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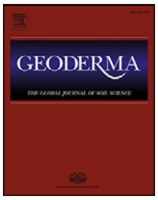

Modelling soil organic carbon 2. Changes under a range of cropping and grazing farming systems in eastern Australia

De Li Liu [a,b,*], Garry J. O'Leary [c], Yuchun Ma [a,b,d], Annette Cowie [e], Frank Yonghong Li [f], Malcolm McCaskill [g], Mark Conyers [a,b], Ram Dalal [h], Fiona Robertson [g], Warwick Dougherty [i]

[a] NSW Department of Primary Industries, Wagga Wagga Agricultural Institute, NSW 2650, Australia
[b] Graham Centre for Agricultural Innovation (An alliance between NSW Department of Primary Industries and Charles Sturt University), Wagga Wagga, NSW 2650, Australia
[c] Department of Economic Development, Jobs, Transport and Resources, PB 260, Horsham, Vic 3400, Australia
[d] College of Applied Meteorology, Nanjing University of Information Science & Technology, Nanjing, Jiangsu 210044, China
[e] NSW Department of Primary Industries, Trevenna Rd, Armidale, NSW 2351, Australia
[f] Ecology, College of Life Sciences, Inner Mongolia University, Hohhot 010021, China
[g] Department of Economic Development, Jobs, Transport and Resources, Mt Napier Rd, Hamilton, VIC 3300, Australia
[h] Department of Science, Information Technology and Innovation, Brisbane, Queensland, Australia
[i] NSW Department of Primary Industries, Elizabeth Macarthur Agricultural Institute, Woodbridge Rd, Menangle, NSW 2568, Australia

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ABSTRACT

The level of soil organic carbon (SOC) that is attained under agriculture largely depends upon rates of carbon input and its decomposition under various agronomic practises such as stubble (crop residue) management and fertiliser application. In this study, we used the APSIM-Wheat and APSIM-Agpasture models to simulate changes in SOC in a range of crop and pasture management systems across nine locations in eastern Australia. We explored the extent to which various crop and pasture management options affect changes in SOC from a sub-tropical to a temperate environment. Specifically, we examined how nitrogen fertilisation, stubble management and stocking rate affect SOC and what strategies might be employed by farmers to increase SOC sequestration across eastern Australia. We modelled a continuous cropping regime, a continuously grazed pasture and a mixed cropping and pasture rotation. Under continuous cropping higher nitrogen application and higher amounts of stubble incorporation increased the SOC levels at all locations. At Roma, the northern-most site, there was little additional gain in SOC from increasing N above 70 kg N ha^{-1} whereas most other sites showed benefits above 70 kg N ha^{-1}. The biggest factor in boosting SOC under cropping was the level of stubble incorporation. At all but one site, continuously grazed pasture generally resulted in SOC increases over the 60 years. However, increasing stocking rate decreased the rates of SOC changes at all sites. Crop-pasture rotations show that the impacts of even 4 years of pasture is likely to be significant in reducing declining SOC at low nitrogen application during cropping phases. N fertilisation and stubble incorporation reduced the impact of stocking rate by reducing the decline in SOC. The difference in SOC changes between nine sites across eastern Australia was largely described by mean temperature and rainfall but high temperature strongly interacted with management practises (stocking rate, N application and residue incorporation) to reduce the sequestration of C despite favourable rainfall. Our results indicate that a mean annual temperature higher than about 20 °C can switch a soil from net sink into a net source of atmospheric CO_2 if other factors affecting soil carbon changes such as stubble incorporation, stocking rate and site rainfall are constant.

1. Introduction

Soil organic matter (SOM) is the largest terrestrial pool of carbon (Lal and Kimble, 1997; Schmidt et al., 2011) and stores more than three times the amount of C in the atmosphere (Lal, 2004). Agricultural land occupies 38% of the earth's land surface and its soil organic carbon (SOC) stock is strongly influenced by human activities (Eswaran et al., 1993). SOC dynamics affect soil quality, agricultural productivity and atmospheric CO_2 concentration (Smith, 2008; Ciais et al., 2011). The potential C sequestration capacity of the soil is highly dependent upon

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[*] Corresponding author at: NSW Department of Primary Industries, Wagga Wagga Agricultural Institute, PMB, Wagga Wagga 2650, Australia.

E-mail addresses: de.li.liu@dpi.nsw.gov.au (D.L. Liu), garry.oleary@ecodev.vic.gov.au (G.J. O'Leary), myc426@163.com (Y. Ma), annette.cowie@dpi.nsw.gov.au (A. Cowie), lifyhong@126.com (F.Y. Li), malcolm.mcaskill@ecodev.vic.gov.au (M. McCaskill), mark.conyers@dpi.nsw.gov.au (M. Conyers), ram.dalal@qld.gov.au (R. Dalal), fiona.robertson@ecodev.vic.gov.au (F. Robertson), warwick.dougherty@dpi.nsw.gov.au (W. Dougherty).

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soil types (Meersmans et al., 2009), rates of primary productivity (Batjes, 1996; Luo et al., 2010) and SOM decomposition, which changes with environmental conditions, management practises and ecosystems (Lal, 2004; De Gryze et al., 2011).

The effects of environmental variables, agricultural management practises and ecosystems on SOC have been widely studied (Ogle et al., 2010; Sleutel et al., 2007; Eclesia et al., 2012; Zhao et al., 2013). However, the effects of the environmental factors on SOC dynamics and content remain inconclusive (Oechel et al., 2000; Dalias et al., 2001). Changes in temperature and rainfall alter crop biomass production, decomposition rates and thus ultimately the resultant changes in SOC content. In general, an increase in precipitation in water limited environments will increase SOC due to increased net productivity, hence more carbon input to the soil through below ground root turnover and deposition of above ground litter. However, an increase in temperature may be unfavourable for SOC sequestration due to higher decomposition rates of SOC (Davidson and Janssens, 2006). In dry and hot environments such as the Australian inland, high decomposition rates and low amounts of crop residues limit soil organic matter increase (Mele and Carter, 1993). Therefore, it is a challenge for farmers to maintain or increase SOC while obtaining agronomic profitability in such environments.

The dynamics of SOC are also influenced by agricultural management practises such as tillage, mulching, removal of crop residues (hereafter also referred as stubble) the retention of stubble and fertilisation (Duiker and Lal, 1999; Lal, 2004). Primary productivity, above and belowground biomass decomposition and vertical root distribution can affect the SOC content and C storage (Jackson et al., 2000). In commercial agriculture much of the above-ground crop dry matter is removed as grain and the straw is often either harvested, grazed or burnt. The limited input of crop biomass to the soil, combined with disturbance due to cultivation, has led to a decrease in SOC content in cropping systems worldwide during the last two centuries with net release of CO_2 to the atmosphere (Alvarez, 2005). Meersmans et al. (2011) reported that under cropland in Belgian, SOC concentrations decreased in all soil types, except clay soils. Heenan et al. (2004) showed that in 21 years of various rotation, tillage and stubble management systems, all treatments that involved burning or tillage treatments caused a decrease in SOC, whereas treatments involving stubble retention and no tillage increased SOC by 185 kg ha^{-1} y^{-1}. Nitrogen fertiliser application slowed, but did not prevent these declines in SOC, a trend also observed by Dalal et al. (2011) and Page et al. (2013) on a Vertisol under long-term tillage, residue management and fertiliser application trial over 40 years. Reeves (1997) reviewed many long-term studies that showed the benefit of manures, adequate fertilisation, and crop rotation on maintaining agronomic productivity that was accompanied by increasing carbon inputs into soil. A pasture phase in cereal rotations or a crop-pasture mixture may prevent or reduce SOC decline (Greenland et al., 1971). Pasture management strategies such as fertilisation which generally aim to increase above-ground biomass yield to sustain animal production can promote C storage in the soil (Franzluebbers and Stuedemann, 2002). Parton et al. (1987) simulated the impact of grazing on SOC and showed that SOC and soil N levels decrease with increased grazing rates. Land use change is another main factor that changes SOC content. Guo and Gifford (2002) showed that SOC decreased by 59% after land use change from pasture to crop, but only increased by 19% after land use change from crop to pasture. Zhao et al. (2013) simulated the SOC changes in wheat cropping system and found that residue removal, initial SOC content and temperature decreased SOC and only fertiliser application resulted in SOC increases over 122 years. These studies provided useful information for developing sound farming practises in order to maintain or increase SOC and agronomic sustainability.

In Part 1 of this study, we evaluated the performance of the agricultural production systems simulator (APSIM) across a diverse range of pasture and cropping systems in eastern Australia (O'Leary et al., 2016). Based on the pre-evaluated model, in this paper (Part 2) we explore how various crop and pasture management options affect SOC across a range of climatic environments. Therefore, the objectives of this study were to: 1) examine the effect of nitrogen fertilisation, stubble management and stocking rate on SOC in various agricultural systems; and 2) identify farming practises that increase SOC sequestration in different locations across eastern Australia.

2. Material and methods

2.1. Study area description

We selected a study area providing a significant climatic gradient in eastern Australia defined by 9 agriculturally important locations (Fig. 1). The study area included southwest Queensland (Roma and Dalby), northern New South Wales (Narrabri and Nyngan), central and southern New South Wales (Deniliquin and Wagga Wagga), northern Victoria (Rutherglen), and western Victoria (Horsham and Hamilton). The study area comprised cereal-cropping and pasture-grazing ecosystems. The majority of the cropping areas in Victoria and southern NSW have a Mediterranean climate and northern NSW and southwest Queensland have a subtropical climate. Long-term weather data from 1900 to 2010 were obtained from the SILO Patched Point Dataset (Jeffrey et al., 2001). Soil chemical and physical parameters were sourced from the APSoil database. A brief description with the general characteristics of the study area is provided in Table 1.

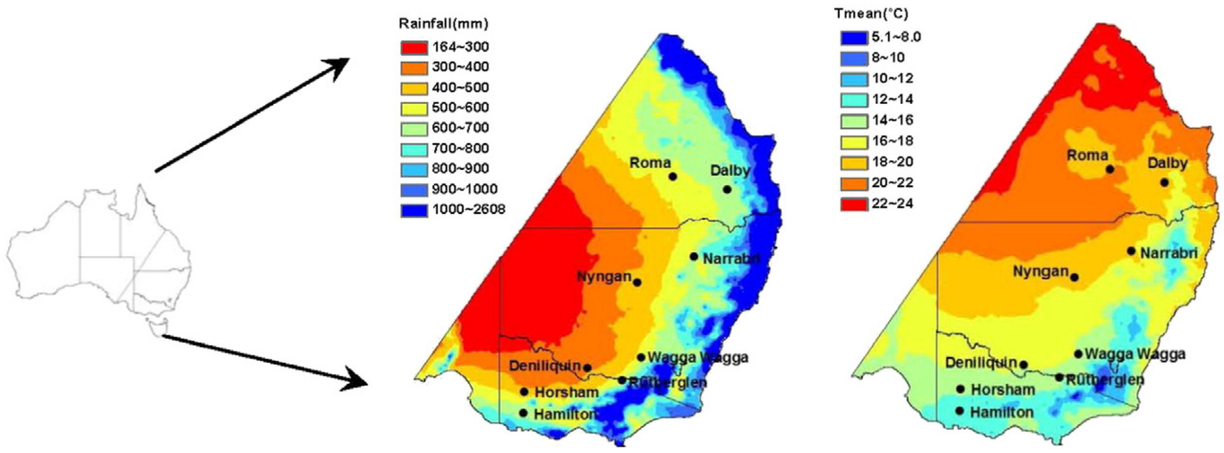

Fig. 1. The 9 sites selected for this study showing in the annual rainfall (mm) and mean temperature (°C) maps.