# LONG-TERM VINEYARD SUSTAINABILITY INDEX

**Marc Greven[(1)], Victoria Raw[(1)], Colin Gray[(2)], Markus Deurer[(3)], Bruce West[(1)] and Claire Grose[(1)]**

[(1)]The New Zealand Institute for Plant & Food Research Limited, Marlborough, PO Box 845, Blenheim 7240, New Zealand
[(2)]Marlborough District Council, 15 Seymour Street, Blenheim 7201, New Zealand
[(3)]The New Zealand Institute for Plant & Food Research Limited, Private Bag 11600, Palmerston North 4442, New Zealand
marc.greven@plantandfood.co.nz

## ABSTRACT

The impact of viticulture on soil can be determined by comparing the biophysical properties that represent soil health at a particular site and depth with those same properties in soil considered to represent the 'pre-vineyard' state (the headland). Information gathered by this method shows the changes in soil properties following the change to viticulture depend on individual vineyard management and environment. Relative changes can be used for comparisons within regions. Our research took place over three years on soils of vineyards of different ages and under different management, in both the Awatere and the Wairau Valleys in Marlborough, New Zealand. Soil properties investigated were: pH (optimal value 5.5-7.0); organic carbon (OC, 3-5%); carbon/nitrogen ratio (C/N,10-20); bulk density (BD, 0.9-1.3 t/m$^3$); macro-porosity (MP, 8-30%); microbial biomass (MB-C, g C/m$^2$ in 15 cm of soil); basal respiration (BR-C, 1.5-4.5 g $CO_2$-C/m$^2$/day), respiration quotient (qCO2, 0.5-1.5 mg $CO_2$-C/g MB-C) and kg carbon/m$^2$ for 15 cm of soil (4.5-9.0 kg-C). Objective descriptions of vineyard soil quality would assist growers to apply and monitor sustainable vineyard management practices. This data set indicates changes in sustainability that can be expected after a change of land-use to grape growing.

Under average vineyard management, soil carbon declined rapidly during the first few years but reached a plateau after two or more years. Soil depth was shown to be influential, with soils below 15 cm much less affected by land use changes, but scoring lower for all soil carbon parameters (except for qCO2). Soils at this depth also scored lower for soil physical properties; they generally had a very high BD, low MP and low pH. These trends for the 15-30 cm layer are typical soil properties – they don't imply that soil depth is a factor in sustainability indices *per se*.

The high variability and generally reduced levels of under-vine soil carbon compared with headland soil carbon, suggest the need to increase vineyard soil carbon content and thereby potentially sequestrate carbon.

**KEYWORDS** vineyard - grape - soil biophysical properties - organic carbon - microbial biomass - basal respiration - macro-porosity

## INTRODUCTION

Sustainability in viticulture has become a worldwide issue, with wine growers moving away from excessive use of pesticides and other management practices that are potentially harmful for the environment. In this context, together with growing concern for global warming, interest in effects of land management on soil quality and the potential for management to play a role in conserving soil carbon is increasing. Currently little historical information on such issues is available for viticulture (Deurer *et al.,* 2008a).

Our work on vineyard soils has focused on determining the presence of soil carbon (C) and soil quality in general. There are no agreed standards of what constitutes soil quality (Sojka & Upchurch, 1999). However, changes in soil microbial properties are an early indication of decreasing soil quality (Powlson *et al*., 1987). Soil carbon (C) is a key property for determining water holding capacity, infiltration rate and fertility of the soil and for many environmental soil functions, such as the ability to bind excessive plant nutrients or contaminants from water (Pierzynski *et al*. 2007). Soil C management is defined as "land management practices that maintain or increase soil C" (Kimble *et al*., 2007). For most vineyards in Marlborough, New Zealand, the level of soil C has been established by active agricultural management, although soil type and climate do influence a soil's C status.

The project looked at past effects of vineyard management on vineyard soils by investigating soil types and ages and management of the vineyards. The work over a three-year period from 2007 to 2009 (Greven *et al.,* 2007, 2008, 2009) determined differences in soil carbon and microbial properties across eight vineyards in Marlborough, the potential long-term effects the grape industry can have on these soil properties, and how these effects can be mitigated. The aim was to develop a simple quality assessment support tool to evaluate the soil's biological quality. Because of the complexity of soil quality, there is a need to evaluate several soil properties simultaneously; one microbial property value does not provide a complete understanding about a soil (Brookes, 1995; Kennedy, Papendick, 1995). Many researchers (Doran, Parkin, 1994; Trasar-Cepeda *et al.,* 1997; de la Paz Jimenez *et al.,* 2002; Hofman *et al.,* 2003) have attempted to put together a list of quality indices for soil analyses to establish a base against which results from other soils can be compared. However, for practical use, the tool should be reliable enough to distinguish vineyard soils with optimum microbial activity from those that need improvement. This benchmark should be available for future comparisons of soils under viticulture.

## MATERIALS AND METHODS

Over a period of three years, soil samples were analysed during the winter from eight vineyards that varied in age, soil type (New Zealand Soil Bureau, 1968; Laffan, Vincent, 1990), location, management and grape variety. The sampling areas within the vineyards included the headland, under-vine, inter-row and wheel track areas. The vine density in the vineyards ranged from 2315 to 1852 vines/ha. Two of the vineyards were organically managed and the rest were under conventional management, although some took an integrated production approach. At each point, triplicate sub-samples were taken and pooled together to make up at least 250 g of soil for one of three replicates for each vineyard position under investigation. The samples were analysed for pH, organic carbon (OC) and C/N ratio, bulk density (BD) and macro porosity (MP) (Klute, 1986; Sparling *et al.,* 1999), microbial biomass (MB-C) and basal respiration (BR-C) (Deurer *et al.,* 2008b). From these last two values, the respiration quotient (qCO2) (Anderson, Domsch, 1990) and kg carbon/m$^2$ for 15 cm of soil (kg-C), were calculated (Wardle, Ghani, 1995).

## RESULTS AND DISCUSSION

We recorded the average values of all the biophysical properties of interest from the 0 -15 cm soil samples of Wairau Plain vineyards, from all of which consistently good wines have been produced. From almost 200 different vineyard soil sampling sites, a distribution profile of each soil trait was developed (Fig. 1). Using these results, we have calculated benchmarks for soil biophysical properties that are indicators for soil quality against which future soil samples can be compared (Tab. 1).

Comparison of the biophysical properties of soils representing the 'pre-vineyard' (the headland) and post-vineyard (the under-vine area) situations can measure the influence of viticulture practices on the soil. The first year of the trial, only OC, BD, MB-C, BR-C, $qCO_2$ and kg-C were measured in the Grove Town and Rapaura 1 vineyards. The following two years in the other vineyards, pH and MP were also measured and C/N ratios were calculated.

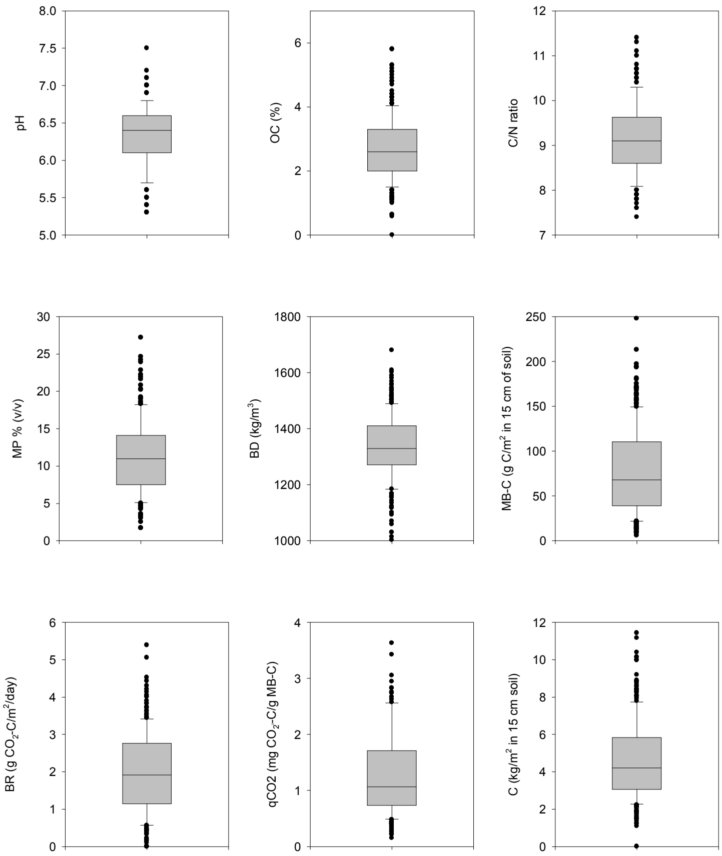
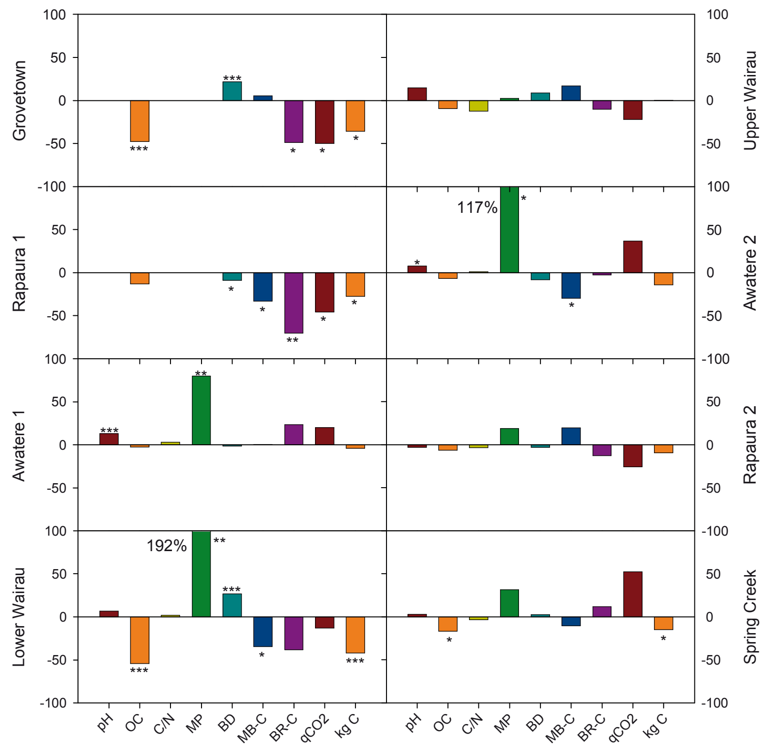



Fig. 1: Box plots of distribution of values of all the soil biophysical properties investigated in the top 15 cm of soils of conventional vineyards in the Wairau valley: pH, Organic Carbon (OC%, %), carbon/nitrogen ratio (C/N), macroporosity (MP, %), bulk density (BD, $kg/m^3$), Microbial Biomass (MB-C, g $C/m^2$ in 15 cm of soil), Basal Respiration (BR-C, g $CO_2$-$C/m^2$/day), Carbon Quotient ($qCO_2$, mg $CO_2$-C/g Microbial Biomass-C) and total soil carbon (kg-C, $kg/m^2$). The boxes represent the $25^{th}$, $50^{th}$ and $75^{th}$ percentile of all values, with error bars down to the $10^{th}$ percentile and up to the $90^{th}$ percentile, and outliers as extra dots.

Fig. 2 illustrates the positive or negative influence of vineyard management (by percentage), from the baseline headland values (set as value = 0). Both OC and MB-C carbon measurements showed a significant reduction in three out of eight vineyard blocks when land use changed from ‘pre-vineyard’ to land under vineyard. Two out of eight vineyard blocks had a significant reduction in BR-C. Four out of eight blocks had reduced kg-C. The reason for reduced levels of many C-indicators in the under-vine area (albeit not always statistically significant) was that the vine row is generally kept weed-free and will have been wetter because of drip irrigation. The higher moisture level creates optimum conditions for carbon mineralisation and hence lower levels of OC and microbial biomass may be expected. Two Awatere vineyards (Awatere 1 and Awatere 2) had improved MP by 117 and 80% respectively, while the other soil properties were not significantly different from the headland baselines. The Grove Town and Rapaura 1 vineyards showed a significant decline over time for many of the attributes analysed. Small not significant differences were found for all attributes at the Upper Wairau, Rapaura 2 and Spring Creek vineyards when compared to the headland values. The Lower Wairau vineyard had a significant positive change in soil physical attributes, but negative effects on C-parameters.

Tab. 1: Benchmarks derived from soil data from 0 - 15 cm depth in conventional vineyards in the Wairau Plain. Soil property descriptions are: pH, Organic Carbon (OC, %), carbon/nitrogen ratio (C/N), macro-porosity (MP, %), bulk density (BD, kg/m$^3$), Microbial Biomass (MB-C, g C/m$^2$ in 15 cm of soil), Basal Respiration (BR-C, g $CO_2$-C/m$^2$/day), Carbon Quotient (qCO2, mg $CO_2$-C/g Microbial Biomass-C) and total soil carbon (kg-C, kg/m$^2$).

| percentile | 10 | 90 |
|---|---|---|
| pH | 6.0 | 6.8 |
| OC | 2.7 | 5.3 |
| C/N | 8.2 | 10.0 |
| MP | 4.5 | 13.5 |
| BD | 1.17 | 1.48 |
| MB-C | 55.0 | 165.0 |
| BR-C | 1.0 | 3.4 |
| qCO2 | 0.5 | 1.9 |
| kg-C | 4.3 | 9.2 |




***= $P < 0.001$, **= $P < 0.01$, *= $P < 0.05$

Fig. 2: For a select number of vineyard blocks, the headland (set at a baseline 0) and the under-vine area in the top 0.15 m of soil were compared for their soil biophysical properties (descriptions as in Fig. 1). In the first year of the research, only OC, BD, MB-C, BR-C, qCO2 and kg C were measured or could be calculated.

This sort of analysis is important to be able to get an overall impression of a vineyard rather than investigating each individual detail, many of which often contradict each other.

The present benchmark is based solely on the work carried out in this Long-term Vineyard Sustainability programme from the Wairau Plains. Currently there are insufficient data from the sub-regions to create benchmarks for each of these. This is however a future goal to achieve with further grower participation. The disadvantage of the vineyard headland for comparison was that this is an internal comparison rather than a comparison across the region. On the other hand, the information collected by this method is accurately related to each individual vineyard, as there are enormous soil as well as climatic and vineyard management differences within the Wairau Plains. Comparing vineyard blocks using average Marlborough values, with many different terroirs and therefore high variability of soils, climate and management (Fig. 1), would be less informative than comparisons within individual vineyards.

## CONCLUSIONS

- Objective descriptions of biophysical properties of Marlborough vineyard soils will assist growers to improve soil quality management in their vineyards.
- Only small differences in all the properties analysed were found between the Marlborough vineyards investigated. However, the use of a benchmark for soil biophysical properties could greatly assist in determining the relative differences between properties.
- Under average vineyard management, soil carbon tended to reduce rapidly during the first few years, but reached a lower plateau after two or more years.
- Soil samples from 15-30 cm depth were much less affected by land use changes, but scored lower for all soil carbon parameters (except for $qCO2$). Soils at this depth also scored low for soil physical parameters, as they generally had a very high BD, low MP and low pH.
- The suggested benchmark standards are a good starting point for a decision support tool that can be used by groups such as Sustainable Winegrowing NZ to improve grower awareness of soil conditions and of the impact of vineyard management on soil quality.
- Soil samples from the headlands could be used as benchmarks for monitoring potential soil quality change over time within one vineyard.
- The high variability in soil carbon and the lower under-vine soil carbon compared with that in the headlands, suggests the need to restore the carbon content of vineyard soils.

## ACKNOWLEDGEMENTS

We thank the Marlborough Research Centre Trust for funding this research. We also thank all the Marlborough vineyards and wine companies that have participated in this work: Villa Maria Estate Ltd., Vavasour Wines Ltd., Pernod Ricard New Zealand Ltd., Ashmore Vineyards, Fromm Winery, Willowbank vineyards, Two Ponds vineyard, Filoli vineyard, Rowley Crescent, Seresin Estate Ltd.

## BIBLIOGRAPHY

Anderson T., Domsch K., 1990. Application of eco-physiological quotients (qCO 2 and qD) on microbial biomasses from soils of different cropping histories. *Soil Biol & Biochem* 22(2): 251-255.

Brookes P., 1995. The use of microbial parameters in monitoring soil pollution by heavy metals. *Biology and Fertility of Soils* 19(4): 269-279.

Deurer M., Clothier B., Greven M., Green S., Mills T., 2008a. Soil carbon stocks and their change in orchards and vineyards in New Zealand HortResearch Client Report No. 1390 to Landcare Research.

Deurer M., Sivakumaran S., Ralle S., Vogeler I., Mclvor I., Clothier B., Green S., Bachmann J., 2008b. 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. Environ. Qual.* 37(3): 915-924.

Doran J., Parkin T., 1994. Defining and Assessing Soil Quality. In: Defining soil quality for a sustainable environment. Doran J., Coleman D., Bezdicek D. and Stewart B., Eds. SSSA Special Publication Number 35. *Soil Sci. Soc. Am*., Madison, WI: 3-21.

Greven M., Raw V., Gray C., Deurer M., West B., 2008. Long-term vineyard sustainability 2008 HortResearch Contract No. 22726 to Marlborough Research Centre Trust. HortResearch Client Report 26092.

Greven M., Raw V., Gray C., Deurer M., West B., Grose C., 2009. Long-term vineyard sustainability index, Plant & Food Research Contract No. 23353 to Marlborough Research Centre Trust. Plant & Food Research Client Report No. 29898

Greven M., Raw V., West B., 2007. Long term vineyard sustainability. Marlborough Research Centre Annual report 2006-2007: 47-48.

Hofman J,, Bezchlebová J,, Dušek L,, Doležal L,, Holoubek I,, Andel P., Ansorgová A., Malý S., 2003. Novel approach to monitoring of the soil biological quality. *Environ. Int.* 28(8): 771-778.

Kennedy A., Papendick R. 1995. Microbial characteristics of soil quality. *Journal of Soil and Water Conservation* 50(3): 243.

Kimble J., Rice C., Reed D., Mooney S., Follet R., Lal R., 2007. Soil C management: Economic, Environmental, and Societal Benefits. In: Soil C Management. Economic, Environmental, and Societal Benefits. Kimble J., Rice C., Reed D., Mooney S., Follet R., Lal R. Eds., CRC Press, Boca Raton.

Klute A., 1986. Water retention: laboratory methods. In: Methods of Soil Analysis Part 1, Klute A. Eds., Madison WI: ASA. Pp. 365-662.

Laffan M., Vincent K., 1990. Soils of Blenheim-Renwick district. In: Water and soil resources of the Wairau, Land and Soil Resources Nelson-Marlborough Regional Council.

New Zealand Soil Bureau. 1968. General survey of the soils of South Island, New Zealand. Soil Bureau Bulletin 27, New Zealand Soil Bureau.

Paz Jimenez de la M., de la Horra A., Pruzzo L., Palma M., 2002. Soil quality: a new index based on microbiological and biochemical parameters. *Biol. Fertil.Soils* 35(4): 302-306.

Pierzynski G., Devlin D., Neel D., 2007. Environmental and ecological benefits of soil carbon management: Surface water quality. In: Soil Carbon Management. Economic, Environmental and Societal Benefits. Kimble J., Rice C., Reed D., Mooney S., Follet R., Lal R., Eds. Boca Raton, CRC Press. Pp. 209-233.

Powlson D., Brookes P., Christensen B., 1987. Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. *Soil Biol. Biochem.* 19(2): 159-164.

Sojka R., Upchurch D., 1999. Reservations regarding the soil quality concept. *Soil Sci. Soc. Am. J. 63*(5): 1039-1054.

Sparling G., Lilburne L., Vojvodic-Vukovic M., 1999. Provisional Targets for Soil Quality Indicators in New Zealand. *Landcare Research Science Series*. Manaaki Whenua Press. Pp. 63.

Trasar-Cepeda C., Leiros C., Gil-Sotres F., Seoane S., 1997. Towards a biochemical quality index for soils: an expression relating several biological and biochemical properties. *Biol. Fertil.Soils* 26(2): 100-106.

Wardle D., Ghani A., 1995. A critique of the microbial metabolic quotient (qCO2) as a bioindicator of disturbance and ecosystem development. *Soil Biol. Biochem.* 27(12): 1601-1610.