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Fate of ^{14}C-labeled dissolved organic matter in paddy and upland soils in responding to moisture

Xiangbi Chen [a,b], Aihua Wang [a], Yang Li [a,b], Lening Hu [a,b], Hua Zheng [a,b], Xunyang He [a,b], Tida Ge [a], Jinshui Wu [a], Yakov Kuzyakov [c], Yirong Su [a,b,*]

[a] Key Laboratory of Agro-ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, The Chinese Academy of Sciences, Changsha 410125, China
[b] Huanjiang Observation and Research Station for Karst Ecosystems, Huanjiang 547100, China
[c] Department of Soil Science of Temperate Ecosystems, Department of Agricultural Soil Science, University of Göttingen, 37077 Göttingen, Germany

HIGHLIGHTS

- Fate of dissolved organic matter (DOM) strongly depends on soil moisture.
- Moisture is not the key factor in determining the lower DOM in paddy soils than in upland soils.
- The lower DOM in paddy soils than in upland soils is controlled by component and structure of DOM.

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ABSTRACT

Soil organic matter (SOM) content in paddy soils is higher than that in upland soils in tropical and subtropical China. The dissolved organic matter (DOM) concentration, however, is lower in paddy soils. We hypothesize that soil moisture strongly controls the fate of DOM, and thereby leads to differences between the two agricultural soils under contrasting management regimens.

A 100-day incubation experiment was conducted to trace the fate and biodegradability of DOM in paddy and upland soils under three moisture levels: 45%, 75%, and 105% of the water holding capacity (WHC). ^{14}C labeled DOM, extracted from the ^{14}C labeled rice plant material, was incubated in paddy and upland soils, and the mineralization to $^{14}CO_2$ and incorporation into microbial biomass were analyzed. Labile and refractory components of the initial ^{14}C labeled DOM and their respective half-lives were calculated by a double exponential model.

During incubation, the mineralization of the initial ^{14}C labeled DOM in the paddy soils was more affected by moisture than in the upland soils. The amount of ^{14}C incorporated into the microbial biomass (2.4–11.0% of the initial DOM-^{14}C activity) was less affected by moisture in the paddy soils than in the upland soils. At any of the moisture levels, 1) the mineralization of DOM to $^{14}CO_2$ within 100 days was 1.2–2.1-fold higher in the paddy soils (41.9–60.0% of the initial DOM-^{14}C activity) than in the upland soils (28.7–35.7%), 2) ^{14}C activity remaining in solution was significantly lower in the paddy soils than in the upland soils, and 3) ^{14}C activity remaining in the same agricultural soil solution was not significantly different among the three moisture levels after 20 days. Therefore, moisture strongly controls DOM fate, but moisture was not the key factor in determining the lower DOM in the paddy soils than in the upland soils.

The UV absorbance of DOM at 280 nm indicates less aromaticity of DOM from the paddy soils than from the upland soils. At any of the moisture levels, much more labile DOM was found in paddy soils (34.3–49.2% of the initial ^{14}C labeled DOM) compared with that in upland soils (19.4–23.9%). This demonstrates that the lower DOM content in the paddy soil compared with that in the upland soil is probably determined by the less complex components and structure of the DOM.

1. Introduction

Dissolved organic matter (DOM) participates in many processes, such as carbon (C) distribution in the soil profile, nutrient delivery and leaching, and pollutant (heavy metals, hydrophobic organic contaminants) and nutrient transport (Chantigny, 2003; Kalbitz et al.,

* Corresponding author at: Institute of Subtropical Agriculture, The Chinese Academy of Sciences, Changsha 410125, China. Tel.: +86 731 84615222; fax: +86 731 84612685.
E-mail address: yrsu@isa.ac.cn (Y. Su).

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2000). Simultaneously, DOM plays a key role in the stabilization and destabilization (mobilization) of soil organic matter (SOM), and thereby, in the C dynamics and C pools of soils (Neff and Asner, 2001). Therefore, great interest has been focused on the DOM dynamics in soils (Buckingham et al., 2008; Kothawala et al., 2009; Williams and Xia, 2009; van den Berg et al., 2012; Wang et al., 2014). To our knowledge, most of the studies were conducted in forests, and few studies have been performed to examine DOM fate in agricultural soils (Kalbitz et al., 2003). Loss of DOM from agricultural soils has a negative impact on soil nutrient cycling and may lead to further soil degradation (Mavi et al., 2012).

Approximately 26% of the farmlands in China are paddy fields (National Bureau of Statistics of China, 2008), which are primarily distributed in the tropical and subtropical regions (Liu et al., 2013). In these regions, the SOM content in paddy soils is generally higher than that in upland soils within the same geomorphic unit (Guo and Lin, 2001; Li et al., 2008; Zhang, 2010). The DOM concentration, however, is lower in paddy soils (Li et al., 2008; Hao et al., 2009). At present, the causes of this phenomenon are largely unknown. The biodegradation, mineralization rate, and adsorption/desorption rate of DOM largely depend on the redox state, which is closely related to soil moisture (Kögel-Knabner et al., 2010; Fiedler and Kalbitz, 2003). In this study, we hypothesize that the soil moisture strongly controls DOM fate and so, leads to differences between two agricultural soils under contrast management.

DOM biodegradability is quantified by CO_2 production during incubation of DOM solutions (Andreasson et al., 2009; Marschner and Kalbitz, 2003). However, the amount of DOM mineralized in soil is only one-sixth to one-third of that mineralized in solution (Kalbitz et al., 2005). Thus, to reflect the actual DOM biodegradability in soil and to eliminate the possible priming effect, a ^{14}C labeling approach was used. The fate of ^{14}C labeled DOM in paddy and upland soils was investigated under three moisture levels. Our objectives were to (1) quantify DOM fate: mineralization to CO_2, incorporation into microbial biomass, and that remaining in the soil solution during 100-day incubation; (2) identify the fast and slow degradable components to clarify the dynamic DOM mineralization in paddy and upland soils; and (3) analyze how the DOM fate responds to the moisture conditions in paddy and upland soils.

2. Materials and methods

2.1. Soils

Typical upland and paddy soils (ultisol) within the same geomorphic unit developed from a quaternary red-earth sediment parent material were sampled from a site (29°15′N, 111°31′E) located in Taoyuan County, in the center of a subtropical hilly region of China. The site has an annual mean temperature of 16.5 °C and an annual rainfall of 1230 mm. Major crops grown in the paddy and upland soils are double rice and peanut-rape rotation, respectively.

Soil samples (0–20 cm depth) were collected in November (crop-free period). Then, samples were sieved (<2 mm) and visible plant residues were removed. Each sample was divided into two parts: 1) for preparing the ^{14}C labeled DOM solution as described below and 2) for incubation experiments to measure the DOM-^{14}C distribution. The soil samples were stored at 4 °C before use. The main soil properties are shown in Table 1.

2.2. Preparation of ^{14}C-DOM

We attempted to obtain ^{14}C labeled DOM as similar as possible to the field DOM. To do so, rice plant materials were harvested after being grown in a continuous $^{14}CO_2$ atmosphere for 60 days (Ge et al., 2012). Further details are given in Supplementary information. The rice plant material was dried at 60 °C, weighed, and cut to <5 mm (39.67% C and 2.18% N). Samples of dried plant materials (150 g) were mixed with 30 g fresh paddy soil or upland soil at a ratio of 5:1 (w/w). Next, the mixture of paddy soil was adjusted to anaerobic conditions by over flooding, whereas the mixture of upland soil was adjusted to aerobic conditions. The two types of samples were individually incubated in sealed 20-L plastic jars with 2 L water at the bottom to maintain 100% humidity in the dark at 25 °C for 30 days. Each jar also contained a cup of 400 mL 2 M NaOH to trap the $^{14}CO_2$. The 20-L jars were opened for 5 min each day to maintain adequate aeration. At the end of the incubation period, the soil samples were extracted two times after fumigation (Wu et al., 1990) using ultra-pure water (mixture of soil and plant material to water ratio of 1:10, w/v) by shaking for 1 h (150 r/min) and were filtered through Whatman No. 42 filter papers. The filtrate was collected and concentrated using a rotary vacuum evaporator at 30 °C for 7 days. The final concentrated solution (about 500 mL for each soil type) was then centrifuged for 10 min at 13,600 $\times g$ at 4 °C (Hitachi, Himac CR 22GII/Rotor, R20A2). The supernatant solution containing the ^{14}C labeled DOM was stored at −18 °C for two weeks. Before use, the DOM solution was thawed and filtered through Whatman No. 42 filter papers. Then, the organic C in the DOM solution was analyzed by an automated total organic carbon (TOC) analyzer (Phoenix 8000, USA). To determine whether the prepared ^{14}C labeled DOM was similar to the field DOM, the UV absorbance at 280 nm (E_{280}, Shimadzu UV-2450, Shimadzu Corporation, Kyoto, Japan) was used to estimate its aromaticity (Kalbitz et al., 2003). Before the UV measurements, the C concentration of DOM was adjusted to 10 mg L^{-1}. The properties of the DOM solution were determined and the results are shown in Table 2.

2.3. Experimental setup

Soil samples were adjusted to 40% of the field water-holding capacity (40% WHC) and were conditioned in the dark at 25 °C for 7 days before incubation. After the organic C content in the DOM solution was determined by a TOC analyzer (Phoenix 8000, USA), the ^{14}C labeled DOM solution was instantly added to the corresponding paddy and upland soil samples to give 300 mg DOM-C kg^{-1} soil.

This study consisted of two experiments. Experiment 1 focused on the mineralization of DOM-^{14}C to $^{14}CO_2$. Experiment 2 was used to determine the DOM-^{14}C incorporation into microbial biomass and the ^{14}C activity remaining in the soil solution as DOM-^{14}C. Both experiments were conducted at three moisture levels 45%, 75%, and 105% WHC. Briefly, DOM at a concentration of 300 μg C g^{-1} soil was added to the soils that had been thinly spread on plastic sheets. Then, the soil was gently, but thoroughly mixed, and finally covered with another plastic sheet for 30 min. Each soil type was divided into three equal parts that were adjusted to 45%, 75%, and 105% WHC using sterile ultrapure water. Each treatment for both experiments contains four replicates.

For experiment 1, the replicate moist soil portions (each containing the equivalent of 50 g oven-dried soil) were weighed into 50-mL beakers. The beakers were separately placed in 1.1-L glass bottles with

Table 1
Physical and chemical properties of the soils.

Land use types	WHC (%)	pH	Organic C (g kg^{-1})	N (g kg^{-1})	C/N ratio	MBC (mg kg^{-1})	C in DOM (mg kg^{-1})	E_{280} of DOM
Paddy	45.1	5.1	13.5	1.7	7.9	412.7	69.0	0.035
Upland	37.9	5.5	10.1	1.3	7.5	368.2	86.4	0.049

Note: E_{280}, UV absorbance of 10 mg L^{-1} DOM-C at 280 nm.

Table 2
General properties of the ^{14}C labeled DOM.

Origins	Radioactivity (Bq μg^{-1}C)	pH	E_{280}	Organic C (mg mL^{-1})	C/N ratio
Paddy soil	0.66	5.84	0.036	5.35	6.83
Upland soil	0.75	6.71	0.049	4.77	8.19

Note: See Table 1 for E_{280}.

10 mL water and a cup containing 20 mL 1 M NaOH (Wu and Brookes, 2005; Schneckenberger et al., 2008). At the same time, two beakers containing 40 mL deionized water without soil served as blanks for scintillation counting and CO_2 analysis. For experiment 2, moist soil (containing the equivalent of 600 g oven-dried soil) was weighed into 700-mL plastic cups. The cups were placed in a 25-L sealed plastic jar with 2 L water and a cup containing 400 mL 1 M NaOH to trap the CO_2 to prevent ^{14}C release.

All bottles and jars were opened for 5 min at 5-day intervals to maintain adequate aeration during the incubation. After 2, 5, 10, 20, 40, 60, 80, and 100 days of incubation, the vials containing NaOH were removed for $^{14}CO_2$ analysis and were replaced with a fresh cup (experiment 1), and the soils were stirred well and removed to measure the amounts of DOM-^{14}C incorporation into the microbial biomass and that remaining in the soil solution (experiment 2).

2.4. Analytical methods

The activity of $^{14}CO_2$-C trapped in NaOH was determined by mixing 1 mL of NaOH solution with 9 mL liquid scintillation cocktail (Beckman Coulter, Fullerton, CA, USA), and ^{14}C radioactivity was counted using an automated liquid scintillation counter (LS-6500, Beckman) for 5 min. The counting efficiency was determined as 95–98%. Scintillation counting data (expressed in counts per minute) were automatically corrected for counting efficiency by using the external standardization technique and an instrument-stored quench curve generated from a series of sealed quenched standards (Wu et al., 2013).

Microbial biomass was measured by the fumigation–extraction method (Wu et al., 1990). Briefly, portions of wet soil (equivalent of about 20 g of oven-dried soil) were fumigated by exposing the soil to alcohol-free $CHCl_3$ vapor for 24 h in a vacuum desiccator. The residual $CHCl_3$ was removed by vacuuming 3–8 times, each for about 5 min. Then, the fumigated and non-fumigated soils were extracted with 80 mL of 0.5 M K_2SO_4 by shaking at 250 rpm for 30 min. The suspensions were filtered through Whatman No. 42 filter papers. Organic C in the extracts was analyzed by an automated TOC analyzer (Phoenix 8000, USA), and ^{14}C activity by liquid scintillation counting as described above. The ^{14}C activity in microbial biomass was the ^{14}C level in the K_2SO_4 extracts from the fumigated soil minus that from the non-fumigated soil, using a conversion factor of 0.45 (Wu et al., 1990). The ^{14}C activity remaining in the soil DOM solution was that determined in the K_2SO_4 extracts of non-fumigated soil.

Organic C in the soil was measured by a K_2CrO_7–H_2SO_4 oxidation procedure, and total N by the Kjeldahl method (Bremner, 1965). Soil WHC was measured using percolation tests. pH was determined with distilled water in a ratio (soil:water) of 1:2.5 (w/v) using a pH meter.

2.5. Calculation of the DOM-^{14}C distribution between the pools

2.5.1. DOM-^{14}C distribution in pools

The distribution of DOM-^{14}C was calculated as a percentage of the initial activity. During incubation, three pools of the initial DOM-^{14}C were monitored, including mineralization to $^{14}CO_2$, incorporation into the microbial biomass and the remaining DOM-^{14}C activity in the soil solution. Biodegradability of the DOM was indicated by the cumulative $^{14}CO_2$ released by DOM-^{14}C mineralization (Kalbitz et al., 2003).

2.5.2. Dynamics of DOM mineralization

Based on the assumption that the initial ^{14}C labeled DOM is a mixture of fast and slow mineralized components, we fitted a double exponential model with two distinct pools (Kalbitz et al., 2003; Qualls and Bridgham, 2005). Curves were fitted using the quasi-Newton algorithm.

$$\text{Mineralized DOM-}^{14}\text{C} = (100-a)\left(1-e^{-k_1 t}\right) + a\left(1-e^{-k_2 t}\right)$$
$$t_{1/2} = \ln 2/k$$

where, t: time (day); a: fast mineralized DOM = labile DOM (%); $(100 - a)$: slow mineralized DOM = refractory DOM (%); k indicates k_1 or k_2; k_1 and k_2: mineralization rate constants of the labile and refractory components (day^{-1}), respectively; and $t_{1/2}$: half-life of the labile or refractory components (day).

2.5.3. Statistics

The experiments were conducted with four replicates. All data in the figures are the means ± standard deviations. The significance of the differences between the two soil types at the same moisture level or the differences among three moisture levels for the same soil type during the incubation were analyzed through one-way ANOVA at a significance level of $p < 0.05$ using a statistical software package (IBM SPSS Statistics 16.0). The figures were created using Origin 8.0.

3. Results

3.1. Properties of soils and of DOM

The water holding capacity (WHC), organic C, N content, C/N ratio, and microbial biomass carbon (MBC) content of the paddy soil were higher than in the upland soil (Table 1). In contrast, the C content in DOM and the pH were higher in the upland soil than those in the paddy soil (Table 1).

The E_{280} values for the prepared ^{14}C labeled DOM were notably close to that extracted from the respective soils under field conditions. E_{280} values were relatively lower in the paddy soil than those in the upland soils (Tables 1, 2). This indicates that the prepared ^{14}C labeled DOM is similar to the field DOM and its composition is less complex in the paddy soil than that in the upland soil.

3.2. DOM-^{14}C distribution in pools depending on the soil moisture

Generally, the mineralization rate of DOM-^{14}C rapidly decreased in the first 20 days, decreased slowly between 20 and 60 days and remained relatively stable after 60 days for all treatments (Fig. 1(a, b)). During the incubation, the cumulative $^{14}CO_2$ release in the paddy soils was significantly higher than that from the upland soils (Fig. 1(a, b)) ($p < 0.05$). At the end of the incubation, 41.9–60.0% of the initial DOM-^{14}C in the paddy soils was mineralized, whereas only 28.7–35.7% was mineralized in the upland soils (Fig. 2). Consequently, at any of the moisture levels, the mineralization of initial DOM-^{14}C to $^{14}CO_2$ was higher in the paddy soils than that in the upland soils. The cumulative $^{14}CO_2$ release was significantly higher at the high WHC of 75% and 105% than that at the low WHC (45%) ($p < 0.05$) (Fig. 1(a, b), Fig. 2).

After 100 days, 8.8–9.4% and 2.4–11.0% of the initial DOM-^{14}C activity were recovered in microbial biomass in the paddy and upland soils, respectively. Generally, the percentage of DOM-^{14}C incorporation into the microbial biomass in the paddy soils was higher than in the upland soils during 0–60 days of incubation at both 75% WHC and 105% WHC ($p < 0.05$) (Fig. 1 (c, d)). Although the DOM-^{14}C incorporation into microbial biomass increased with the moisture of paddy soil during 0–80 days of incubation, the moisture did not significantly affect the DOM-^{14}C incorporation into microbial biomass at the end of the incubation

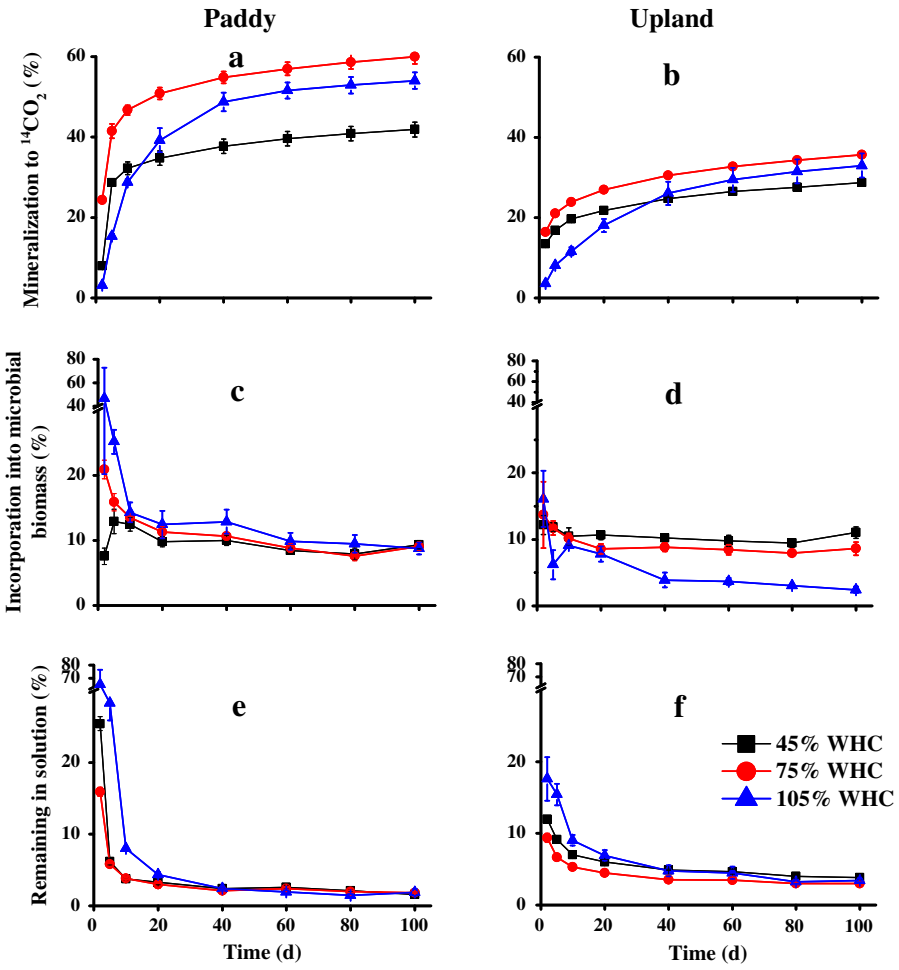

Fig. 1. Distribution of initial DOM-^{14}C in three pools including mineralization to $^{14}CO_2$ (a, b), incorporation into microbial biomass (c, d) and remaining in solution (e, f) during the incubation. Note: Vertical bars indicate the standard deviations of the means.

(Fig. 1(c), Fig. 2). In the upland soils, however, the DOM-^{14}C incorporation into microbial biomass significantly decreased with increased moisture ($p < 0.05$) (Fig. 1(d), Fig. 2).

At the end of incubation, less than 4% of the initial DOM-^{14}C activity remained in the soil solution in all treatments. After 10 days, in particular, the ^{14}C activity remaining in the solution at the same moisture level was significantly lower in the paddy soils than in the upland soils ($p < 0.05$) (Fig. 1(e, f), Fig. 2). And, the same trend was observed at any of the moisture levels after 20 days (Fig. 1(e, f), Fig. 2). During the first 20 days of incubation, the ^{14}C activity in solution was the

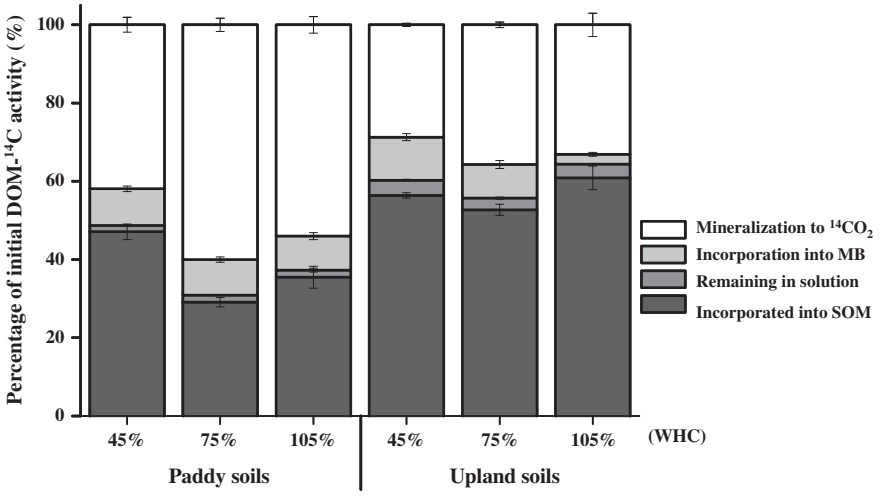

Fig. 2. Distribution of initial DOM-^{14}C in different pools at the end of 100-day incubation. Note: MB means microbial biomass. Values represent the mean ± SD of four replicates. Vertical bars indicate the standard deviations of the means.

Table 3
Results of the kinetic analysis of the ^{14}C labeled DOM.

Parameter	Paddy (WHC)			Upland (WHC)		
	45%	75%	105%	45%	75%	105%
Labile component						
a (%)	34.3	48.3	49.2	19.4	23.7	23.9
k_1 (day^{-1})	0.2385	0.3510	0.0793	0.5054	0.5126	0.0596
$t_{1/2}$ (day)	2.9	2.0	8.7	1.4	1.4	11.6
Refractory component						
100-a	65.7	51.7	50.8	80.6	76.3	76.1
k_2 (day^{-1})	0.0013	0.0028	0.0010	0.0014	0.0019	0.0013
$t_{1/2}$ (day)	533	248	693	495	365	553
R^2	0.95[a]	0.99[a]	0.99[a]	0.97[a]	0.97[a]	1.00[a]

Note: a% and (100 − a)% indicate the labile and refractory components in initial ^{14}C labeled DOM, respectively, expressed as percentages; k_1 and k_2 are the decomposition rate constants of labile and refractory component, respectively; $t_{1/2}$ is the half-life; and DR is the decomposition resistance. R^2 reflects the imitative effect.
[a] Indicates the ^{14}C activity remaining in the soil was adequately ($p < 0.001$) described using a two-component exponential decay model.

highest at 105% WHC for both soils ($p < 0.05$) (Fig. 1 (e, f)). However, the soil moisture did not affect the ^{14}C activity in the same agricultural soil solution after 20 days (Fig. 1 (e, f)).

Under simulated field conditions, the cumulative mineralization of initial DOM-^{14}C in the paddy soil (105% WHC) was approximately two times higher than that in the upland soil (45% WHC) up to 100 days of incubation. A reverse trend was found for the ^{14}C activity in the soil solution ($p < 0.05$) (Fig. 1 (a, b, e, f), Fig. 2). Generally, the DOM-^{14}C incorporation into microbial biomass was highest under the simulated field conditions for both soils (105 and 45% WHC) during the incubation but was not significantly different between the two agricultural soils.

3.3. Labile and refractory DOM depending on soil moisture

Two-component exponential decay model fits the data well (Table 3). 23.7% to 49.2% of the initial ^{14}C labeled DOM were labile components (Table 3). More labile components were found in the paddy soils (34.3–49.2% of the initial ^{14}C labeled DOM) compared with those in the upland soils (19.4–23.9%). The k_1 values of the labile components with a half-life ($t_{1/2}$) of 1 to 12 days were higher than those in the refractory components. In contrast, the k_2 values of the refractory components were two orders of magnitude lower (half-life of 248–693 days).

DOM decomposition rates (k) were highly dependent on the soil moisture (Table 4). The soil moisture had three main effects. First, the percentages of labile component in both soils were higher at intermediate and high moisture (75% WHC and 105% WHC) than those at low moisture (45% WHC) (Table 3). By analysis of the relationship between the water content and the decay rate constants (k) of ^{14}C labeled DOM, we determined that the moisture conditions at 56 to 75% WHC were favorable to DOM decomposition (Table 4). Second, the half-lives ($t_{1/2}$) of both the labile and refractory components (100 − a) in both soils were highest at 105% WHC, intermediate at 45% WHC, and lowest at 75% WHC (Table 3). Third, the $t_{1/2}$ of both the labile and refractory components and the proportion of labile components in the paddy soil (105% WHC) were higher than those in the upland soil (45% WHC) under simulated field conditions (Table 3).

4. Discussion

4.1. Biodegradability of the DOM depending on land-use and soil moisture

We could confirm that mineralization strongly contributed to the losses of DOM in the agricultural soil used in our study, as already described in a previous investigation (Kalbitz et al., 2003). The percentages of DOM-^{14}C mineralized during 100 days in the paddy soils (41.9–60.0% of the initial DOM-^{14}C activity) were approximately 1.5 times higher than those in the upland soils (Fig. 1(a, b)). This demonstrated that the extent and the rate of DOM biodegradation were closely related to its properties (Kalbitz et al., 2003). As indicated by the E_{280}, the DOM composition from the paddy soils had less aromatic and complex compounds than that from the upland soils (Tables 1 and 2). Additionally, the proportion of labile DOM components could reflect the trend of DOM mineralization (Sanderman and Amundson, 2008). The labile components in DOM in the paddy soils were approximately two times higher than those in the upland soils (Table 3), leading to the higher mineralization. At the end of incubation, the percentages of DOM-^{14}C mineralized were obviously higher than the portions of labile components in all treatments (Fig. 2, Table 3). This implies that a portion of refractory components were also mineralized.

Similar to previous observations (Craine and Gelderman, 2011), SOM mineralization in the typical subtropical soils was at a maximum at intermediate moisture (56–75% WHC) (Fig. 2) because of the high biological activity in the presence of both O_2 and water (Falkengren-Grerup and Tyler, 1993). DOM mineralization in the paddy soil was more affected by moisture than that in the upland soil (Fig. 1 (a, b), Fig. 2). This may result from the discrepancies of the hydrophobicity and hydrophilicity of DOM in the paddy and upland soils. Generally, DOM extracted from the paddy soils is more hydrophilic compared to that from the upland soils (Imai et al., 2001; Dai et al., 2004). The hydrophilic fractions of soil organic matter are more sensitive to moisture changes than the hydrophobic fractions (Janhom et al., 2007). In addition, the microbial communities in the paddy and upland soils responded differently to moisture (Stres et al., 2008). The biodegradability of DOM strongly depends on soil moisture (Kalbitz et al., 2000) because only soluble substances can be used by microorganisms (Kuzyakov, 2010).

4.2. DOM distributions depending on the land-use and soil moisture

It is generally accepted that sorption of low-molecular organic compounds to the soil matrix is one of the main fates of DOM, in addition to decomposition to CO_2 and incorporation into microbial biomass (Fischer and Kuzyakov, 2010; Guggenberger and Kaiser, 2003; Kögel-Knabner et al., 2010). Thus, the "incorporated into SOM" C in

Table 4
Relationship between the water content and the decay rate constants of ^{14}C labeled DOM.

DOM components	Land use types	Correlative equation	R^2	Maximum of k	When k is maximum	
					Water content	$t_{1/2}$ (day)
Labile component	Paddy	$y = -1.7165x^2 + 2.3459x - 0.488$	0.8636	0.3135	68% WHC	2.2
	Upland	$y = -2.2092x^2 + 2.4753x - 0.1388$	0.9463*	0.5545	56% WHC	1.2
Refractory component	Paddy	$y = -0.0178x^2 + 0.0263x - 0.007$	0.9930**	0.0027	74% WHC	256.7
	Upland	$y = -0.006x^2 + 0.009x - 0.0015$	0.9659**	0.0019	75% WHC	364.8

Note: x, water content; y, decay rate constant of ^{14}C labeled DOM; R^2, coefficient of determination.
* $p < 0.05$.
** $p < 0.01$.

this study could be considered as C adsorbed on clay minerals and sesquioxides (Fig. 2).

The DOM in all of the treatments was rapidly transformed in the first 5 days: 1) the mineralization consumed 8.1–41.5% of the initial DOM-^{14}C activity (Fig. 1(a, b)) and represented 31.2–88.9% of the labile component within the first 5 days (data not shown); 2) 6.2–25.2% of the initial DOM-^{14}C was assimilated by microbial cells within the first 5 days (Fig. 1(c, d)), implying the fast DOM uptake by active microorganisms (Fischer and Kuzyakov, 2010); 3) only 5.8–28.3% of the initial DOM-^{14}C activity existed in the soil solution after 5 days (Fig. 1(e, f)).

During 5–60 days, ^{14}C activity in all pools changed slowly: the mineralization rate and the ^{14}C activity remaining in the solution decreased slowly, and the ^{14}C activity in microbial biomass fluctuated slightly. After 60 days, all of the three pools remained relatively steady. During this period, the ^{14}C activity remaining in the solution was consumed through mineralization and was replenished by soluble microbial metabolites and desorption.

During the incubation, the soil moisture had important effects on the distribution of ^{14}C labeled DOM. 1) Mineralization and adsorption had a reverse response to the soil moisture. For example, in accordance with previous studies, the optimal moisture condition (75% WHC) stimulated DOM mineralization (Wang et al., 2010) but may inhibit DOM adsorption (Fig. 2). 2) The simulated field moisture conditions (paddy soil at 105% WHC and upland soil at 45% WHC) were beneficial for the growth of microorganisms, as indicated by the high ^{14}C activity in microbial biomass (Fig. 1(c, d)). However, DOM mineralization is not controlled by the quantity of microorganisms (Fig. 1) (Kuzyakov et al., 2009), because the active microorganisms and the production of functional enzymes strongly depend on the external environment (Torsvik and Øvreås, 2002), especially on C availability. 3) Contrary to mineralization, the DOM-^{14}C incorporation into the microbial biomass in the upland soils was more affected by moisture than that in the paddy soils (Figs. 1, 2). Although the causes of this phenomenon are largely unknown, the composition of DOM (hydrophilic and hydrophobic fractions), clay content, redox potential and microbial activities (as reviewed by Kalbitz et al., 2000) from the two soil types affects the DOM dynamics under different moisture conditions. 4) Generally, the highest $t_{1/2}$ for both the labile and refractory components of DOM in both soils was at 105% WHC (Table 3), confirming that DOM storage in soil is longer under anaerobic conditions (Kalbitz et al., 2000). Low microbial activity (Fig. 1(c, d)) and precipitation of DOM by Fe^{2+} under anaerobic conditions may be the primary reasons (Kögel-Knabner et al., 2010; Nierop et al., 2002).

4.3. Why DOM content in paddy soil is less than in the upland soil?

Our study confirmed that in subtropical China, the DOM content in paddy soils is lower than that in upland soils (ultisol), although the SOC and microbial biomass C contents are much higher in paddy soils (Table 1) (Li et al., 2007; Li et al., 2008). The moisture condition partially leads to the less DOM content in the paddy soils because 1) the cumulative $^{14}CO_2$ release was significantly higher at 105% WHC (simulated paddy field condition) than that at 45% WHC (simulated upland field conditions) ($p < 0.05$) (Fig. 1(a, b), Fig. 2); 2) at any of the moisture levels, the mineralization of DOM-^{14}C was 1.2–2.1-fold higher in the paddy soils than that in the upland soils (Fig. 1(a, b)). However, moisture condition was not the key factor in determining the lower DOM in the paddy soils than that in the upland soils because 1) at any of the moisture levels, DOM remaining in the solution was significantly lower in the paddy soils than that in the upland soils after 20 days; 2) DOM remaining in the same agricultural soil solution was not significantly different among the three moisture levels after 20 days (Fig. 1(e, f)).

Based on our data, three intrinsic reasons may contribute to the lower DOM content in the paddy soils: 1) compared to the upland soils, less complex DOM and more labile components resulted in more DOM mineralization in the paddy soils at any of the moisture levels (Fig. 1, Tables 1, 2 and 3); 2) absorbed DOM (incorporated into SOM) was significantly lower in the paddy soils than that in the upland soils (Fig. 2), suggesting weaker capability of DOM protection by adsorption in paddy soils (Kaiser and Guggenberger, 2000); 3) the longest $t_{1/2}$ was observed at 105% WHC, suggesting that DOM-^{14}C could exist longer as stable SOC in the paddy soil (105% WHC) compared to that in the upland soil (45% WHC) under simulated field moisture conditions (Table 3). These results suggest that the intrinsic discrepancy of the components and structure of DOM controls the processes of mineralization and adsorption, and may thereby lead to the difference in DOM content between these two agricultural soils.

5. Conclusions

Our results demonstrate that moisture strongly controls the fate of DOM. DOM mineralization depends more on moisture in the subtropical paddy soils than that in the upland soils. The incorporation of DOM into the microbial biomass exhibits the reverse trend. However, moisture was not the key factor in determining the lower DOM in the paddy soils than that in the upland soils because 1) at any of the moisture levels, DOM remaining in the solution was significantly lower in the paddy soils than that in the upland soils and 2) DOM remaining in the same agricultural soil solution was not significantly different among the three moisture levels after 20 days. The less complex and more labile components of DOM in the paddy soils resulted in higher DOM mineralization at any of the moisture levels, and thus probably contribute to the lower DOM in the paddy soils than that in the upland soils.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2014.04.071.

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