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Limited potential for soil carbon accumulation using current cropping practices in Victoria, Australia

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ABSTRACT

The extent to which soil C storage can be increased in Australian agricultural soils by adoption of improved management practices is poorly understood. There is a pressing need for such information in order to evaluate the potential for soil C sequestration to offset greenhouse gas emissions. In this study we used the RothC model to assess whether soil C accumulation under cropping using stubble retention and pasture rotations could be a significant offset for greenhouse gas emissions. We chose eight regions to represent the climatic range of the Victorian cropping industry: Walpeup, Birchip, Horsham, Bendigo, Rutherglen, Lismore, Bairnsdale and Hamilton (annual rainfall 330–700 mm). For each region, we chose two representative soil types, varying in clay and total organic C contents. For each region × soil combination, we compared the effects of five rotations: Canola–wheat–pulse–barley (C–W–P–B); Canola–wheat–triticale (C–W–T); Canola–wheat–barley–5 year perennial pasture (C–W–B–Pt5); Canola–wheat–fallow (C–W–F) and Continuous pasture (Pt). We compared the cropping rotations with cereal stubble burnt and with cereal stubble retained and, for two regions, with cereal stubble grazed by sheep. The results of the simulations showed that, across all scenarios, the equilibrium C density varied between 19 and 135 t C/ha to 300 mm depth, with potential soil C change being strongly influenced by crop yield, crop rotation, climate, initial soil C content, stubble management and continuity of management. The simulations suggested that soil C stocks could be increased under a crop-pasture rotation (C–W–B–Pt5) with stubble retention, with rates of increase of 0.3–0.9 t C/ha yr over 25 years. If all of Victoria's cropland were converted to C–W–B–Pt5 rotation with stubble retention, and if 50% of the modelled potential C change were achieved, this would represent 3.0–4.5 $MtCO_2$-e/year, equivalent to 2.5–3.7% of Victoria's greenhouse emissions. Less C accumulation would be possible under continuous cropping with stubble retention; even using the most conservative rotation (C–W–T) rates of C change varied from loss of 0.3 t C/ha yr to accumulation of 0.5 t C/ha yr over 25 years. If all of Victoria's cropland were converted to C–W–T rotation with stubble retention, and if 50% of the modelled potential C change were achieved, this would be equivalent to 0.8–2.3 $MtCO_2$-e/year, or 0.7–1.9% of Victoria's greenhouse emissions. It would generally take 10–25 years for the soil C changes to become measurable using conventional soil sampling and analytical methods. Thus we conclude that, with current technology, the potential for significant and verifiable soil C accumulation in Victoria's croplands is limited.

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1. Introduction

It is recognised that, on a global scale, soil organic matter contains more than twice as much carbon (C) as the atmosphere (Post et al., 1982; Batjes, 1996). This global soil organic C stock is considered to have been significantly diminished through human-induced changes to natural ecosystems (Lal, 2001), leading to the hypothesis that increasing the storage of C in soil through enhanced fixation of atmospheric carbon dioxide (C sequestration) will contribute to reducing atmospheric carbon dioxide concentrations and help to mitigate climate change (Swift, 2001; IPCC, 2007). The principal means suggested for enhancing soil C storage in agricultural soils is adoption of practices such as minimum tillage, retention of harvest residues and inclusion of pastures in crop rotations (Swift, 2001; Lal, 2004).

Around 16% of Australia's greenhouse gas emissions are attributed to agriculture (Department of Climate Change and Energy Efficiency, 2011) and participation of the agricultural sector in C trading is currently being considered by the Australian Government. Consequently, there is a great deal of interest in the possibility of enhancing soil C stocks in order to reduce greenhouse

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gas emissions from agriculture, offset greenhouse emissions from other sources, generate income from C trading and maintain or improve soil quality and productivity.

Large declines in soil organic C due to conversion of native forest and grassland to cultivated agriculture have been documented in Australia (Russell and Williams, 1982; Dalal and Mayer, 1986; Chan et al., 1995). These declines are related to reduced plant C inputs and the duration and intensity of agricultural management, in particular the number of times the soil has been cultivated (Russell, 1960; Russell and Williams, 1982; Dalal and Mayer, 1986). Long-term sown pastures, on the other hand, have sometimes increased soil organic C levels above those under the original native vegetation (Williams and Donald, 1957; Russell, 1960). It follows, therefore, that it may be possible to increase the organic C content of cultivated soils by reducing the intensity or frequency of cultivation and increasing C inputs through residue retention or pasture rotations (Russell and Williams, 1982; Dalal et al., 1995). However, understanding of the extent to which soil C stocks can be increased is generally poor in Australian cropping soils and particularly so in the state of Victoria, for which little data are available on the long-term effects of agricultural management on soil C.

Dryland cropping occupies around 2.5 million ha of land in Victoria (ABARE, 2007). The cropping regions include a diversity of climates from semi-arid to temperate, with rainfall ranging from 250 to 1200 mm/year. Wheat and barley are the most important crops, representing 78% of the cropped area and 86% of total grain production (ABARE, 2007). Pulses and oilseeds make up much of the remainder. Grain yields generally average <2.5 t/ha for cereals and <1.5 t/ha for pulses and oilseeds, but vary greatly between years and between regions in response to rainfall patterns (Connell and Cooper, 2000; ABARE, 2007).

Land preparation and sowing practices in Australian cropping regions, including in Victoria, have changed considerably in the last 30 years. Concerns about soil loss and escalating costs (Connell and Cooper, 2000) and expectations of improved soil moisture retention (Llewellyn and D'Emden, 2009) have helped to motivate a move away from conventional practices such as multiple-pass cultivation, fallowing, and burning crop residues after harvest. Census data from 2001 to 2002 suggest that, of the total area cropped to grains in Victoria, 24% received no cultivation (apart from sowing), 46% received 1–2 cultivations, and 30% received >2 cultivations (ABS, 2003). The census data also suggest that 57% of crop residue was retained (either mulched or cultivated into the soil) and 43% removed, either by burning after harvest (hot burn), burning in the autumn (cool burn), grazing or, in a minority of cases, baling. There is, however, likely to be considerable variation within and among regions (Karunaratne et al., 2001; Karunaratne and Barr, 2001a,b,c). More recent data for some regions (Llewellyn and D'Emden, 2009) suggests that adoption of minimum tillage and stubble retention has increased. Sown grass or legume pasture phases are included in some crop rotations in some regions.

The objective of this study was to test the hypothesis that soil C accumulation under cropping in Victoria using stubble retention and pasture rotations could be a significant offset for greenhouse gas emissions.

2. Methods

In order to estimate potential medium- to long-term changes in total soil organic C under various climate, soil type and management scenarios we used the Rothamsted carbon model (Jenkinson et al., 1994; Coleman and Jenkinson, 1996), RothC version 26.3 in Microsoft Excel® format. The model has been calibrated in Australian conditions and tested at a number of long-term experimental sites in Australia, with generally very good performance (Skjemstad and Spouncer, 2003; Skjemstad et al., 2004).

Eight regions were chosen to represent the climatic range of the Victorian cropping industry: Walpeup, Birchip, Horsham, Bendigo, Rutherglen, Lismore, Bairnsdale and Hamilton (see Fig. 1 and Table 1). For each region, two representative soil types were chosen, varying in clay and total organic C contents (Table 1). For each region × soil combination, the effects of five rotations were compared: (1) Canola–wheat–pulse–barley (C–W–P–B); (2) Canola–wheat–triticale (C–W–T); (3) Canola–wheat–barley–5 year perennial pasture (C–W–B–Pt5); (4) Canola–wheat–fallow (C–W–F) and (5) Continuous pasture (Pt).

The cropping rotations were compared with cereal stubble burnt and cereal stubble retained (with canola and pulse assumed to have stubble retained as per usual grower practice). Pulse crops were either lentil or chickpea. For Hamilton and Horsham, an additional comparison in the analysis was grazing of all stubbles (including cereals, canola and pulses) by sheep. For all sites, it was assumed that the soils had been under medium- to long-term cropping at the start of the simulation period. For Hamilton only, an additional comparison was included for soil that had been

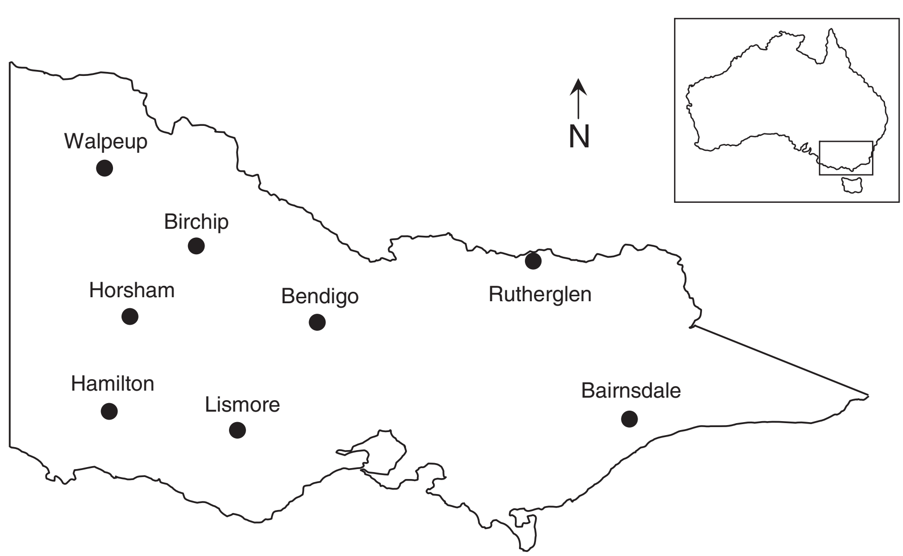

Fig. 1. Map of Victoria, Australia, showing locations used in this study.

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