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Drying and rewetting frequency influences cumulative respiration and its distribution over time in two soils with contrasting management

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ABSTRACT

Understanding the factors determining cumulative respiration upon rewetting of dry soil is critical for predicting C efflux from soils. The response of respiration to drying and rewetting may be influenced by land management due to its effect on the soil organic C pool and differ between soil size fractions. An incubation experiment was conducted with soils collected from two plots with a long history of different management (wheat-fallow and permanent pasture). The soils were sieved to 4–10 mm and <2 mm to obtain two size factions. There were five moisture treatments with the same length (48 days). The constantly moist control (CM) was maintained at 50% of WHC throughout. In the drying and rewetting (DRW) treatments, the number of dry and moist days was equal but the number of DRW events ranged from one to four (1–4DRW). Respiration was measured daily, microbial biomass C (MBC) was determined six days after rewetting in each DRW cycle and on day 48 (end of the experiment). The proportion of soil in the 4–10 mm size fraction decreased over time with a greater decrease in pasture than in wheat soil and in the DRW treatments compared to the constantly moist treatment (CM). Cumulative respiration at the end of the experiment was greater in the <2 mm than in the 4–10 mm fraction in both soils and was highest in CM and 1DRW. In wheat soil, cumulative respiration decreased from 1DRW to 3DRW, whereas it decreased only between 2 and 3DRW in pasture soil. In treatments with two to four DRW, the proportion of total cumulative respiration was lowest in the last cycle. In 2DRW, cumulative respiration was smaller in the second than in the first moist period whereas the reverse was true for 3DRW and 4DRW. Cumulative respiration in the second moist period was greater in 3DRW than in 2DRW (8 and 12 prior moist days) whereas cumulative respiration in the third moist period was greater in 4DRW than in 3DRW (12 and 16 prior moist days). At the end of the experiment, the MBC concentration in the 4–10 mm fraction was unaffected by moisture treatment, whereas in the <2 mm fraction, it was greatest in CM and lowest in 4DRW. We conclude that the response of respiration to drying and rewetting is more strongly influenced by management than size fraction. In a given soil, the cumulative respiration upon rewetting is influenced not only by the number of DRW cycles but also the number of moist days prior to rewetting.

1. Introduction

Soil organic C is the main organic C pool in terrestrial ecosystems. Therefore it is critical to better understand factors influencing sequestration and turnover of soil organic C (Swift, 2001; Olson, 2010). Land management influences soil organic C content through its impact on input and turnover of organic C (Lal, 1997). Conventional tillage increases the decomposition of organic matter (Six et al., 2000) and can result in net loss of organic C. In pasture compared to conventional tillage, belowground organic C input is greater due to permanent plant cover and decomposition rates are lower because the soils are not disturbed (Oades, 1984); further, stabilization of organic C is increased by improved soil structure.

In arid and semi-arid ecosystems, soil moisture varies due to occasional rainfall events or irrigation interspersed by long dry periods. The influence of drying and rewetting (DRW) on microbial activity has been studied extensively (Bottner, 1985; Degens and Sparling, 1995; Fierer and Schimel, 2003; Borken and Matzner, 2009). In dry soil, microbial activity is constrained by limited diffusion of substrates and high water potential which can lead to death of some microorganisms. Others can survive by accumulating osmoregulatory solutes (Van Gestel et al., 1993; Yao et al., 2011). Rewetting of dry soil causes an abrupt decrease in water potential.

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This can lead to microbial death by bursting of cells whereas other microbes survive by quickly releasing the accumulated solutes. It is generally accepted that the respiration flush upon rewetting is due to increased substrate availability to the surviving microbes. Substrate sources are cell lysis, release of accumulated solutes (Borken and Matzner, 2009; Kim et al., 2012) and exposure of previously physically protected substrates through aggregate breakdown (Fierer and Schimel, 2002; Navarro-Garcia et al., 2012). The respiration flush upon rewetting often decreases with increasing number of DRW cycles (Wu and Brookes, 2005; Baumann and Marschner, 2013), but this is not always the case (Chowdhury et al., 2011; Mavi and Marschner, 2012). There are contradictory views about the relative importance of these to the respiration flush which may differ with soil properties, land management and size fraction. Further, the effect of DRW on total cumulative respiration compared to the constantly moist control is inconsistent (Mikha et al., 2005; Miller et al., 2005; Baumann and Marschner, 2013) which may be due to differences in cycle number and lengths of dry and moist periods. In the experiment described here dry and moist periods were of equal length and the incubation period was the same for all treatments (48 days) which was divided into 1–4DRW cycles.

Aggregate breakdown upon rewetting is influenced by aggregate size. In the study by Denef et al. (2001) large aggregates were more vulnerable to drying and rewetting than small aggregates. They explained this by the larger pores in large aggregates which allowed rapid infiltration of both air and water. However, there are only few systematic studies on the effect of different DRW regimes in different soil size fractions (Navarro-Garcia et al., 2012). Organic matter content can also influence respiration upon rewetting. By comparing similar textured soils with a gradient of organic matter content, Harrison-Kirk et al. (2013) found that the respiration flush upon rewetting was greater in soils with high than with low organic C content. Understanding the factors influencing respiration upon rewetting dry soil is critical for predicting C flux between the terrestrial ecosystems and the atmosphere. Particularly given future climate scenarios which predict that extent and length of drought and precipitation periods will increase (Muhr et al., 2010; Jin et al., 2013).

For this study, soils were collected from two plots with more than 80 years of different management: wheat-fallow rotation and permanent pasture. The soils were sieved to different size factions (4–10 mm and <2 mm) and exposed to one to four DRW cycles in which the dry and moist periods were of equal length. Respiration rate and microbial biomass C were measured to test the following hypotheses: (1) cumulative respiration upon rewetting will be greater in the soil or the soil fraction with higher organic matter content, (2) cumulative respiration upon rewetting will decrease with increasing number of DRW cycles, and (3) total cumulative respiration at the end of the experiment will be greatest in the constantly moist soil and decrease with increasing number of DRW cycles.

2. Materials and methods

2.1. Soils

Two soils were collected from 0 to 10 cm depth in Urrbrae (Longitude 138°38′3.2″ E, Latitude 34°58′0.2″ S) in South Australia. The area is in a semi-arid region and has a Mediterranean climate with cool, wet winters and hot, dry summers interspersed by occasional rainfall events. The soils are red-brown earths (Isbell, 2002) which are Xeralfs according to US Soil Taxonomy (Oades et al., 1981). The soils were collected from plots in the Waite Long term Rotation trial and had different management history for over 80 years. One soil was collected from a plot which had been managed as a wheat-fallow rotation (hereafter referred to as wheat). The other soil was from an adjacent plot with permanent pasture (mainly Kikuyu grass, hereafter referred to as pasture).

2.2. Separation into size fractions

The soils were collected at the end of summer and therefore dry. Upon collection, they were sieved through 4- and 10-mm mesh sieves to obtain three size fractions: <4 mm, 4–10 mm and >10 mm. Stones and visible plant material were removed manually. The proportions of different size fractions differed little between the two soils: 42% in the <4 mm fraction, 25 and 27% in the 4–10 mm fraction and 33 and 30% in the >10 mm fraction for wheat and pasture soil, respectively. The <4 mm fraction was ground and sieved through a 2-mm sieve to obtain the <2 mm fraction. In the experiment described below, only two fractions were used: 4–10 mm and <2 mm. The properties of different size fractions were measured after drying at 60 °C for 24 h as described in detail in Shi and Marschner (2012) and shown in Table 1.

Before the onset of the experiment, the <2 mm and 4–10 mm fractions were pre-incubated for 10 days at 50% of water-holding capacity (WHC) to reactivate the microbes. This water content was chosen because (i) 50% of WHC is the optimum water content for microbial activity in soils with similar texture (Setia et al., 2011a), and (ii) slaking of the 4–10 mm fraction was not observed at this water content.

2.3. Experimental design

After wetting to 50% of WHC, 20 g soil (dry weight) was placed into PVC cores (height 5 cm and radius 1.85 cm) with a nylon mesh base (0.75 μm, Australian Filter Specialist) for pre-incubation. The soil in the cores was adjusted to the bulk density found in the field (1.35 g cm^{-3}) after which the cores were kept at 22 °C in the dark for 10 days before the onset of the experiment. This pre-incubation was carried out to minimize interference of mechanical soil disturbance (sieving and placing the soil in the cores) with the effect of drying on microbial activity at the beginning of the experiment. After the 10-day pre-incubation, the cores were transferred to 1 L glass jars (Ball®, Jarden Corporation).

There were five moisture treatments (Fig. 1) which all had the same length (48 days). The constantly moist treatment was maintained at 50% of WHC throughout. In all drying and rewetting (DRW) treatments, the number of dry and moist days was equal, but the number of cycles varied between 1 and 4 among the treatments (referred to as 1DRW, 2DRW, 3DRW and 4DRW) and therefore the length of each DRW cycle varied between 48 (1DRW) and 12 days (4DRW). At the onset of each dry period, the soils were

Table 1
Properties of the <2 mm and 4–10 mm size fractions of wheat and pasture soil.

Soil properties	Wheat		Pasture	
	<2 mm	4–10 mm	<2 mm	4–10 mm
Sand %	27.4	26.2	26.2	25.5
Silt %	49.9	48.9	47.4	48.3
Clay %	22.7	24.9	26.4	26.2
EC dS m^{-1}	0.1	0.1	0.1	0.2
pH	5.7	5.8	5.6	5.7
Maximum water-holding capacity g kg^{-1}	358	236	406	285
TOC g kg^{-1}	18.9	14.6	30.9	29.2
Total N g kg^{-1}	0.7	0.4	1.5	1.3
C/N ratio	27	37	21	23