

Quantification and comparison of shelterbelt carbon stocks within and between an organic mixed-cropping farm and a conventional dairy farm

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Abstract

Although woody ecosystems provide a key carbon sink to compensate for current and future greenhouse gas emissions, the potential utility of such sinks within agroecosystems has not yet been fully investigated. We quantified shelterbelt carbon variability, within above- and below-ground pools, for two contrasting farms: a conventional dairy farm and an organic mixed-cropping farm. Shelterbelts comprised deciduous, evergreen and mixed-native species occurring on silt loams, as well as adjacent paddock soils for comparison. Considering all above- and below-ground components, woody shelterbelts contained up to fifteen times more carbon ($>600 \text{ t C ha}^{-1}$) than sampled paddock soils ($c. 45 \text{ t C ha}^{-1}$). Carbon quantities within organic farm shelterbelt soils were 2.5 times higher than dairy farm soils, suggesting a potential land use effect. Soil carbon comprised about 10 % of total ecosystem carbon within shelterbelts. This study indicates that farm shelterbelts can serve a role as relevant carbon sinks within New Zealand agroecosystems.

Keywords: Above-ground, below-ground, carbon stocks, agroecosystem, *Macrocarpa*, *Pinus*, *Populus*, shelterbelt, variability, native

Introduction

Agriculture and land use change contribute approximately 20 % to anthropogenic CO₂ emissions at a global level (Dumanski and Lal, 2004) and approximately 50 % in New Zealand (MfE, 2014). These rising contributions could potentially be mitigated by maintaining existing large forest carbon pools, while increasing carbon sequestration by additional vegetation and soil pools, such as those on agricultural lands (Batjes, 1998, House et al., 2002, UNEP, 2011). For example, agroforestry practices, such as the planting of shelterbelts on farm margins and in other non-productive zones, may offer great promise to sequester carbon (Czerepowicz et al., 2012, D'Acunto et al., 2014).

A number of studies have highlighted the potential of shelterbelt carbon sequestration in the Americas (Baggio and Heuvelink, 1984, D'Acunto et al., 2014, de Jong et al., 1995, Romero et al., 1991), Europe (Follain et al., 2007) and Australia (Smith and Reid, 2013). While much effort has been put into assessing and quantifying carbon pools within forest plantations and natural forests in New Zealand (i.e., Beets et al., 2014, Beets et al., 2011, Maclaren, 1996, Mason et al., 2012), comparatively few studies have been carried out for shelterbelts and other more linear woody vegetation features within the agricultural landscape (Perry et al., 2009). The only study, to our knowledge, on shelterbelt carbon stocks in New Zealand suggested that about 6 t C ha⁻¹ is currently missing from the agricultural "grassland with woody biomass" carbon pool because shelterbelts have been essentially excluded from carbon accounting exercises (Czerepowicz et al., 2012). Although soils in the agricultural landscape

represent a significant low-to-no-cost carbon sink (Lal, 2004, Pacala and Socolow, 2004, Schipper et al., 2007), little is known about their soil carbon stocks and their variability, particularly beneath shelterbelts, in New Zealand.

Land use clearing and agricultural intensification over the past century in New Zealand has probably impacted agroecosystem processes such as carbon sequestration and storage, although the nature and extent of these effects is poorly understood. The Canterbury region is one of New Zealand's key agricultural production areas. It is located on the east coast of the South Island of New Zealand. Canterbury is still experiencing an increase in intensification of farming practices in combination with reductions in shelterbelts and other woody vegetation as part of contemporary farm management activities (Welsch et al., 2014). Thus, quantifying above- and below-ground carbon pools and testing the extent to which they vary with differing shelterbelt tree species, underlying soil characteristics, and adjacent land use and management contexts, is an important first step towards understanding the effect of land use on carbon sequestration and storage in New Zealand agroecological landscapes. In this study, we quantified above- and below-ground carbon stock variation for different shelterbelt species on two contrasting farm types on the Canterbury Plains, New Zealand: an organic mixed cropping farm operated for over 20 years and a conventional dairy farm that had been established for almost 15 years. The shelterbelts studied were of similar age and spatial extent on both farms. We quantified carbon stocks in five separate pools: above-ground biomass, coarse-woody debris, herbaceous biomass, litter, and soil. Additionally,

soil carbon was quantified within adjacent farm paddocks as a comparison to shelterbelt soil carbon.

Materials and methods

Study sites

The two farms were located near Lincoln, Canterbury, New Zealand (Fig. 1). Mean annual rainfall in the area is 666 mm, and the mean maximum temperature is 32 °C in summer and 4 °C in winter (SIDDC, 2014). The two farms have similar land use histories and both are situated on the Wakanui silt loam soil type, which is a mottled immature pallic soil (USDA: Udic Haplustept) (Hewitt, 1993, Lilburn et al., 2004). The organic mixed cropping farm site (43.650°S, 172.455°E) was established in the early 1980s and had since been farmed under organic management systems. The conventional dairy farm (43.639°S, 172.461°E) was converted from sheep farming after more than 15 years of

grazing in 2001 and had an average herd size of 679 cows at the time of sampling (DairyNZ, 2013). The shelterbelts on both farms had been established for over 30 years (see Table 1) and were oriented N–S/ NE–SW. The shelterbelt species investigated were; (a) poplar (*Populus nigra*), (b) radiata pine (*Pinus radiata*), (c) macrocarpa (*Cupressus macrocarpa*), (d) oak (*Quercus* spp.) and (e) a native mix of harakeke (flax, *Phormium tenax*), tī kōuka (cabbage tree, *Cordyline australis*), and kōhūhū (*Pittosporum tenuifolium*), and (f) adjacent paddocks comprised mainly of perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.) and tall fescue (*Festuca arundinaceae* Schreb.) (Table 1). The shelterbelts on the organic farm were annually-to-biannually trimmed back to within the fenced area (see Table 1 for shelterbelt dimensions). The paddocks adjacent to the shelterbelts were never grazed, nor had they received any mineral fertiliser or pesticides since organic farm establishment. The

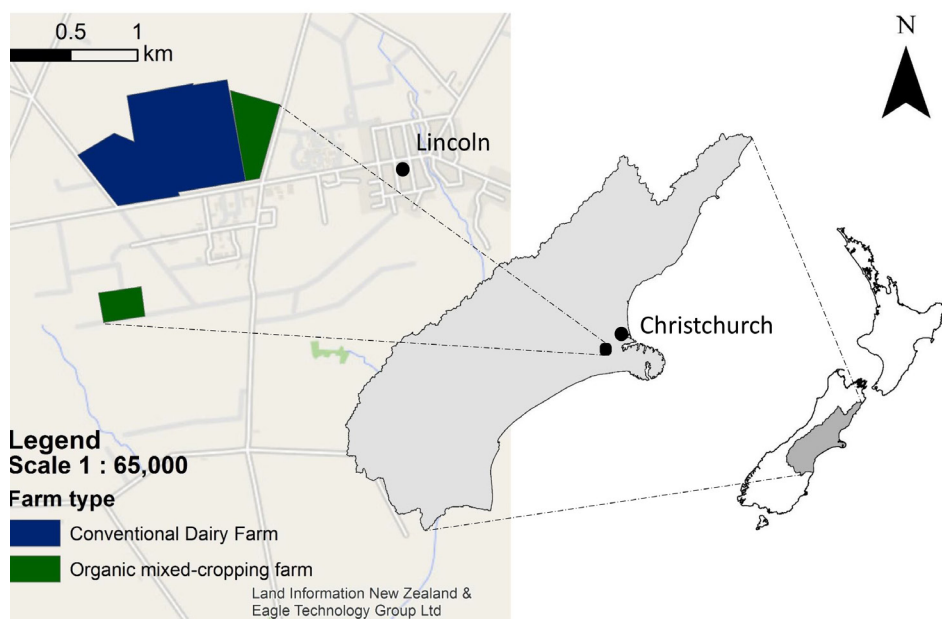


Figure 1. The two study farms near Lincoln, Canterbury are shown in the map on the left, as well as their locations within the Canterbury region and New Zealand on the right.

conventional dairy farm shelterbelts were trimmed annually and adjacent paddocks had been intensively farmed under standard sheep and dairy pasture management regimes.

Study design and field sampling

Shelterbelt carbon stocks were quantified along one, 20 m transect within each shelterbelt, centred approximately on each shelterbelt's midpoint. At five metre intervals along each transect (five locations per shelterbelt), above- and below-ground carbon compartments, including live woody vegetation, coarse-woody debris, herbaceous vegetation, litter, and soil to a 15 cm soil depth, were sampled using established protocols

(IPCC, 2003).

To quantify above-ground shelterbelt carbon stocks for different shelterbelt vegetation cover types, allometric equations were first used to estimate the total tree above-ground biomass (kg tree^{-1}) of five representative trees in the shelterbelt. A New Zealand-specific tree biomass equation published by Moore (2010) for coniferous species was used to estimate tree biomass for radiata pine. No allometric equation was found in the literature for macrocarpa, therefore, we estimated biomass quantities for this species based on Czerepowicz (2011). There were also no available New Zealand-specific allometric equations for either poplar or oak, nor for the three shelterbelt species in the native

Table 1. Summary of general shelterbelt and soil characteristics at the two farm study sites. Values presented for soil pH and percent moisture for each vegetation cover type are means and standard deviations.

Farm	Cover type	Genus	No. of sites	Trees per transect	Age	Shelterbelt height (m)	Shelterbelt width (m)	pH	Soil moisture (%)
Dairy farm									
	Paddock	<i>Lolium</i> <i>Trifolium</i> <i>Festuca</i>	2	--	15	--	--	6.05±0.15	2.9±1.17
	Macrocarpa	<i>Cupressus</i>	2	13	30	8	5	5.85±0.18	6.27±2.08
	Native	<i>Cordyline</i> <i>Pittosporum</i> <i>Phormium</i>	1	1 1 7	4-5	2.3	3.3	5.85±0.13	6.24±2.24
	Pine	<i>Pinus</i>	2	30	30	8	4	4.54±0.08	9.14±1.33
	Poplar	<i>Populus</i>	2	26	30	24	1.5	4.9±0.90	3.2±0.90
Organic farm									
	Paddock	<i>Lolium</i> <i>Trifolium</i> <i>Festuca</i>	2	--	20	--	--	6.46 ±0.09	1.96±0.76
	Macrocarpa	<i>Cupressus</i>	1	13	25	4.5	5	5.73±0.13	3.6±1.68
	Native	<i>Cordyline</i> <i>Phormium</i>	2	3.5 7.5	4-5	2.3	3.3	5.16± 0.56	3.27±0.99
	Oak	<i>Quercus</i>	1	10	35	18.5	5	5.94±0.07	2.5±1.01
	Poplar	<i>Populus</i>	2	25.5	30	24	1.5	6.51±0.39	3.33±1.16

mixed plantings. Therefore, an equation developed in Canada for *Populus tremuloides* by Case and Hall (2008) was used for the poplar. The equation for oak was based on Austrian temperate forest biomass calculations by Hochbichler (2002). For all shelterbelts, the approach described in Czerepowicz (2011) was used to up-scale tree-level biomass estimates to per hectare carbon quantities for shelterbelt species (tree biomass in tonnes C ha⁻¹) using field measurements of shelterbelt width (m), height (m), length (m), the number of rows of trees and the number of trees and the average spacing of trees in each row. For the native species, the biomass of the individual natives recorded within these shelterbelts was estimated by measuring the shelterbelt dimensions and quantifying the number of the different species (Table 1). This procedure resulted in biomass quantities on a kg per plant basis of: 11.3 kg for cabbage tree, 3.9 kg for kōhūhū, and 3.32 kg for flax. These estimates were then extrapolated to both a kg C m⁻² and a tonnes C ha⁻¹ basis (Gisborne District Council, 2009, Marden et al., 2005, McGruddy, 2006, Watson and Marden, 2004).

Coarse-woody debris (CWD) was sampled in shelterbelts by collecting all woody pieces >5 mm within 50 × 50 cm sample quadrats at each of the five sampling locations. Where debris crossed the quadrat boundary, the dimensions of the specimen portions falling within the quadrat was used in calculations. Similarly, herbaceous biomass and litter were sampled using 50 × 50 cm and 25 × 25 cm sampling quadrats, respectively, as per published measurement procedures (Smith and Reid, 2013, Tothill et al., 1978). All specimens were dried at 25 °C for two weeks, weighed, and converted to carbon content based on a 50 % conversion factor by weight (Smith,

2010, Snowdon et al., 2000). Because we were mainly interested in among-species and between-farm differences in coarse-woody debris, herbaceous vegetation and litter carbon quantities, quadrat-based data for each of these components were pooled for each species before scaling values up to per-hectare carbon quantities.

Soil C was sampled using a 15 cm step-on soil coring device. At each farm, soil cores were obtained at the five sampling points within each shelterbelt and 25 m away in the paddocks. Mixed sub-samples of each soil core were analysed for total soil carbon and nitrogen using an Elementar Vario-Max CN Elemental Analyser (Elementar GmbH, Hanau, Germany). Total soil organic carbon was quantified using the low-cost, loss on ignition method (LOI) (Blackmore et al., 1987). For each soil sample, the 'driving hammer' method (10 cm × 15 cm) (Blake and Hartge, 1986) was also used to remove soil samples for soil bulk density measurement. To allow for proper comparison of carbon quantities among soil samples, total and organic carbon concentrations were corrected for equivalent mass using bulk density values and represented as per-unit-area carbon stock values (t C ha⁻¹). Additionally, a sub-sample from each sample point was used to quantify soil moisture and pH value (Blackmore et al., 1987).

Data analysis

We first explored how shelterbelt-scale carbon stocks for each of the five ecosystem components, and their totals (t C ha⁻¹), compared overall among four vegetation cover types (paddock, poplar, pine, macrocarpa, oak, native) at each of the two study farms (conventional dairy and organic farm). Second, we used one-way analysis of variance to test for differences in soil total carbon

and soil organic carbon densities (t C ha^{-1}) among vegetation cover types, and between the two farms, using soil-core-level samples undertaken within each cover type; additionally, we investigated how ratios of soil organic carbon to soil total carbon varied among cover types and farms. Third, based on our sample data, we estimated for each of the two farm types the potential difference in farm-scale carbon stock with and without shelterbelts on these farms, based on the total area of each study farm and the calculated proportions of shelterbelt area per farm. From these values, we then extrapolated the potential gain of carbon that might be achieved with incremental increases in the relative area of shelterbelt on each farm type. Statistical analyses were performed using R version 3.10 implemented in RStudio version 0.98 (R Core Team, 2015).

Results

Sampled shelterbelt cover types that were common between the two farms (macrocarpa, poplar and native shelterbelt species) were of similar ages and dimensions (Table 1). However, native shelterbelts were relatively recently planted 4 to 5 years ago, while the other tree species were all relatively mature (20–30 years old); paddock establishment for the current land use occurred 15–20 years ago for the two sites. The number of trees per shelterbelt varied based on the species (10–30 trees per transect; see Table 1). The organic farm had consistent soil moisture levels of approximately 3 % that were similar among vegetation cover types. In contrast, soil moisture in the paddock on the conventional dairy farm was low (2.8 %) but higher, and more variable, under shelterbelts (3–9 %). Soil pH did not vary appreciably within

or between farms and ranged between pH 5 and 6.

The majority of total shelterbelt carbon was stored in the above-ground vegetation biomass (Fig. 2); values ranged between 2 and 650 t C ha^{-1} , increasing in the order of native < macrocarpa < radiata pine < oak < poplar. On average, across the sampled shelterbelt cover types on each farm, shelterbelts on the organic mixed cropping farm had higher vegetation carbon stocks (225 t C ha^{-1}) compared with those on the conventional dairy farm site ($186.5 \text{ t C ha}^{-1}$). Coarse-woody debris and soils comprised the next largest carbon stock components, with considerable differences among cover types. Overall, both farms had similar shelterbelt coarse-woody debris stocks, on average, across the four shelterbelt cover types sampled (conventional = 22.5 t C ha^{-1} , organic = 17.9 t C ha^{-1}). However, soil carbon stocks associated with the organic farm (316 t C ha^{-1}) were, on average, over 1.5 times those of soil carbon stocks for the dairy farm ($201.6 \text{ t C ha}^{-1}$) (Fig. 2). Carbon stocks of the herbaceous vegetation and litter components were relatively low compared to the other components, with carbon quantities generally below 3 t C ha^{-1} for most sampled shelterbelts on both farms. Herbaceous carbon was highest for native shelterbelts and litter carbon was highest for pine and oak shelterbelts.

Soil total carbon densities varied significantly both between farms ($F_{1,63} = 40.46$, $P < 0.001$) and within cover types ($F_{4,60} = 9.01$, $P < 0.001$) (Fig. 3). On the whole, the organic mixed cropping farm site had higher mean soil total carbon across all cover types (6.79 kg m^{-2}) compared with the conventional dairy farm site (4.12 kg m^{-2}). On the conventional dairy farm, macrocarpa shelterbelts had the highest and most variable soil carbon quantities while native shelterbelts had

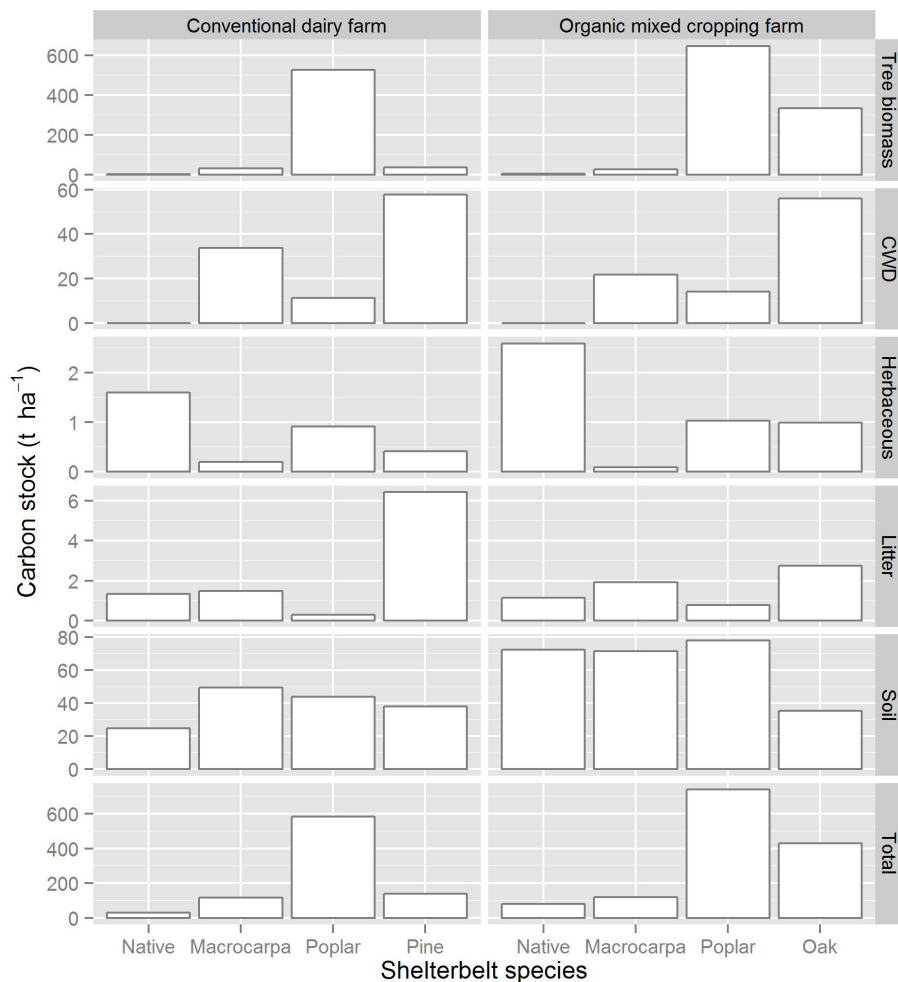


Figure 2. A comparison of shelterbelt-scale carbon stocks (t ha^{-1}), quantified for five ecosystem components (above-ground vegetation, coarse-woody debris, herbaceous vegetation, litter, and soils), among four different shelterbelt species on two contrasting farm types. Carbon stocks are total carbon quantities at the shelterbelt scale, calculated by compositing all sampled quantities within a given vegetation cover type and then converting to a per-hectare density. The 'Tree biomass' component does not include roots, 'CWD' is coarse-woody debris, 'Soil' comprises the top 15 cm soil stratum, and 'Total' is the sum of all component carbon stocks. Note the differences in the range of y-axis values among the ecosystem components.

the least. On the organic farm, poplar shelterbelts contained the highest and most variable carbon quantities while oak shelterbelts had the lowest soil carbon quantities by far compared to the other shelterbelt species. Across both farms, soil carbon quantities within paddock soils were generally comparable to shelterbelt soils, although stocks were slightly higher

on the organic farm as compared to the dairy farm.

Soil organic carbon (SOC) varied significantly between the farms ($F_{1, 63} = 64.02$, $P < 0.001$) and within cover types ($F_{4, 60} = 9.01$, $P < 0.001$). However, shelterbelt and paddock soil organic carbon did not differ significantly on average at either site (organic farm $F_{1, 38} = 0.35$,

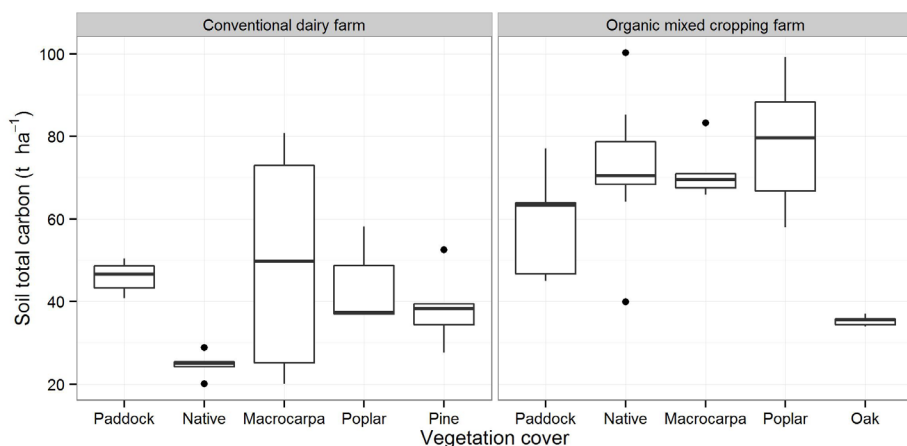


Figure 3. Variability in soil total carbon stocks (t ha^{-1}) in the top 15 cm soil stratum, across five sampling locations within each of four different shelterbelt cover types and their adjacent paddocks, for two contrasting farm management types. Lines inside each box are median values, outer box lines are 25th and 75th percentile values, the whiskers extend to 1.5 times the interquartile range, and dots signify outliers.

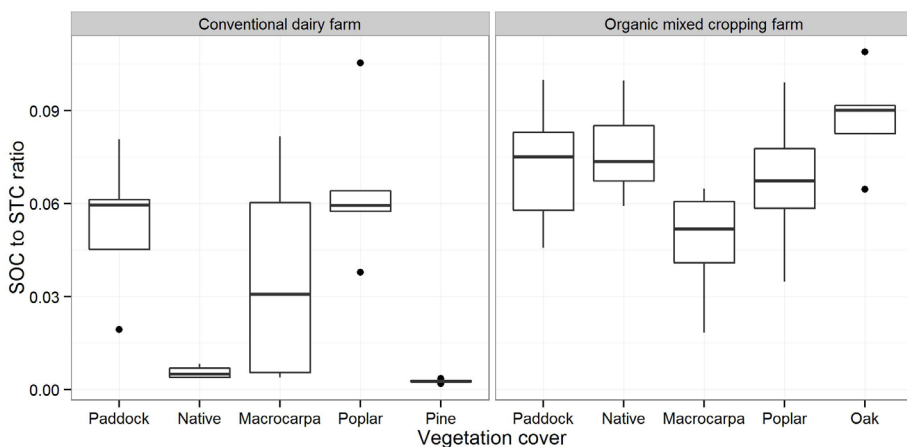


Figure 4. Variability in the ratio of soil organic carbon (SOC) to soil total carbon (STC) stocks (t ha^{-1}) in the top 15 cm soil stratum, across five sampling locations within each of four different shelterbelt cover types and their adjacent paddocks, for two contrasting farm management types. Lines inside each box are median values, outer box lines are 25th and 75th percentile values, the whiskers extend to 1.5 times the interquartile range, and dots signify outliers.

$P = 0.560$; dairy farm $F_{1, 33} = 1.61$, $P = 0.213$). The ratio of soil organic to total carbon also showed considerable variability (Fig. 4). As a percentage of total carbon, the amount of soil organic carbon in the top 15 cm on the organic farm (7.0 %) was on average about 2.5 times that of the dairy farm (2.8 %) across all the

vegetation cover types. Soils beneath the oak shelterbelt on the organic farm had the highest proportion of organic carbon (c. 9 %) while the pine shelterbelts on the dairy farm had the lowest (< 1 %). For species that were present on both farms, the largest differences in the proportion of soil organic carbon to total carbon

between farm types were observed for native and macrocarpa shelterbelts, while the poplar shelterbelts and paddocks showed the least difference.

Estimates of the overall carbon quantities at the farm scale showed that the dairy farm with no shelterbelts would have a carbon stock of 43.9 t C ha^{-1} and the organic farm a carbon stock of $59.06 \text{ t C ha}^{-1}$ (Fig. 5). As a proportion of their farm areas, shelterbelts comprised 1.3 % of the dairy farm and 3.8 % of the organic farm. The inclusion of shelterbelts at their current proportions increased the overall carbon stock on the dairy farm to $46.05 \text{ t C ha}^{-1}$ and on the organic farm to 69.7 t C ha^{-1} . Based on these values, each

additional hectare of shelterbelt would add 4.93 times more t C ha^{-1} than pasture on the dairy farm and 5.79 times more t C ha^{-1} compared to pasture on the organic farm; thus, a projected 20 % increase in the proportion of shelterbelt cover on both farms, for example, would result in potential carbon stocks of 78.4 t C ha^{-1} on the dairy farm and $115.7 \text{ t C ha}^{-1}$ on the organic farm (Fig. 5). The trend shows an increasing diversion between the organic farm and the conventional dairy farm potential in C per hectare and indicates that a small increase in woody vegetation cover can lead to a large increase in C per hectare.

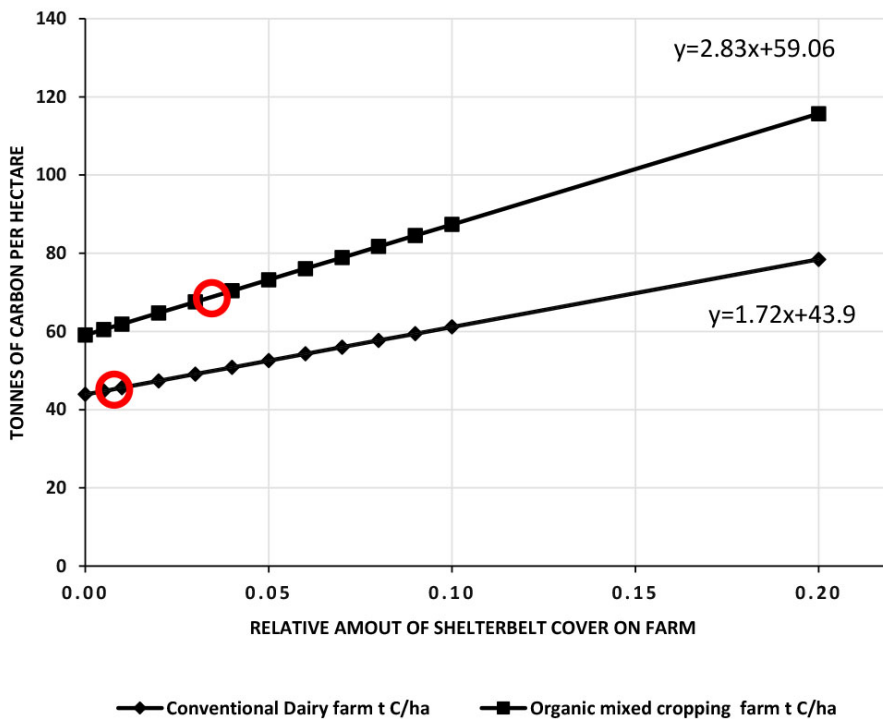


Figure 5. Projected changes in carbon quantities for both the dairy and organic farms with incremental increases in the relative proportion of shelterbelt area on each farm, based on carbon measurements taken in this study. The y-intercepts of each line indicate estimated carbon stocks under a no shelterbelt, paddock only scenario. Red circles indicate the current shelterbelt proportions and carbon stocks per hectare on each farm. The slope of the regression equations of the projected trends give the potential incremental gain in carbon for each additional one percent increase in shelterbelt area, as a proportion of farm area.

Discussion

This study indicates that farm shelterbelts constitute relevant carbon stocks within New Zealand farming landscapes. Considering all above- and below-ground components comprising shelterbelt carbon quantities, woody shelterbelts in this study contained up to fifteen times more carbon in the tree biomass than in the sampled paddock soils alone. Further, there was more soil total and organic carbon within both shelterbelt and paddock soils on the organic farm as compared to the dairy farm, equating to about a 2.5 fold difference on average. The high degree of variability in shelterbelt carbon pools among the different shelterbelt cover types at both the conventional dairy and organic mixed cropping farms shows that the type of vegetation can make a large difference to potential carbon sequestration; this effect was driven by both above- and below-ground carbon pools. Soil carbon stocks comprised a substantial proportion (about 10 %) of total ecosystem carbon stocks within shelterbelts.

The large observed variability in ecosystem carbon pools across the sampled shelterbelts largely reflected among-shelterbelt differences in a number of factors including the dominant cover types, shelterbelt structural characteristics (dimensions and tree spacing), shelterbelt management activities and shelterbelt ages. For example, the popular shelterbelts on the two farms were well-established (30 years old) and were unpruned, resulting in the highest above-ground carbon stock densities relative to the other species. In contrast, the native shelterbelts were recently established and were relatively widely-spaced, resulting in extremely low above-ground carbon stocks. It is likely that differences in both

cover type and structural characteristics resulted in the carbon stock variation observed within the other ecosystem pools by influencing litter and coarse-woody debris types and amounts and ultimately the incorporation of carbon into the soil (Smith, 2010). For example, deciduous and evergreen species might have differing effects on soil carbon stocks through the variable amount of coarse woody debris and leaf litter produced (Brown, 2002). Thus, these shelterbelts represent small, but relatively undisturbed wooded patches where ecosystem processes such as leaf and woody litter accumulation, decomposition and mineralisation can occur and provide a feedback of carbon and nutrients to the soil (Simón et al., 2013).

The studied shelterbelts displayed a small but indicative pattern of variability between species and farms for total soil carbon and the proportion of soil organic carbon. Of particular interest is the result that, while shelterbelt and paddock soil carbon did not differ on average at either site, there were considerable differences between the two farm types. These findings suggest that land use has an effect on the quantity of carbon stored in the soil and merit further investigation. Indeed, soil organic carbon was significantly higher on the organic farm compared to the dairy farm, the latter being subjected to both animal stocking and soil tillage. Lower soil organic carbon quantities on the dairy farm may be due to the differences in such management practices (Schipper et al., 2010). Indeed, higher stocking rates and greater N fertilizer inputs that are often associated with conventional dairy farming can lower soil organic carbon stocks (Khan et al., 2007), although this is not always the case (Zhang et al., 2010). Animal urine has also been shown to mobilise soil

organic matter and result in soil organic carbon loss (Lovell and Jarvis, 1996). Further, while this study did not investigate if shelterbelts have a “shadow effect” on paddock soil carbon extending into the adjacent paddock, other studies have suggested that such an effect exists (D’Acunto et al., 2014, Simón et al., 2013) and should be investigated more thoroughly as a possible carbon management tool.

Consistent with previous findings on the relative proportions of woody vegetation cover on different farm types in New Zealand (Welsch et al., 2014), the organic farm had a shelterbelt cover of almost three times more (3.76 %) than the dairy farm (1.25 %). This may reflect the priority placed by farmers on maximising productivity on their properties, a finding highlighted in other studies (i.e., Mattison and Norris, 2005, Rolfe, 2000), reflecting the influence of activities such as fertiliser application and/or irrigation over time on both paddock and associated shelterbelt soil conditions on farms (Kelliher et al., 2012, Kelliher et al., 2014). Our results also show the potential for shelterbelts to enhance carbon sequestration and storage on farms, with clear gains in carbon achieved with relatively small incremental increases in shelterbelt area on both farm types. This highlights the value of using marginal production land for increasing carbon stocks and the possible trade-offs between agricultural production and providing carbon sequestration services as one of a number of ecosystem services and functions under a so-called land-sharing approach (Tscharntke et al., 2012). This would lead to a more balanced, multifunctional agricultural landscape management with the aim of reconciling both ecological and production aims across agro-ecosystems (Rey Benayas and Bullock, 2012).

In summary, this study has provided a preliminary quantification of shelterbelt carbon quantities within above- and below-ground pools and how these quantities vary among a range of common shelterbelt cover types and in the context of adjacent farming practices. To our knowledge, this is also the first study to quantify ecosystem carbon pools for agricultural shelterbelts within New Zealand. Carbon quantities from this study are comparable to those presented by (Mason et al., 2012) and consistent with indicative Ministerial statistics (MfE, 2013, MfE, 2009). Although our sample was relatively small, our results indicate the possible range of variability expected in ecosystem carbon quantities for the main shelterbelt types found across New Zealand and also provide initial evidence for a land use effect on shelterbelt carbon pools. Extending this work across a greater number of farms and farm types would afford further insight into the role of shelterbelts as carbon sinks across New Zealand’s agroecosystems.

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Appendix

Appendix I: A comparison of shelterbelt carbon stocks (t ha⁻¹), quantified for five ecosystem components (tree biomass (not including roots), coarse-woody debris (CWD), herbaceous vegetation, litter, and soils), among different shelterbelt tree species and for two contrasting farm management types. Carbon stocks were calculated by compositing all sampled quantities within a given vegetation cover type and then converting to a per-hectare total. Total carbon is the sum of component carbon stocks.

Farm type	Compartment	Native	Macrocarpa	Poplar	Pine
Conventional dairy farm					
	Tree biomass	2.2	31.7	525.6	35.2
	CWD	0.0	33.7	11.4	57.7
	Herbaceous	1.6	0.2	0.9	0.4
	Litter	1.3	1.5	0.3	6.4
	Soil	24.7	49.5	43.7	37.8
	Total	29.9	116.5	581.9	137.6
Organic cropping farm					
	Tree biomass	3.3	25.6	646.3	333.8
	CWD	0.0	21.7	14.1	56.0
	Herbaceous	2.6	0.1	1.0	1.0
	Litter	1.1	1.9	0.8	2.7
	Soil	72.3	71.4	77.7	35.4
	Total	79.3078	120.7165	739.8865	428.9256