# Management Effects on Carbon Sequestration in Pasture and Cropping Systems in Northern NSW

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**Abstract:** There may be significant potential for carbon sequestration in agricultural soils through better management. However, the balance between improvements in carbon storage and greenhouse gas emissions must be carefully analysed to verify the net benefits. Soil carbon models can be used to simulate the behaviour of soil carbon in response to land management changes, but variability in soils and systems processes means that accurate analysis for accounting purposes is difficult. Analysis of alternative management scenarios involves estimation of the magnitude, direction and likely effects rather than accurate quantification of carbon stocks. This paper describes transfer of soil carbon response signals from simulations with the CENTURY model to a spatial framework for analysis of management effects on carbon storage in a northern NSW study region. The study region comprised the area east of Moree and north of the Hunter. The CENTURY model was parameterised for 32 climate sites and nine` major soil types. Agricultural land management options were simplified into a few classes; native and improved pasture, continuous wheat, conservation tillage, and long and short cereal rotations with lucerne. The model was run for a single land use and management type with starting carbon values based on field data for timber and scrub land. The simulations revealed considerable variation in carbon storage due to starting carbon levels, soil properties and crop and pasture management. The derived signals with uncertainty estimates will be incorporated into a spatial framework in ArcInfo GRID for modelling of carbon sequestration outcomes.

***Keywords:*** Carbon sequestration; CENTURY model; Signal transfer; Spatial framework; Agriculture

## 1. INTRODUCTION

There may be significant potential for carbon sequestration in agricultural soils through changes to agricultural management practices such as no-till cropping, pasture-crop rotations and better grazing management [Sampson and Scholes, 2000]. However, a range of factors need to be carefully analysed to verify the net benefits since management changes may affect the flux of other greenhouse gases such as methane and nitrous oxide. Variability in soils and systems processes make statistically reliable accounting difficult. There is a need to develop scenario analysis capability to enable approximate estimation of the consequences for carbon storage of various management approaches. There is also a need to understand the dimensions and dynamics of socio-economic factors which control adoption rates for desirable changes. Scenario analysis aims to capture the magnitude, direction and likelihood of effects and uncertainty associated with human-induced changes to soil biogeochemistry.

A signal transfer approach [Luxmoore et al., 2000] is a potentially useful tool for scenario analysis and assessment of uncertainty in predicting outcomes for complex systems. Monte Carlo-style simulations are used to generate indices or variables with statistical distributions that describe generic responses. Soil carbon models such as CENTURY [Parton *et al.*, 1988] may be used to generate soil carbon response signals for land management changes. The use of a model enables temporal response, so important in terms of specific commitment period outcomes, to be characterised on the basis of mechanistic processes. These signals can be scaled to landscapes and regions using spatial

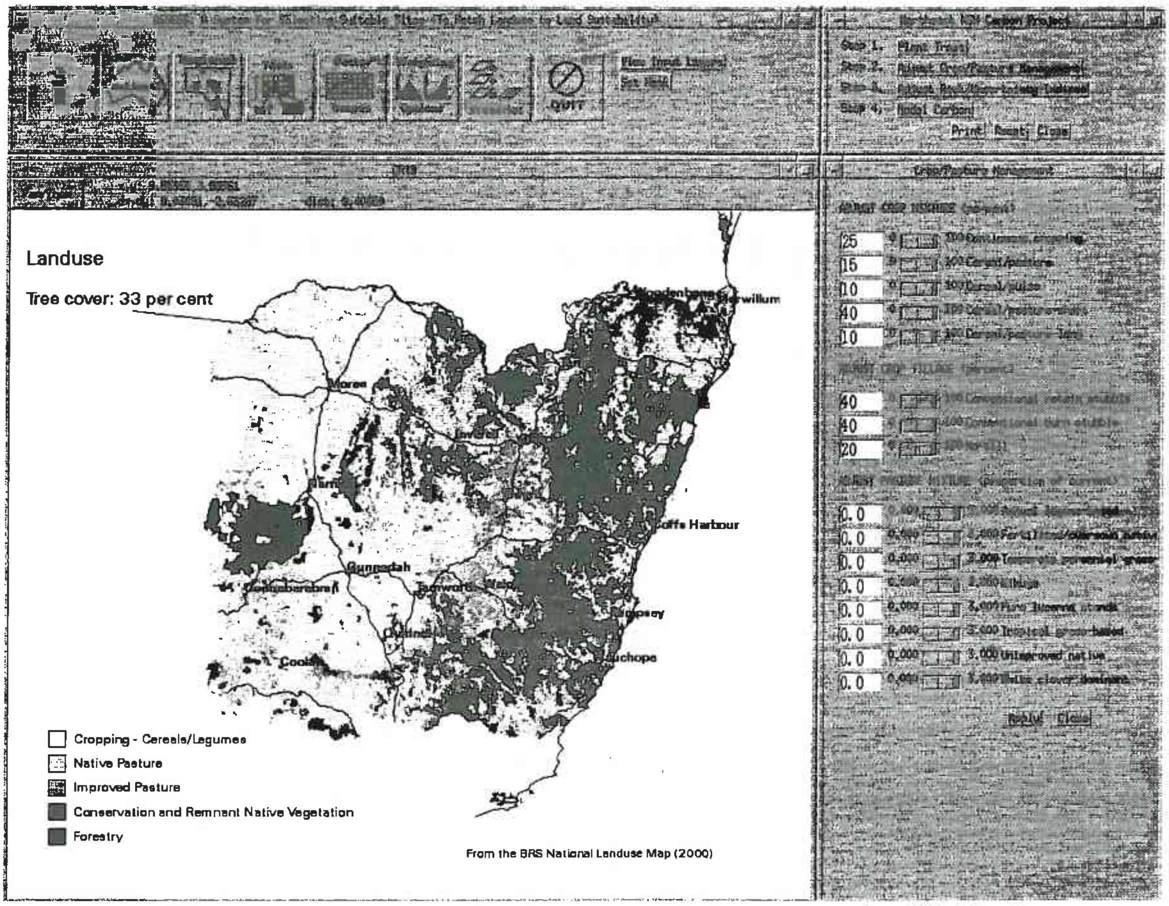


**Figure 1.** ASSESS interface for the agricultural scenario analysis showing a simplified land use map and menu for adjusting land management practices and systems.

data containing information on land use, soils and management practices provided assumptions and levels of spatial definition are explicitly defined. This paper describes the generation of generic carbon response signals using the CENTURY model for incorporation into a spatial framework for analysis of management practice effects on carbon storage in agricultural lands in northern NSW.

## 2. STUDY REGION

The northern NSW study region was (Figure 1) bounded by Moree in the west, the Queensland border in the north, and the lower edge of the Hunter region in the south. This area was chosen for its diversity of cropping systems and predominantly perennial pastures suitable for modelling with CENTURY. The boundary was defined by Statistical Local Area to facilitate use of agricultural statistics. The 1996/97 Land Use of Australia 1;1,000,000 map provides the spatial definition of crop and pasture land use and the Australian Soils Atlas describes the most common principal profile forms in the region.

## 3. STATE AND TRANSITION CONCEPT

State and transition models are used to describe changes in rangeland vegetation in response to natural and anthropogenic drivers [Westoby et al., 1989]. They provide a simple mechanism for capturing the potential changes in carbon stocks and the factors controlling these changes in agricultural lands. State conditions may be represented by expert knowledge, statistical properties of field measurements associated with land uses, or multiple simulations with suitable models in situations where measured data are scarce, and variability and uncertainty are high.

In natural systems, drivers for change in carbon states can be related to the interaction between climate and ecological processes such as grazing, fire, etc. In agriculture, drivers of changes in land use or management practices which control soil carbon states are principally economic and social. For example, in making a decision to change from continuous cultivation to no-till wheat cropping a land manager will consider such issues as yield and hence profit, the presence or accessibility of trash-

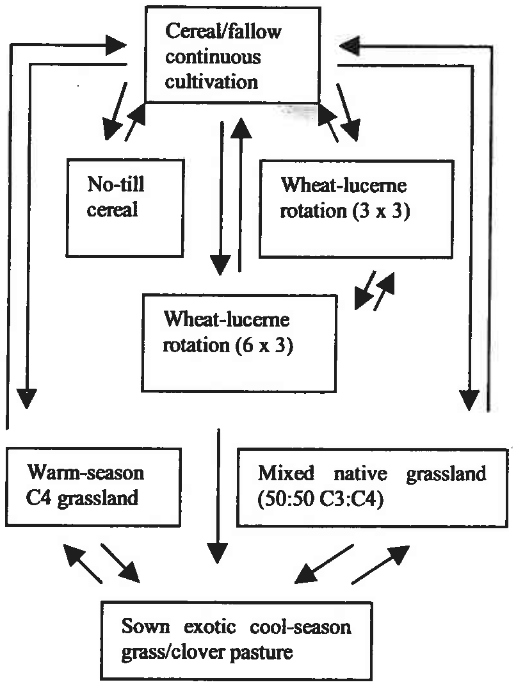


**Figure 2.** Highly simplified partial state and transition structure for cropping and pasture scenarios in northern NSW

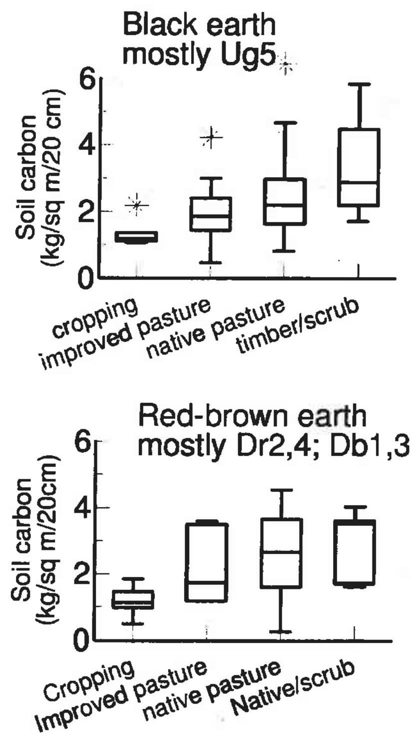


**Figure 3.** Fence plots showing median, upper and lower quartiles and 95% confidence values for soil carbon by land use for two major soil types in NSW (data courtesy of NSW Agriculture).

handling planting equipment, the potential negative impacts arising from high trash loads such as increased pest and disease occurrence, and their personal risk profile and openness to change. We have yet to incorporate drivers of changes into the system. In this study we simply sought to capture the rates of change and progressive values for some of the carbon states represented in a simplified form in Figure 2.

## 4. SIGNAL TRANSFER APPROACH

We used simulations with a factorial array of site and management variable inputs to represent the dataspace of potential outcomes. The signal transfer approach is implemented as an uncoupled system; modelled responses are summarised into appropriate temporal response sets and then incorporated as a lookup table or response equations within the spatial interface (Figure 1). The interface is based on ASSESS (A System for Selecting Suitable Sites) developed for rapid appraisal of natural resource management issues [Veitch and Bowyer, 1996].

## 5. CENTURY SETUP

CENTURY 5 is a well established, tested and bounded model that has been used to capture the general responses of soil carbon to changes in land management in a range of systems [Kelly *et al.*, 1997]. We made no attempt to capture the nitrogen dynamics other than to apply nominal rates of fertiliser nitrogen (30 kg/ha) to continuous crops. Model behaviour was monitored by examining the live carbon output variable and ensuring that annual accumulation of live carbon was reasonable (1 – 2 tonnes) and remained relatively stable except where a decline would be expected due to the effects of prolonged cultivation. The parameter space for the Century model was established by testing the model against observed data from three locations in and around the study region – continuous cultivation of wheat in SE Queensland [Dalal and Mayer, 1986]; a long term rotation trial with wheat, sorghum and lucerne at Tamworth [Kelly et al., 1997]; and a long term rotation trial with maize, oats and red clover at Glen Innes [Norton et al., 1999]. CENTURY simulated the published results for the Tamworth study, and satisfactory fits between the model and observed data were obtained for the other sites provided that a substantial component of the starting soil carbon was allocated to the fast and medium pools.

On the basis of these results, a factorial modelling regime was designed (Table 1). We based the modelling regime around a statistical description of site measurements of soil carbon (10 cm) (Figure

**Table 1.** Factorial modelling regimes for cropping and pasture.

| Factor | Variable |
|---|---|
| Climate | 32 weather sites with 100 years data |
| Soil | 9 most common great soil groups |
| Soil properties | Upper and lower quartile sand and clay content; and water content at wilting point and field capacity. |
| Initial soil carbon | Upper and lower quartile |
| Proportion of carbon in pools | Fast:medium:slow – 10:40:50 and 10:65:25 |

**Table 2.** Starting carbon levels and pool structures for three soils.

| Soil | Quar-tile | Pool struc-ture | C Pools g/m$^2$/20cm | | |
|---|---|---|---|---|---|
| | | | Fast | Med-ium | Slow |
| Black | Lower | 10:40:50 | 220 | 880 | 1100 |
| Earth | Lower | 10:65:25 | 220 | 1430 | 550 |
| | Upper | 10:40:50 | 448 | 1792 | 2240 |
| | Upper | 10:65:25 | 448 | 2912 | 1120 |
| | | | | | |
| Grey | Lower | 10:40:50 | 58 | 232 | 290 |
| Clay | Lower | 10:65:25 | 58 | 377 | 145 |
| | Upper | 10:40:50 | 279 | 1116 | 1395 |
| | Upper | 10:65:25 | 279 | 1814 | 697 |
| | | | | | |
| Red | Lower | 10:40:50 | 166 | 664 | 830 |
| Brown | Lower | 10:65:25 | 166 | 1079 | 415 |
| Earth | Upper | 10:40:50 | 383 | 1532 | 1915 |
| | Upper | 10:65:25 | 383 | 2490 | 958 |

3), and soil properties for a range of soil types in selected areas of NSW (Chapman, pers. comm.). The soil database includes land use at the site, and soil classification by great soil groups and principal profile forms. We sought to capture variation by using upper and lower quartile values for soil properties and carbon levels. This was designed to provide an envelope of responses within the main range of variation for each major soil group. The carbon levels and pool allocations for two soil groups, black earths with high clay content and red brown earths with high sand content, are shown in Table 2.

A simplified set of crop and pasture states (Figure 1) were used in CENTURY with existing parameter sets and settings (Table 3). The temperate grass/clover settings represent a northern hemisphere system unlikely to be found away from the high rainfall coastal highlands in our study area, however we include it here for reference.

**Table 3.** Crop and grassland state realisations with existing Century parameter sets and settings

| State | Century |
|---|---|
| Continuous wheat-fallow | Medium yield wheat; 3g N/m$^2$; 4 cultivations; 50% straw removal |
| No-till wheat-fallow | Medium yield wheat; 3g N/m$^2$; herbicide and no-till drill; 50% straw removal |
| Wheat-lucerne rotations | Medium yield wheat; 2 cultivations; no nitrogen; 50% straw removal; alfalfa parameter set; grazed 3 monthly |
| Grassland | C4 grassland<br>50/50 C3/C4 grassland<br>Temperate grass/clover<br>With continuous (monthly) hard or light grazing |

## 6. SIGNAL REALISATION

The variation in soil carbon levels exhibited by the factorial simulations was initially summarised using frequency histograms of percentage change in soil carbon after 30 years (Figure 4). The filled and clear histograms show responses from low and high starting C values respectively. The variation within each histogram represents the effects of soil properties and climate. In general, there were small differences in relative response between upper and lower quartile starting carbon levels for the continuous cropping – soil carbon levels declined to varying degree with a small increase when a no-till parameter setting was used.

Crop rotations resulted in maintenance of high initial soil carbon levels and substantial relative increases from low levels. The magnitude of these increases was greater from low starting values. The range in sand and clay content of red brown earths was much greater than for the black earths and grey clays. Hence, there was a greater spread in the frequency histograms for this soil between the lower upper quartile for sand and driest climate and the lower quartile for sand and the wettest climate. These patterns were also evident in the frequency histograms for the grassland simulations (Figure 4 lower). The hard grazing setting caused a small shift downwards in % change in soil carbon relative to the light grazing setting (Figure 4).

With the exception of C4 grassland, with a high starting carbon on either soil type, simulated soil carbon either remained the same or increased after

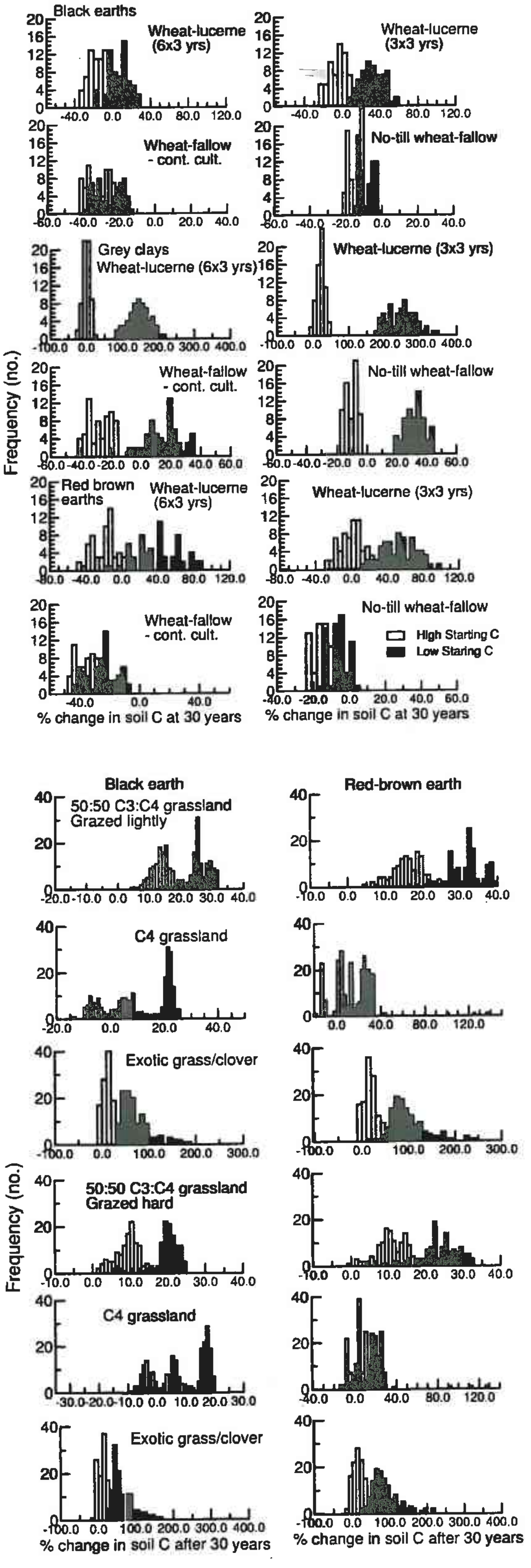


**Figure 4.** Frequency plots for four cropping regimes on three soil types at 15 climate sites (upper) and for three grassland types at two grazing intensities on two soil types at 32 climate sites (lower) Open bars indicate high starting carbon and shaded bars low starting carbon values.

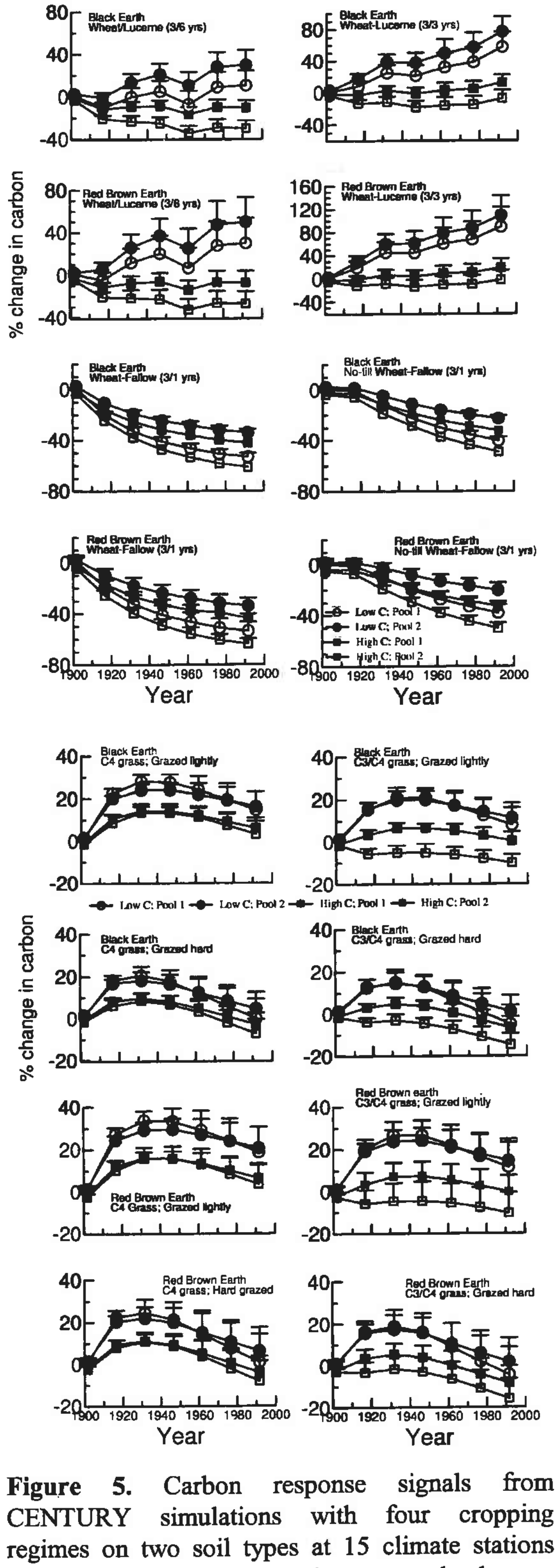


**Figure 5.** Carbon response signals from CENTURY simulations with four cropping regimes on two soil types at 15 climate stations (cropping regions only) and two grassland types systems under light and hard grazing for two soil types and 32 climate stations. Symbols indicate curves for high and low starting carbon values and high and low proportions of carbon in the fast and medium pools. The standard deviation bars show the variation due to soil properties and climate.

30 years. The spread in the frequency histograms for crop and grassland systems became wider after 100 years, with the effects of climate and soil texture magnified.

Relative temporal carbon response signals for crop and grassland systems are shown in Figure 5. The curves show the patterns produced with high and low starting carbon levels and high and low proportions of carbon in the fast and medium pools. The response curves show the divergence of responses with time between starting carbon levels and pool structures for the cropping regimes. They also show higher variability in response due to soil and climate for the crop rotations, especially for the lighter red brown earth soils. The simulations indicate modest responses to changes in tillage, but major benefits from perennial rotations, dependent on rotation length, and whether soils are starting with low or high carbon levels.

Simulated grassland responses are very different to those of the cropping systems. The systems show a tendency for long term decline after an initial increase, under light or heavy grazing. Allocation of carbon to pools appears to be less important for the black earth soil setup, but affects the response for the more variable red brown earth soil under high starting carbon levels. When a selected number of these simulations are run for 2000 years, soil carbon equilibrates at levels well below the high starting values. These responses may reflect the effects of nutrient deficiency occurring with no inputs over long model runs. However, over a range of soil carbon levels, the simulation results show no change or some increase in soil carbon from establishment of perennial grassland within the time frames involved in planned commitment periods. The response signals from grasslands systems appear more amenable to simplification and generalisation than those from cropping systems in these simulations.

## 7. CONCLUSIONS

Substantial sensitivity in soil carbon response to variation in starting carbon, pool allocation, soil properties and climate is demonstrated by these simulations. Further analysis of simulation outputs to examine responses to climate and soil properties is required. Good data and better understanding of how soil measurements can be translated into pool allocations are needed for more accurate and reliable simulation of soil carbon responses to crop and grazing management practices with CENTURY. Factorial simulations provide one approach to quantification of uncertainty in responses for different management systems. Signals of this form will be used as the basis for analysis of management scenarios in our northern NSW study area.

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