G Model
FIELD-6278; No. of Pages 6
ARTICLE IN PRESS
Field Crops Research xxx (2014) xxx–xxx
Contents lists available at ScienceDirect
Field Crops Research
journal homepage: www.elsevier.com/locate/fcr

A review of organic carbon accumulation in soils within the agricultural context of southern New South Wales, Australia

Mark Conyers[a,b,*], De Li Liu[a,b], John Kirkegaard[a,c], Susan Orgill[a,b], Albert Oates[a,b], Guangdi Li[a,b], Graeme Poile[a,b], Clive Kirkby[a,c]

[a] Graham Centre for Agricultural Innovation (an alliance between NSW Department of Primary Industries and Charles Sturt University), Wagga Wagga 2650, NSW, Australia
[b] NSW DPI, Wagga Wagga Agricultural Institute, PMB Pine Gully Road, Wagga Wagga 2650, NSW, Australia
[c] CSIRO Agriculture, Clunies Ross Street, Acton 2601, ACT, Australia

ARTICLE INFO

Article history:
Received 25 March 2014
Received in revised form 21 July 2014
Accepted 22 July 2014
Available online xxx

Keywords:
Crop residue
Organic nitrogen
Pasture
Tillage

ABSTRACT

The accumulation of carbon (C) in soil as organic matter (SOM) is considered to be a win–win situation for agriculture and the environment. Retention of crop and pasture residues should contribute to this accumulation of organic C in soil. However the retention of crop stubble has not necessarily resulted in increases in soil organic matter in long term field trials in southern New South Wales (NSW), Australia. Even under permanent pasture, annual or perennial, the rates of accumulation of soil organic matter are only about 500 kg C/ha/year at best in the environment of southern NSW. Hence the C accumulation rates in soil are not likely to generate a significant income stream from C trading. Further, in the mixed farming systems of the inland areas, the traditional rotation has relied upon the build up of organic matter during the pasture phase and the mineralisation of nitrogen (N) (and hence C) during the cropping phase. A change from this system requires increased reliance on the use of N fertiliser. Either way, an additional problem is that the accumulation of organic matter during a pasture phase, or the use of N fertiliser, is commonly associated with soil acidification, requiring the application of limestone and the release of CO_2 in order to maintain agricultural productivity. In addition to these soil based processes, the climatic variability that is commonly experienced in the semi-arid environment of southern NSW means that year to year variability in dry matter return to soil and in decomposition rates of residues will be relatively large. The net result is that the signal to noise ratio of any trend in SOM accumulation is low.

1. Introduction

Accumulation of carbon in soil as organic matter is considered desirable from an environmental perspective (Paustian, 2002) as it mitigates increased atmospheric CO_2. It is also desirable from an agricultural viewpoint (Baldock and Skjemstad, 1999), as soils with more organic matter are generally more physically stable and chemically fertile than similar soil with less organic matter. The retention of crop and pasture residues would be expected to contribute to an increase in the concentration of organic C in soils as organic matter. In southern NSW there were several long term experiments (15–34 years) in which soil organic C measurements had been made. These trials included crop and pasture sequences either continuously or in rotations, and various forms of tillage and crop residue management. This has provided an opportunity to assess the agricultural context in which organic C changes have occurred in the soils of southern NSW.

Historic data on organic C in soils did not differentiate between particulates (fine detritus), humus and charcoal (Baldock et al., 2013) because appropriate methods were not readily available. Thus the data reviewed here refer to total organic C in non-calcareous soils (i.e. no carbonate C). The annualised net rates of organic C accumulation in southern NSW have previously been reported as being very slow and often negative (Chan et al., 2011). However there were sequences of seasons where gains and losses of soil organic C were very different to the average long term trend. An over riding factor for agriculture in this region is the variable rainfall in a largely water limited growing environment. In a climate

* Corresponding author at: Wagga Wagga Agricultural Institute, Graham Centre for Agricultural Innovation (an alliance between NSW Department of Primary Industries and Charles Sturt University), PMB Pine Gully Road, Wagga Wagga, NSW 2650, Australia.. Tel.: +61 2 69381830; fax: +61 269381809.
E-mail addresses: mark.conyers@dpi.nsw.gov.au, mconyers@bigpond.ne.au (M. Conyers), de.li.liu@dpi.nsw.gov.au (D.L. Liu), john.kirkegaard@csiro.au (J. Kirkegaard), susan.orgill@dpi.nsw.gov.au (S. Orgill), albert.oates@dpi.nsw.gov.au (A. Oates), guangdi.li@dpi.nsw.gov.au (G. Li), graeme.poile@dpi.nsw.gov.au (G. Poile), clive.kirkby@csiro.au (C. Kirkby).

http://dx.doi.org/10.1016/j.fcr.2014.07.013
0378-4290/

of hot dry summers and cool wet winters, and of low and variable rainfall, the opportunity for plant production can be limited yet the potential for decomposition of crop and pasture residues after summer and autumn rain is extensive. Therefore the potential to accumulate soil organic C from plant residues in soils of southern NSW is apparently low compared with more temperate climates or with alpine environments (Spain et al., 1983).

While an increase in the concentration of organic C in soil is generally regarded as beneficial, the notion that accumulated C should be maintained indefinitely must be challenged within the wider agricultural context. Of what value to agricultural production is a higher concentration of soil organic matter that is produced on site? Is there evidence of a direct relationship between soil organic matter (or C) concentration or C stock and grain yield, or with wool, meat and milk production? Rather, the benefits of soil organic matter (and C) in soil to agricultural productivity are diffuse. Amongst these diffuse benefits, such as stable soil structure and increased water holding capacity, is the notion that increased soil organic matter improves soil chemical fertility. However within the agricultural context, nutrients such as nitrogen (N), phosphorus (P) and sulphur (S) are of little value to primary production whilst remaining in soil organic matter but need to be mineralised to plant-available forms; this requires relatively labile organic matter sources and active micro-organisms in the soil. This mineralisation necessarily results in a decrease in organic C concentration in soil, unavoidably reducing the environmental benefit of “C sequestration”. Further, as these nutrients cycle in the soil, and are removed in agricultural products or leached from the soil, there are changes to the acid-base balance within the soil (Helyar and Porter, 1989). Where soils are poorly buffered the resulting acidity generally limits agricultural production and requires limestone application to maintain productivity. The reaction of limestone with acidic soils releases carbon dioxide both from the limestone itself and from the soil.

Clearly, in the wider context of mixed farming systems of southern NSW, there is a need to carefully consider the impacts of crop and pasture sequence, tillage and residue management and soil acidity management and how these interact with soil organic matter. In this review we consider the available data on the effect of management, especially of crop residue, on the rate of organic C accumulation in soils of southern NSW and the agricultural context within which this accumulation occurs. We seek clarity about the scope and scale of likely accumulation of C in soil as organic matter. The data and its context do not necessarily indicate a win–win for the environment and agriculture.

2. Pools of C in soil

The forms of C in soil, and their relationship with organic matter, are well explained by Nelson and Sommers (1996). In more recent times the organic matter within soils has been divided into the categories “particulate” organic C (POC), humus and charcoal (resistant) (Baldock et al., 2013). Particulates are regarded as detritus that has not yet been microbially decomposed. The humus fraction is a more stable pool though not resistant to decomposition. The charcoal pool that is left after fires is regarded as mostly resistant to microbial decomposition.

The concentration of organic C in soil is often associated with clay content. As such some workers suggest that there is a limit to the quantity of C that can accumulate in soils, that is, there is a C saturation capacity for a given soil and climate (Six et al., 2002). Hence the impact of management and environmental factors on the concentration of C in soil might vary with the antecedent concentration of soil C.

The historic long term data with which we are working only provides a measure of total organic C in soil, with no indication of the various pools.

2.1. The effect of tillage and crop residue management on the rate of C accumulation in soil

The long term experiments in southern NSW on which the current review is based are summarised in Table 1. Chan et al. (2011) summarised three long term experiments in the Wagga Wagga district showing that rates of change in soil organic C under crop (540 mm a.a.r) were slow, of the order of ±250 kg C/ha × 30 cm/year. Under pasture (540 to 650 mm a.a.r) the C accumulation rate was +200 to 550 kg C/ha × 30 cm/year. In cropping systems the retention of crop residue did not cause an increase in soil organic C concentration at any trial site. Even where no-till (with narrow tyne ‘knife points’) was practised, the retention of crop residue still resulted in a calculated loss rate of −52 kg C/ha × 30 cm/year in a wheat–lupin rotation, though this was not statistically different to a zero rate of change in soil C. Hence the conclusion was that crop residue retention and no-till maintained soil organic C, rather than increased it. On the same trial, where three passes of a tillage implement was used, the loss of soil organic C was at a similar rate whether crop residue was burnt or retained. The only treatment where soil organic C increased during the trial was where a clover pasture phase was included in the rotation. At a nearby site Helyar et al. (1997) showed that as the proportion of pasture in the rotation increased from 1/3 to 2/3, soil organic C accumulation increased from 216 to 403 kg C/ha × 30 cm/year. Therefore pastures might hold the key to increasing soil organic C concentration, although the longevity of this increase will be discussed later in this review.

The long term experiment on 100% pasture (MASTER, Table 1) at higher rainfall (650 mm a.a.r) showed C accumulation rates of ∼500 kg C/ha × 30 cm/year for both annual and perennial pastures. Field surveys on farmers’ properties (Chan et al., 2010) showed that the main driver of C accumulation in soil was the regular application of superphosphate; it did not matter whether the pastures were annual or perennial, native or introduced, set stocked or rotationally grazed.

At a drier site near Condobolin (430 mm), northwest of Wagga Wagga, Fettell and Gill (1995) measured the concentration of organic C in soil under long term cropping. Although there was no time trend data (nor initial data), fifteen continuous years of either

Table 1
Long term experiments in the region with published soil organic C data.

Trial label	Location	Average annual rainfall (mm)	Trial duration at time of reporting (years)	Current state of trial
Tillage trial	Condobolin, central NSW	430	15 (1979–1994)	Ongoing
SATWAGL	Wagga Wagga, Southern NSW	540	25 (1979–2004)	Completed 2005
WWPCRE (KohnRot)	Wagga Wagga, Southern NSW	540	18 (1963–1981)	Completed 1981
MASTER	Wagga Wagga, Southern NSW	650	18 (1992–2010)	[a]Terminated 2010
SR1	Rutherglen, NE Victoria	590	28 (1981–2009)	[b]Abandoned 2009
RGL6	Rutherglen, NE Victoria	590	34 (1975–2009)	[b]Abandoned 2009

[a] The new property owner requested that the trial be dismantled.
[b] The trials were left unmanaged due to public sector budget cuts.

Please cite this article in press as: Conyers, M., et al., A review of organic carbon accumulation in soils within the agricultural context of southern New South Wales, Australia. Field Crops Res. (2014), http://dx.doi.org/10.1016/j.fcr.2014.07.013