Geoderma 214–215 (2014) 70–79

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

# Sensitivity of soil carbon to management and environmental factors within Australian perennial pasture systems

S.E. Orgill [a,b,*], J.R. Condon [b], M.K. Conyers [a], R.S.B. Greene [c], S.G. Morris [d], B.W. Murphy [e]

[a] NSW Department of Primary Industries, Wagga Wagga Agricultural Institute, NSW 2650, Australia
[b] Graham Centre for Agricultural Innovation, School of Agricultural & Wine Sciences, Charles Sturt University, Wagga Wagga, NSW 2650, Australia
[c] Australian National University, Acton, ACT 2601, Australia
[d] NSW Department of Primary Industries, 1243 Bruxner Highway, Wollongbar, NSW 2477, Australia
[e] 5 Amaroo Avenue, Cowra, NSW 2794, Australia

ARTICLE INFO

*Article history:*
Received 12 June 2013
Received in revised form 24 September 2013
Accepted 2 October 2013
Available online 21 October 2013

*Keywords:*
Carbon stock
Organic matter
Subsoil
Paired sites
Inter-annual climate variability
Vegetation type

ABSTRACT

Environmental factors such as parent material and climate can have a large effect on total carbon concentration and soil carbon stocks, yet unlike vegetation type, fertiliser use and grazing pressure, these cannot be changed by management. The relative effects of these environmental and land management factors were compared in the Monaro and Boorowa regions of New South Wales (NSW), Australia. Parent material, geographic region, soil depth and soil fertility had a significant influence on soil carbon stocks to 0.70 m while pasture type (introduced vs native pastures) did not. Parent material and soil depth significantly ($P < 0.05$) influenced the mean soil carbon stock (Mg C/ha) in the Monaro region; 159 (11 se) in basalt-derived soils, 77 (11 se) in deep granite-derived soils and 43 (3 se) in shallow granite-derived soils. Climate also significantly ($P < 0.05$) influenced the mean carbon stock, with deep granite-derived soils in the Monaro region having 76.5 (11 se) compared with 51.8 (3 se) Mg C/ha in the Boorowa region. A considerable proportion of the total carbon stock to 0.70 m for all sites was measured in the subsoil (0.30 to 0.70 m). In the Monaro region, basalt-derived soil contained 43% of the total carbon stock in the subsoil, compared with 28% in deep granite and shallow granite-derived soil. In the Boorowa region, deep granite-derived soil contained 33% of the total carbon stock in the subsoil. Restricting soil carbon measurements to the surface 0.30 m of soil may result in erroneous conclusions with respect to the influence of land management on the accumulation of carbon in soil. Total carbon concentration was positively correlated with labile carbon, total nitrogen, cation exchange capacity and extractable sulfur, suggesting that for a given parent material and climate, maintaining adequate pasture nutrition may substantially increase soil carbon stocks.


## 1. Introduction

Sequestration of carbon (C) in agricultural soils has been recognised as a potentially important tool to mitigate climate change (IPCC, 2007). Globally, perennial pastures are an important land use. Evaluating the sensitivity of soil C stocks under perennial pastures to environmental factors such as parent material (soil texture, soil type, soil depth and soil fertility) and climate (Blanco-Canqui and Lal, 2008; Lal, 2004; Sherrod et al., 2005; Sparling, 1992) will aid C inventory efforts as well as highlight management practices that may increase soil C sequestration. Sequestration of C in soil occurs when C inputs from biomass or C-rich organic soil amendments exceed C losses through the decomposition of organic matter (OM) by micro-organisms or removal by soil erosion. Parent material and climate factors such as rainfall, temperature and evaporation, influence the water and nutrient content of the soil, thereby determining the quantity of biomass grown (Blanco-Canqui and Lal, 2008; Lal, 2004; Sherrod et al., 2005) and the activity of soil microbes (Six et al., 2002; Sparling, 1992). For perennial pasture systems, land management factors such as the type of pasture, soil nutrient status and grazing management offer opportunities to influence soil C stocks (Lal, 2004) however, the extent to which these land management practices influence C in deep mineral soil horizons is unknown.

Pastoral systems in southern New South Wales (NSW), Australia are predominantly sheep and cattle grazing on native and introduced perennial grass pastures which have a leguminous annual component. Introduced perennial pastures were established in southern NSW throughout the 1950s and 60s following the release of Australian Phalaris (*Phalaris aquatica L.*) and Currie Cocksfoot (*Dactylis glomerata L.*) (Donald, 1970; Garden et al., 2000, 2001). It has been hypothesised that the greater herbage mass produced from the introduced species, compared with native species, may increase C accumulation in soils (Oades, 1995; Six et al., 2002; Stewart et al., 2007). In Australia, research on the influence of perennial pastures on C stocks in soil has primarily focused on introduced

* Corresponding author at: NSW Department of Primary Industries, Wagga Wagga Agricultural Institute. NSW, 2650 Australia.
*E-mail addresses:* Susan.Orgill@dpi.nsw.gov.au (S.E. Orgill), JCondon@csu.edu.au (J.R. Condon), Mark.Conyers@dpi.nsw.gov.au (M.K. Conyers), Richard.Greene@anu.edu.au (R.S.B. Greene), Stephen.Morris@dpi.nsw.gov.au (S.G. Morris), brian.murphy@environment.nsw.gov.au (B.W. Murphy).

0016-7061/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geoderma.2013.10.001

pastures and pasture improvement with phosphate fertilisers (Chan et al., 2010; Crocker and Holford, 1991). However, little is known of the significance of C accumulation deeper than 0.30 m in soil or the time period required for systems to reach a new higher steady state of soil C when a native perennial pasture is replaced by an introduced perennial pasture. Reports using international data, estimated that increases in annual C accumulation following pasture improvement would peak at 5 years and continue at a declining rate for up to 45 years (West and Six, 2007). Assuming this is correct, it is likely that the mass of C in soil under introduced pastures sown in the 1950–60s in southern Australia has now reached a steady state.

This paper compares average C stocks under native and introduced perennial pastures in agricultural systems where OM input is solely supplied by biomass grown on-site. The influence of soil depth, parent material, climate and soil fertility are quantified and the effects of environmental factors and management practices (type of pasture, soil nutrient status and grazing management) on soil C accumulation are discussed. Ultimately, we aimed to determine the potential of management to increase C accumulation under set soil and climate conditions.

## 2. Materials and methods

### 2.1. Study sites

Two study regions were selected in southern NSW, Australia (Fig. 1) to compare the influence of climate, namely rainfall distribution and low winter temperatures, on the concentration of C in soil and therefore soil C stocks. The Monaro region covers approximately 16,000 km$^2$ and includes the headwaters of the Snowy and Murrumbidgee Rivers. The Boorowa region covers approximately 2600 km$^2$ and is located on the south west slopes of NSW. Both regions are classified as Cfa (temperate, without dry season, warm summer) using the Köppen–Geiger climate classification (Peel et al., 2007) with an average annual rainfall of 500 mm in the Monaro region and 610 mm in the Boorowa region. However, the Monaro region is located 800 to 1000 m above sea level and receives most of its rainfall in summer (December to February), compared with the Boorowa region which is located 550 m above sea level and has a relatively uniform rainfall pattern (Fig. 2). In the Monaro region, average minimum temperatures are less than 5 °C for at least one month longer than the Boorowa region and on average 4 °C colder in winter (Bureau of Meteorology, 2012a, 2012b).

Soils were classified according to the World Reference Base for Soil Resources (WRB) (Working Group World Reference Base IUSS, 2007) and the Australian Soil Classification (ASC) (Isbell, 2002). In the Monaro region, 19 sites with granite-derived duplex soils (WRB: Lixisols and Acrisols; ASC: Chromosols and Kurosols) and 13 sites with basalt-derived gradational soils (WRB: Luvisols; ASC: Dermosols) were selected. Granite-derived soils in the Monaro region were divided into two categories: 13 sites were deep granite-derived soils where the C horizon was deeper than 0.50 m and 6 sites were shallow granite-derived soils where the C horizon was within 0.50 m of the soil surface. In the Boorowa region, deep granite-derived duplex soils (WRB: Lixisols and Acrisols; ASC: Chromosols and Kurosols) were sampled at 20 sites. In both regions, the granite-derived soils were predominantly Lixisols (Working Group World Reference Base IUSS, 2007; ASC: Chromosols) that were characterised by coarse sandy loams (10–20% clay) over light to medium clays (35–55% clay). These soils are naturally acidic, with low water holding capacity and low fertility in the A horizon, and a highly bleached and acidic A2 horizon. The granite-derived soils typically had a moderate to well-structured A1 horizon, a poorly structured and bleached A2 horizon and a poor to moderately structured B horizon. In contrast, the basalt-derived Luvisols (Working Group World Reference Base IUSS, 2007; ASC: Dermosols) sampled in the Monaro region were typically well-structured throughout the profile, with clay loams (30–35% clay) over light to medium clays (35–55% clay) resulting in characteristically high water holding capacity and relatively high fertility, particularly available phosphorus (P).

Paired study sites (100 m distance) were selected, comprising long term (>12 yrs) native and introduced pasture of known land use history. The paired sites had the same parent material, and similar soil and landscape attributes. At most sites, the native pastures were typically composed of wallaby grasses (*Rytidosperma* spp.[1]), speargrasses (*Austrostipa* spp.), weeping grass (*Microlaena stipoides*), and also snowgrass (*Poa sieberiana*) in the Monaro region. Introduced pastures were typically comprised of phalaris (*P. aquatica L.*) and cocksfoot (*D. glomerata L.*). Both native and introduced perennial pastures included exotic annual species such as subterranean clover (*Trifolium subterraneum*). Only native pastures were sampled on shallow granite-derived soil as we were unable to locate suitable pairs where introduced pastures had persisted.

In order to provide an indication of the soil C stocks pre-agriculture, four remnant sites (representing the native state of vegetation and soil type) that had not been under agricultural use or management for at least 30 years, were selected. In the Monaro region, two remnant sites were sampled; one each on basalt and deep granite-derived soil. The basalt-derived site was a cemetery established circa 1840 on native grassland. The deep granite-derived site was remnant woodland located adjacent to an old link road used in the late 1800 s which is now surrounded by pine plantation. In the Boorowa region, two remnant sites were selected; one was a road side reserve protected because of threatened flora and the other was on private land in a location that was fenced out in the late 1970s to protect biodiversity. Table 1 provides a summary of the parent material and vegetation of study sites within each region.

#### 2.1.1. Land management information

Management information, including nutrient management, soil conditioner and amendment (for example lime and gypsum) application, soil disturbance and grazing management, was provided by landholders for each site for the 15 years prior to sampling (i.e. since 1995). The native pasture sites had never been cultivated, and introduced pasture sites were established between 1955 and 1998, with a mean establishment age of 31 years and median establishment age of 29 years. Sites varied in soil nutrient management programs; from low input systems where mineral fertilisers were not used to systems that applied phosphorus (P) and sulfur (S) in mineral forms as part of a regular soil nutrient management program. On granite-derived soils, mineral phosphate fertilisers were commonly applied to pastures that have a legume component and on basalt-derived soils gypsum was applied to address inherent S deficiencies. However, most landholders reported below-average applications of mineral fertilisers for more than 10 of the 15 years covered by the management survey period due to below-average rainfall.

For all pasture sites, information on grazing management, including annual stocking rate (DSE/ha), livestock type, livestock class and duration of grazing was collected. In the Monaro region, sites were not selected to discriminate between grazing management (i.e. rotational vs continuous grazing). In the Boorowa region 10 sites (5 pairs) were selected, including native and introduced perennial pasture pairs that were continuously grazed (i.e. without rest, CG) and 8 sites (4 pairs) that were rotationally grazed (RG) in order to encourage pasture regeneration and growth. The duration of the average annual period without grazing varied between RG sites and years, and ranged from 4 to 50 weeks per year.

### 2.2. Soil sampling

Sites were sampled according to protocols developed by McKenzie et al. (2000) and later modified by Sanderman et al. (2011). Soil sampling was done on a 40 × 40 m sampling area, located in a representative

[1] Formerly *Austrodanthonia* spp.