Carbon dynamics in apple orchards in New Zealand and their integration into Life Cycle Assessment

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Abstract

Soil carbon sequestration can help mitigate climate change and soil carbon contributes to many of the ecosystem services provided by the soil; thus soil carbon contributes to the sustainability of food production systems. However, changes in soil carbon are difficult and costly to measure due to two constraining characteristics: the spatial variability of the stocks as well as the typically small changes in carbon stocks over time. Consequently, environmental assessment tools such as Life Cycle Assessment (LCA) and carbon footprinting (CF) generally exclude the changes in soil carbon stocks from their analyses. Yet global supermarket chains use the results from these tools to inform consumers about greener products.

In New Zealand (NZ), production of horticultural products such as apples is very focussed on export markets. Therefore, if it can be demonstrated that the production of New Zealand apples maintains or increases the carbon stock of the orchard soil and above-ground biomass, this could lead to a reduced net CF and might enhance access to prime retailers' shelves in major export markets.

The main aims of this research were (a) to develop a practical method for measuring a statistically significant and powerful change in the soil-carbon stock of an apple orchard block in New Zealand, and (b) to assess a method to estimate the standing woody biomass carbon stock in apple orchards, in order to provide reliable data for the CF of NZ apples. Since there are no data available, this research sought to quantify the changes in soil-carbon stocks in apple orchards by means of a chrono-sequence.

A review of LCA and CF case studies accounting for changes in soil-carbon identified the need to focus on collecting deep, site specific, geo-localised and time-dependent soil-carbon data, as well as communicating its variability and statistical uncertainty for interpretation and transparency of LCA and CF results. Therefore, in a first step to develop a protocol for quantifying the carbon stocks in the soil, a four-year-old apple orchard block was intensively sampled to one meter depth to measure the soil-carbon stock and the spatial patterns. It was found that the soil-carbon stock was influenced

by tree planting pattern, and the minimum sampling requirements were determined to detect, from sampling every 20 years, a change of the mean (175.1± 10.8 t C/ha) of 10 % due to the spatial and temporal characteristics of soil carbon. This required sampling nine sites in a systematic grid in the orchard block, with four pooled samples per site evenly distributed between and outside the wheel tracks, at a total cost of NZ$1,590 per sampling campaign. This cost of monitoring seems affordable as it is equivalent to just 0.5% of the value of export apples at ship-side in New Zealand. While price premiums could compensate for it, using the carbon market seems unrealistic at present because the price of carbon would need to reach at least NZ$182/tonne.

To inform development of a protocol for quantifying the carbon stocks in the woody biomass in a commercial apple orchard block, the relationship between the trunk cross-sectional area (TCA) and the woody dry mass (DM) of the trees was assessed using 10 trees that were destructively harvested. It was found that using this relationship together with a high number of TCAs measured *in situ* in the orchard block facilitated the rapid and cost effective estimation of the woody biomass carbon stocks at the orchard block scale. At the end of the orchard life, the carbon has been stored out of the atmosphere for the lifetime of the trees and this contributes to reduced climate change. Furthermore, at the end of life the trees may be burned for convenience, chopped for firewood or transformed into biochar and applied to soils. It was found that the biochar scenario provided the largest reduction, and that this benefit was equivalent to 0.7% of the carbon footprint of apples exported to Europe. The choice of a time horizon for the assessment was found to be critical, with comparative results varying up to three fold between the 20 year and the 100 year time horizons.

Regarding changes in soil carbon stocks over time, the four-year-old orchard block was part of a 12 year-old chronosequence, also including a one-year, a six-year and a twelve-year old block. The same sampling protocol was carried out in these three other blocks. It was found that all orchard blocks had relatively high soil-carbon stocks. Moreover, there was no significant difference in soil-carbon stocks at the 5% level between the one-year-old, the six-year-old and the twelve-year-old blocks of the chronosequence. Based on the soil-carbon stocks of these three blocks, current management practices seem to be maintaining these carbon stocks over time. Therefore, unless management practices are modified, monitoring may not be required. However, this maintenance of relatively high soil-carbon stocks in orchard systems is beneficial for climate change and the ecosystem services provided by the soil. It should therefore be treated as such in LCA and CF studies although a method is yet to be developed.

In addition, despite a high similarity with the other blocks, the four-year-old block showed a higher, significantly different soil-carbon stock, and the levels of variability in soil-carbon stocks were found to be different between all the blocks. This demonstrates the high local specificity of soil-carbon stocks. The six year-old block displayed a coefficient of variation (14%) larger than the other blocks, and so an analysis of sampling requirements was conducted for this block. A change of 10% of the mean could, in theory, be observed by collecting a total of 78 samples, bulked two by two, for carbon content, and using 39 bulk density profiles, all to one meter depth. The associated cost of monitoring is NZ$ 9,420 and is equivalent to 1% of the value of export apples at ship-side in New Zealand. Monitoring soil-carbon stocks would seem therefore affordable, even in the more variable orchard block.

Overall, this research has made four main contributions to the science. Firstly, a robust, practical and adaptable protocol for monitoring soil-carbon stocks in apple orchards has been developed. Secondly, a rapid and cost effective method to estimate the carbon stock in standing woody biomass has been verified for use in commercial apple orchard blocks; accounting for this biomass carbon stock may lead to a net reduction of up to 4.6% of the New Zealand based (cradle to NZ port) CF of apples exported to Europe; Thirdly, a chrono-sequence of orchard blocks has suggested that current management practices in apple orchards appear to achieve the maintenance of high soil-carbon stocks over time, and it is suggested that this maintenance should be recognised as beneficial in CF and LCA studies. Finally, soil carbon stocks have been found to be spatially variable within and between similar orchard blocks; therefore LCA and CF studies should use site specific data and communicate the uncertainty of their soil-carbon stock estimates.

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%C	Carbon content
ATA	Allocated Tree Area
BD	Bulk Density
C	Carbon
CF	Carbon Footprint
CV	Coefficient of Variation
LCA	Life Cycle Assessment
NZ	New Zealand
NZD	New Zealand Dollar
SD	Standard Deviation
SE	Standard Error