of one study where the carbon sequestration potential of land management options in Europe was estimated (Smith 2004). However, that study focused on arable farming.

The highest carbon sequestration was achieved by a conversion from cropland to grassland. This is another indication that a cover crop on the entire orchard/vineyard floor, and not just in the alleys, is probably the most promising soil carbon management, management difficulties notwithstanding. Table 2 below gives estimates for several options that could be relevant for horticulture, even though they refer to arable farming.

Table 2. Soil carbon (C) sequestration potential of different land management options in Europe. The details of the table are taken from Smith (2004).

Practice	Soil C sequestration potential [t C ha^{-1} $year^{-1}$]	Estimated uncertainty
Deep-rooting crops	0.62	>>50%
Animal manure	0.38	>>50%
Cereal straw	0.69	>>50%
Sewage sludge	0.26	>>50%
Composting	0.38	>>50%
Organic farming	0-0.54	>>50%
Convert cropland to grassland	1.2-1.69	>>50%

BIOCHAR AS AN OPTION FOR SOIL-CARBON MANAGEMENT IN ORCHARD/VINEYARD SYSTEMS

Biochar is a charcoal produced from biomass. The context of biochar as a soil carbon sequestration strategy relies on biomass of charcoal produced by pyrolysis. Biochar is the residue of pyrolysis. Under complete or partial exclusion of oxygen, 'waste' biomass is heated to moderate temperatures, usually between 400 and 500°C (namely low temperature pyrolysis), yielding fuel energy, and biochar as a carbon-rich and more stable by-product.

Biochar seems especially well suited for a use in orchard/vineyard systems. For example, it should not increase vegetative vigour. As opposed to other biomass-derived carbon materials (e.g. compost), biochar is not easily decomposed. As a consequence, the application of biochar does not lead to large amounts of plant-available nutrients such as nitrogen in soil. Also biochar could improve the efficiency of fertilizers, and possibly reduce the leaching of nitrogen and phosphorus, thus improving the overall eco-efficiency of nutrient management in orchards/vineyards (see below).

Recently biochar has been discussed nationally, and internationally, as a potential strategy for soil-carbon sequestration. Biochar needs to fulfill at least four criteria to be a successfull strategy for soil carbon sequestration in orchards/vineyard systems

1) The half-life of biochar that is incorporated into soil needs to be at least 100 years. This is the criterion for any strategy to be considered as a soil carbon sequestration under the IPCC and other regulatory frameworks such as the proposed PAS 2050.

2) The use of biochar results in a net reduction of equivalent CO_2 emissions for a horticultural enterprise. A full life cycle analysis, including the energy needed for its production, transport and incorporation into the soil thus needs to be considered.

3) Biochar could become locally available at a cost-effective price and large amounts of biochar could be incorporated into soils without compromising the product yield and quality in orchards/vineyards.

4) There would, at present, seem to be no short or long-term negative consequences of biochar applications for product yield and quality or for the environment.

Stability of biochar in soils

Large accumulations of charred material with residence times in excess of 1000 years have been found in soil profiles (Saldarriaga & West 1986; Glaser et al. 2001; Forbes et al. 2006). Most authors (Glaser et al. 2003) attribute the presence of large stocks of pyrogenic black carbon, as can be found in Amazonian dark earths or terra preta, several hundred years after the cessation of activities that added it to the soil. This is due to its chemical recalcitrance.

However, very little is known about the half-life of specific types of 'industrial' biochar. The recalcitrance of biochar in soils depends on a multitude of factors, including the type of biomass used for pyrolysis, the pyrolysis conditions, soil properties, and local climate. Typically, the half-life of biochar from low-temperature pyrolysis is longer than 100 years (Lehmann et al. 2006; Singh & Cowie 2008).

The adaption of microorganisms in the soil to biochar, as a carbon source, might lead to a shorter half-life of biochar. For example, there are microorganisms which exist that are able to live with biochar as the sole carbon source (Hamer et al. 2004).

Net reduction of equivalent CO_2 emissions due to the use of biochar

Biochar leads to a reduction of equivalent CO_2 emissions from soils due to its long half-life, as compared to other biomass-derived carbon (e.g. compost). However, the slow pyrolysis-based bioenergy systems produce not only biochar for soil carbon sequestration, but also energy. The combined use of energy production and soil carbon sequestration avoids about 2-19 t CO_2e ha^{-1} $year^{-1}$. Some 41-64% of these avoided emissions are related to the retention of carbon in biochar, with the rest to offsetting fossil fuel use for energy, fertilizer savings, and avoidance of soil emissions other than CO_2, such as nitrous oxide (Gaunt & Lehmann 2008).

The proportion of carbon retained in biochar during pyrolysis, varies with pyrolysis temperature and the type of biomass (Lehmann et al. 2006). A typical level of carbon recovery is 50% of the initial carbon content. This carbon has a typical half-life of more than 100 years (Lehmann et al. 2003; Lehmann et al. 2006).

Practicality and cost-effectiveness of biochar use

Currently, no large-scale facility for low-temperature pyrolysis is available in New Zealand, but this might change in the future. Another question with respect to the practicality of the use of biochar is in relation to how much biochar can be effectively and practically applied to soils.

From the data available for highly weathered tropical soils it appears that crops respond positively to biochar additions up to 50 t C/ha, and may only show growth reductions at very high application rates (Lehmann et al. 2006). For most plant species and soil conditions, this maximum was not reached even with 140 t C/ha (Lehmann et al. 2006). We note that most knowledge is derived from experiments with highly weathered tropical soils and very low natural soil organic carbon contents. Little is known about the effect of biochar additions to relatively fertile soils in a temperate climate.

The cost of incorporating biochar in soil, instead of using biomass solely for electricity generation, was estimated as U.S. \$47 /t of CO_2 contained in biochar (Gaunt & Lehmann 2008). This does not incorporate the additional costs associated with the transport of biochar from the pyrolysis plant to the site of application, and the 'costs' of incorporation of biochar into soil in existing enterprises. Currently, the market price for one tonne of CO_2 is U.S. \$9-16 /t, and, therefore, the incorporation of biochar in soil is not a cost-effective option, just yet (Gaunt & Lehmann 2008). However, the carbon prices and emissions-trading costs could be much higher in the future. For example, in the European Union Emission Trading Scheme the price is U.S. \$20, and would lie around U.S. \$25-85 if the social costs of climate change were used as the basis for the calculation (Stern 2007).

Possible short- or long-term consequences of biochar applications

There are no published data available on the possible negative consequences of biochar applications in soil, at least those that are based on field-scale studies. Field-scale studies of biochar incorporated into soils have only recently started. In the following, we will give an assessment of the potential risks that have not yet been evaluated thoroughly, especially under the horticultural conditions of New Zealand's soils and climate.

The type of biomass and pyrolysis conditions can modify the amount and composition of phytotoxic and potentially carcinogenic organic materials that are a byproduct of pyrolysis (Lima et al. 2005).

Biochar contains aromatic and aliphatic organic compounds that may cause, or enhance, the occurrence of soil water repellency. Many NZ soils have been found to be water repellent after dry summers which causes a decrease in pasture growth (Deurer et al. 2008b). The run-off of water and nutrients into surface waters is also another deleterious consequence of repellency (Doerr et al. 2000). Many topsoils in New Zealand already have very high carbon contents, and the carbon content is generally positively correlated with the occurrence of water repellency (Doerr et al. 2000). No studies have yet been undertaken to investigate if biochar could cause, or enhance, soil water repellency. However, water repellency was reported to occurr in reclaimed mine soils that contain sandy sediment mixtures with significant proportions of lignite (brown coal) (Gerke et al. 2001). Another indication of the potential risk of using biochar and causing soil water repellency is that hydrophobicity often occurs in topsoils after forest fires which in a way 'mimics' pyrolysis (Doerr et al. 2000).

The potential of biochar for soil-carbon sequestration might be being overstated. This is the conclusion of a study in boreal forests (Wardle et al. 2008). In this study, charcoal was prepared and mixed with the forest soils, and then left in the soil of different contrasting forest stands in northern Sweden for ten years. Microorganisms then significantly increased, due to the incorporation of biochar. As a consequence, the loss of "native" soil organic matter increased, and the net soil carbon sequestration was small. How this might relate to productive enterprises, such as orchards/vineyards is unknown.

Impact of biochar on physical and chemical soil properties

It has been found that in highly weathered coarse-textured soils, biochar improves the soil's filtering and buffering capacity for nutrients.

Biochar adsorbs more cations per unit carbon than most other soil organic matter, due to its greater surface area, greater negative surface charge, and greater charge density (Liang et al. 2006). However, the magnitude of the cation-exchange capacity depends on the type of biomass, and pyrolysis conditions. Also, the biochar's properties can change considerably with time during the exposure to the soil environment (Lehmann 2007).

Biochar retains nutrients, especially nitrogen and phosphorus (Glaser et al. 2002; Lehmann et al. 2003), and also increases the nitrogen fertilizer-use efficiency for plants (Chan et al. 2007). Biochar was found to have reduced the leaching of nitrate, ammonium, phosphorus and other ionic compounds (Beaton et al. 1960; Radovic et al. 2001; Lehmann et al. 2003; Mizuata et al. 2004). Also, biochar, it has been observed, absorbs hydrophobic organic contaminants (Gustaffson et al. 1997; Accardi-Dey & Gschwend 2002).

In highly weathered coarse-textured soils, biochar improves the soil's water retention properties. In Amazonian charcoal-rich anthrosols, the field water-retention capacity was 18% higher than for surrounding soil without charcoal (Glaser et al. 2002). However, in another study (Tryon 1948) with three different textures (sandy, clayey and loamy), charcoal increased the plant-available water contents in the sandy soil, but had no effect in the loamy soil, and decreased it in the clayey soil.

Implication of biochar sequestration for non CO2-emissions and romovals

In greenhouse experiments, with biochar additions of 20g per kilogram of crop, N_2O emissions were reduced by 50% in a soybean crop, 80% in a forage grass stand and methane emissions were completely suppressed in both (Rondon et al. 2005). A reduction of N_2O emissions was also found in short-term incubation experiments (Yanai et al. 2007). A possible explanation for the reduction of N_2O emissions is a better aeration of the soil, along with a shift in the C:N ratio.

PRIORITISED RESEARCH PLAN

- Presently there are insufficient data to answer key questions on soil carbon stocks, their change over time, and on the impact of soil carbon management options in orchards/vineyards. We need to increase the number of sites sampled, cover other soil orders used by horticulture, and systematically include management options. Standardised depth of sampling, archiving and global positioning system (GPS) location recordings need to be carried out. These should be carried out primarily for New Zealand's 'big three' crops of apples, kiwifruit and grapes, in New Zealand's 'big three' horticultural regions of Hawke's Bay, Bay of Plenty, and Marlborough.
- For New Zealand's horticultural products price premiums are critical, and increasingly there are pressures coming from international protocols (GlobalGap), national standards (PAS 2050, British Standards Institute), and supermarkets (notable Tescos

and Walmart) to eco-verify practices and to certify the carbon footprint. Because the profit of horticultural export products might in the future depend on their carbon footprints and other environmental measures, we need to provide confirmation of the changing stocks of soil carbon in vineyards/orchards.

- What are the role, the impact and the practicality of the use of horticultural waste recycling to change soil carbon stocks? There is a high rate of wastage of fruit in apple and kiwifruit production because of export quality standards, and there could be useful options to return this to the orchard/vineyard. Marc, the crushed grapeskins and pips provide a waste-stream in viticulture that could likewise be used. There should be a comparison of the cost-benefits and practicality of using such waste as fresh, composted, or biocharred.
- The mechanisms involved, and the feasibility of the incorporation of biochar into the soils of orchards and vineyards needs to be carefully tested in the field.
- Biophysical modelling of carbon capture by horticultural crops need to be advanced, and this modelling linked to carbon turnover and fate processes in the soil.

REFERENCES

Accardi-Dey A, Gschwend PM 2002. Assessing the combined roles of natural organic matter and black carbon as sorbents in sediments. Environ. Sci. Tech. 36: 21-29.

Beaton JD, Peterson HB, Bauer N 1960. Some aspects of phosphate adsorption by charcoal. Soil Sci. Soc. Am. Proc. 24: 340-346.

Chan KY, van Zwieten L, Meszaros I, Downie A, Joseph S 2007. Agronomic values of greenwaste biochar as a soil amendment. Aust. J. Soil Res. 45: 629-634.

Deurer M, Sivakumaran S, Ralle S, Vogeler I, McIvor I, Clothier BE, Green S, Bachmann J 2008a. A new method to quantify the impact of soil carbon management on biophysical soil properties: The example of two apple orchard systems in New Zealand. J. Env. Qual. 37(3): 915-924.

Deurer M, Slay M, Mueller K, Sivakumaran S, Clothier BE 2008b. Can hydrophobicity explain the dry patch syndrome of Hawke's Bay hillcountry pastures? In: Currie JA, Yates LJ ed. Carbon and nutrient management in agriculture. Palmerston North, New Zealand

Doerr SH, Shakesby RA, Walsh RPD 2000. Soil water repellency: its causes, characteristics and hydro-geomorphological significance. Earth Science Reviews 51: 33-65.

Droogers P, Bouma J 1997. Soil survey input in exploratory modeling of sustainable soil management practices. Soil Sci. Soc. Am. J. 61: 1704-1710.

Fisher MJ, Rao IM, Ayarza MA, Lascano CE, Sanz JI, Thomas RJ, Vera RR 1994. Carbon storage by introduced deep-rooted grasses in the South American savannas. Nature 371: 236-238.

Fliessbach A, Oberholzer H-R, Gunst L, Mäder P 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agric. Ecosyst. Environ. 118: 273-284.

Forbes MS, Raison RJ, Skjemstad JO 2006. Formation, transformation and transport of black carbon (charcoal) in terrestrial and aquatic ecosystems. Science of The Total Environment 370: 190-206.

Gaunt JL, Lehmann J 2008. Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production. Environ. Sci. Tech. in press.

Gerke HH, Hangen E, Schaaf W, Huettl RF 2001. Spatial variability of potential water repellency in a lignitic mine soil afforested with Pinus nigra Geoderma 102: 255-274.

Glaser B, Guggenberger G, Zech W, De Lourdes Ruivo M 2003. Soil organic matter stability in Amazonian Dark Earths. In: Lehmann J ed. Amazonian Dark Earths: Origin, Properties, Management, Kluwer Academic Publishers. Pp. 141-158.

Glaser B, Haumaier L, Guggenberger G, Zech W 2001. The 'Terra Preta' phenomenon: a model for sustainable agriculture in the humid tropics. Naturwissenschaften 88: 1.

Glaser B, Lehmann J, Zech W 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - a review. Biol. Fertil. Soils 35: 219-230.

Gunapala N, Scow KM 1998. Dynamics of soil microbial biomass and activity in conventional and organic farming systems. Soil Biol. Biochem. 30: 805-816.

Gustaffson Ö, Hagsheta F, Chan C, Macfarlane J, Gschwend PM 1997. Quantification of the dilute sedimentary soot phase: Implications for PAH speciation and bioavailability. Environ. Sci. Tech. 31: 203-209.

Hamer U, Marschner B, Brodowski S, Amelung W 2004. Interactive priming of black carbon and glucose mineralisation. Organic Geochemistry 35: 823-830.

Janzen HH 2006. The soil carbon dilemma: Shall we hoard it or use it? Soil Biol. Biochem. 38: 419-424.

Kimble JM, Rice CW, Reed D, Mooney S, Follet RF, Lal R 2007. Soil carbon management: Economic, Environmental, and Societal Benefits. In: Kimble JM, Rice CW, Reed D, Mooney S, Follet RF, Lal R ed. Soil Carbon Management. Economic, Environmental, and Societal Benefits. Boca Raton, CRC Press. Pp. 3-11.

Lal R 2004. Soil carbon sequestration to mitigate climate change. Geoderma 123: 1-22.

Lehmann J 2007. Bio-energy in the black. Frontiers in Ecology and the Environment 5: 381-387.

Lehmann J, da Silva Jr. JP, Steiner C, Nehls W, Zech W, Glaser B 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol in the Central Amazon bais: fertilizer, manure and charcoal amendments. Plant and Soil 249: 343-357.

Lehmann J, Gaunt J, Rondon M 2006. Biochar sequestration in terrestrial ecosystems: a review. Mitigation and Adaption Strategies for Global Change 11: 403-407.

Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luizao FJ, Petersen J and others 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J. 70: 1719-1730.

Lima A, Farrington J, Reddy C 2005. Combustion-derived polycyclic aromatic hydrocarbons in the environment: a review. Environ. Forensics 6: 109-131.

Lorenz K, Lal R 2005. The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. Adv. Agronomy 88: 35-66.

Mackay A, Ghani A, Ross C, Curtin D, Francis G, Sparling G, Beare MH, Clinton P, McIvor I, Simcock R and others 2006. Current knowledge on soil quality indicators for sustainable production and environmental protection in New Zealand. Palmerston North, Sustainable Land Use Research Initiative

McGourthy GT, Reganold JP 2004. Managing vineyard soil organic matter with cover crops. In: Christensen LP, Smart DR ed. Soil environment and vine mineral nutrition symposium. San Diego, California, USA, University of California.

Mizuata K, Matsumoto T, Hatate Y, Nishihara K, Nakanishi T 2004. Removal of nitrate-nitrogen from drinking water using bamboo powder charcoal. Bioresource Techn. 95: 255-257.

Montanaro G, Celano G, Dichio B, Sofo A, Xylloyanis C 2008. Soil fertility remediation in fruit tree orchards in Mediterranean areas. EGU General Assembly 2008. Vienna, Geophysical research abstracts.

Probst B, Schueler C, Joergensen RG 2008. Vineyard soils under organic and conventional management - microbial biomass and activity indices and their relation to soil chemical properties. Biol. Fertil. Soils 44: 443-450.

Pulleman MM, Bouma J, van Essen EA, Meijles EW 2000. Soil organic matter content as a function of different land use history. Soil Sci. Soc. Am. J. 64: 689-693.

Radovic LR, Moreno-Castilla C, Rivera-Utrilla J 2001. Carbon materials as adsorbents in aqueous solutions. In: Radovic LR ed. Chemistry and Physics of Carbon. New York, Marcel Dekker. Pp. 227-405.

Rondon M, Ramirez JA, Lehmann J 2005. Charcoal additions reduce net emissions of greenhouse gases to the atmosphere. 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration in Agriculture and Forestry, 21-24 March, 2005. University of Delaware, Baltimore, MD

Saldarriaga JG, West DC 1986. Holocene fires in the Amazon basin. Quaternary Research 26: 358-366.

Schlesinger WH 2000. Carbon sequestration in soils: some cautions amidst optimism. Agric. Ecosyst. Environ. 82: 121-127.

Singh B, Cowie AL 2008. A novel approach, using 13C natural abundance, for measuring decomposition of biochars in soil. In: Currie LD, Yates LJ ed. Carbon and Nutrient Management in Agriculture. Palmerston North, New Zealand

Smith P 2004. Carbon sequestration in croplands: the potential in Europe and the global context. Europ. J. of Agronomy 20: 229-236.

Smith P, Martino D, Cai Z, Gwary D, Janzen HH, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C and others 2007. Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA ed. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom, and New York, USA, Cambridge University Press.

Soussana J-F, Loiseau P, Viuchard N, Ceschia E, Balesdent J, Chevallier T, Arrouays D 2004. Carbon cycling and sequestration opportunities in temperate grasslands. Soil Use and Management 20: 219-230.

Sparling GP, Wheeler D, Vesely ET, Schipper LA 2006. What is soil organic matter worth? J. Env. Qual. 35: 548-557.

Stern N 2007. The economics of climate change: The Stern review. Cambridge, Cambridge University Press.

Tate KR, Wilde RH, Giltrap DJ, Baisden WT, Saggar S, Trustrum NA, Scott NA, Barton JP 2005. Soil organic carbon stocks and flows in New Zealand: System development, measurement and modelling. Canadian J. Soil Sci. 85: 481-489.

Tesic D, Keller M, Hutton RJ 2007. Influence of vineyard floor management practices on grapevine growth, yield, and fruit composition. Am. J. Enol. Vitic. 58: 1-11.

Tryon EH 1948. Effect of charcoal on certain physical, chemical, and biological properties of forest soils. Ecol. Monogr. 18: 81-115.

Tworkoski TJ, Glenn DM 2001. Yield, shoot and root growth, and physiological responses of mature peach trees to grass competition. HortScience 36: 1214-1219.

Wardle DA, Nilsson M, Zackrisson O 2008. Limitations of charcoal as an effective carbon sink. Science in press.

Yanai Y, Toyota K, Okazaki M 2007. Effects of charcoal addition on N2O emissions from soil resulting from rewetting air-dried soil in short-term incubation experiments. Soil Sci. Plant Nutr. 53: 181-188.

APPENDIX

DATA SET 1

Name of the data set 1: Soil carbon management of two apple orchard systems (organic, integrated) in Hawke's Bay

Primary contact: M Deurer, B Clothier (HortResearch Ltd, Palmerston North)

Data ownership / accessibility: via HortResearch

Data storage: Microsoft® Excel spreadsheets

Broad Land-use/Land form sampled: Tree rows and alleys of two apple orchards

Number of sites: Two. The sites are adjacent to each other. They have the same soil type and climate. Before their use as apple orchards, both sites were used for market gardening (a very similar initial soil organic carbon content can be assumed).

Geographical spread: Havelock North, Hawke's Bay

Soil orders: Recent

Depth of sampling: 0-30 cm Yes

Specific sampling depths (e.g. 0-7.5, 0-10, 0-15, 7.5-15, 10-20, 15-30, 30-100 cm depths or sampling by horizon?): 0-10, 10-20, 20-30 cm depths

Bulk Density measurements: Yes

Multiple sampling through time: No

Pre-1990 soil sampling: No

GIS reading of the site: No

Soil description Yes

Are soil samples archived? No

Total change in carbon (C) or rate of change in soil C recorded? No

Land use history recorded: Apple orchards for the last 10+ years preceding last sampling

Intensity of land use: Recorded at the time of sampling. One orchard is under integrated, and the other under organic (BioGro) production.

Supplementary information on soils e.g. % total N, pH, production: Information on various biophysical and chemical soil properties available (% C, % N, Olsen P, pH, water infiltration rates, aggregate stability, macropore topology, microbial activities, soil texture …)

Management history?

Few details (especially for the organic) known (only generic information available)

Mitigation opportunities to minimise or improve soil C?

Evaluation of the potential of different generic soil carbon management for soil carbon sequestration: Within the tree rows, the two orchards differ in soil carbon management over the last 10+ years: On the integrated orchard the tree rows were regularly herbicided (no pasture or weeds), received no organic matter additions (apart from prunings) and were drip-irrigated. On the organic orchard the tree rows had pasture, regularly received compost, and were not irrigated.
Conclusion: A soil carbon conservation management as practiced on the organic apple orchard can lead to significantly higher carbon contents in the topsoil (especially 0-10 cm) (Figure A1).

Associated publications in journals, proceedings, Client reports to MfE (Ministry for the Environment), MAF (Ministry of Agriculture and Forestry), Regional Councils etc.

Deurer M, Sivakumaran S, Ralle S, Vogeler I, McIvor I, Clothier B, Green S, Bachmann J 2008. A new method to quantify the impact of soil carbon management on biophysical soil properties: The example of two apple orchard systems in New Zealand. J. of Env. Qual. 37, 915-924.

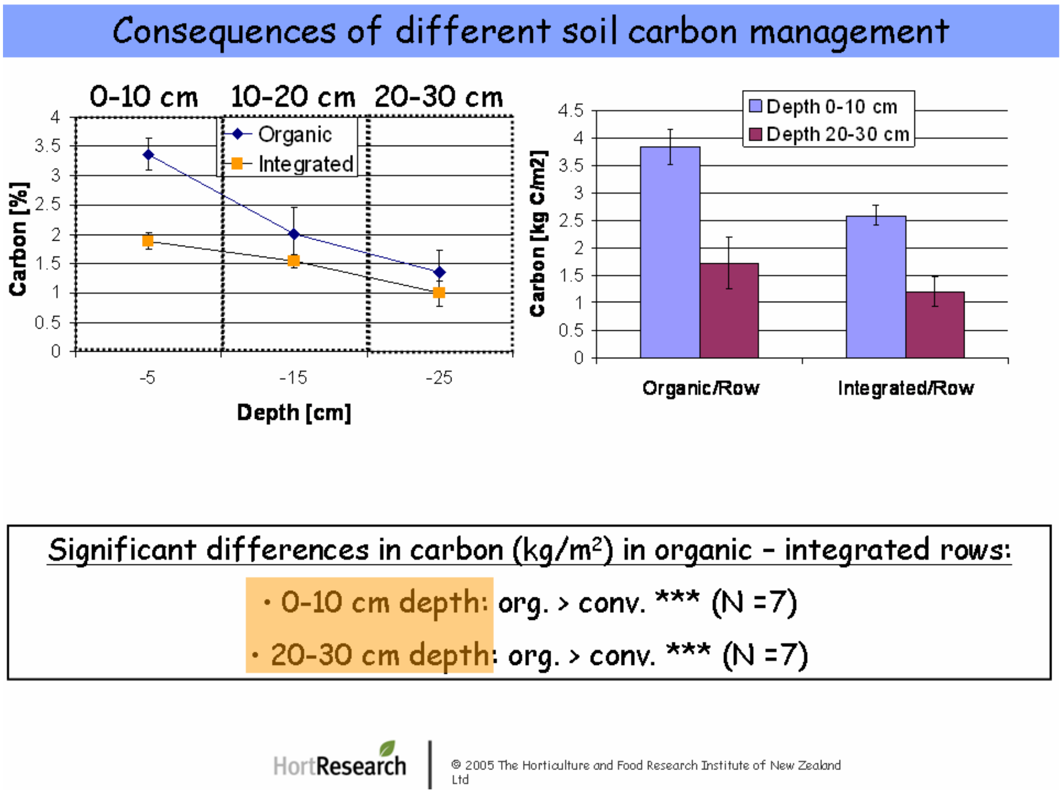

Figure A1. Soil carbon contents in the topsoil of an organic and an integrated apple orchard in Hawke's Bay. Both orchards are adjacent to each other and operated for 10+ years. They have the same soil type and climate and a very similar land-use history.

DATA SET 2

Name of the data set 2: Soil carbon status and management of vineyard systems in Marlborough

Primary contact: M Greven (HortResearch, Blenheim)

Data ownership / accessibility: HortResearch

Data storage: Microsoft® Excel spreadsheets

Broad Land-use/Land form sampled: Vineyard rows and inter-rows

Number of sites: 5 vineyards with 2-4 sites each, active database with new sites being added at the time of writing

Geographical spread: Wairau Valley, with Awatere Valley to be added in next few months

Soil orders: Recent

Depth of sampling: 0-15 cm

Specific sampling depths (e.g. 0-7.5, 0-10, 0-15, 7.5-15, 10-20, 15-30, 30-100 cm depths or sampling by horizon?): 0-15 cm depth

Bulk Density measurements: Yes

Multiple sampling through time: No

Pre-1990 soil sampling: No

GIS reading of the site: No

Soil description No

Are soil samples archived? No

Total change in C or rate of change in soil C recorded? Yes when using headlands is used as a base line reference

Land use history recorded: Yes
History for what period? (e.g. for 10+ years preceding last sampling)
Varies per vineyard from 10-20 years

Intensity of land use: Recorded

Supplementary information on soils e.g. % total N, pH, production: Information on various biophysical and chemical soil properties available

Management history?
Little known (only generic information)

Mitigation: We compared different soil carbon management (mulching v. no mulching, organic v. headland) on the same soil types, climate and general management. We found that mulching led to significantly higher carbon contents in the topsoils (Figure A2). Organic management with pasture in the rows led to soil carbon contents that were comparable with those of the headland (= situation of previous use as pasture) (Figure A2).
Comparing rows within the vineyard (same soil type, same climate) that were under vineyard use for different time lengths, we found a decrease of soil carbon in the vine row over 15 years (no longer times were available) (Figure A2).

Associated publications in journals, proceedings, Client reports to MfE, MAF, Regional Councils etc.

Deurer M, Greven M, Clothier B 2007. Carbon in horticultural soils – Digging for gold? In: "Carbon cost and climate change", Proceedings of a workshop, Auckland, HortResearch, 7-8 May 2007.

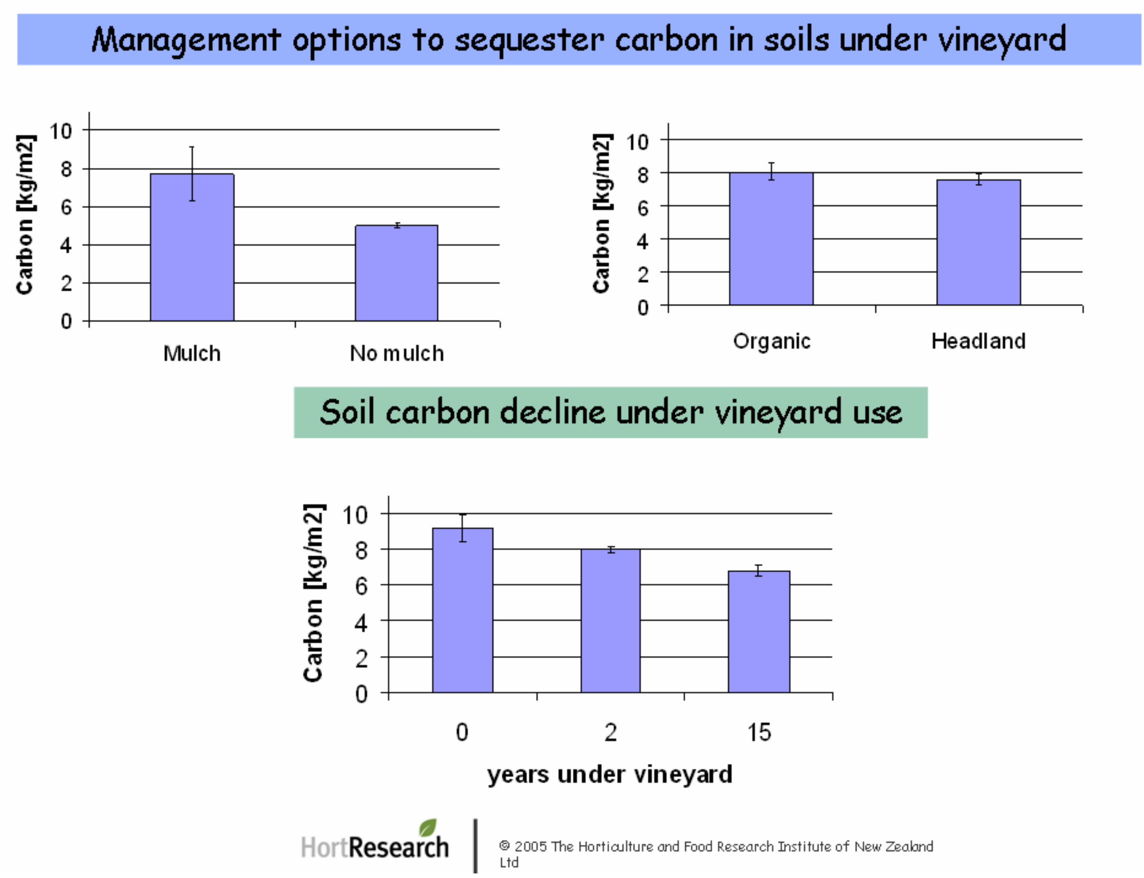

Figure A2. Conclusions from this preliminary study on soil carbon under vineyard use in Marlborough: **Top**: Management options for carbon sequestration in soils under vineyard **Bottom**: The decline of soil carbon over time under vineyard use.

DATA SET 3

Name of the data set 3: Soil carbon status of vineyards in Hawke's Bay

Primary contact: T Mills, M Deurer (HortResearch, Palmerston North)

Data ownership / accessibility: HortResearch

Data storage: Microsoft® Excel spreadsheets

Broad Land-use/Land form sampled: Wine grapes (Chardonnay, Cabernet)

Number of sites: 5

Geographical spread: Hawke's Bay

Soil orders:

Depth of sampling: 0-20 cm Yes

Specific sampling depths (e.g. 0-7.5, 0-10, 0-15, 7.5-15, 10-20, 15-30, 30-100 cm depths or sampling by horizon?): 0-20 cm depth

Bulk Density measurements: Yes

Multiple sampling through time: No

Pre-1990 soil sampling: No

GIS reading of the site: No

Soil description Yes

Are soil samples archived? No

Total change in C or rate of change in soil C recorded? No

Land use history recorded: Yes, some details available

History for what period? (e.g. for 10+ years preceding last sampling)

Following information should be available:
1) When was it converted from pasture
2) Yield records
3) Irrigation or not
4) Fertiliser applications

Intensity of land use: Yield recorded

Supplementary information on soils e.g. % total N, pH, production:

Mineral N at the time of sampling, C:N ratio, soil microbial dehydrogenase levels at time of sampling,

Management history?

Little known (only generic information)

Associated publications in journals, proceedings, Client reports to MfE, MAF, Regional Councils etc.

DATA SET 4

Name of the data set 4: Soil carbon status of kiwifruit orchards in the Bay of Plenty (4), Nelson (1) and Northland (1)

Primary contact: T Mills, M Deurer (HortResearch, Palmerston North)

Data ownership / accessibility: HortResearch

Data storage: Microsoft® Excel spreadsheets

Broad Land-use/Land form sampled: Pergola-grown ZESPRI™ GOLD kiwifruit (‘Hort16A’)

Number of sites: 6

Geographical spread: Bay of Plenty, Nelson and Northland

Soil orders: Recent (Nelson), Volcanically derived (Bay of Plenty), ? (Northland)

Depth of sampling: 0-20 cm Yes

Specific sampling depths (e.g. 0-7.5, 0-10, 0-15, 7.5-15, 10-20, 15-30, 30-100 cm depths or sampling by horizon?): 0-20 cm depth

Bulk Density measurements: limited (Te Puke sandy loam)

Multiple sampling through time: No

Pre-1990 soil sampling: No

GIS reading of the site: No

Soil description Yes

Are soil samples archived? No

Total change in C or rate of change in soil C recorded? No

Land use history recorded: Yes (good option for some generic information to be pulled together for kiwifruit management)

History for what period? (e.g. for 10+ years preceding last sampling)

Probably not to difficult to obtain

1) When was it converted from pasture
2) Yield records
3) Irrigation or not
4) Fertiliser applications

Intensity of land use: Recorded

Supplementary information on soils e.g. % total N, pH, production:

Have information on mineral N at the time of sampling, C:N ratio, soil microbial dehydrogenase levels at time of sampling,

Management history?

Little known (only generic information)

Associated publications in journals, proceedings, Client reports to MfE, MAF, Regional Councils etc.