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Short-term respiration responses to drying–rewetting in soils from different climatic and land use conditions

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ABSTRACT

Many surface soils, including those that have rarely experienced dry conditions, may experience more frequent and/or intense drying–rewetting (DRW) events in the future. Such DRW events are likely to induce large and sudden CO_2 pulses derived from increased substrate availability owing to their release from non-biomass soil organic C (SOC) and microbial biomass C (MBC); however, few studies have investigated respiration rates following DRW at high time resolutions (e.g., 1 h) or in soils from humid areas. In this study, DRW effects on the dynamics of respiration rates at hourly intervals for 12 h and substrate-induced respiration (SIR) rates were investigated. Soils previously subjected to different DRW frequencies were collected from forest and arable or grassland sites in Japan (humid), Thailand (semi-humid) and Kazakhstan (semi-arid). The relatively humid Japanese and Thai soils were further subjected to five DRW cycles in the laboratory to compare the effects of the first and fifth DRW. Respiration rates after the first and fifth DRW and first DRW to the Japanese and Thai forest soil, respectively, were not fitted by models employing exponentially-decaying functions, and were initially similar to SIR rates. In such cases, C-saturated conditions for surviving microbes would occur probably because of increased substrate availability following release from dead MBC, suggesting the importance of incorporating microbial parameters into SOC models. Respiration rates after DRW to other samples decreased exponentially to a constant rate. In such cases, when increases in the labile and stable C pools by DRW were estimated by the respiration kinetics, the labile C pool would be primarily derived from dead MBC.

1. Introduction

Predictions of global climate models show that many regions of the earth may experience longer periods of drought and more intense precipitation events in the future (Giorgi et al., 2011; Trenberth, 2011). Under these scenarios, many surface soils are likely to experience more frequent and/or intense rewetting in response to rainfall events that occur following dry conditions (Borken and Matzner, 2009). The drying–rewetting (DRW) of soils influences the turnover of soil organic carbon (SOC), which plays an important role in the global C cycle (Göransson et al., 2013; Moyano et al., 2013). It is widely recognized that DRW events induce a large and sudden increase in mineralization of SOC, producing a pulse of CO_2 (Birch, 1958). Such CO_2 pulses are derived from increased availability of substrates used and partially respired by microbes after rewetting. The increased substrate sources are from both non-biomass SOC and microbial biomass C (MBC) (Xiang et al., 2008). Substrates from MBC are derived from the death of microbial biomass during soil DRW (Bottner, 1985; Van Gestel et al., 1993) and microbial osmoregulatory compounds (i.e., osmolytes) accumulated during drying and released on rewetting (Halverson et al., 2000; Warren, 2014). Although understanding the relative contributions of these sources to the rewetting respiration pulse is essential to modeling of the global C cycle (Xiang et al., 2008), it would be difficult because the relative contributions will vary by soil type (Wu and Brookes, 2005; Borken and Matzner, 2009). In addition, rewetting respiration pulses have often been observed with no changes in MBC (Fierer and Schimel, 2003); therefore, the importance of dead MBC to the pulse is still the subject of debate (Moyano et al., 2013).

The respiration pulse following DRW events often decreases with increasing numbers of DRW cycles (Fierer and Schimel, 2002; Mikha et al., 2005). In addition, the sizes of the reduction in MBC by DRW have been shown to be larger in soils subjected to fewer fluctuations in moisture content because the microbial

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communities in such soils have not yet adapted to the DRW stress (Van Gestel et al., 1993). Furthermore, Butterly et al. (2009) observed that the rewetting respiration pulse was related to the reduction in MBC in the first and second DRW events, but not in subsequent events. Therefore, the impacts of DRW on the respiration pulse and MBC may decrease as soils undergo more frequent DRW events in various soils subjected to different DRW frequencies in the field and/or laboratory.

It is important to measure respiration rates following DRW at a high time resolution (e.g., 1 h) to avoid missing peak rates and enable accurate estimations (Kim et al., 2012). When respiration rates after rewetting of soils dried for less than 1 week were measured hourly, they were found to be highest within one hour of DRW and then decrease exponentially (Iovieno and Bååth, 2008; Lundquist et al., 1999). Conversely, hourly measurement of respiration rates after rewetting of soils dried for more than 2 months revealed that they remained stable for less than 16 h, then increased (Göransson et al., 2013; Meisner et al., 2013). Respiration rates would depend on both the concentration of available substrate C and the quantity of living MBC which is linked to the microbial capacity to mineralize labile C (Smith et al., 1985). Meisner et al. (2013) suggested that prolonged drying may induce the release of highly available substrate C because of death of the microbial biomass, probably resulting in C-saturated conditions for surviving microbes upon rewetting. Accordingly, the respiration rate after rewetting is initially stable under C-saturated conditions, then increases owing to microbial growth. Indeed, the initial stable respiration rate in C-saturated soils is a well-known indicator of MBC according to the substrate-induced respiration (SIR) method (Anderson and Domsch, 1978).

In Asia, more intense precipitation events were predicted in the future, especially in Southeast Asia and Japan (Christensen et al., 2007). In addition, it is predicted that the number of dry days with daily precipitation of less than 1 mm will increase in humid Japan where the average annual precipitation is about twice the global average (Japan Meteorological Agency, 2013). The soils from humid areas such as Japan may be more affected by future DRW events. In such cases, the majority of MBC may be killed and changed to an easily available substrate C following DRW events because microbial communities in such soils would not be adapted to the DRW stress. Under these conditions, it was hypothesized that the rewetting of soils dried for less than 1 week may induce C-saturated conditions owing to the dead MBC in soils from humid sites. However, studies of the effects of DRW on the rewetting respiration pulse have typically focused on desert, semi-arid and Mediterranean soils (Tiemann and Billings, 2011), although there were a few studies on respiration pulse in humid climate (Kim et al., 2012). Therefore, it is important to investigate the influence of soil DRW on respiration pulse and MBC in soils collected from more humid regions.

The objective of this study was to examine whether DRW treatment had different effects on short-term respiration pulse and MBC in various soils subjected to different DRW frequencies in the field and/or laboratory, especially in soils from humid areas. The short-term respiration rates before and after DRW were measured at hourly intervals for 12 h for glucose-amended and unamended samples. Glucose was added to ascertain whether DRW induced C-saturated conditions and to estimate the size of MBC according to the SIR method (Anderson and Domsch, 1978). Finally, we assessed the contribution of dead MBC to the rewetting respiration pulse.

2. Materials and methods

2.1. Soils

Soil samples were collected from six sites under different climatic and land use conditions in Japan, Thailand and Kazakhstan. In Japan, a forest soil (hereafter referred to as JF) was collected from a mixed deciduous and evergreen forest (*Quercus serrata*) in Kyoto (N35°01′ E135°47′), where the mean annual temperature is about 15.5 °C and the annual precipitation is about 1490 mm. The soil is classified as a Cambisol according to the World Reference Base for Soil Resources (IUSS Working Group, 2006). Additionally, an arable soil (JA) was collected from Chinese cabbage fields at the Experimental Farm of Kyoto University, Osaka (N34°51′ E135°38′), where the mean annual temperature is about 17.0 °C and the annual precipitation is about 1260 mm (Experimental Farm, Kyoto University, 2011). This soil developed on the alluvial fan of a small river and is classified as a Fluvisol (IUSS Working Group, 2006). In Thailand, forest and arable soils (TF and TA, respectively) were collected from the village of Du La Poe, Mae Hong Son Province, northern Thailand (N18°24′ E98°05′), where a traditional style of shifting cultivation is still used. This region is characterized by a mean annual temperature of about 20.2 °C and an annual precipitation of about 1220 mm, with soils classified as Acrisols (IUSS Working Group, 2006) (Funakawa et al., 2006). Soil TF was collected from natural forests, while TA was collected from an upland rice field that had been cultivated for 2 months following slash and burn agricultural practices. In Kazakhstan, forest and grassland soils (KF and KG, respectively) were collected from a study site located in the northern foothills of the Tianshan Mountains (locally known as the Ketmen Mountains) east of Almaty (43°11′N, 79°27′E). This area is characterized by a mean annual temperature of about 1.2 °C and an annual precipitation of about 670 mm, with soils classified as Umbrisols (IUSS Working Group, 2006). The KF and KG soils were collected from a coniferous forest (*Picea schrenkiana)* and natural grassland, respectively, where the coniferous forest was scattered in natural grassland vegetation.

The sites in Japan have humid climates, while those in Thailand have a distinct dry season, and those in Kazakhstan have a drier climate than the other sites. In addition, the forest soils would have been subjected to fewer DRW events than the arable and grassland soils because of the presence of a litter layer and canopy shading (Fierer and Schimel, 2003). Overall, the JF soil likely experienced the fewest DRW events, followed by the TF soil, and then the JA, TA, KF and KG soils, which experienced occasional DRW events.

Table 1
Basic soil properties.

Soil name	Site	pH (H_2O)	Organic C ($mg\,C\,g^{-1}$ soil)	Total N ($mg\,N\,g^{-1}$ soil)	Clay content (%)
JF	Japanese forest	3.7	69	4.0	20
JA	Japanese arable	7.0	31	1.8	8
TF	Thailand forest	4.8	88	5.7	42
TA	Thailand arable	6.7	32	2.2	41
KF	Kazakh forest	5.7	163	10.1	28
KG	Kazakh grassland	5.4	66	7.0	33