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Soil organic matter and texture affect responses to dry/wet cycles: Changes in soil organic matter fractions and relationships with C and N mineralisation

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ABSTRACT

The extent to which SOM content and texture affect C and N dynamics during dry/wet cycles is poorly understood. A laboratory incubation study was conducted to quantify short-term changes in SOM (C & N) fractions and their relationship to C and N mineralisation in response to dry/wet cycles along a SOM gradient in two soil types of differing texture. The experiment consisted of three phases: pre-incubation, treatment and recovery. Three soil water content (SWC) treatments were established: continuously wet (WW; field capacity (FC)), moderately dry (MD; 120% of SWC at wilting point (WP)) and very dry (VD; 80% of SWC at WP). Each of the two 'dry' treatments were either maintained continuously dry (MD & VD) or subjected to three sequential 20 d-long dry/wet cycles (MDW & VDW) during the experiments treatment phase. All soils were returned to FC at the start of the recovery phase and analyses were carried out at the end of each phase. Over all, the results of this study showed that SOC content and texture are important factors affecting the size of several commonly measured fractions of soil organic matter, but the stability and resilience of these fractions depended on the duration and amplitude of dry/wet cycles. Whereas most of the measured C and N fractions (cold water extractable C [CWEC] and hot water extractable C [HWEC], microbial biomass C [MBC] and N [MBN], inorganic N) were affected by both the duration (e.g. MDW vs. MD) and amplitude (e.g. MDW vs. VDW) of dry/wet cycles, the response differed between fractions and the effects tended to be much stronger in silt loam than in clay loam soils. The duration and amplitude of dry/wet cycles also suppressed the rate of both C and N mineralisation in both soils compared to continuously wet conditions. There was also strong evidence that the C mineralised from both soils during the recovery phase (i.e. following rewetting of dry soils) compensated for the reduction in C mineralised during the treatment phase. For N mineralisation, the amplitude of dry/wet cycles was at least as important as the duration of the cycles in affecting N mineralisation during the recovery phase. Much higher rates of N mineralisation were observed in soils that had previously been exposed to very dry conditions, particularly in the silt loam soil. There was some evidence that HWEC was the primary source of the C made available during the rewetting of dry soil and that it contributed to the increased availability of CWEC and supported an increase in MBC and C mineralisation in both soils during the recovery phase. In contrast, there was no evidence that differences in availability of C and N fractions affected the rate of N mineralisation following the return of dry soils to continuously wet conditions. Further research is need to resolve the primary factors that regulate N mineralisation response to the recovery from dry soil conditions.

1. Introduction

Soil organic matter (SOM) and texture are important factors affecting the rate of carbon (C) and nitrogen (N) mineralisation in soils under conditions of constant temperature and water content (Hassink, 1992; Franzluebbers et al., 1996; Craine and Gelderman,

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2011). These effects appear to be associated with differences in the storage and supply of mineralisable substrates (e.g. Hassink, 1992; Hassink et al., 1993; Wang et al., 2003). However, the extent to which SOM content and texture affect C and N dynamics under conditions of variable soil water content, such as occur during dry/wet cycles, is poorly understood (Thomsen et al., 1999; Franzluebbers, 1999b). Differences in the C and N content of fine- and coarse-textured soils may be due to differences in SOM input, rather than decomposition dynamics, since fine-textured soils tend to be more fertile than coarse-textured soils (Oades, 1988). However, texture also influences the water release characteristics of soils owing to differences in their water holding capacity and the size distribution and connectivity of pores (Thomsen et al., 1999). These differences may, in turn, affect the range of soil water conditions under which microorganisms remain active and their access to suitable metabolic substrates, hence observed effects of texture on C and N dynamics may be a function of soil water relations, rather than a direct effect of texture on the formation of mineral-organic matter complexes (Thomsen et al., 1999).

Where dry/wet cycles of soil occur naturally due to fluctuating water contents, they are likely to be important in the storage and release of SOM and plant available nutrients (Wu and Brookes, 2005). It is well known that wetting dry soil can cause a flush of C and N mineralisation (Birch, 1958; Soulides and Allison, 1961; Orchard and Cook, 1983; Kieft et al., 1987) with elevated rates of mineralisation persisting for up to 2 weeks following wetting (Franzluebbers et al., 2000; Fierer and Schimel, 2002; Beare et al., 2009). This response to rewetting can vary with soil properties (e.g. texture, quality and quantity of SOM) and environmental conditions (temperature, frequency and intensity of dry/wet cycles) (Cabrera, 1993; Franzluebbers et al., 2000; Fierer and Schimel, 2002; Mikha et al., 2005; Cable et al., 2008; Beare et al., 2009; Butterly et al., 2010; Harrison-Kirk et al., 2013).

The flush of mineralisation that follows the rewetting of a dry soil has been attributed to the mineralisation of non-biomass SOM made available to soil microbes due to physical processes associated with rewetting (aggregate disruption, SOM redistribution, desorption) (Sorensen, 1974; Utomo and Dexter, 1982; Appel, 1998; Denef et al., 2001; Xiang et al., 2008). It has also been attributed to the release of microbial C due to cell lysis or the release of intracellular osmoregulatory solutes caused by the osmotic shock microbes experience when the soil water potential increases rapidly during rewetting (Harris, 1981; Kieft et al., 1987; Fierer and Schimel, 2003). It is likely that both mechanisms are involved, though their relative importance may vary. Several studies have suggested that microbial substrates contribute less to the mineralisation that follows rewetting of dry soils than do non-microbial substrates. Wu and Brookes (2005) estimated that 60% of the CO_2 evolved from a grassland soil subjected to five-day long dry/wet cycles came from non-biomass C. Van Gestel et al. (1993) found that the reduction in microbial biomass due to drying and rewetting was greater in soil with high vs. low microbial metabolic activity. They attributed the enhanced mineralisation after drying and rewetting mainly to increased bioavailability of non-living (rather than microbial) organic substrates.

Rates of N mineralisation have also been shown to increase and are typically highest in the first few days following the wetting of dry soil, yet the mechanisms responsible for this effect are not well understood (Birch, 1958; Appel, 1998; Fierer and Schimel, 2002). Saetre and Stark (2005) found a generally good correlation between the patterns of C mineralisation and gross N mineralisation and N immobilisation rates following rewetting of dry soils, indicating that microbial consumption of C substrates and biomass production were the primary factors regulating N dynamics. However, the relationship varied with time and vegetation type, suggesting that factors other than substrate quality (e.g. C:N ratio) may also influence N flux rates.

Understanding how dry/wet cycles affect C and N transformations is important in predicting SOM dynamics, determining the effects of climate change on greenhouse gas (GHG) emissions from soils and estimating the contribution of organic matter mineralisation to the supply of plant available N. Very few studies have considered how soil physical and chemical conditions influence the effects of dry/wet cycles on the mineralisation of C and N and the microbial transformations that follow. This study evaluated the response of C & N fractions to dry/wet cycles and their availability as substrates for C and N mineralisation along a SOM gradient in two soils of differing textures.

2. Materials and methods

2.1. Site selection and soil collection

As this is the second of two papers presenting results from a common set of experiments, only a brief description of the site selection and soil collection is given here; full details can be found in Harrison-Kirk et al. (2013). Two soil types commonly found on the Canterbury Plains of New Zealand were selected for study: Lismore silt loam (LIS) (NZ classification: Typic orthic brown soil, FAO classification: Dystric Cambisol), and Temuka clay loam (TEM) (NZ classification: Melanic orthic gley soil, FAO classification: Mollic Gleysol). A total of six sites were sampled to establish a SOM gradient for each of the silt loam (22–49 mg C g^{-1}) and clay loam (20–41 mg C g^{-1}) soil types. One of the clay loam soils (TEM 1) was later excluded from the study because it was not representative of the soil type.

Soil samples were collected from the A horizon at six locations within each site. In the laboratory, samples were passed through a 4 mm sieve and combined to form a single composite sample representing each site. The composite soil samples were air-dried and stored prior to initiating the experiment. Basic physical and chemical properties of the soils (Table 1) and the methods used to derive them were previously reported by Harrison-Kirk et al. (2013), but the values are included here for easy reference and to aid in interpretation of the findings.

2.2. Experimental design and management

Three soil water content (SWC) treatments were established to simulate wet (WW, soils held at FC), moderately dry (MD, 120% of SWC at WP) and very dry (VD, 80% of SWC at WP) field conditions. To each of the two ‘dry’ water content treatments two different dry/wet treatments were imposed where the soil was either: 1)

Table 1
Some chemical and physical properties of the soils investigated.

Soil id[a]	Current land use	C	N	C:N	Sand	Silt	Clay	pH
		mg g^{-1}		Ratio	%			
LIS 1	Pasture	49	4.4	11.1	25	59	16	5.4
LIS 2	Pasture	47	4.1	11.5	21	63	16	5.1
LIS 3	Pasture	44	4.0	11.0	27	56	17	5.9
LIS 4	Cropping	29	2.6	11.1	22	62	16	5.5
LIS 5	Cropping	26	2.4	10.8	21	64	15	5.7
LIS 6	Cropping	22	2.2	10.0	22	60	18	5.4
TEM 2	Cropping	41	3.8	10.8	11	60	29	5.1
TEM 3	Cropping	37	3.1	11.9	9	69	22	5.1
TEM 4	Cropping	31	2.7	11.5	21	52	27	6.1
TEM 5	Cropping	32	2.8	11.4	20	55	25	5.5
TEM 6	Cropping	20	1.9	10.5	23	58	19	5.3

[a] LIS = Lismore silt loam soil; TEM = Temuka clay loam soil.