Soil carbon and the New Zealand Agricultural Greenhouse Gas Research Centre

F.M. Kelliher[A,B], H. Clark[C], B.E. Clothier[D], A.D. Mackay[C], A.J. Parsons[C], G. Rys[E] and D. Whitehead[F]

[A]AgResearch, Lincoln Research Centre, Private Bag 4749, Christchurch 8140, New Zealand. Email frank.kelliher@agresearch.co.nz
[B]Department of Soil and Physical Sciences, Faculty of Agriculture & Life Sciences, Lincoln University, PO Box 84, Lincoln 7647, New Zealand.
[C]AgResearch, Private Bag 11008, Palmerston North 4442, New Zealand.
[D]Plant and Food Research, Private Bag 11-600, Palmerston North 4442, New Zealand.
[E]Ministry of Agriculture and Forestry, PO Box 2526, Wellington 6011, New Zealand.
[F]Landcare Research, PO Box 40, Lincoln 7640, New Zealand.

Abstract
The New Zealand Agricultural Greenhouse Gas Research Centre was recently established. One of three core science areas will develop management guidelines for the conservation and, where likely, sustainable increase of soil carbon (C) storage associated with land-based food and fibre producing activities. It has been estimated that soils beneath grazed pasture store 85% of New Zealand's soil C to a depth of 0.3 m. Research has improved estimation at a national scale, but pastoral soils data remains fragmented, geographic coverage limited, and most samples obtained from a depth < 0.1 m. There has been little research about manipulating and verifying C storage rate in soils beneath grazed pasture. For these soils, C storage is already substantial including some from primal forest vegetation cleared by European settlers around 150 years ago. Modelling will develop better understanding of influential soil C cycling processes in grazed pasture systems. A potential for soil C storage will be estimated as well as the proportion that has been realised. Measuring and verifying the likely slow, relatively small and variable changes in soil C storage will be difficult. Connecting models and field measurements, accounting 'rules' are envisaged, guiding soil C storage management on New Zealand's farms.

Key Words
Pastoral agriculture, measurement, model, scaling, accounting.

Introduction
The New Zealand Agricultural Greenhouse Gas Research Centre was recently established for science to develop management guidelines for the mitigation of atmospheric change associated with land-based food and fibre producing activities. This synopsis begins with some New Zealand context to set the scene, then describes planned science about conserving and, where likely, sustainably increasing soil carbon (C) storage. Substantial additional work planned by the Centre about reducing enteric methane and soils nitrous oxide emissions will not be described here. For soil C, significant motivation comes from the realisation that organic matter underpins the provision (for example, water and nutrient supply) and regulation (for example, incubation and filtering) of the many valuable services from agricultural soils. In New Zealand, the most widespread land use is pastoral agriculture (11.1 M ha, 42% of total land area) with up to 85 M sheep and cattle fed by year round grazing. In contrast, agriculture in the forms of crop and horticulture production directly for human consumption involves ~0.5 M ha. It has been estimated that C storage in soils to a depth of 0.3 m beneath grazed pasture comprises 85 % of the national total for all land uses (Tate *et al.* 2005). These pastoral soils will be a major, initial focus of the proposed research.

Across New Zealand's South (aka main) and North islands, grazed pasture area was recently classified according to the land's dominant slope as < 15º called lowland and the rest hill country (Dr Andrew Manderson, pers. comm.). This distinction reflected the different animals and farming intensity, the latter commonly involving significantly greater stocking density and fertiliser application. The lowland area was 5.9 M ha, equally split between the two islands. Lowland dairy farms are the most intensive with ~1.5 M ha of grazed area countrywide during the 9-month-long milking season. Another ~0.7 M ha supports these farms by supplemental cattle feed production and spelling of grazed land during winter when the cows are not milked. Some cattle from dairy farms become involved in beef production. For beef cattle and sheep, there are intensive lowland fattening and finishing farms but mostly, these animals extensively graze the hill country (5.2 M ha with 56% located in the North Island). To illustrate C flowing through a pastoral agriculture system in New Zealand, indicative dairying estimates will be presented as an example. Gross photosynthesis sequestered 20 t C/ha/y from the atmosphere. Approximately half returned to the atmosphere by plant respiration, so the net C assimilation rate was 10 t C/ha/y. This was split equally between herbage utilisation (5 t C/ha/y ~ 12 t DM/ha/y where DM denotes dry matter or biomass) and plant litter and roots. For the consumed herbage, respiration was 2.7 t C/ha/y, faeces 1.5, milk and meat 0.5, methane 0.2 and urine 0.1 t C/ha/y. This suggested 1.6 t C/ha/y returned to the soil as dung and urine. Roots were reckoned to be 1 – 2 t C/ha/y, so plant litter was 3 – 4 t C/ha/y, the largest contribution to the soil.

Soil C has come from plants. In principle, farmers can increase the net C assimilation rate of pasture plants by, for example, applying fertiliser. Farmers can increase herbage utilisation by increasing the animal stocking density and vice versa. Following Parsons et al (2009), combination leads to a potential rate of C 'entering' soils, the difference between net C assimilation and herbage utilisation rates (Figure 1). Thus, increasing net C assimilation or decreasing net herbage utilisation should increase the potential C flow rate to the soil surface and vice versa. While valuable as an illustration of some involved principles, simultaneous changes in C assimilation and herbage utilisation complicate prediction.

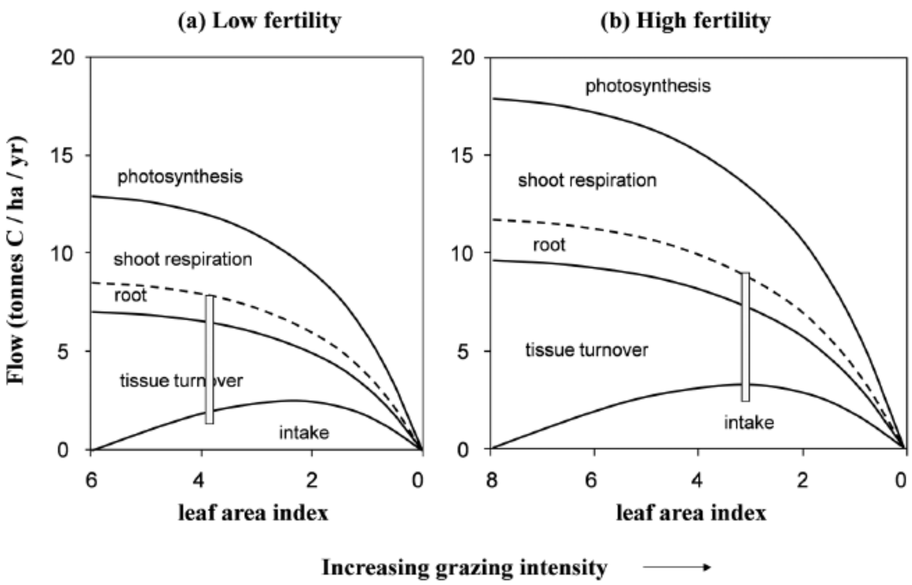

Figure 1. Relations between C flow rates through plants and animals (intake) in a grazed pasture system and grazing intensity, indicated by the pasture leaf area index, for soils of relatively low and high fertility. The vertical bars are examples, showing potential C flow rates to the soil surface (after Parsons *et al.* 2009).

The fate of C in soils has been classified using 'pools' on the basis of decomposition rate. Commonly, and risking impertinence by subsuming the complexity in a classification system, three pools have been associated with fast (annual), slow (decadal to centennial) and passive (millennial) rates. Such pools can be useful to determine the fate of C in soils (Stout and Goh 1980), including C from the primal vegetation (Tate *et al.* 1994). As an example, stable aggregates can form in soils containing particulate organic C, reckoned to be in the slow pool. Though undoubtedly challenging, if likely with reasonable accuracy and certainty, there could be considerable merit in connecting measurements and pools using models (Stewart *et al.* 2008).

In New Zealand, the quantity of C stored in soils beneath grazed pasture is already substantial. For example, soil was sampled repeatedly to a depth of 1 m on 23 dairy farms in the North Island by Schipper *et al.* (2007). Soil C storage averaged 232 ± 92 and 219 ± 109 t C/ha (± standard deviation) in the years 1983 and 2004, respectively (Dr Louis Schipper, pers. comm.). Thus, over 21 years, C storage changed by -14 ± 37 t C/ha, the negative sign indicating a net loss. With no change as a null hypothesis and a two-tailed test, the average change was significantly different ($p < 0.10$). The average change was considered a minimum detection limit estimate of 6 ± 16% ([14/232]*100 = 6%) over 21 years. It will be challenging to credibly verify the maintenance of soil C storage over time and relatively small changes that may be spatially variable.

Given context, we move on in the next section to briefly describe the Centre's proposal of a 5-year soil C research plan. Development began with a situation analysis. Scientists and stakeholders agreed there will be major challenges and a research strategy was needed.

Research strategy

The Centre's proposed work has been designed to understand the processes driving C storage rate in pastoral agriculture soils. In this C cycling system, processes include capture (net C assimilation) and supply, including amendment, as well as transfer in soils, incorporation and stability. The research will be evaluated regularly by policy stakeholders. The aspiration is an outcome, enabling farmers to conserve and, where likely, sustainably increase the rate and stability of C stored in soils. This provides another level of evaluation including, prior to recommendation, the establishment and verification of a practice's efficacy.

Envisaged first steps will be estimating a potential for sustainable C storage in soils, the current, relative position and the uncertainties. Questions can be helpful, so in short, 'how much?', 'how stable?' and 'can C storage rate be increased sustainably and verified?' (Table 1). Measurements will be undertaken in systems that can be manipulated, and measurements that can be connected to models will be most valuable, both fit for purpose. Measuring and verifying the likely slow, relatively small and variable changes in soil C storage will be difficult. Though challenging, measurements must be involved with models for acceptable accounting rules to credibly verify C storage rates as well as responses to manipulation.

Table 1. Themes, projects and key questions of a proposed research plan to enable the conservation and, where likely, sustainably increase of C storage rate in soils beneath grazed pasture.

Theme	Project	Question
Potential to increase C storage	C storage across New Zealand	How much C is stored currently and how stable is it?
	Geo-physical, geo-chemical, and climate limits	Are there upper limits for C storage?
Drivers of C storage rate	Forecasting C storage rate	Can process-based models elucidate the key drivers of C storage rate
	Determining C storage rate responses to manipulation	Can process-based models guide and verify the manipulation of C storage?
Measuring C storage rate	Verification methods	Can measurements be connected to models for acceptable accounting rules to verify C storage rate responses to manipulation?

Process-based model development and application will be major, on-going activities involving inter-disciplinary collaboration of numerate soil, plant, animal and climate scientists. Models will be essential for examining the drivers of C storage rate in soils. As stated, models and measurements will interact to identify and test hypotheses during field and controlled-environment trials. Models and measurements will also be used to develop and evaluate management practices to conserve C storage in soils and, where possible, sustainably increase the C storage rate (Table 2).

Table 2. Potential intervention practices to manipulate inputs and processes determining C storage in soils beneath pasture grazed by farmed animals with examples in brackets.

	Manipulation	Description
Inputs – C capture & supply	Land use	Land uses across a farm (feed production)
	Land practice	Fertiliser and water (precision application), functional plant traits (root: shoot ratio) and community composition (biodiversity), grazing management (herbage utilisation), pasture renewal (no tillage).
	Adding external carbon	C-rich amendments (bio char)
Processes – C transfer, incorporation & stability	Soil environment	Physical (stock density), chemical (lime) and biological (earthworms)
	Amendments	Substances (allophane) to affect the stable C pool

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In closing, the Centre has been created for the people actually managing C in soils on New Zealand's farms. The planned science will be challenging, but the outcomes can be worthwhile. The sustainability of profitable pastoral agriculture depends on natural capital including what can be a wealth of C stored in soils.

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