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Research paper

Impact of agricultural management practices on the nutrient supply potential of soil organic matter under long-term farming systems

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ABSTRACT

Soil organic matter (SOM) has the potential to supply substantial quantities of nutrients [*i.e* nitrogen (N), phosphorus (P) and sulphur (S)] for plant uptake. Yet there is little understanding of the impact of management on the nutrient supply potential in soils (particularly, P and S). To quantify N, P and S availability from SOM, surface soils (0–10 cm) were collected from 14 management practices across three long-term (16–46 years) experimental sites under semi-arid (Luvisol), Mediterranean (Luvisol) and sub-tropical (Vertisol) environments in Australia. The practices comprised conventional (CT) and reduced tillage (RT) with mixed farming, no-till with continuous cropping (NT), and perennial pasture (PP) in the semi-arid Luvisol, while in a Mediterranean direct-drilled continuous cropping system, stubble was either retained (SR) or burnt (SB). Practices on the Vertisol comprised a factorial combination of CT, NT, SR, SB with either 0 (0N) or 90 kg urea-N ha^{-1} (90N) in a continuous cropping system. Soils were incubated under controlled soil moisture and temperature, and cumulative organic C mineralised (C_{min}), and net available N, P and S were measured over 126 days. In the semi-arid Luvisol, CT and/or RT showed significantly higher C_{min} and net available N, P and S than NT and PP. In the Mediterranean Luvisol, C_{min} and net available P were not influenced by stubble management. In the Vertisol, CT-SR (*cf.* CT-SB and NT-SR/SB) with or without N fertilisation significantly increased C_{min}, and CT-SR and/or -SB with N fertilisation (*cf.* CT-SR/SB without N fertilisation and NT-SR and/or -SB with or without N fertilisation) significantly increased net available N and P. This study found a continuous release of net available N (11–49 kg N ha^{-1} over 126 days) across all management practices, whereas, the release of available P and S was evident only during the first 30 days (6–74 kg P ha^{-1}, −4 to 22 kg S ha^{-1}), after which microbial immobilisation or clay fixation of P and S predominated, particularly in the Vertisol. In conclusion, the results indicate that SOM is a ready source of plant available P and S (in addition to N), and tillage and stubble retention generally enhanced SOM mineralisation and nutrient release, which varied with soil type.

1. Introduction

Soil organic matter (SOM) is a key indicator of soil quality and plays an important role in enhancing a range of soil physical, chemical and biological functions (Murphy, 2015). SOM is both a source and sink of organic forms of carbon (C) and major plant nutrients, such as nitrogen (N), phosphorus (P), and sulphur (S) (Kirkby et al., 2011; Murphy, 2015). Over the last decade, there has been increasing interest on the impact of agricultural management practices on SOC and nutrient cycling and storage worldwide, including in Australia (Bhupinderpal-Singh et al., 2004, 2006; Dalal et al., 2011; Hoyle and Murphy, 2011; Hoyle et al., 2013; Kopittke et al., 2016a,b). However, knowledge of how management practices influence availability of nutrients for plant growth, a key function of SOM, across diverse managed agro-ecosystems is limited (Hoyle and Murphy, 2011; Murphy 2015).

The nutrient contents of soil may be maintained or enhanced by

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certain management practices, possibly facilitated by high organic matter inputs or retention into the system. For example, long-term no-till (NT) with stubble retention (SR) along with fertilisation in cropping systems, and mixed crop–pasture and perennial pasture (PP) dominated farming systems are usually recommended as improved management systems which may increase or maintain SOM and associated nutrients (Bhupinderpal-Singh et al., 2004; Dalal et al., 2011; Hoyle et al., 2013; Kopittke et al., 2016b). These and other contrasting practices such as conventional tillage (CT), reduced tillage (RT) and stubble burning (SB) may impact soil microbial biomass and activity differently (Haynes 1999; Hoyle and Murphy, 2011; Rui et al., 2016) and the physical-chemical environment (Luo et al., 2010; Page et al., 2013), and consequently the release plant available nutrients from SOM reserves (Guppy et al., 2005; Hoyle and Murphy, 2011; Curtin et al., 2016; Rui et al., 2016).

Studies have shown that CT breaks down soil structure (Six et al., 2000), increases soil aeration (Carter et al., 1994), and exposes mineral protected SOM to microbial attack (Gathala et al., 2011; Zhang et al., 2013). As a result, there is the potential to release high quantities of plant available nutrients through SOM mineralisation (Hoyle and Murphy, 2011; Dimassi et al., 2014). On the other hand, in a 100-day incubation study, Curtin et al. (2014) found that the cumulative SOC mineralisation per unit mass of SOC in an undisturbed perennial pasture system was almost double that of arable cropping systems, likely due to relatively high plant C input and relatively labile SOC in perennial pasture systems (Crawford et al., 2000). However, other studies reported that improved land management (*e.g.* PP or NT) may preserve soil structure (Six et al., 2000; Devine et al., 2014), while protecting SOC in micro-/macro-aggregates (Six et al., 2000), reducing soil pore spaces (Jensen et al., 1996), and consequently decreasing soil microbial biomass and activity (Raiesi, 2006; Tan et al., 2015). Thus, it is important to understand the impact of alternative agricultural management practices on the nutrient supply potential of SOM, and this knowledge can thus be useful to optimise productivity and profitability of farming systems.

The rate of turnover for SOM *via* mineralisation and the associated nutrient supply with different management practices also varies depending on soil texture and clay minerology. Soils with a high proportion of clay-sized particles provide greater stabilisation of SOM than soils dominated by sand-sized particles (Christensen, 2001). Furthermore, clay-rich soils dominated by 2:1 clay minerals (such as smectite *versus* kaolinite) provide larger specific surface areas and numerous reactive sites where SOM and nutrients can be adsorbed *via* ligand exchange and polyvalent cation bridging to lower SOM mineralisation (von Lützow et al., 2007; Saidy et al., 2013; Lehmann and Kleber, 2015). Also, the self-mulching nature of smectitic-rich soils, for example, Vertisols, may override the effect of tillage on SOC mineralisation (Dalal et al., 2011).

In Australia, few long-term farming system trials exist and although a number of studies have examined the influence of management practices on SOC accumulation and mineralisation rates, and soil microbial activity (Hoyle and Murphy, 2006; Thomas et al., 2007; Dalal et al., 2011), far fewer have considered the subsequent nutrient value of SOM for plants (Raiesi, 2006). The aims of this study were therefore to quantify the impact of long-term management practices on the dynamics of SOC mineralisation and net supply of plant available N, P and S in different soils (Luvisol *versus* Vertisol) under contrasting tillage, cropping and/or pasture systems. Consistent with common paradigms, we expected higher SOC mineralisation and net release of plant available nutrients in systems with high *versus* no tillage intensity, and/or where stubble was retained *versus* burnt or where N fertiliser was applied, regardless of soil type. Further, soils such as Vertisol, which is rich in smectite and possibly also polyvalent cations, could significantly impact the release of plant available nutrients, particularly P and S, once organic matter depletes during decomposition, compared with relatively clay-poor Luvisol.

Table 1
Basic information of the long-term sites, including soil properties (0–10 cm depth). Values in brackets are standard errors (n = 3).

	Condobolin	Merredin	Hermitage
Soil classification	Luvisol	Luvisol	Vertisol
Coordinates	33°05′19″S, 147°08′58″E	31°28′S, 118°16′E	28°12′S, 152°06′E
Trial established	1998	1987	1968
Mean annual rainfall (mm)	~461[a]	~325[a]	~682[b]
Rainfall distribution	No clear seasonality	Winter-dominant	Summer-dominant
Mean annual min (°C)	~10[a]	~11[a]	~10[b]
Mean annual max (°C)	~25[a]	~25[a]	~24[b]
WHC (g g^{-1})	0.30(0.4)	0.26(0.3)	0.56(0.3)
Sand/%	62(2.0)	66(0.8)	15(2.6)
Silt/%	11(1.3)	8(1.2)	22(2.5)
Clay/%	27(0.8)	25(0.7)	63(1.2)
Bulk density (g cm^{-3})	1.3 – 1.5	1.3	1.1
Na^+ (cmol kg^{-1})	0.13(0.01)	0.62(0.1)	1.3(0.2)
K^+ (cmol kg^{-1})	2.1(0.1)	0.97(0.04)	1.1(0.1)
Ca^{2+} (cmol kg^{-1})	6.2(0.1)	3.5(0.4)	28(0.4)
Mg^{2+} (cmol kg^{-1})	1.9(0.05)	3.3(0.4)	25(0.7)
Fe_d (mg kg^{-1})	18150(450)	4280(90)	12650(150)
Al_d (mg kg^{-1})	1060(20)	568(22)	2040(20)
Clay minerals	Mi–Kaol–Sm***, Qtz**,Hem**, Goe**, Ant*	Kaol***, Mi **, Qtz*, Ant*, Ort*	Sm***, Kaol**

Mi = mica; Kaol = kaolinite; Sm = smectite; Qtz = quartz; Goe = goethite; Hem = hematite; Ant = anatase; Ort = Orthoclase. The asterisks ***, **, * represent > 60% (dominant or co-dominant), 5–20% and < 5%, respectively.

[a] 1987–2016.

[b] 1996–2016.

2. Materials and methods

2.1. Site descriptions

Long term field trial sites were selected for this study as SOC concentrations take many years to reach a new equilibrium when land use or management practices are changed (Lam et al., 2013). The sites include: (i) a 16-year-old (established in 1998) farming system trial at the Condobolin Agricultural Research and Advisory Station, New South Wales; (ii) a 27-year-old (established in 1987) crop stubble management trial at the Merredin Research Station, Western Australia; and (iii) a 46-year-old (established in 1968) tillage-stubble-N fertiliser management trial at the Hermitage Research Station, Queensland. The site information and basic soil properties (0–10 cm depth) are given in Table 1. For analysing most of the basic soil properties, such as soil texture, clay mineralogy, water holding capacity (WHC), and basic cations (Table 1), soil samples were composited across the practices because of their limited impact on these properties.

At the Condobolin site, the following four treatments were selected: (1) CT and (2) RT under mixed pasture–wheat farming systems; (3) NT under continuous cropping system; and (4) PP. The experimental plots across the four major farming systems were established in 1998 in a randomised block design, with five rotational phases and four replicates (Central West Farming System Inc., 2015). The rotations in the CT treatment were: long fallow-wheat (LFW; *Triticum aestivum* L.), short fallow-wheat (SFW) with under-sown pasture, and three years of grazed pasture. The rotations in the RT treatment were: LFW, no crop, LFW with under-sown pasture, and two years of grazed pasture. The rotations in the NT treatment were: wheat, barley, pulse, wheat, pulse/green manure. Stubbles were incorporated in the CT treatment, while in the RT and NT treatments stubbles were retained on the soil surface. Tillage was performed to 10 cm depth using a chisel tyne with two to three passes in the CT, and to 2 cm using a trash-worker with one pass in the RT (Fang et al., 2016). The rotational phases in the cropping systems at the time of soil sampling were: (a) after wheat (*Triticum aestivum* L.) phase that was transitioning to pasture in the CT and RT