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# Changing rainfall frequency affects soil organic carbon concentrations by altering non-labile soil organic carbon concentrations in a tropical monsoon forest

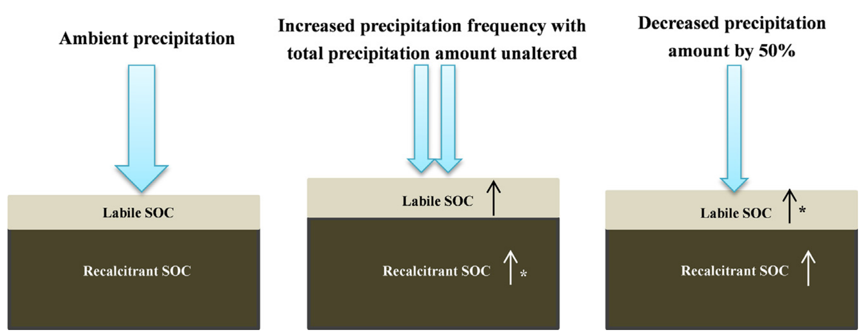
Xiaomei Chen [a], Qi Deng [b], Guojun Lin [c], Meizhen Lin [a], Hui Wei [d,*]

[a] School of Geographical Sciences, Guangzhou University, Guangzhou 510006, China
[b] Key Laboratory of Vegetation Restoration and Management of Degraded Ecosystems, South China Botanical Garden, Chinese Academy of Sciences, Guangzhou 510650, China
[c] Institute of Water Resources Protection in Yangtze River, Wuhan 430051, China
[d] Department of Ecology, South China Agricultural University, Guangzhou 510642, China

## HIGHLIGHTS

- This study was conducted to clarify effects of precipitation changes on SOC fractions.
- Increased rainfall frequency and decreased rainfall amount were manipulated.
- Rainfall frequency increase with the amount unaltered increased the SOC concentration.
- The non-labile fraction contributed a substantial proportion to this increase.
- Rainfall amount decrease by 50% did not significantly change the SOC concentration.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Soil stores a substantial proportion of carbon (C), making it the greatest terrestrial C pool and pivotal to stabilizing the global climate system. Rainfall amounts and regimes have been changing in many places, but effects of precipitation changes on soil organic C (SOC) stabilization are not completely understood. Considerable attention has been focused on the consequences of changes in rainfall amounts, with rainfall regimes having been less studied. This study was conducted in a tropical climax forest to clarify the effects of rainfall changes on SOC fractions, with permanganate oxidation and density fractionations employed to divide the labile and non-labile SOC fractions. Two rainfall manipulation treatments, i.e., increased rainfall frequency with the total rainfall amount unchanged (IRF) and decreased rainfall amount by 50% with rainfall frequency unaltered (DRA), were conducted for two years, with ambient rainfall (AR) as the control. As a result, the IRF treatment increased the SOC concentration that mainly originated from increases in the non-labile SOC content. Relative to the AR control, the DRA treatment did not change the total SOC concentration although the labile SOC concentration increased. This typically is due to a small proportion of the labile fraction to the total SOC content. Our results suggest that this water-rich mature forest is resistant to rainfall amount changes to a great extent (e.g., decrease of 50% as in the present study) from the SOC stabilization perspective, while changes in rainfall frequency could exert more notable effects.



* Corresponding author at: Department of Ecology, South China Agricultural University, 483 Wushan Road, Tianhe District, Guangzhou 510642, China.
*E-mail address:* weihui@scau.edu.cn (H. Wei).

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## 1. Introduction

Soil is the greatest terrestrial carbon (C) pool that is more than the total of the vegetation and atmospheric C pools, making soil vital to stabilizing the climate system. Globally, the first 1 m of surface soil stores approximately 1500 Pg C (Jobbágy and Jackson, 2000; Scharlemann et al., 2014), with a substantial percentage sequestrated in low latitude forests (Jobbágy and Jackson, 2000). Thus, any small change in the soil organic C (SOC) pool may cause a drastic fluctuation in the atmospheric C concentration (Cox et al., 2000), consequently accelerating global climate changes such as warming and precipitation changes (IPCC, 2013). Although considerable attempts have been made for decades, drawing a firm conclusion on soil C dynamics under climate change scenarios remains difficult, due to many factors affecting soil C balances (Allison et al., 2010; Schimel et al., 2001; Schmidt et al., 2011). Moreover, available data are distributed unevenly across different regions and generate great uncertainties for soil C predictions (Scharlemann et al., 2014). Specifically, there have been few data of SOC content available in China that include diverse ecosystems (Scharlemann et al., 2014). Increasing research in these data-poor regions would help to improve the modelling precision of global and regional C dynamics.

SOC is a C continuum that consists of various classes of organic materials with different decomposability by soil microorganisms (Schmidt et al., 2011). Although an emerging view shows that turnover of soil organic compounds could be determined by a combination of the decomposer community and the energy needed for their activity, properties and abundance of soil minerals, and supply of numerous resources (Lehmann and Kleber, 2015), these C-containing materials are often regarded as a black box (i.e., the total SOC) or divided into different pools (such as labile and non-labile SOC pools) to simplify studies in practice (von Lützow et al., 2007). In previous literature, physical, chemical and biological methods have been proposed to quantify the labile and non-labile SOC fractions (Blair et al., 1995; McLauchlan and Hobbie, 2004; Six et al., 2001). Despite the diverse methodologies, labile C fractions typically constitute organic compounds that are active and sensitive to environmental changes, whereas non-labile fractions are often considered as containing the mineral-associated and stable organic compounds (von Lützow et al., 2007). Labile and non-labile SOC fractions have been widely used to study the response of SOC to environmental changes (Chen et al., 2012; Durigan et al., 2017; Schnecker et al., 2016), and they are likely to respond differently to environmental changes (Chen et al., 2012; McLauchlan and Hobbie, 2004). Previous studies suggest that labile SOC is more sensitive than non-labile SOC due to its relatively lower molecular recalcitrance and structural protection (Six et al., 2002; von Lützow et al., 2006).

Climate changes can influence hydrologic cycles and precipitation patterns (including precipitation amount, timing, intensity, and frequency), which have been altering in many places (Beier et al., 2012; IPCC, 2013; Knapp et al., 2015). Precipitation changes are expected to obviously influence soil water content (Deng et al., 2012; Harper et al., 2005; Thomey et al., 2011). The resulting changes in water supply may affect the growth and community composition of plants that provide C inputs to the soil via litterfall and root exudates and death (Kardol et al., 2010; Thomey et al., 2011; Zhao and Running, 2010), and soil C outputs by modifying gaseous C emissions (Harper et al., 2005; Huang et al., 2015; Knorr et al., 2008) and aqueous C loss via leaching of dissolved organic C and runoff (Deng et al., 2018; Ma et al., 2014). Finally, trade-offs between altered soil C inputs and outputs determines the direction and magnitude of SOC responses under precipitation changes. Moreover, soil moisture conditions could affect SOC stabilization by means of modifying the abundance of functional soil microbial groups (Canarini et al., 2016), and shifted soil microbial communities may consequently give rise to changes in SOC accumulation due to the varied microbial contribution (e.g., bacteria vs. fungi) (Shao et al., 2017). Although considerable attention has been given to precipitation in recent decades, most studies have focused on changes in precipitation amounts (e.g., Chen et al., 2015; Talmon et al., 2011), with other precipitation attributes having been less studied (Beier et al., 2012). Precipitation changes (such as timing and frequency), however, could even exhibit substantially greater effects than altered precipitation amounts in several ecosystems (Deng et al., 2018; Wu et al., 2012) and deserve further studied.

Moreover, a majority of precipitation manipulation has been conducted at the medium latitudes ranging from 30 to 60°, with only 4% of the manipulations occurring at latitudes < 30° and no one has taken into account changes in precipitation variability in forests (Beier et al., 2012; Vicca et al., 2014). Southern China has been experiencing precipitation changes since the 1980s; although total precipitation has been not altered, no rain and heavy rain days have increased, while light rain has decreased (Zhou et al., 2011). Associated with increased air temperature, soil moisture has been significantly declining in this region (Zhou et al., 2011). Chen et al. (2015) showed that in three forests of southern China, a four-year precipitation removal significantly decreased the SOC content (especially the non-labile fraction), which was accompanied with changed C inputs in terms of both quantity and quality, while a doubling of precipitation had negligible effects. Although a growing body of literature has reported changes in precipitation attributes (IPCC, 2013; Knapp et al., 2015; Zhou et al., 2011), the consequences, e.g., whether precipitation regime change affects SOC fractions in diverse ways, remain less studied (Beier et al., 2012). Limited results derived from studies manipulating precipitation frequency greatly increase the uncertainty related to quantifying soil C dynamics.

Forests contribute to 92% of the global biomass, and tropical forests account for two-thirds of the total forest biomass (262.1 Pg C; Pan et al., 2013). With substantially high gross and net primary productivity, this results in a great proportion of C stock in tropical forests (Pan et al., 2013), and therefore, it is critical to the global C balance. Old-growth monsoon forests in southern China can sequester C in the soil, and this region has been projected to be a significant C sink (Piao et al., 2009; Zhou et al., 2006). With ongoing precipitation changes in the region, however, whether SOC fractions and the soil C sink function would be altered has not been well addressed. Although precipitation change was reported to influence soil respiration (Deng et al., 2018; Moyano et al., 2013; Vicca et al., 2014) and soil C stocks in other ecosystems (Aanderud et al., 2010), 100% higher precipitation did not significantly alter soil respiration or SOC content (including both of the labile and non-labile fractions) in this regional climax forest relative to ambient precipitation (Chen et al., 2015; Deng et al., 2012). A recent study showed that precipitation seasonality greatly affected the dominant soil fungal taxa in a neighbouring evergreen forest (Zhao et al., 2016), and our parallel study demonstrated that an increase in precipitation frequency stimulated the total and dissolved organic carbon (DOC)-driven soil respiration rates (Deng et al., 2018), suggesting an altered microbial community structure and activity under precipitation changes. This scenario could further affect the SOC fractions because soil microbial communities drive soil C processes (Cotrufo et al., 2013).

This precipitation manipulation experiment was conducted in a tropical monsoon forest of southern China to observe how precipitation changes affect the contents of the total, labile and non-labile SOC fractions. Two precipitation treatments were included in the experiment: 1) increase rainfall frequency with the total rainfall amount remaining unchanged (IRF) and 2) decrease the total rainfall amount by 50% (DRA) relative to ambient rainfall (AR). The IRF treatment that reduces the water amount of each precipitation event could be beneficial to water retention for plant and microbial activities (Deng et al., 2018) rather than favouring runoff loss (Laporte et al., 2002). Higher plant productivity and microbial activities could transfer more C into the soil rapidly as microbial products. This scenario may favour soil C stabilization (Cotrufo et al., 2013; Schmidt et al., 2011) because microbial products have been observed to contribute substantially to stable soil organic matter possibly due to a high organo-mineral association and patchy fragment formation between soil aggregates and microbial products