Using paired plots to verify soil carbon change associated with land-use change as predicted from historical soil inventory

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Abstract
A system of paired plots is being established in New Zealand to determine the direction and magnitude of soil carbon change associated with major land-use changes that have occurred since 1990, i.e. afforestation of grassland, and reversion of grassland to shrubland. Some data exist for afforestation of grassland, but uncertainties are high and more data are needed, particularly for depths below 0.1 m. Limited data are available for the effects on soil C of pasture reversion to shrubland. This work aims to strengthen the current Carbon Accounting System (CAS) by providing the data needed to verify predictions based on the CAS and on process-based models being developed.

Three sets of pasture-shrubland paired plots were established in 2003. They comprise pairs of 20 x 20 m plots in close proximity that have, as far as possible, identical soils, slope, aspect, elevation and land-use history until 1990, but differing land use since 1990. The shrubland consisted of the indigenous species manuka at two higher rainfall sites and the exotic leguminous species broom at the third site. The estimated time since the sites began to revert to shrubland was 9-12 years. Statistical analysis of data from the initial three sites showed there was no significant difference in soil C between pasture (112 Mg ha^{-1}) and shrubland (120 Mg ha^{-1}) to a depth of 0.3 m. Between-site variance was large, however, and additional sampling is required to accurately determine the magnitude and direction of change in soil C with land use change from grassland to shrubland.

Key Words
Soil carbon, paired plots, grassland, shrubland

Introduction

New Zealand is obliged under the United Nations Framework Convention on Climate Change and the Kyoto Protocol to report on greenhouse gas emissions and removals arising from land use, land-use change and forestry activities. The NZCAS will use historic soil databases and new process based models to account for C fluxes in soils arising from these activities (Tate *et al*. 2003, Scott *et al*. 2002). Paired plot or chronosequence studies are required to verify the direction and magnitude of C fluxes from these estimates. Paired plots have the advantage of providing immediate results, unlike chronosequence studies that may require years or decades of monitoring to measure such changes.

The two major land-use changes to have occurred in New Zealand since the beginning of 1990, the baseline year for C accounting, are from grassland to shrubland and from grassland to planted forest. As part of the NZCAS it is proposed to install paired plots at 32 sites (16 in each land use change) during the 10-year period from 2003 until 2012 to verify estimates of C flux in soils arising from these land use changes. Although some paired plot data already exist for afforestation of grassland (Davis & Condron 2002) uncertainties are high and more data are needed, particularly for soil depths below 0.1 m. Few data are available for the effects on soil C of shrubland establishment and growth in grassland. The paired plots selected in the first few years of the project will address this particular issue. This note outlines plot selection and sampling procedures adopted for paired site establishment for the grassland-shrubland transition, and presents some initial results.

Methods

Suitability criteria based on Conteh (1999) and Davis *et al*. (2004) were followed for the selection of plot pairs. Potential locations for plot pairs were identified from field knowledge, discussion with landowners, or from satellite images, maps, and aerial photographs. The most promising sites were visited and a brief

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examination of the site and soils for their suitability was made. For selection, the site pair was required to have, as far as possible, similar soils (hence similar parent materials, climate, original vegetation, topography and age), slope, aspect and elevation, but contrasting land use. One 20 x 20 m plot of each pair was located on land that had been in long-term grassland, and the other on nearby land where shrubland had developed since about 1990. Following initial selection, similarity was verified (or rejected) after soil examination by an independent pedologist. This involved examination and pedological description of eight soil profiles evenly spaced around the perimeter of each plot of the selected pair.

Soil sampling procedures for soil C determination followed Davis *et al.* (2004). Briefly, plots were divided into four quarters, and one sampling point was randomly located in each quarter. At each sampling point litter (L) and ferment humus (FH) samples, where present, were collected from three 0.1 m^2 quadrats spaced 1 m apart across the slope, with the centre quadrat located at the randomly selected sample point. The three samples were bulked within plot quarters. Soil samples from 0–0.1 m, 0.1–0.2 m and 0.2–0.3 m depths were collected at the random point using 98 mm diameter by 100mm deep stainless steel sampling rings. Additional samples were collected, using a 25-mm diameter core sampler, in 0.1 m increments to 0.3 m depth at eight locations spaced 0.25 m apart across the slope and centred on the random sampling point. Within each quarter-plot, these 25 mm diameter core samples were bulked by depth.

To enable future location of the plots, plot corners were marked with flagging tape and wooden pegs. Additionally, 15-mm diameter steel pegs were driven into the soil at plot corners and the plot centre to enable exact future location using a metal detector. GPS co-ordinates at plot centres were also recorded together with their placement errors as shown by the GPS instrument (to the nearest 10 m).

Litter and FH layer material was oven dried (70^{o}C) and weighed, and a sub-sample was ground for determination of C and nitrogen concentration. Soil collected using 0.1 m diameter corers was air dried and passed through a 2 mm sieve, and the weight of <2mm soil and > 2mm fractions were determined after oven drying. Soil collected using 25 mm diameter corers was air dried and passed through a 2 mm sieve for analysis. Carbon and nitrogen concentrations (nitrogen concentrations not presented here) were determined in sub-samples of < 2 mm soil and L and FH layer materials using a LECO CNS analyser. Carbon mass was determined by applying the C concentration data to the appropriate mass data.

Initial Results

The three initial paired sites selected were all located on Orthic Brown Soils (New Zealand Soil Classification, Hewitt 1998), that fall into the IPCC (Intergovernmental Panel on Climate Change) High Clay Activity soil grouping (Table 1). Grassland plots were dominated by high fertility pasture species at the Waitotara site, and by low fertility species at the Puketoi and Balmoral sites. At the two higher-rainfall North Island sites the shrubland plots were dominated by a single species, the native myteraceous shrub manuka (*Leptospermum scoparium*). At the South Island site the shrubland plot was again dominated by a single species, broom (*Cytisus scoparius*), an exotic legume. From stem-ring counts the oldest plants at the Waitotara and Balmoral sites were about 9 and 12 years old respectively. Anecdotal evidence indicated that the oldest plants at Puketoi were also about 12 years, and stem diameters at 0.5 m height there (40-70 mm) were within the range of those at Waitotara (20-90 mm). Thus all three shrublands appeared to have developed since 1990.

Soil C mass varied greatly between the three sites (Fig 1). Site mean C mass to 0.3 m depth amounted to 62 Mg ha^{-1} at Balmoral, 92 Mg ha^{-1} at Waitotara, and 193 Mg ha^{-1} at Puketoi. There were no significant differences between grassland and shrubland at any of the depths measured, nor did mean total soil C mass to 0.3 m differ significantly between grassland (112 Mg ha^{-1}) and shrubland (120 Mg ha^{-1}).

An FH layer was present at both manuka shrubland plots, but not in the broom shrubland plot. The C mass in this layer amounted to 1.3 and 0.4 Mg ha^{-1} at the Puketoi and Waitotara sites respectively.

Table 1. Paired site soil, rainfall and vegetation characteristics.

Site and Region	NZSC[1]	IPCC[2] soil code	Rain-fall (mm)	Major grassland plot species[3]	Major shrub-land plot species	Shrub-land age (years)	Shrub-land height (m)	Shrub-land cover (%)
Waitotara, Taranaki	Pallic Orthic Brown	High clay activity	1500	Ryegrass white clover	Manuka	8-9	5-6	>90
Puketoi, Wairarapa	Andic Orthic Brown	High clay activity	1700	Browntop Lotus	Manuka	10-12	4	>90
Balmoral Canterbury	Typic Orthic Brown	High clay activity	900	Browntop matagouri	Broom	5-12	1.5	80-90

[1] New Zealand Soil Classification
[2] Intergovernmental Panel on Climate Change
[3] Ryegrass, *Lolium perenne;* white clover, *Trifolium repens;* browntop, *Agrostis capillaris;* lotus, *Lotus pedunculatus;* matagouri, *Discaria toumatou*.

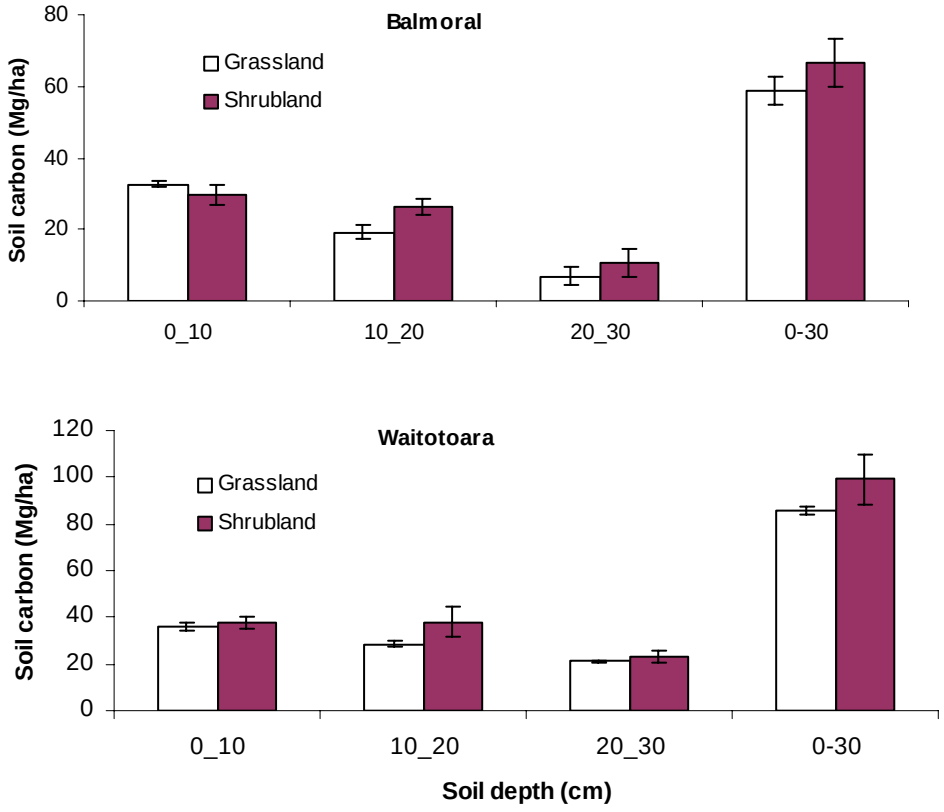

Fig. 1. Soil carbon mass for three paired grassland and shrubland sites. Values are means of four subplots, bars show standard errors.

Conclusion

Results from sampling of the initial three paired sites showed no significant difference between grassland and shrubland soil C to a depth of 0.3 m. Between-site variance was large, however, and additional sampling is required to accurately determine the magnitude and direction of change in soil C with land use change from grassland to shrubland.

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