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Cumulative respiration in two drying and rewetting cycles depends on the number and distribution of moist days

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ABSTRACT

Surface soils in arid and semi-arid climates are exposed to drying and rewetting (DRW) which can influence soil organic matter decomposition. However, factors influencing cumulative respiration in DRW treatments remain unclear, as total cumulative respiration compared to constantly moist control (CM) has been found to be higher, lower or not different. An incubation experiment was conducted to determine the influence of the number of dry and moist days and their distribution in two DRW cycles on respiration rate and cumulative respiration in each DRW cycle and at the end of the experiment. The number of moist or dry days ranged in either the first or second DRW cycle between 10 and 35. The other cycle consisted of 5 dry and 5 moist days. The CM treatment was maintained at 70% of field capacity throughout. Cumulative respiration in CM was greater than that in DRW treatments with the difference stronger in treatments with varying numbers of dry days than those with varying numbers of moist days. In DRW treatments, cumulative respiration in the dry period differed little between treatments. The size of the respiration flush upon rewetting increased with increasing number of prior dry days with a stronger effect in the first DRW cycle. Cumulative respiration in the moist period increased with number of moist days, particularly when the number of moist days varied in the first cycle. It is concluded that in DRW, the respiration flush upon rewetting increases with the number of dry days whereas cumulative respiration is a function of the number of moist days. Further, varying the number of dry or moist days has a greater effect in the first than in the second cycle.

1. Introduction

In arid or semi-arid climate, soils are often exposed to long dry periods which are occasionally interrupted by rainfall or irrigation. The effect of soil water content and drying and rewetting (DRW) has been investigated extensively in the past. In dry soil, microbial activity is low due to decreased substrate diffusion and water uptake (Bottner, 1985; Van Gestel et al., 1993; Wilson and Griffin, 1975). Adapted microbes accumulate osmolytes to minimize water loss from the cell (Boot, 2011; Warren, 2014). Rewetting of dry soil results in a flush of respiration which is explained by high substrate availability due to the release of osmolytes, cell burst and exposure of previously occluded soil organic matter (Borken and Matzner, 2009; Fierer and Schimel, 2002). The respiration flush usually decreases with the increasing number of DRW events (Butterly et al., 2010; Mikha et al., 2005).

Total cumulative respiration in DRW treatments compared to the constantly moist control (CM) was found to be greater (Beare et al., 2009; Jin et al., 2013; Miller et al., 2005; Wu and Brookes, 2005), lower (Guo et al., 2012; Harrison-Kirk et al., 2013; Muhr et al., 2010) or similar (Baumann and Marschner, 2013). In a review by Borken and Matzner (2009), about half of the DRW studies reported increased cumulative respiration in the DRW treatments, whereas other studies found decreased cumulative respiration or no difference between DRW and CM. This was true in almost one third of the studies mentioned in their review and occurred when the total number of dry days was greater than that of moist days. However, in the case of 2 cycles, the influence of number of dry or moist days on respiration in DRW treatments could be different depending on which cycle the length of the dry and moist periods are varied. To investigate this, the number of dry and moist days in two DRW cycles would have to be systematically changed in either the first or second DRW cycle. Understanding how length and distribution of dry and moist periods in DRW cycles influence respiration is important for predicting their impact on C flux between soil and the atmosphere.

In this study, a soil was exposed to two DRW cycles where the number of dry and moist days ranged between 10 and 35 with the greater number of dry or moist days either in the first or second cycle. The other DRW cycle consisted of 5 dry and 5 moist days. The experimental design allowed studying the effect of total cycle length and distribution of moist and dry days in the first and second cycle on respiration flush upon rewetting and on cumulative respiration per cycle as well as at

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the end of the experiment (total cumulative respiration). We hypothesised that (i) cumulative respiration per cycle is positively related with the number of moist days whereas the number of dry days has little effect; (ii) the respiration flush upon rewetting is greater in the first than in the second cycle (which has been shown previously) and that in a given cycle, the respiration flush in the second cycle decreases with increasing number of moist days in the first cycle; and (iii) total cumulative respiration is greater in DRW treatments than in CM when the number of moist days is greater than that of dry days.

2. Material and methods

2.1. Soil

The soil was collected from 0 to 10 cm depth in Urrbrae (Latitude 34°58′0.2″ S, Longitude 138°38′3.2″ E) in South Australia. The area is in a semi-arid region and has a Mediterranean climate with cool, wet winters and hot, dry summers. The soil is classified as Chromosol (Isbell, 2002). The soil was managed for over 80 years in the Waite Long-term Rotation Trial as wheat-fallow rotation. Soil was collected from three locations within the plot and pooled to give one composite sample.

The soil was collected in summer and therefore dry. It was passed through a 2 mm sieve and stored air-dry; stones and visible plant materials were removed manually. The soil had the following properties: soil $pH_{1:5}$ 5.7, soil $EC_{1:5}$ 0.1 dS m^{-1}, sand 27%, silt 50% and clay 23%, field capacity 358 g kg^{-1}, total organic C (TOC) 18.9 g kg^{-1} by dichromate oxidation and total N 0.7 g kg^{-1} by micro-Kjeldahl (see Shi and Marschner (2013) for details about measurement of soil properties).

2.2. Experimental design

Twenty gramme soil (dry weight) was placed into the PVC cores (height of 5 cm and diameter of 3.7 cm) with the bottom covered by a nylon mesh (0.75 μm, Australian Filter Specialist, Sydney). Then reverse osmosis (RO) water was added to achieve 70% of field capacity. This water content was chosen because it was found to be optimal for respiration for this soil in a preliminary experiment. To adjust to the bulk density found in the field (1.35 g cm^{-3}), the soil was compacted to a certain height. The cores were pre-incubated at 22 °C in the dark for 10 days during which the moisture content was checked by weight and RO water added if required. The purpose of pre-incubating the soil in the cores was to minimize the interference of physical disturbance (weighing the soil and adjusting bulk density) 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 with gas-tight lids equipped with a stainless steel septum for measurement of CO_2 release.

Two DRW cycles were imposed in which the number of moist or dry days was 10, 15, 20, 25, 30 or 35 in the first or the second cycle. The other cycle consisted of 5 dry and 5 moist days. Thus the number of dry or moist days varied only in either the first or second cycle. The 24 DRW treatments are shown in Table 1, where the four numbers in each treatment name indicate the number of dry and moist days in the first cycle (first and second numbers) and in the second cycle (third and fourth numbers), e.g., 25–5–5–5 had 25 dry days and 5 moist days in the first DRW cycle and 5 dry and 5 moist days in the second DRW cycle. The constantly moist control (CM) was maintained at 70% of field capacity throughout (0.2 g H_2O g^{-1} soil). Cumulative respiration in the DRW treatments was compared to that of CM at the same total length. For example, cumulative respiration of treatment 5–5–15–5 (total length of 30 days) was compared to that of CM on day 30. There were three replicates per treatment.

To ensure rapid soil drying, a cloth pouch (approximately 6 × 6 cm) containing about 10 g self-indicating silica gel (BDH Chemicals) was placed in each jar at the start of the dry period and exchanged daily as the soil dried (Butterly et al., 2010). For regenerating, the pouches were dried at 105 °C overnight. After addition of the silica pouch, the jars were sealed immediately and kept at 22 °C in the dark during which CO_2 release was measured as described below. The water content was checked gravimetrically daily during drying otherwise every 1–2 days. During the drying period, the gravimetric water content rapidly decreased to 0.008 g H_2O g^{-1} soil on day 5 after which it remained unchanged. Therefore, the silica gel pouch was only exchanged in the first five days. For longer dry periods, the silica pouch was not changed after the first 5 days. At the start of the moist period, the soils were wet to 70% of field capacity within less than a minute by adding RO water in a circular motion with an automatic pipette to ensure uniform wetting. During the moist period, RO water was added if necessary to maintain 70% of field capacity.

Table 1
Experimental design of two drying and rewetting (DRW) cycles with varying numbers of dry or moist days in the first or second cycle.

Treatments	Number of days				
	First cycle		Second cycle		Total
	Dry	Moist	Dry	Moist	
CM	–	–	–	–	50
10–5–5–5	10	5	5	5	25
15–5–5–5	15	5	5	5	30
20–5–5–5	20	5	5	5	35
25–5–5–5	25	5	5	5	40
30–5–5–5	30	5	5	5	45
35–5–5–5	35	5	5	5	50
5–10–5–5	5	10	5	5	25
5–15–5–5	5	15	5	5	30
5–20–5–5	5	20	5	5	35
5–25–5–5	5	25	5	5	40
5–30–5–5	5	30	5	5	45
5–35–5–5	5	35	5	5	50
5–5–10–5	5	5	10	5	25
5–5–15–5	5	5	15	5	30
5–5–20–5	5	5	20	5	35
5–5–25–5	5	5	25	5	40
5–5–30–5	5	5	30	5	45
5–5–35–5	5	5	35	5	50
5–5–5–10	5	5	5	10	25
5–5–5–15	5	5	5	15	30
5–5–5–20	5	5	5	20	35
5–5–5–25	5	5	5	25	40
5–5–5–30	5	5	5	30	45
5–5–5–35	5	5	5	35	50

2.3. Measurements

Soil respiration was measured daily by quantifying the CO_2 concentration in the headspace of the jars using a Servomex 1450 infra-red analyser (Servomex Group, Crowborough, UK). After each measurement (t1), the jars were vented to refresh the headspace using a fan, and then resealed followed by determination of the CO_2 concentration (t0). The CO_2 respired (ml) during a given interval was calculated as the difference in CO_2 concentration between t1 and t0. Linear regression based on injection of known amounts of CO_2 (ml) in similar jars was used to define the relationship between CO_2 concentration and detector reading. The amount of CO_2 respired (mg CO_2–C) was calculated using the following formula:

$$Y = \frac{V \times 1000 \times \text{Atomic weight of C}}{V_{STD} \times \text{Times(days)} \times M}$$

where, Y = mg CO_2–C g^{-1} soil day^{-1}, V = Volume of CO_2 respired (ml) between t1 and t0, V_{STD} = Volume of 1 mol of CO_2 given temperature calculated from ideal gas law, and M is the soil mass (g). To assess the decomposability of soil organic C, respiration is expressed per g TOC.