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Soil carbon and nitrogen changes after clearing mulga (*Acacia aneura*) vegetation in Queensland, Australia: Observations, simulations and scenario analysis

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Abstract

In the work reported here we examine the changes in soil (organic) carbon and nitrogen that are observed after converting a stand of nitrogen-fixing mulga trees (*Acacia aneura*) to buffel-grass (*Cenchrus ciliaris*) pasture that contained no nitrogen-fixing legumes. A range of previously reported field measurements was compared against the output of CenW 3.1, a reformulated version of the CENTURY model.

The model successfully reproduced the observed patterns of soil carbon, C:N ratios and nitrogen mineralisation rates under mulga vegetation. This included relatively small changes in carbon concentration down to 1 m, C:N ratios of around 11–13 across all soil depths, substantial nitrogen mineralisation rates to a depth of 90 cm and, after clearing, an on-going decrease in soil organic carbon and nitrogen stocks.

Interpretation of experimental observations was made difficult by the addition of a large amount of 'dead' organic matter from killed mulga roots after clearance. This material may be excluded through sieving (to 2 mm) in measurements taken shortly after tree removal, but may be included in later-year sampling as the partly decomposed material might be able to pass through sieves. Past work has usually ignored consideration of dead coarse roots. For the site carbon budget, changes in live biomass and surface litter significantly outweighed the small changes in soil organic carbon, and changes in decaying coarse roots were quantitatively more important than changes in other organic carbon pools.

Modelled nitrogen mineralisation rates were lower under buffel-grass than those under mulga and showed significant year-to-year variations that were in line with varying rainfall. It showed no consistent trend over the first 20 years after clearing because the effect of decreasing nitrogen stocks was balanced by an increase in organic matter quality with the change from lignin-rich mulga litter to buffel-grass litter with lower lignin concentration. Nitrogen mineralisation rates gradually decreased thereafter as nitrogen stocks continued to decrease but litter quality stabilised.

A scenario analysis showed that soil carbon and nitrogen trends could be affected by changing the nitrogen budget through inclusion of legumes or cessation of nutrient removal by grazing animals. Inclusion of legumes was needed to halt the decline in soil nitrogen and to ensure the long-term maintenance, or increase, in nitrogen stocks.

Keywords: CenW; Deforestation; Mulga; Land-use change; Model; Soil carbon; Soil nitrogen

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1. Introduction

With a contribution of 22% of total anthropogenic greenhouse gas emissions in 1990, land-use change was a major contributor to Australia's net emissions. Fortunately, rates of land clearing and associated greenhouse gas emissions have gradually decreased since 1990 (AGO, 2005). Nonetheless, land-use change continues to be an important contributor to Australia's total emissions, and effective management of net greenhouse gas emissions can only be accomplished if all significant sources and sinks are adequately considered. This includes consideration of changes in above and below-ground carbon stocks following land-use change.

Mulga (*Acacia aneura*) ecosystems occupy 150 million hectares of arid and semi-arid lands in Australia. Some of these lands are being converted to pasture, and the associated loss of above-ground biomass constitutes an important contribution to Australia's net greenhouse gas emissions. From 1991 to 2001, nearly 400,000 ha yr^{-1} were cleared in Queensland alone, with 95% of cleared area used for pasture development (DNRM, 2003). Changed land use can potentially also lead to a loss of below-ground carbon and nitrogen stocks.

Australia's National Carbon Accounting System (NCAS) has devoted considerable resources to monitor land-use change in Australia and quantify associated changes in biomass carbon (AGO, 2005). An understanding of changes in soil organic carbon in response to land-use change is potentially more difficult than the quantification of changes in above-ground carbon stocks. This is because changes in soil organic carbon are less readily observable than changes above ground, and scientific understanding in terms of the dependence of trends on specific underlying driving forces is still emerging.

A number of literature surveys have shown that the conversion of forests to cultivated land uses usually leads to significant soil organic carbon losses (Mann, 1986; Dalal and Mayer, 1986; Davidson and Ackerman, 1993; Murty et al., 2002; Guo and Gifford, 2002). In contrast, soil organic carbon usually changes little, or not at all, when the new land use is uncultivated grazing land (Lugo and Brown, 1993; Fearnside and Barbosa, 1998; Murty et al., 2002; Guo and Gifford, 2002).

In a more detailed study of soil carbon changes after tree-pasture conversions in Queensland, Australia, Harms et al. (2005) measured an average 8% loss of soil carbon for the top 30 cm. An interesting pattern in the work of Harms et al. (2005) was an apparent dependence of trends in soil carbon on the characteristics of the original woody vegetation. Soils under nitrogen-fixing mulga (*A. aneura*) and brigalow (*Acacia harpophylla*) stands lost more carbon upon conversion than soils under non-fixing 'box' (*Eucalyptus populnea*) eucalypt stands although another non-fixing system, 'box-ironbark' eucalypts (*Eucalyptus melanophloia*) lost a similar amount of carbon as the nitrogen-fixing systems.

As we are interested in understanding the general reasons for the patterns of soil carbon changes after land clearing, the differences between clearing the different vegetation types are intriguing. They lead to the interesting generic question of whether nitrogen-fixing systems are inherently vulnerable to losses of soil nitrogen and associated carbon if the vegetation is changed to one without nitrogen-fixers, such as the conversion from nitrogen-fixing trees to grass vegetation that contains few legumes.

After clearing mulga stands, and with no fertiliser application, the buffel-grass pasture depends almost entirely on the 'inherited' nitrogen capital in the soil derived from the previous nitrogen-fixing vegetation. This capital is only marginally supplemented by atmospheric inputs estimated at 5 kg nitrogen per hectare per year (kgN ha^{-1} yr^{-1}), but subject to volatilisation losses during nitrogen mineralisation, leaching and removal by grazing stock.

A number of studies have modelled changes in soil carbon after deforestation (e.g. Falloon et al., 2000; Cerri et al., 2004; Power et al., 2004; Skjemstad et al., 2004; Grace et al., 2006), but a full understanding of the relevant factors in explaining patterns of soil carbon changes after land-use change is yet to emerge. In particular, some models, such as the CENTURY model, include a fully coupled nitrogen cycle to constrain possible changes in soil carbon after deforestation (Cerri et al., 2004), whereas other models, such as Roth-C (Falloon et al., 2000; Skjemstad et al., 2004) and SOCRATES (Grace et al., 2006) have no nitrogen-cycling constraints. It remains an unresolved question whether nitrogen-cycling constraints could and should usefully constrain carbon dynamics in disturbed or undisturbed ecosystems (Rastetter et al., 1992; Kirschbaum et al., 2003).

In the present work, we studied changes in carbon and nitrogen stocks and dynamics following clearing of a (nitrogen-fixing) mulga stand in central Queensland to better understand the key drivers that may lead to changes in soil carbon and nitrogen and to the long-term supply of mineral nitrogen. In addition to its important role for carbon storage in the context of net greenhouse gas emissions, the long-term supply of mineralised nitrogen is a key aspect of the fertility of the system and, thus, a determinant of the long-term sustainability of pasture production after land-use change.

The objectives of the present study were to simulate the observed patterns of soil carbon and nitrogen dynamics under a mulga stand and then to simulate the patterns following clearing and maintaining the land under buffel-grass pasture. The model was also used to explore the expected response of soil carbon and nitrogen to modification of key aspects of the system's nitrogen economy, such as inclusion of legumes or cessation of produce removal.