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Organic matter in the agricultural soils of Tasmania, Australia – A review

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ABSTRACT

A review of both the living and non-living components of soil organic matter (SOM) in the agricultural soils of Tasmania, Australia, and the relationship of SOM to the functions of soil has been undertaken. The relationships between soil organic carbon (SOC) and other inherent and dynamic soil properties of Tasmanian soils, SOC stocks, the components and the controlling factors are reviewed. The dynamic nature of SOM is reviewed as targets, rates of change and trends on different soil orders and under different management as well as the correlation to soil physical, chemical and biological properties. Information on macro fauna, *meso* fauna, fungi and bacteria is considered to acknowledge that SOM is a dynamic, changing resource that reflects the balance between the living components that add new organic matter and the loss of organic matter from the dead component.

1. Introduction

Soil organic matter (SOM) consists of living organisms, slightly altered plant and animal residues, and well decomposed organic residues (Magdoff, 1992). SOM is a reservoir of plant nutrients in soils, and is important in maintaining soil tilth, aiding infiltration of air and water, promoting water retention, reducing erosion and controlling the efficacy and fate of applied pesticides (Sikora and Stott, 1996). Its dark pigmentation also assists in the absorption of heat, thus acting as a heat reservoir. An understanding of organisms in soil and soil biology is highly relevant to maintaining or increasing yields and reducing losses from soil borne diseases in Australian cereal and pasture production (Martin, 1993). SOM is a dynamic, changing resource that reflects the balance between addition of new organic matter and loss of organic matter already in the soil that is in part controlled by the living biological activity. The potential effects of SOM on the productive capacity of soils are of practical and economic importance to famers and others who have an interest in land management. Soil organic carbon (SOC) as a measure of SOM, is widely considered an important measure of soil quality because of the role SOM plays in soil physical, chemical and biological processes (Doran and Parkin, 1994; Gregorich et al., 1994; Baldock and Skjemstad, 1999). Changes in SOM status have been associated with an improvement or deterioration in the behaviour of agricultural soils (Loveland et al., 2001).

When soils are sampled and the organic matter analysed, both the living and non-living components are incorporated. There is a body of research on the methods of analysis and the characteristics, stabilisation and turnover times of the non-living SOM (Baldock and Nelson, 2000; Lützow et al., 2006) and a seemingly separate body of research on the living soil biology that includes both the macro-fauna and microbiology (Paul, 2014; De Deyn et al., 2003). The objective of this review of both the living and non-living components of SOM is to describe what are the amounts and distribution of SOM in Tasmanian soils, the inherent factors controlling SOM, and also to quantify how dynamic it is and what influences these differences. This review acknowledges that SOM is a dynamic, changing resource that reflects the balance between the living components that add new organic matter and the loss of organic matter from the dead component. This review is probably only feasible because of the limited geographic extent of the study area, Tasmania, an island state of Australia that is located 240 km south of the Australian mainland (42°S 147°E) and covers 68,400 km^2. It has a cool temperate climate and contains a diverse range of soils due to variations in climate, landscape and geology with all of the 13 Australian soil orders represented (Cotching et al., 2009; Isbell, 2002). Tasmania is an example of a cool temperate climate in which agriculture operates on a range of soil types.

2. Methods

This review considers published manuscripts, contract reports and university theses on what is known about SOM in Tasmanian soils and places the knowledge in a broader Australian context. The relationships between SOC and other inherent and dynamic soil properties, targets and trends for Tasmanian soils, what role amendments play and also living soil biology components are canvassed. Soil biology is potentially the most dynamic component of SOM that includes earthworms and

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other soil macro-fauna, meso-fauna such as mites, arthropods and nematodes, and micro-fauna including fungi and bacteria. The ecosystem function of the different organisms is not reported here, but rather their dynamic nature and diversity. Suggestions are made about management practices, knowledge gaps and potential future areas of research.

3. Results

3.1. Carbon stocks and distribution

Tasmanian soils have C stocks of 49–117 MgC ha^{-1} in the upper 0.3 m as reported by Cotching (2012). Ferrosols had the largest soil C stocks (117 MgC ha^{-1}) and are a significant soil order (8.4% of land area) occurring throughout Tasmania (Cotching et al., 2009). Carbon stock to 1 m depth of 117 MgC ha^{-1} was measured in an apple orchard in southern Tasmania (Gentile et al., 2016a). Cotching et al. (2013) reported that Ferrosols had 139 MgC ha^{-1} with 150 Mg ha^{-1} under pasture and 125 Mg ha^{-1} under cropping but stocks as great as 285 MgC ha^{-1} have been reported from Red Ferrosols under perennial pasture (Cotching, 2009). The amounts of organic matter in Ferrosols increases with distance from the coast as both rainfall and elevation increase (Loveday and Farquhar, 1958). High organic matter content in Ferrosols mapped as "snuffy" soils that are hard to wet and erodible, has been found to be associated with very old pastures that have had no recent history of cropping or pasture renovation (Eldridge, 2000). The high SOC stocks are likely to be in part due to the dominance of poorly crystalline iron (Fe) and aluminium (Al) oxides and hydroxides in Ferrosols, as these minerals have a larger surface area for SOC sorption than do crystalline minerals such as goethite and hematite Fe oxides, or silicate clays.

Dermosols, which are the dominant soil order in Tasmania (24%), with predominantly clay loam surface textures and rainfall > 1000 mm/year, also had high soil C stocks. Cotching et al. (2009) reported 103 MgC ha^{-1} with 102 MgC ha^{-1} under pasture and 83 MgC ha^{-1} under cropping at 0–0.3 m depth (Cotching et al., 2013). Organosols did not have the largest soil C stocks in Tasmania, due to the low bulk density (BD) in organic rich materials of 0.17–0.25 Mg m^{-3} in the surface 0.3 m. Also, many of the Organosols in Tasmania are shallow, ranging from 0.2–0.4 m in thickness, and overlie a range of substrates from massive quartzite to gravels. Chromosols, Kurosols, Sodosols, and Tenosols had lower soil C stocks of 69–78 MgC ha^{-1} due to their sandy surface textures. Doyle (2013) reported texture contrast soils to have 65 MgC ha^{-1} under pasture and 58 MgC ha^{-1} at 0–0.3 m depth under cropping. Hydrosols and Podosols, both of which have wet hydrologic regimes in Tasmania, had relatively large soil C stocks (116 and 98 MgC ha^{-1}, respectively), as these soils have high C inputs under high rainfall and long periods of saturation, which result in accumulation rather than oxidation of organic matter. Vertosols were reported as having 107 MgC ha^{-1} under pasture and 96 MgC ha^{-1} under cropping (Doyle, 2013). The range in carbon stocks at 0–0.3 m depth in Tasmanian soils (49–285 MgC ha-1) is greater than the 2–239 MgC ha^{-1} reported in Victorian soils (Robertson et al., 2016). Organic carbon stocks in Tasmanian soils at both 0–0.3 and 0–1.0 m depths are significantly greater than those in other eastern Australian states (Table 1). The increase in soil C stocks from Queensland to Tasmania is likely to be the result of decreasing mean annual temperature and increasing annual precipitation from north to south, which results in greater production and less oxidation of organic matter and so greater accumulation under cooler temperatures (Baldock and Skjemstad, 1999).

Measuring carbon as a stock in MgC ha^{-1} can mask the true carbon story as land use affects soil bulk density. The carbon stocks as measured in the 0–0.3 m depth can be significantly influenced by compaction causing increased bulk density of the soil (Ellert and Bettany, 1995). Also, any simple or quick field assessment of soil carbon will be hampered by the need to take adequate BD measurements needed to calculate stocks. Carbon stock figures are quite different to the TOC figures due to differences in bulk density between land uses being different for different soil orders. Ferrosols were found to have little change in stock between pasture and cropping compared to the change in TOC (33% compared with 35%). This indicates that the Ferrosols do not increase in bulk density with cropping to the same degree as Vertosols which had a greater difference between TOC and stock percentage changes with land use (36% for TOC compared with 20% for carbon stock) (Doyle, 2013).

The range in C stock values within soil orders indicates that there would be considerable uncertainty if an assumed baseline value for any particular soil order were to be used for soil carbon accounting. Thus, it is critical to determine initial soil C stocks at individual sites and farms for C accounting and trading purposes, because the initial soil C content will determine whether there is potential for current or changed management practices to result in soil C sequestration or emission. The calculated carbon storage in the upper 0.3 m of soils for individual farms was found to vary depending on the data used and the scale of investigation. Broad scale assessment using the on-line Australian soil resource information system (ASRIS) information ranged from being 16–83% less than that determined from farm scale information (Table 2; Cotching, 2009). The differences are similar or much greater than those found by Frogbrook et al. (2009) who found differences of 8% and 45% for areas in Scotland and Wales respectively when comparing field survey data with information from the national UK database. The differences in the Tasmanian study are likely to be due to a

Table 1
Profile soil carbon stocks in Australian soil orders by State (Cotching, 2012).

Soil order	State	Soil C[a] 0–0.3 m		Soil C 0–1.0 m	
		Mg ha^{-1}	se	Mg ha^{-1}	se
Chromosol	Queensland	49.4	0.9	147.2	8.3
	NSW	46.4	4.3	97.3	12.7
	Victoria	36.9	nd	88.8	nd
	Tasmania	75.6	10.9	105.0	13.2
Dermosol	Queensland	42.9	nd	77.1	nd
	NSW	110.8	9.1	175.6	14.3
	Tasmania	124.0	21.8	228.2	31.8
Ferrosol	Queensland	34.0	1.1	60.0	0.7
	NSW	133.9	8.1	228.3	17.2
	Tasmania	122.7	16.3	212.2	29.2
Hydrosol	NSW	72.3	14.8	112.3	8.2
	Tasmania	129.6	27.9	235.4	45.2
Kandosol	NSW	86.9	4.6	132.0	6.1
Kurosol	NSW	50.4	19.6	85.2	22.5
	Tasmania	71.0	8.9	136.7	11.3
Podosol	Tasmania	82.2	18.8	163.4	24.8
Sodosol	Queensland	43.3	3.4	81.1	5.2
	NSW	50.5	4.5	76.7	6.9
	Victoria	26.8	1.9	49.1	4.7
	Tasmania	77.2	7.2	129.0	10.6
Tenosol	NSW	69.5	7.1	98.6	13.1
Vertosol	Queensland	40.3	1.0	97.2	4.0
	NSW	37.3	1.3	74.5	3.7
	Tasmania	171.2	nd	327.5	nd

[a] LECO carbon (Rayment and Higginson, 1992).

Table 2
Soil carbon stocks mapped at different scales in Tasmania (Cotching, 2009).

	Farm area (ha)	No. ASRIS[a] map units	ASRIS soil carbon (MgC)	No. farm scale map units	Farm scale soil carbon (MgC)
Farm A	460	1	39,117	8	46,446
Farm B	753	2	13,777	14	82,446
Farm C	305	2	38,997	17	58,212

[a] Australian Soil Resource Information System available at: http://www.asris.csiro.au/.