Dear editor and reviewers:

We appreciate your diligent review of our manuscript and the comments to the purposes. We believe your question is an appropriate and critical comment to improve this manuscript.

We have carefully read your comments and learned a lot from them.

We believe that editor and reviewers' comments on methods, statistics, tables and figures and language through the text are very important to improve this manuscript. We have had cautious answers and improved all the parts according your advices that help us further strengthen the paper. Please find details below and in the revised manuscript as well.

After these, we believe we have a pleasant communication with editor and reviewers about the manuscript, hope your further comments on this study.

Let us say thank you for your hard work again!

Sincerely yours,

Wen–Jun Zhou, Yi–Ping Zhang, Li-Qing Sha and all the co-authors

#1 Answer to the first referee

Major comments

1. there were several issues, affecting on the quality of this manuscript: The most important issue was the statistical testing: the use of one-way Anova seems to be not really appropriate for this kind of time-series data. I would suggest using a linear mixed model with repeated measures. Missing or unbalanced data are usually no problem for this kind of analyses.

Answer: *Thanks for your valuable suggestion.*

We detected $\delta^{13}C_{DOC}$ *of every mixed samples of rainfall, throughfall, litter leachate, and soil water at 20cm depth sepeartely. We got only* $\delta^{13}C_{DOC}$ *data of each kind sample for every ANALYSIS time.Tthat is mean, the data did not satisfied with the repeated measurement analyzing of the linear mixed model with repeated measures Otherwise, we just want to detect the difference between hydrological processes in* $\delta^{13}C_{DOC}$ *in the rainy season and dry season separately, so one way nova analysis was used in this manuscript.*

2 The second point is that, although the authors made some statistical testing, it hardly was shown anywhere. Please show the results, either in a table or incorporated into the text.

Answer: *Thanks for your kind suggestion. We have added statistic results in the table as below.*

Table 2 DOC δ^{13}C dynamics along the hydrological processes (R, rainfall, TF, throughfall, LL, litter leachate) and the δ^{13}C in leaves, litter, and surface soil in the tropical rainforest at Xishuangbanna, southwest China

Season	R	TF	LL	Soil water (0–20 cm)	Leaves	Litter	Soil (0–20 cm)
Rainy season	–23.9 ±3.3[a]	–28.7 ±1.7 [bc]	–28.1 ±2.7 [bc]	–23.9 ±1.6 [a] *	–32.4 ±0.6[d]	–30.4 ±0.2[cd]	–27.3 ±0.1[b]
Dry season	–23.8 ±1.3[a]	–29.1 ±1.6 [bc]	–28.1 ±1.5 [bc]	–27.1 ±2.2[b]	–32.5 ±0.5[d]	–30.2 ±0.1[cd]	–27.3 ±0.1[bc]

R indicates rainfall, TF indicates throughfall, LL indicates litter leachate, SW20 indicates soil water at a depth of 20 cm.

Different superior letters indicate significant differences between the treatments according to Lsd test ($P < 0.05$).

*indicates the significant seasonal difference according to independent sample t test ($p < 0.1$)

3 The third issue was that I was missing data on soil temperature and moisture. For example, it could be easily incorporated into Figure 2, as such.

Answer: *We have combined the soil temperature and moisture in Figure2 as your suggestion. Thanks.*

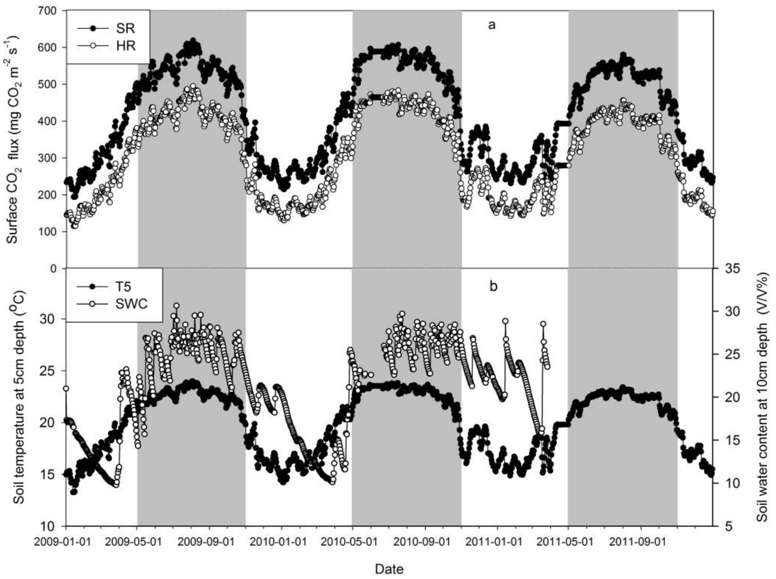


Figure 2 *Dynamics of soil respiration (SR) and heterotrophic respiration (HR) (a) and soil temperature at 5cm and soil water content at 10cm (b) in the tropical rainforest at Xishuangbanna, southwest China.*

The shaded area indicates the rainy season.

4 Finally, it was not clear to me how the authors calculated all the sensitivity indices.

Answer: *Firstly, weekly soil respirations fluxes, weekly average of soil temperature (T) and soil water content (SWC), weekly water and DOC fluxes were standardized by ratio of measured value to mean value during the observation period. Secondly, linear regression equitations was used* *between the standardized soil respirations values and T, SWC, water and DOC fluxes respectively. Thirdly, we considered the slope of the linear regression as the sensitivity indices which showed the soil respirations variation rate with soil temperature, soil water content, water and DOC fluxes changing.*

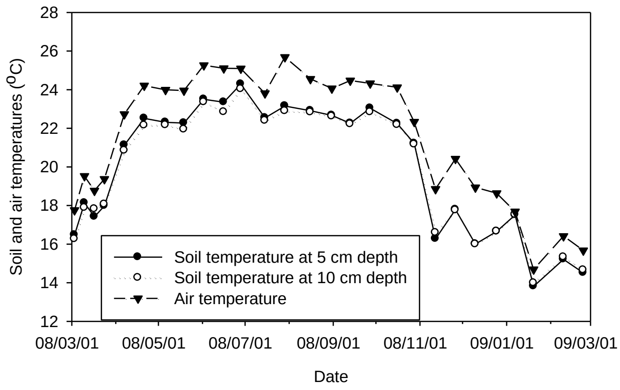
More detailed comments:

1) Lines 24–28: this sentence is not easy to understand for the reader. Line 24: “role” could be changed to “effect”. Line 25: “in” could be changed to “on” . Line 27: what processes do you mean? .Line 28: what do you mean by “surface soil”?

Answer: *Thanks, We have revised lines 24-28 according to your comments, as the following “To better understand the effect of the dissolved organic carbon (DOC) transported by hydrological processes (throughfall, litter leachate, and surface soil water (0–20 cm)) on soil respiration in tropical rainforests, we detected the DOC flux in rainfall, throughfall, litter leachate, and surface soil water (0–20 cm), compared the seasonality of $\delta^{13}C_{DOC}$ in each hydrological process, and $\delta^{13}C$ in leaves, litter, and surface soil, and analyzed throughfall, litter leachate, and surface soil water (0–20 cm) effect on soil respiration in a tropical rainforest in Xishuangbanna, southwest China.”*

2) Figure S2: why there is a gap in the temperature data? No data is presented between 18 and 21 degrees?

Answer: We observed soil respiration every 2 weeks, this may lead a gap of soil temperatures during the spare time. According to the original field data, there were not data observed from 18.2 to 21.0 as the following Answer-Figure1 showed.



Answer-Figure1 Dynamics of air and soil temperature at 5cm and 10 cm depths during soil respiration observation period in the tropical rainforest at Xishuangbanna, southwest China.

#2 Answer to the second refree

Major comments

1 One is about the sensitivity index. We know that soil respiration increases with increasing temperature, and Q10 is widely used to determine the temperature sensitivity. The authors developed similar sensitivity index for soil respiration to water fluxes, DOC fluxes and soil water content. I believe that these kinds of sensitivity index are useful when comparing them among different sites, as is the Q10. However, I don't think we can compare among the temperature sensitivity, soil water content sensitivity, water flux sensitivity, DOC flux sensitivity within the same site, because they are different parameters and the units for each parameter are different. Thus the authors need to provide the rationales for these comparisons, otherwise the conclusions stated by lines 35 to 38 are different to stand.

Answer: *Thanks for your significant comments and suggestion on the sensitivity indices. In order to be able to evaluate the sensitivity of soil respiration towards soil temperature, soil water content, water and DOC fluxes to soil respirations in tropical , we have standardized all the parameters by the ratio of measured value to the means of the observation period. And consider the slop of linear regression between soil respiration and soil temperature, soil water content and water and DOC fluxes as the sensitivity indies. In this way, we compared sensitivity of soil respirations to all of these parameters which originally have different unit.*

2 The other concern is about the importance of DOC. DON input from throughfall accounted for about 7% of the net ecosystem C exchange. However, it may be even minor when compared to soil respiration. So it needs to not overstate the importance of DOC in C budget. The phrase of "key" in the abstract (line 32) and throughout the manuscript may be not proper, to my point of view. It may be better to use "important" instead "key".

Answer: *thanks for your advise, we use the "important" for all the description of DOC role the text.*

Specific comments:

1) Line 96, in a tropical forest;

Answer: *This sentence was revised to "Our study was performed in a tropical rainforest at Xishuangbanna in southwest China, on the northern edge of a tropical region." As your suggestion.*

2) Line 124, how large is your study plot?

Answer: *We have added the plot area as the following description "At the study plot (a 23.4 ha catchment)".*

3) Line 127, "the" may be not necessary;

Answer: *Thanks for your careful suggestion, we have deleted "the" in this sentence and revised to "To sample throughfall, litter leachate, and soil water (20 cm depth), four groups of replicate collectors were set for each of these measurements."*

4) Line 179, 2 to 6 mg? what standards were used to calibrate the measured values for plant and soil samples, as well as for DOC samples?

Answer: *We revised the sample weights to"1.00-3.00 mg plant samples and 10-40 mg soil sample dried and sieved through 100 mesh size "according to the analyzing original records.*

We used low organic soil standard (CatNo.B2153) for soil and DOC and wheat flour standard (CatNo.B2157) for plant sample determination of $\delta^{13}C$ respectively. The standards were certified in Organic Analytical Standard (IAS/OAS) at Elemental Microanalysis Ltd(Oakhampton, Devon, UK).

5) Line 291, the contribution of HR to total soil respiration was 72%, which is in higher than many reports for forests? Is this normal?

Answer: *Hanson et al (2000) showed heterotrophic respiration is about 54% of total soil respiration* *globally. The ratio is 30-83% of the total soil respiration in temperature and tropical forests(Behera et al,1990; Epron et al 1999, Tomotsune et al, 2013) and 7-50% in boreal forest (*Matsushita,2015). *So HR contributed 72% of the total soil respiration of this research is in the higher level compared to the research in the global.*

Behara, N., Joshi ,S. K., Pati, D. P.: Root contribution to total soil metabolism in a tropical forest soil from Orissa, India, Forest Ecology and Management. 36: 125–134, 1990.

Epron, D., Farque, L., Lucot, E., Badot, P-M.: Soil CO_2 *efflux in a beech forest: the contribution of root respiration, Ann For Sci. 56: 289-295,1999.*

Hanson, P., Edwards, N., Garten, C. & Andrews, J. Separating root and soil microbial contributions to soil respiration: a review of methods and observations, Biogeochemistry. 48, 115–146,2000.

Matsushita,K., Tomotsune, M., Sakamaki, Y., Koizumi,H.: Effects of management treatments on the carbon cycle of a cool-temperate broad-leaved deciduous forest and its potential as a bioenergy source, Ecological Research. 30(2): 293-302,2015.

Tomotsune, M., Yoshitake, S., Watanabe, S., Koizumi, H. (2013). Separation of root and heterotrophic respiration within soil respiration by trenching, root biomass regression, and root excising methods in a cool-temperate deciduous forest in Japan. Ecological Research, 28, 259-269.

6) Line 299, sensitivity of soil respiration to soil moisture has not shown in Fig S2.

Answer: *Thanks for your reminder, we added this in FigS2 as following*

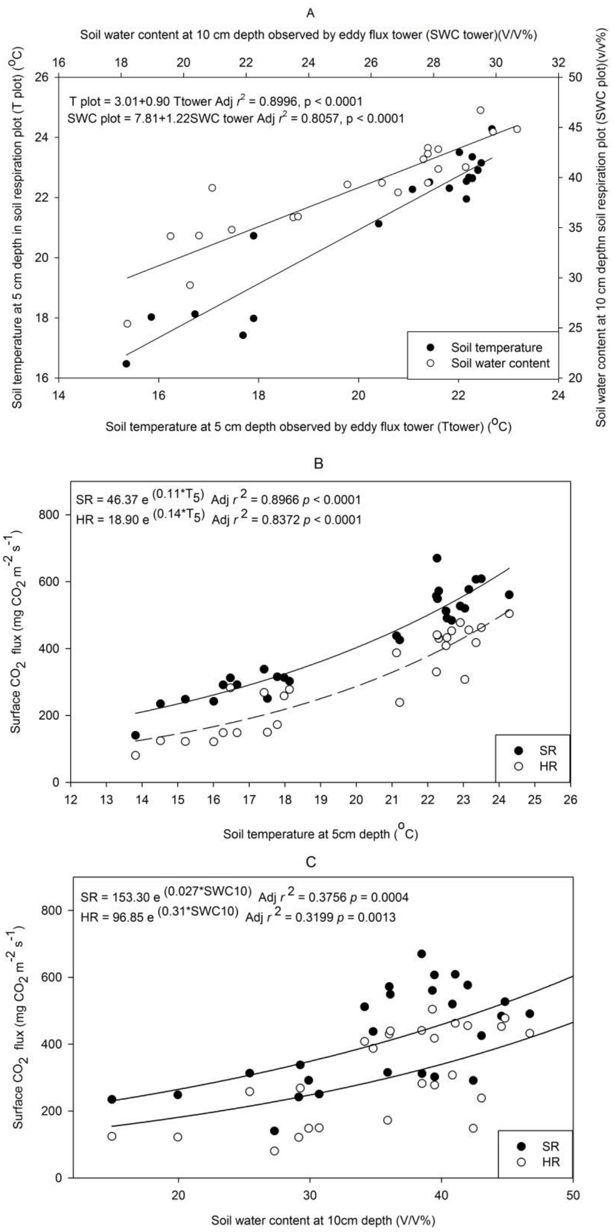


Figure S2 Correlation between soil temperature and soil water content of CO_2 from eddy flux tower explained during soil respiration observation plot from Feb. 2008 to Jan. 2009 (a), soil respiration and temperature at 5 cm depth (b), and soil water content at 10 cm depth (c) in the tropical rainforest at Xishuangbanna, southwest China

7) Line 309-310, how did you calculate DOC-flux-dependent sensitivity indices for SR (3.62) and HR (5.12)? These numbers are not shown in Table 2.

Answer: *We calculated all the hydrological processes DOC-flux-dependent sensitivity as the mean ± standadr deviation for both SR and HR accdording to the new methods.*

8) Table 1, it is better to have significance test for the differences between rainy and dry season.

Answer*: Thanks, We have added the statistic results in the table which has been changed to Table 2 between rainy and dry season and between hydrological processes.*

Table 2 DOC δ^{13}C dynamics along the hydrological processes (R, rainfall, TF, throughfall, LL, litter leachate) and the δ^{13}C in leaves, litter, and surface soil in the tropical rainforest at Xishuangbanna, southwest China

Season	R	TF	LL	Soil water(0–20 cm)	Leaves	Litter	Soil (0–20 cm)
Rainy season	–23.9±3.3[a]	–28.7±1.7[bc]	–28.1±2.7[bc]	–23.9±1.6[a] *	–32.4±0.6[d]	–30.4±0.2[cd]	–27.3±0.1[b]
Dry season	–23.8±1.3[a]	–29.1±1.6[bc]	–28.1±1.5[bc]	–27.1±2.2[b]	–32.5±0.5[d]	–30.2±0.1[cd]	–27.3±0.1[bc]

R indicates rainfall, TF indicates throughfall, LL indicates litter leachate, SW20 indicates soil water at a depth of 20 cm.

Different superior letters indicate significant differences between the treatments according to Lsd test ($P < 0.05$).

*indicates the significant seasonal difference according to independent sample t test ($p < 0.1$)

2. Lines 52 and 54: first you state that laboratory studies have shown, later you write: however, most studies have been performed in the laboratory.

带格式的

Answer: *Thanks for your kind reminding, we revised this sentence as "Laboratory studies have shown that DOC also plays a key role in SR in the surface soil (De Troyer et al., 2011, Fröberg et* *al., 2005, Qiao et al., 2013). However the mechanisms underlying the effects of DOC on the carbon budget and SR in the field remain unclear."*

3. Line 66: do you mean both in terms of absolute and relative numbers?

Answer: *Yes. We have clarify it in the textto "Because of the massive rainfall in tropical rainforests, more DOC flux is transported to the soil by throughfall and litter leachate than in other forests."*

4. Line 118: do you have any additional tree data, like age or tree density?

Answer: *Yes, we hav*e.and revised it as following" The dominant trees are Terminalia myriocarpa and Pometia tomentosa, which are typical tropical forest trees. Canopy height is about 45m, the land cover ratio is 100%, there are 311 species that diamater at breast height (DBH) is larger than 2cm (Cao et al., 1996)."

5. Line 137: how long were the tubes?

Answer*: The tube is about 3 meters for avoiding the disturbance from sampling on surface soil and litter layer.*

6. Line 156: you removed the roots?

Answer*: We did not remove the roots. But we set trenched treatment before soil respiration measured 3 months, and let the died roots decomposed in the trenched treatments.*

7. Line 198: how often they occurred during the dry season?

Answer: *Water sampling frequency depended on each hydrological progresses occurred frequency. If there was rainfall events, then we got rainfall sample in the next day, and the same to throughfall, litter leachate and soil water samples.*

8. Line 221: how this was calculated? Weekly divided by 7?

Answer: *We calculated the weekly (7 days) water and DOC flux by summed up the daily water and DOC flux respectively.*

9. Lines 221–224:from this sentence it is not entirely clear, what was compared to what

***Answer**: To clarify the meaning, we revised this sentence to "nonlinear regression tests was used to simulate tee correlations between daily water flux and DOC concentration , between SR, HRand soil moisture, and soil temperature."*

10. Line 259: is this annual average?

***Answer:** Yes, it was.*

We also revised this sentence to "The highest annual interception rate was between the litter leachate and the surface soil (63.85 ± 7.98%)" . Thanks.

11. Lines 256–269: how about putting interception values into a table for better comparison?

***Answer**: Thanks, we have filled the water and DOC flux interception values in Table 1as following.*

Table 1 The interception rate of the water between hydrological processes in the tropical rainforest at Xishuangbanna southwest China

	Interceptation	Annual	Rainy season	Dry season
Water flux	Between TF and R	53.9 ±11.7	43.1 ±2.7	41.3 ±14.8
	Between LL and TF	33.9 ±6.6	33.9 ±9.8	34.1 ±27.6
	Between SW20cm and LL	63.8 ±8.0	62.2 ±15.1	81.6 ±23.3
DOC flux	Between TF and R	137.0 ±19.9	182.0 ±16.0	170.8 ±7.8
	Between LL and TF	1.1 ±17.0	16.1 ±9.4	12.7 ±4.3
	Between SW20cm and LL	-96.7 ±4.4	-93.9 ±2.6	-94.4 ±1.2

.

12. Lines 272–287: somehow I could not follow all these differences from table 1

***Answers**: Thanks, we have added all the statistic results in this table.*

13. Line 292: this is already discussion, please move it there

***Answers:** Thanks, we have removed it.*

14. Lines 304–308: it was not clear to me how you calculated the sensitivity indices

***Answers**: Here we have recalculated it according the third referee's comments, please see the calculated details in the answer for question 4.*

15. Fig.s1: what about a possible dilution effect, resulting in lower doc with more water?

***Answer:** Yes, there were some dilution effect on DOC concentration as the follows regression equations used for the water flux and DOC concentration ($Y = ae^{bx}$)*

$C_{TF} = 48.69e^{-0.097x}$ *adjusted* $r^2 = 0.3883, p = 0.002$ (2)

$C_{LL} = 60.93e^{-0.048x}$ *adjusted* $r^2 = 0.4131, p < 0.001$ (3)

$C_{sw} = 6.78e^{-0.02048x}$ *adjusted* $r^2 = 0.5840, p < 0.001$ (4)

where C_{TF}, C_{LL}, *and* C_{sw} *are the DOC concentrations (mg* L^{-1}*) in the throughfall, litter leachate, and soil water (0–20 cm), respectively, and x is the water flux per day (mm).*

#3 Answer for the third refree

Major comments

1 The authors found that there was clear seasonal variability in soil respiration, increasing in rainy season and decreasing in dry season. The variation of soil respiration strongly correlated with soil temperature, more than those with soil moisture content and water fluxes. Does this mean seasonal variation from rainy season to dry season was clearer in soil temperature than in soil moisture content and water fluxes? Since rainy and dry season is generally defined by the amount of precipitation, it is hard to understand why the seasonal variation of soil respiration was explained by temperature, not water relating factors. The author should add the seasonal data of these explanatory factors in Fig. 2 to show how it looks like and also check the auto-correlation between them.

***Answer:** 1)Thanks, we have added the dynamics figure of soil temperature at 5cm and soil water content at 10cm depth as Fig2b.*

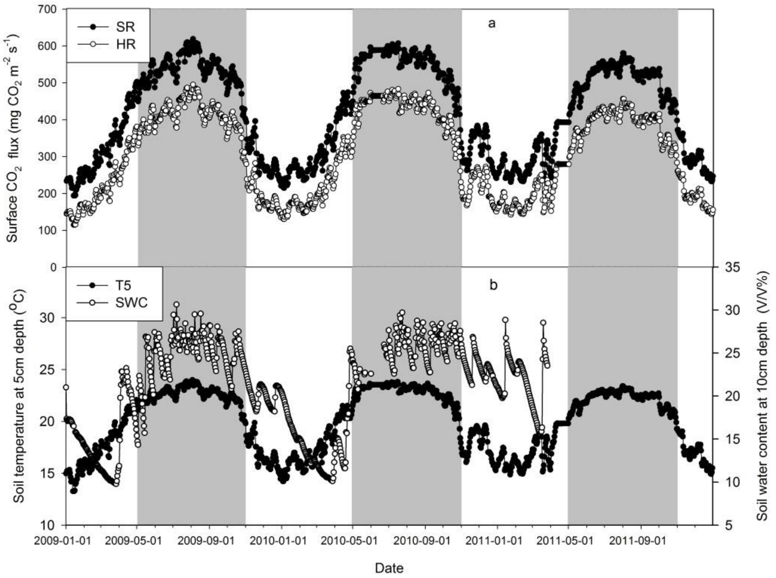


Figure 2 *Dynamics of soil respiration (SR) and heterotrophic respiration (HR) (a) and soil temperature at 5cm and soil water content at 10cm (b) in the tropical rainforest at Xishuangbanna, southwest China. The shaded area indicates the rainy season.*

2) We have checked the correlation between soil temperature at 5cm depth (T5) and soil water content at 10 cm (SWC10) showed SWC10 = 1.38+1.00 T5 (r^2 = 0.3293, $p < 0.0001$), this indicated soil temperature at 5cm depth explained 32.93% soil water content. This showed soil temperature was not all in covariance with soil water content(Fig 2b). This can induce that soil respiration is in the similar dynamic with soil temperature. While with the water input, soil microbe will be influenced by soil water content and DOC- the more activity C fraction, thus, water input also contributed to the good correlation between soil temperature and soil respiration which can proved by table 3.

2 The are no information how many locations where soil moisture content was measured. Since spatial heterogeneity of soil moisture content is very high in tropical forest ecosystem, certain amount of replicate is necessary.

Answer: *Thanks, we have detected 30 chambers(5 trench plots×3 chambers + 5 control plots ×3 chambers) soil moisture and soil temperature.*

3 It is questionable whether the sensitivity of soil respiration can be compared between

the different explanatory variables that has different ranges of variation. I think the range of seasonal variation have to be standardized to compare the sensitivity of SR between different variables.

Answer: *First of all, thanks for your question of great insight. We have standardized all the parameters and recalculated the sensitive indices as the following steps: Firstly, weekly soil respirations fluxes, weekly average of soil temperature (T) and soil water content (SWC), weekly water and DOC fluxes were standardized by the ratio of measured valueto the mean value during the observation period. Secondly, linear regression equitation was used between the standardized soil respirations values and T, SWC, water and DOC fluxes respectively. Thirdly, we considered the slope of the linear regression as the sensitivity indices which showed the soil respirations variation rate with soil temperature, soil water content, water and DOC fluxes changing.*

We also have explained this in the caculation and statistic in method.

Specific comments

1) Line 102, relative high: What means “relatively”? With do you compare?

Answer: *Thanks, this sentence is confused, so we revised it to “We hypothesized that throughfall and litter leachate DOC flux are important in carbon budget” with more clear expression.*

2) Line 128: It is unclear how many replicate each group has.

Answer: *Each group has a throughfall, a litter leachate, and a soil water (20 cm depth) collectors in each group, so there are 4 replicates for every hydrological processes. We revised this sentence to “To sample throughfall, litter leachate, and soil water (20 cm depth), four groups of replicate collectors were set for each of these measurements” to “There were four replicates of throughfall, litter leachate, and soil water (20 cm depth) respectively. All the collectors were set around the eddy flux tower randomly.”*

(3) Line 155, in the soil of tropical rainforests: Reference is needed.

Answer: *Thanks, we have added the reference in the text and the reference list.*

(4) Line 158: You just mentioned the information of gas analyzer. Please explain how you measured

soil respiration using the analyzer.

Answer: *The soil respiration was measured using a Li-820 system (Li-Cor Inc., Lincoln, NE, USA), which consisted of an infrared gas analyzer with a polyvinyl chloride chamber(diameter of 15cm and height of 15.0 cm). A polyvinyl chloride collar(diameter of 15cm an height of 5cm) was installed in the forest floor to a depth of ~3 cm. All the leaf litter and small branches were left in the collar. Soil respirations were detected from 09:00 to 14:00 local time when was taken to represent respiration in that day (Sha et al. 2005, Yao et al. 2011).*

We have revised it in the method.

(5) Line 298 sensitivity indices: I recommend you to explain this in the Calculation and statistics.

Answer: Thanks, we have added it in the calculation and statistics details.

"*In order to evaluate the variation of soil temperature, soil water content, water and DOC fluxes to soil respirations in tropical, we have standardized all the parameters by the measured value sub the means of the observation period. And consider the slope of linear regression between soil respiration and soil temperature, soil water content and water and DOC fluxes as the sensitivity indices. In this way, we compared sensitivity of soil respirations to all of these parameters."*

(6) Line 422-429: This is a repeat of previous sentences.

Answer: *We have deleted these lines.*

Hydrologically transported dissolved organic carbon influences soil respiration in a tropical rainforest

Running title: DOC influences soil respiration

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Keywords:

Dissolved organic carbon (DOC), Soil temperature, Soil water content, Soil respiration, Tropical rainforest

Paper type:

Primary research articles

Abstract

To better understand the role effect of the dissolved organic carbon (DOC) transported by hydrological processes (rainfall, throughfall, litter leachate, and surface soil water (0–20 cm)) in on soil respiration in tropical rainforests, we measureddetected: (1) the DOC flux in rainfall, throughfall, litter leachate, and surface soil water (0–20 cm), (2) compared the seasonality of $\delta^{13}C_{DOC}$ in each hydrological process, and $\delta^{13}C$ in leaves, litter, and surface soil, and (3)analysed throughfall, litter leachate, and surface soil water (0–20 cm) effect on soil respiration in a tropical rainforest in Xishuangbanna, southwest China. Results showed: The surface soil intercepted 94.4 ± 1.2% of the annual litter leachate DOC flux and is a sink for DOC. The throughfall and litter leachate DOC fluxes amounted to 6.81% and 7.23% of the net ecosystem exchange, respectively, indicating that the DOC flux through hydrological processes is an key important component of the carbon budget, and may be a keyn important link between hydrological processes and soil respiration in a tropical rainforest. The difference in $\delta^{13}C$ between the soil, soil water (at 0–20 cm), throughfall, and litter leachate indicated that DOC is transformed in the surface soil. Even Tthe variability in soil respiration is more dependent on the hydrologically transported water than DOC flux insignificantly, than on the soil temperature and soil water content (at 0–20 cm),). and The difference in $\delta^{13}C$ between the soil, soil water (at 0–20 cm), throughfall, and litter leachate indicated that DOC is transformed in the surface soil and decreased the senstivity indices of soil respiration of DOC flux to water flux,is more sensitive to the soil water DOC flux (at 0–20 cm) than to the soil temperature, which suggests that soil respiration is more sensitive to the DOC flux in hydrological processes, especially the soil water DOC flux, than to soil temperature or soil moisture.

1. Introduction

Dissolved organic carbon (DOC), the most active form of fresh carbon, stimulates microbial activity and affects CO_2 emissions from the surface soil (Bianchi, 2011, Chantigny, 2003, Cleveland *et al*., 2006). This indicates that the proportion of DOC that leaches from the soil is a crucial component of the carbon balance (Kindler *et al*., 2011, Stephan *et al*., 2001), which is also estimated as the high ratio of DOC flux to net ecosystem exchange (NEE) in forests, grasslands, and croplands (Sowerby *et al*., 2010). The DOC from water-extractable soil carbon is regenerated quickly and functions as an important source of substrate for soil respiration (SR), especially microbial heterotrophic respiration (HR) (Cleveland *et al*., 2004, Jandl and Sollins, 1997, Schwendenmann and Veldkamp, 2005), which contributes more to SR than does autotrophic respiration. Laboratory studies have shown that DOC also plays an ~~key~~ important role in SR in the surface soil (De Troyer *et al*., 2011, Fröberg *et al*., 2005, Qiao et al., 2013). However~~, most studies have been performed in the laboratory, and~~ the mechanisms underlying the effects of DOC on the carbon budget and SR in the field remain unclear.

Hydrological processes that transport DOC, such as throughfall and litter leachate, are important sources of DOC in surface soil water (De Troyer *et al*., 2011, Kalbitz *et al*., 2000, Kalbitz *et al*., 2007, Kindler *et al*., 2011). The soil retains most of the DOC that reaches the soil surface from the throughfall and litter leachate (Chuyong *et al*., 2004, Dezzeo and Chacón, 2006, Liu and Sheu, 2003, Liu *et al.*, 2008, McJannet *et al.*, 2007, Schrumpf *et al.*, 2006, Zimmermann *et al.*, 2007). Qiao et al. (2013) suggested that the addition of labile organic carbon increases the decomposition of the native soil organic carbon (SOC) by exerting a priming effect, and augments the CO_2 emissions in subtropical forests. Because of the massive rainfall in tropical rainforests, more DOC flux is transported to the soil by throughfall and litter leachate than in other forests. The high temperature and leaching in tropical forests may mean that the fresh DOC from hydrological processes affects SR differently in tropical rainforests than in boreal and temperate forests (De Troyer *et al.*, 2011, Fröberg *et al.*, 2005, Qiao *et al.*, 2013). For this reason, research into the role of hydrologically transported DOC in the SR in tropical rainforest is essential.

The fate of DOC intercepted by the surface soil can be determined from variations in the DOC flux and $\delta^{13}C_{DOC}$ among soil water, soil, litter leachate, and throughfall. Based on the seasonal and source (canopy leaf, litter, or soil) differences in $\delta^{13}C$ (De Troyer *et al.*, 2011), $\delta^{13}C_{DOC}$ studies have shown that DOC transported from aboveground water and from the desorption of soil aggregates is retained in the surface soil by soil absorption or is involved in surface carbon biochemical dynamics through soil water leaching and microbiological activity (Comstedt *et al.*, 2007, De Troyer *et al.*, 2011, Fang *et al.*, 2009, Kindler *et al.*, 2011). This proposal has been confirmed in a laboratory leaching experiment simulating a temperate forest, as performed by Park *et al.* (2002), who reported that the cumulative amount of CO_2 evolved is positively related to the availability of carbon (Park *et al.*, 2002).

Furthermore, fresh DOC fed to the surface soil influences soil CO_2 emissions in both the short term (3–14 days) and long term (month to years) (Davidson *et al*., 2012). Therefore, several models of the surface soil carbon efflux indicate that DOC is a factor that influences CO_2 emissions (Blagodatskaya *et al.*, 2011, Guenet *et al*., 2010, Yakov, 2010) based on recent research with controlled experiments. However, the natural mechanism underlying the effects of the hydrologically transported DOC flux on CO_2 emissions remains unclear. The precipitation rate, NEE, and litterfall are all high in tropical forests (Tan *et al*., 2010, Zhang *et al*., 2010), and several studies have shown that DOC plays an important role in the carbon balance in these settings (Fontaine *et al.*, 2007, McClain *et al.*, 1997, Monteith *et al.*, 2007). Here, we investigate the relative contribution of hydrologically transported DOC to SR in a rainforest compared with the contributions of soil temperature and moisture, which has not been extensively studied until now.

Our study was performed in a tropical rainforest at Xishuangbanna in southwest China, on the northern edge of a tropical region. This forest has less annual rainfall (1557 mm), a smaller carbon sink (1667 kg C ha^{-1}) (Tan *et al*., 2010, Zhang *et al*., 2010), lower SR (5.34 kg CO_2 m^{-2} yr^{-1}) (Sha et al., 2005), and less litterfall (9.47 ± 1.65 Mg C ha^{-1} yr^{-1}) (Tang *et al*., 2010) than typical rainforests of the Amazon and around the equator. We hypothesized that ~~the ratio of~~ throughfall and litter leachate DOC flux ~~to NEE is~~ are important in carbon budget~~relatively high~~, and that hydrologically transported DOC significantly affects SR in the tropical rainforest at Xishuangbanna. To test these hypotheses, we determined the SR, HR, and DOC fluxes in the rainfall, throughfall, litter leachate, and surface soil water (0–20 cm depth), the seasonal variability in $\delta^{13}C$ (isotopic abundance ratio of ^{13}C) in DOC ($\delta^{13}C_{DOC}$) and in the carbon pools in the soil, litter, and canopy leaves in this tropical forest.

2 Materials and methods

2.1 Study site

The study site is located at the center of the National Forest Reserve in Menglun, Mengla County, Yunnan Province, China (21°56′N, 101°15′E), and has suffered relatively little human disturbance. The weather in the study area is dominated by the north tropical monsoon and is influenced by the southwest monsoon, with an annual average temperature of 21.5 ℃, annual average rainfall of 1557 mm, and average relative humidity of 86%. Based on the precipitation dynamics, the rainy season occurs between May and October (with 84.1% of the total annual precipitation) and the dry season between November and April.

The dominant trees are *Terminalia myriocarpa* and *Pometia tomentosa*, which are typical tropical forest trees. Canopy height is about 45m, the land cover ratio is 100%, there are 311 species that diamater at breast height (DBH) is larger than 2cm (Cao *et al*., 1996). The topographic slope is 12 °–18 °, and the soil type is oxisol, formed from Cretaceous yellow sandstone, with a pH of 4.5–5.5 and a clay content (d < 0.002 mm) of 29.5% in the surface soil (0–20 cm) (Tang *et al*., 2007).

2.2 Experimental set-up

At the study plot (a 23.4 ha catchment), three rainfall collectors were set above the canopy on a 70 m eddy flux tower to collect rain samples. Each collector had a polytetrafluoroethylene (PTFE) funnel (2.5 cm diameter) connected to a brown glass bottle, which was rinsed with distilled water before each collection. There were four replicates of ~~To sample the t~~throughfall, litter leachate, and soil water (20 cm depth) respectively. All the collectors were set around the eddy flux tower randomly. ~~, four groups of replicate collectors were set for each of these measurements.~~ All the collectors were distributed randomly around the eddy flux tower. The throughfall collectors were 200 × 40 cm^2 V-shaped tanks made of stainless steel. A PTFE tube connected the collector to a polyethylene sampling barrel. The litter leachate was collected in 40 cm × 30 cm × 2 cm PTFE plates. In the plate, we layered 100-, 20-, and 1-mesh silica sand from the bottom to the upper edge, to a depth of 2 cm, to ensure that the litterfall fragments did not reach the bottom of the plate and to filter the leachate. The bottom of the plate was curved into an arc shape, causing the leachate to flow together at the bottom funnel. The funnel was connected by a PTFE tube to a 10 L bottle further down the slope. The soil water collector was designed like the litter leachate collector. The collection system was buried in soil at a depth of 20 cm along the surface slope. To reduce the disturbance from digging as much as possible, all the soil collectors were placed in holes that were approximately the size of the PTFE collector, and all soil was added from the bottom to the surface, layer by layer. All the soil water and litter leachate collectors were set in place 3 months before the samples were collected, to minimize the influence of their installation.

The water fluxes from rainfall and throughfall were estimated with an installed water-level recorder. The recorder was set to measure the average discharge at 30 min intervals. The daily and biweekly water fluxes from rainfall and throughfall were calculated from the data recorded automatically between 08:00 and 08:00 on the following day (local time). The water fluxes from the litter leachate and soil water were determined daily by manual observation.

We set four 5 m × 5 m plots around the eddy flux tower to measure SR and HR using the trenching method. In each plot, three paired trenches and control treatments were used to detect both HR and SR. Each treatment covered an area of 50 × 50 cm^2. Most fine roots occur in the first 0–20 cm of soil and few occur below a depth of 50 cm in the soil of tropical rainforests. In each trenched treatment, a polyvinyl chloride panel was installed, and a 50-cm-deep trench was filled with *in situ* soil to protect root respiration during the trenching treatment.

The soil respiration was measured using a Li-820 system (Li-Cor Inc., Lincoln, NE, USA), which consisted of an infrared gas analyzer with a polyvinyl chloride chamber(diameter of 15cm and height of 15.0 cm). A polyvinyl chloride collar (diameter of 15cm an height of 5cm) was installed in the forest floor to a depth of ~3 cm. All the leaf litter and small branches were left in the collar. Soil respirations were detected from 09:00 to 14:00 local time when was taken to represent respiration in that day (Sha et al. 2005, Yao et al. 2011) biweekly from February 2008 to February 2009.

Surface respiration was determined with an Li-820 CO_2 Analyzer (LI-COR, Lincoln, NE, USA). From February 2008 to February 2009, SR was detected biweekly between 10:00 and 13:00 (local time) (Sha et al., 2005).

Soil temperature and moisture

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From 2008 to 2011, Ssoil temperature and moisture at a depth of 5 cm were measured every 15 min with a Campbell Scientific data logger (Campbell Scientific, North Longan, Utah, USA) which was fixed to the eddy flux tower. The daily average soil temperature and moisture were calculated as the daily means of the data collected every 15 min.

During soil respiration observation period between February 2008 and January 2009, soil water content (0–12 cm) was detected by time-domain reflectometry (TDR100, Campbell Scientific, USA) in the soil close to every chamber. At the same time, the soil temperature (0–10 cm) and the air temperature were recorded with a needle thermometer.

Soil, leaf, and litter sampling

Soil (0–20 cm depth) near the soil water collectors, and leaf samples and litter samples from around the water collector were collected in August and October, 2010, and in January, March, and May, 2011. The leaves of the dominant species were randomly picked from the canopy around the plots, and litter samples were collected from around the plots. Soil samples were collected with a steel foil soil sampler (diameter = 5 cm, height = 20 cm). All the leaf and litter samples were oven-dried to constant weight at 60 ℃. After drying, the leaf and litter were ground and passed through a 1 mm screen. Wind-dried soil was manually broken by hand and sieved (100 mesh) to remove larger particles, roots, and visible soil fauna. Plant and soil samples were analyzed for total C and $\delta^{13}C$ values with an elemental analyzer (Elementar vario PYRO cube, Germany) coupled to an continuous flow system isotope ratio mass spectrometer (IsoPrime 100 Isotope Ratio Mass Spectrometer, Germany, EA-MS). Samples (0.21.00-3.00 mg plant samples and 10-40 mg-0.600mg soil sample dried and sieved through 100 mesh size) were wrapped in a tin boat and loaded into the auto-sampler (EA3000, Eurovector, Milan, Italy) coupled to the EA-IRMS. The sample was flash combusted in a combustion reactor held at 1120℃. The produced CO_2 was separated by the CO_2 absorption column, and carried by helium to ion source for measurements. The reference CO_2 (>99.999%) flowed in at 420 seconds and lasted for 30 seconds. The isotopic results are expressed in standard notation ($\delta^{13}C$) in parts per thousand (‰) relative to the standard Pee Dee Belemnite:

$$\delta^{13}C = [{}^{13}R_{sample}/{}^{13}R_{standard} - 1] \times 1000 \qquad (1)$$

where R is the molar ratio ${}^{13}C/{}^{12}C$.

2.3 Water sampling and analysis

All the 24 h cumulative water samples were collected at the sampling sites between 08:00 and 10:00 (local time), following the procedure outlined by Zhou et al. (2013), using high-density polyethylene bottles. The sampling bottles were completely filled, allowing no headspace. After the bottles were washed with 3% HCl solution, they were rinsed with distilled water. Before sample collection, the bottles were pre-rinsed three times with the sample water. The study was performed over three full calendar years, from January 1, 2009, to December 31, 2011. The water samples were collected on the day following a rain event during the dry season and once a week during the rainy season in 2009, and once a week in 2010 and 2011. All the water samples were immediately transported to the laboratory in insulated bags to prevent DOC decomposition.

Based on the analytical method of Zhou *et al*. (2013), all the samples were vacuum-filtered through a 0.45 μm glass fiber filter (Tianjinshi Dongfang Changtai Environmental Protection Technology, Tianjin, China) and were pre-rinsed with deionized water and the sample water under vacuum. The filtered samples were analyzed for DOC within 24 h of collection using a total organic carbon/total nitrogen (TOC/TN) analyzer (LiquiTOC II, Elemental Analyses System GmbH, Germany). To analyze the water DOC isotopic δ^{13}C-DOC ($\delta^{13}C_{DOC}$), the samples were collected on the same day as the leaves, litter, and 0–20 cm soil samples were collected. Subsamples (500 mL) of the rain, throughfall, litter leachate, and soil water samples were passed through a 0.45 μm glass fiber filter and transferred to another 500 mL polyethylene terephthalate bottle. All the filtered water was frozen and placed in a freeze dryer until it was reduced to a fine powder. The δ^{13}C of the freeze-dried DOC was analyzed with a method similar to that for the plant and soil samples. Considering the lower C content, more sample amount (20-60mg) were weighted, the combustion temperature was set at 920℃, and the reference CO_2 flowed in at 475 seconds, laterer than for the soil and plant samples. The sample δ^{13}C abundance were calculated according to Eq (1).

2.4 Calculations and statistics

The correlations ~~between~~ among the daily water flux and DOC concentration, SR, HR, soil moisture, and soil temperature from February 2008 to January 2009, and the weekly SR and HR rates and the amounts of DOC and water in 2009–2011~~the following parameters~~ were tested with Pearson's correlation (two-tailed) and nonlinear regression tests.~~: the daily water flux and DOC concentration, SR, HR, soil moisture, and soil temperature from February 2008 to January 2009, and the biweekly SR and HR rates and the amounts of DOC and water in 2009–2011~~. One-way analysis of variance (ANOVA) was used to compare the hydrological DOC fluxes ~~and $\delta^{13}C_{DOC}$~~ among different hydrological processes. The seasonal difference of hydrological DOC fluxes, $\delta^{13}C_{DOC}$ was tested by independent sample t test. ~~The dry season and rainy season data were compared with a paired *t* test.~~ The SPSS 15.0 software was used for all calculations.

Because the individual correlations between the water flux and the DOC concentration in the throughfall, litter leachate, and soil water were significant (Fig. S1), the regression equations used for the water flux and DOC concentration ($Y = ae^{bx}$) were as follows:

$C_{TF} = 48.69e^{-0.097x}$ adjusted $r^2 = 0.3883$, $p = 0.002$ (2)

$C_{LL} = 60.93e^{-0.048x}$ adjusted $r^2 = 0.4131$, $p < 0.001$ (3)

$C_{sw} = 6.78e^{-0.02048x}$ adjusted $r^2 = 0.5840$, $p < 0.001$ (4)

where C_{TF}, C_{LL}, and C_{sw} are the DOC concentrations (mg L^{-1}) in the throughfall, litter leachate, and soil water (0–20 cm), respectively, and x is the water flux per day (mm). We did not collect all the individual rainfall events, throughfall, litter leachate, and soil water samples to analyze the DOC concentrations, but interpolated all the DOC concentrations and water fluxes according to eq(2)–(4).

The daily DOC flux was calculated as

$$F = CV/100 \quad (5)$$

where F is the daily DOC flux (kg C ha^{-1} d^{-1}), C is the DOC concentration (mg L^{-1}), and V is the water flux (mm d^{-1}) per day.

The biweekly carbon flux was calculated as the sum of the daily DOC fluxes.

Soil temperature and soil water content of eddy flux tower explained 89.96% and 80.57% dynamic of that of soil respiration observation plot from Feb. 2008 to Jan. 2009 respectively, and tThe correlations between soil temperature at a depth of 5 cm and both SR and HR were strong (Fig. S2) between February 2008 and January 2009. SR and HR during the period from January 1, 2009 to December 31, 2011 were calculated based on the equation $Y = ae^{bx}$ from the data collected between February 2008 and January 2009, as follows:

$$SR = 46.37e^{(0.11T5)} \quad r^2 = 0.8966, p < 0.0001 \quad (6)$$

$$HR = 18.90e^{(0.14T5)} \quad r^2 = 0.8372, p < 0.0001 \quad (7)$$

where SR is total soil respiration (mg CO_2 m^{-2} s^{-1}), HR is heterotrophic respiration (mg CO_2 m^{-2} s^{-1}), and T5 is soil temperature at 5 cm depth.

sensitivity indices caculations

Firstly, weekly soil respirations fluxes, weekly average of soil temperature and soil water content, weekly water and DOC fluxes were standardized by the ratio of measured valueto the mean value during the observation period. Secondly, linear regression equitation was used between the standardized soil respirations values and T, SWC, water and DOC fluxes respectively. Thirdly, we considered the slope of the linear regression as the sensitivity indices which showed the soil respirations variation rate with soil temperature, soil water content, water and DOC fluxes changing.

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3 Results

3.1 Water and DOC fluxes in a tropical rainforest

The seasonal and annual water fluxes decreased from the rainfall to the surface soil (Fig. 1a). The interception rate of the water between hydrological processes was higher in the dry season than in the rainy season (Fig. 1a, Table 1). The highest annual interception rate was between the litter leachate and the surface soil (63.85 ± 7.98%), which was 62.19 ± 15.07% in the rainy season and 81.64 ± 23.38% in the dry season. The seasonal dynamics of the DOC flux were similar to those of the water flux (Fig. 1, Table 1). The annual DOC flux increased from rainfall (41.9 ± 3.8kg C ha^{-1} yr^{-1}) to throughfall (113.5 ± 8.5 kg C ha^{-1} yr^{-1}) and to litter leachate (127.7 ± 8.5 kg C ha^{-1} yr^{-1}), and then decreased sharply to the surface soil at 0–20 cm (7.07 ± 1.4 kg C ha^{-1} yr^{-1}) (Fig. 1b). The surface soil intercepted most of the DOC coming from the previous layer (annual: 94.4 ± 1.2%, dry season: 96.7 ± 4.4%, rainy season: 93.9 ± 2.6%). That the interception rates for water and DOC were greatest in the surface soil indicates ~~that~~ the surface soil is the most important water and DOC sink in this tropical rainforest (Table 1).

3.2 Isotopic characteristics of DOC in the hydrological processes of a tropical rainforest

During the transfer of rainfall to soil water (0–20 cm), $\delta^{13}C_{DOC}$ was highest in the rainfall DOC and lowest in the throughfall DOC in both the rainy and dry seasons

(~~Table 1~~Table 2). The seasonal difference in $\delta^{13}C_{DOC}$ was highest in the surface soil water (3.25‰) and lowest in the litter leachate (0.11‰). From the litter leachate to the surface soil water, $\delta^{13}C_{DOC}$ increased significantly by 4.26‰ (p = 0.05) in the rainy season, but increased by only 1.12‰ (not significant, p = 0.39) in the dry season. $\delta^{13}C$ increased from the canopy leaves to the soil and did not differ significantly between seasons (~~Table 1~~Table 2).

In both the dry and rainy seasons, $\delta^{13}C_{DOC}$ in water was higher than $\delta^{13}C$ in the corresponding element (comparing throughfall with leaves, litter leachate with litter, and soil water with soil at 20 cm depth) (~~Table 1~~Table 2). The smallest difference between $\delta^{13}C_{DOC}$ and $\delta^{13}C$ in each compartment occurred between soil water DOC and soil carbon in the dry season, which was only 0.23‰. The greater difference between $\delta^{13}C_{DOC}$ and $\delta^{13}C$ in the rainy season than in the dry season for soil water and soil (~~Table 1~~Table 2) indicates that the biogeochemical dynamics of DOC are more active in the rainy season than in the dry season in soil.

3.3 Surface soil CO_2 flux dynamics in a tropical rainforest

In the tropical rainforest at Xishuangbanna, SR was dominated by HR (Fig. 2). HR contributed more to SR during the rainy season (76.8 ± 0.8%) than during the dry season (66.5 ± 0.5%), and the annual contribution of HR to SR was 71.7 ± 0.7%. ~~This indicates that HR is more important to the surface CO_2 flux than is root respiration.~~ SR and HR were higher in the rainy season than in the dry season, similar to the dynamics of the hydrological and DOC fluxes (Fig. 1).

Standrized Ssoil temperature explained 8998.07% and 8498.2.0% of the variation in standrized SR and HR, respectively, and standrized soil moisture explained 37.655.8% and 31.256.8% of the variation in standrized SR and HR, respectively (Table 2Table 3). The sensitivity indices of SR and HR for soil temperature at a depth of 10 cm were 3.000.56 and 4.060.46, respectively, whereas their sensitivity indices for soil moisture were 1.320.65 and 1.370.53, respectively, based on observational data (Table 2Table 3, Fig. S2).

3.4 Influence of DOC flux on soil CO_2 flux in a tropical rainforest

There were significant correlations between the mean standarized biweekly SR and HR and the standarized biweekly water fluxes and DOC fluxes through the hydrological processes (Table 2Table 3). Based on the definition of the temperature-dependent sensitivity index (Q_{10}) for Srsoil respirations, which is the increase slope in of standarized SR soil respirations caused by a 10 ℃ increase in standarized temperature, we also defined a soil-water-content-dependent sensitivity index, a DOC-flux-dependent sensitivity index, and a water-flux-dependent sensitivity index in this study, analogous to the temperature-dependent sensitivity index for SR (Table 2Table 3). An independent *t* test showed that the DOC-flux-dependent sensitivity indices for SR (3.62.72 ± 4.360.51) and HR (5.122.21 ± 7.120.42) were significantly higher lower than the water-flux-dependent sensitivity indices for SR (1.072.87 ±0.01952, F t = -8.912.68, *p* = 0.02406) and HR (1.092.33 ±0.02243, F t = -2.578.94, *p* = 0.02406), respectively, which indicates that SR and HR were more sensitive to the water flux ~~DOC flux~~ than to the DOC flux~~water flux~~ through the hydrological processes. ~~No~~ The significant difference was observed between the water-flux-dependent indices (t = 13.78, $p<0.001$) for SR (~~1.07~~2.87 ± 0.~~019~~52) and HR (~~1.09~~2.33 ± 0.~~022~~43), or between the DOC-flux-dependent indices (t = 13.12, $p<0.001$) for SR (~~3.62~~2.72 ±~~4.36~~0.51) and HR (~~5.1~~2.21 ±~~7.12~~0.42). The soil-water-content-dependent sensitivity indices for HR (0.53) and SR (0.65) were ~~higher~~ than the soil-temperature-dependent sensitivity indices (HR 0.46; SR 0.56),but less than all the water-flux-dependent and DOC-flux-dependent sensitivity indices~~, and smaller than the DOC-flux-dependent sensitivity indices~~ for SR and HR (~~Table 2~~Table 3). This indicates that SR and HR are more sensitive to the ~~DOC~~ hydrological water flux and DOC flux than to the soil water content and soil temperature. ~~The soil-temperature-dependent sensitivity indices for HR and SR were higher than all the water-flux- and DOC-flux-dependent sensitively indices, except the soil-water (0–20 cm) DOC-flux-dependent sensitivity index.~~ A comparison of the sensitivity indices for water flux, DOC flux, soil temperature, and soil moisture in all the hydrological processes reveals that SR and HR were most sensitive to the water ~~DOC~~ flux (3.70) dynamics which is a little higher than DOC flux (3.57) in the soil water (0–20 cm depth) when ~~bi~~weekly variations in the Xishuangbanna tropical rainforest were considered.

4 Discussion

Our results showed that the throughfall carried most of the DOC (113.5 ± 8.5 kg C ha^{-1} yr^{-1}) through the hydrological processes in the Xishuangbanna tropical rainforest, which amounted to 6.81% of the NEE (1.67 × 10^{3} kg C ha^{-1} yr^{-1}) (Tan e*t al*., 2010) in this tropical rainforest in southwest China. The litter leachate DOC (127.7 ± 8.5 kg) accounted for 7.23% of the NEE in this forest. This result indicates that the throughfall DOC is ~~a key~~an important component of the tropical rainforest carbon budget. The litter leachate fed a great deal of DOC to the soil, but the surface soil intercepted 94.4 ± 1.2% (127.7 ± 8.0 kg) of the DOC, and the surface soil water DOC flux was only 7.1 ± 1.4 kg C ha^{-1} yr^{-1}, which was slightly less than that at the headwater stream outlet (10.31 kg C ha^{-1} yr^{-1}) (Zhou *et al*., 2013). The surface soil intercepted the bulk of the litter leachate DOC and transported little DOC to the deep layer, indicating that the surface soil is the DOC sink in the tropical rainforest in Xishuangbanna.

The small seasonal differences in $\delta^{13}C_{DOC}$ in the rainfall, throughfall, and litter leachate indicate that the DOC in the aboveground water is seasonally stable (~~Table 1~~Table 2). However, $\delta^{13}C_{DOC}$ in the soil water (at 0–20 cm) was higher in the rainy season (3.25‰) than in the dry season, indicating that the DOC reaction in the surface soil is seasonal. In the dry season, $\delta^{13}C_{DOC}$ in the surface soil water (–27.1 ± 2.2‰) was similar to $\delta^{13}C_{DOC}$ in the soil (–27.3 ± 0.1‰), indicating that the soil is the major source of soil water DOC. This is attributable to the combined absorption effects of the high clay content (Fröberg, 2004, Lemma *et al*., 2007, Sanderman and Amundson, 2008, Tang *et al*., 2007) and the lack of water carrying DOC through the different compartments in the dry season. Therefore, most DOC is locally produced rather than transported. Less water and the lower DOC input from litter leachate and throughfall to the surface soil (Fig. 1) also contribute to a reduction in microbial activity, which contributes negligibly to the soil DOC when the soil moisture and soil temperature are low in the dry season (Wu *et al.*, 2009). In the rainy season, the soil water content and soil temperature are higher, so there is more vigorous biogeochemical activity in the surface soil (Bengtson and Bengtsson, 2007). Therefore, more DOC is released from the soil to be mineralized by microorganisms, and there is more ^{13}C in the soil water DOC ($\delta^{13}C$ = –23.9 ± 2.2‰) than in the soil ($\delta^{13}C$, –27.3 ± 0.1‰). The relatively low $\delta^{13}C_{DOC}$ in the litter leachate ($\delta^{13}C_{DOC}$ = –28.1 ± 2.7‰) compared with the soil water indicates that the DOC from the litter leachate has attended in the carbon cycle in the surface soil (Cleveland *et al.*, 2006, De Troyer *et al.*, 2011). Furthermore, most of the DOC from the throughfall, litter leachate, and litter was fed to the surface soil, and the soil water $\delta^{13}C_{DOC}$ value was higher than that of the throughfall, litter leachate DOC, and $\delta^{13}C$ soil (0–20 cm) values (~~Table 1~~Table 2). These data indicate that all the DOC transported by the throughfall and litter leachate was ultimately involved in the surface soil carbon cycle (Fröberg *et al.*, 2003, 2005, Kammer *et al.*, 2012), and has also contributed to the SR because it is an important part of the surface soil carbon cycle in the tropical rainforest at Xishuangbanna.

Laboratory-based studies of tropical forests have shown that DOC primes the soil CO_2 flux (Qiao *et al.*, 2013). A study of a temperate forest showed that the rate of DOC production is one of the rate-limiting steps for SR (Bengtson and Bengtsson, 2007). Comparative studies of ^{13}C and ^{14}C in DOC and SOC have also shown that fresh organic carbon stimulates the activity of old carbon, and increases the emission of CO_2 because DOC is the substrate of microbial activity (Cleveland *et al.*,2004, 2006, Hagedorn and Machwitz, 2007, Hagedorn *et al.*, 2004, Qiao *et al.*, 2013). Because the microbial biomass and potential carbon mineralization rates are higher in soils with higher DOC contents than in soils with lower DOC contents (Montaño *et al.*, 2007), the DOC turnover rate (Bengtson and Bengtsson, 2007) is rapid and the transformation period is short (3–14 days) (Cleveland *et al.*, 2006, De Troyer *et al.*, 2011). This indicates that DOC is involved in the surface soil carbon cycle in the short term by affecting SR (Cleveland *et al.*, 2004, 2006). Although we did not determine the period of the DOC turnover cycle, the ~~bi~~weekly DOC flux passing through the hydrological processes (throughfall, litter leachate, soil water, and interception by the surface soil) significantly explained SR and HR, with higher sensitively indices than the indices for the soil water content and ~~water flux~~soil temperature (~~Table 2~~Table 3), predicting that DOC has a significant impact on soil CO_2 emissions in this tropical rainforest.

~~The DOC-flux-dependent sensitivity indices for the different parts of the hydrological processes in this tropical rainforest were higher than the amount-of-water-dependent sensitivity indices, which shows that the DOC flux affects SR more significantly than the amount of water passing through the system, because of the combined effects of water and DOC on SR.~~

It is important to consider which part of the DOC flux in the hydrological processes of this tropical rainforest most strongly influences SR. Previous studies have shown that of all the factors affecting SR, it is most sensitive to soil temperature (Bekku *et al.*, 2003, Reichstein *et al*., 2003, Zheng *et al.*, 2009), as in the tropical forest at Xishuangbanna (Sha *et al.*, 2005). Although soil temperature better explained SR and HR than the DOC flux, the sensitivity indices for the soil water DOC fluxes were higher than the sensitivity indices for soil temperature, although temperature explained the rate of SR better than the DOC flux (~~Table 2~~Table 3). At this study site, HR, which depends predominantly on microbial activity and substrates, contributed the major fraction of SR (Fig. S2), so not only HR, but also SR depends most strongly on the microbial and respiratory substrates in this tropical rainforest. Therefore, the DOC transported by the forest hydrological processes, from litter decomposition, root exudates, and the soil itself, will contribute to SR (~~Table 1~~Table 2). The bioavailability of the DOC transported by hydrological processes is greater than that of SOC (De Troyer *et al*., 2011, Kindler *et al*., 2011). The DOC from throughfall and litter leachate is also an important contributor because $\delta^{13}C_{DOC}$ differs between the surface soil water and the litter leachate and throughfall (~~Table 1~~Table 2). Although ectotrophic mycorrhizae contribute significantly to SR in the rhizospheres of some temperate and boreal forests (Neumann *et al*., 2014; Tomè *et al*., 2016), in this tropical rainforest, EMF: *Paraglomus*, a kind of endomycorrhiza, occupies more than 90% of the mycorrhizal community (Shi, 2014). Together with roots, and root exudate, it contributes to the autotrophic SR, which is only 28.9% of the total SR, so the mycorrhiza is not the dominant contributor to SR in this tropical rainforest. The other details of the biogeochemical processes affecting DOC in the surface soil are not obvious in this study. However, according to both laboratory and field studies, the DOC intercepted by the surface soil clearly affects HR (~~Table 2~~Table 3), together with the DOC from litter decomposition and the soil itself (Cleveland *et al.*, 2004, 2006, Hagedorn and Machwitz, 2007, Hagedorn *et al.*, 2004, Jandl and Sollins, 1997, Keiluweit *et al.*, 2015; Montaño *et al.*, 2007, Qiao *et al.*, 2013, Schwendenmann and Veldkamp, 2005;). Considering the effect of DOC on SR, the surface soil water DOC is the most sensitive index of HR and SR (~~Table 2~~Table 3). ~~The details of the biogeochemical processes affecting DOC in the surface soil are not obvious in this study. However, according to both laboratory and field studies, the DOC intercepted by the surface soil clearly affects SR (Table 2), together with the DOC from litter decomposition and the soil itself (Cleveland *et al.*, 2004, 2006, Hagedorn and Machwitz, 2007, Hagedorn *et al.*, 2004, Jandl and Sollins, 1997, Montaño *et al.*, 2007, Qiao *et al.*, 2013, Schwendenmann and Veldkamp, 2005). Considering the effect of DOC on SR, the surface soil water DOC is the most sensitive index of HR and SR (Table 2).~~

The DOC-flux-dependent sensitivity indices for the different parts of the hydrological processes in this tropical rainforest were a little less but insignificant than the amount-of-water-dependent sensitivity indices, which shows that the DOC flux affects SR less than the amount of water passing through the system, because of the combined effects of water and DOC on SR. According the DOC significant contribution of soil respirations (Cleveland *et al.*,2004, 2006, Hagedorn and Machwitz, 2007, Hagedorn *et al.*, 2004, Qiao *et al.*, 2013), the little diference mechansisms between DOC and water flux of tropical rainforest should be declared in the future study.

This study demonstrates that the surface soil is a sink for the DOC transported by hydrological processes (Fig. 1), and that HR and SR are sensitive to the DOC flux through these processes. The most sensitive indicator of SR is the soil water ~~DOC~~ flux (at 0–20 cm) and floowed by soil water DOC flux, both exceeding the sensitivity of the soil temperature, soil water content, and other water flux, and DOC flux along all the hydrological processes (~~Table 2~~Table 3). The variations in δ^{13}C in DOC, soil, and plants also partly support the notion that the soil water DOC flux is the ~~most~~ more sensitive index of SR in this tropical rainforest. The results suggest that the DOC transported by hydrological processes plays the ~~most~~ more important role in the SR processes. In the context of global climate change, more attention must be paid to the contribution of hydrologically transported DOC in future studies of the mechanisms of SR.

Author contribution

W.-J. Zhou and D. Schaefer, H.-Z. Lu, Sha L-Q, Y.-P Zhang designed the experiments and W.-J. Zhou, H.-Z. Lu, Q.-H. Song, Y. Deng, X.-B. Deng carried them out. W-J Zhou prepared the manuscript with contributions from all co-authors.

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Table legends

Table 1 The interception rate of the water between hydrological processes in the tropical rainforest at Xishuangbanna southwest China

~~Table 1~~Table 2 DOC δ^{13}C dynamics along the hydrological processes (R, rainfall, TF, throughfall, LL, litter leachate) and the δ^{13}C in leaves, litter, and surface soil in the tropical rainforest at Xishuangbanna, southwest China

~~Table 2~~Table 3 Results of a regression analysis of the ~~bi~~weekly water flux, DOC flux, soil respiration (SR), and heterotrophic respiration (HR) along the hydrological processes (TF, throughfall, LL, litter leachate) in the tropical rainforest in Xishuangbanna, southwest China.

Figure captions

Figure 1 Amount of water (A) and DOC flux along the hydrological processes in the tropical rainforest at Xishuangbanna, southwest China.

Figure 2 Dynamics of soil respiration (SR) and heterotrophic respiration (HR) (a) and soil temperature at 5cm and soil water content at 10cm (b) in the tropical rainforest at Xishuangbanna, southwest China. The shaded area indicates the rainy season.

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	Interceptation	Annual	Rainy season	Dry season
Water flux	Between TF and R	53.9±11.7	43.1±2.7	41.3±14.8
	Between LL and TF	33.9±6.6	33.9±9.8	34.1±27.6
	Between SW20cm and LL	63.8±8.0	62.2±15.1	81.6±23.3
DOC flux	Between TF and R	137.0±19.9	182.0±16.0	170.8±7.8
	Between LL and TF	1.1±17.0	16.1±9.4	12.7±4.3
	Between SW20cm and LL	-96.7±4.4	-93.9±2.6	-94.4±1.2

R indicates rainfall, TF indicates throughfall, LL indicates litter leachate, SW20 indicates soil water at a depth of 20 cm.

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Table ~~1~~2

Season	R	TF	LL	Soil water (0–20 cm)	Leaves	Litter	Soil (0–20 cm)
Rainy season	–23.9 ±3.3[a]	–28.7 ±1.7[bc]	–28.1 ±2.7[bc]	–23.9 ±1.6[a] *	–32.4 ±0.6[d]	–30.4 ±0.2[cd]	–27.3 ±0.1[b]
Dry season	–23.8 ±1.3[a]	–29.1 ±1.6[bc]	–28.1 ±1.5[bc]	–27.1 ±2.2[b]	–32.5 ±0.5[d]	–30.2 ±0.1[cd]	–27.3 ±0.1[bc]

R indicates rainfall, TF indicates throughfall, LL indicates litter leachate, SW20 indicates soil water at a depth of 20 cm.

Different superior letters indicate significant differences between the treatments according to Lsd test ($P < 0.05$).

*indicates the significant seasonal difference according to independent sample t test ($p < 0.1$)

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Table 23

		SR				HR			
		a	b	R^2	*p*	a	b	R^2	*p*
DOC flux	T	0.56	0.54	0.987	<0.001	0.46	0.64	0.982	<0.001
	SWC	0.65	0.41	0.558	<0.001	0.53	0.52	0.568	<0.001
	R	2.31	-1.17	0.423	<0.001	1.86	-0.74	0.425	<0.001
	TF	2.36	-1.25	0.429	<0.001	1.91	-0.83	0.413	<0.001
	LL	2.71	-1.57	0.355	<0.001	2.21	-1.10	0.366	<0.001
	SW20	3.57	-2.23	0.227	<0.001	2.91	-1.62	0.240	<0.001
	LL-SW20	2.66	-1.53	0.352	<0.001	2.17	-1.07	0.363	<0.001
Water flux	R	2.42	-1.35	0.323	<0.001	1.96	-0.92	0.331	<0.001
	TF	2.55	-1.44	0.316	<0.001	2.06	-0.99	0.323	<0.001
	LL	3.02	-1.83	0.301	<0.001	2.46	-1.31	0.312	<0.001
	SW20	3.70	-2.34	0.166	<0.001	3.02	-1.71	0.178	<0.001
	LL-SW20	2.64	-1.54	0.257	<0.001	2.14	-1.08	0.267	<0.001

	Parameters		a	b	r^2	*P*	Sensitivity index
Water flux	TF	SR	354.80	0.0064	0.4271	<0.0001	1.07
		HR	252.17	0.0075	0.4178	<0.0001	1.08
	LL	SR	380.19	0.0058	0.2469	<0.0001	1.06
		HR	273.98	0.0068	0.2556	<0.0001	1.07
	LL-SW20	SR	375.65	0.0095	0.2525	<0.0001	1.10
		HR	269.67	0.0112	0.2469	<0.0001	1.12
	SW20	SR	404.49	0.0062	0.1194	<0.0001	1.06
		HR	294.92	0.0073	0.119	<0.0001	1.08
DOC flux	TF	SR	341.71	0.0441	0.4681	<0.0001	1.55
		HR	240.71	0.0524	0.459	<0.0001	1.69
	LL	SR	355.26	0.0316	0.4061	<0.0001	1.37
		HR	251.47	0.0405	0.3971	<0.0001	1.50
	LL-SW20cm	SR	355.00	0.0336	0.4021	<0.0001	1.40
		HR	251.47	0.0402	0.3971	<0.0001	1.49
	SW20	SR	392.50	0.2318	0.2053	<0.0001	10.16
		HR	284.09	0.276	0.276	<0.0001	15.80
	T5	SR	46.37	0.11	0.89	<0.0001	3.00
		HR	18.90	0.14	0.84	<0.0001	4.06
	swc	SR	153.30	0.0274	0.3756	0.0004	1.32
		HR	96.85	0.0314	0.3199	0.0013	1.37

Equations used to calculate the sensitivity indices: sensitivity index = $e^{(10b)}a$, where b is the parameter

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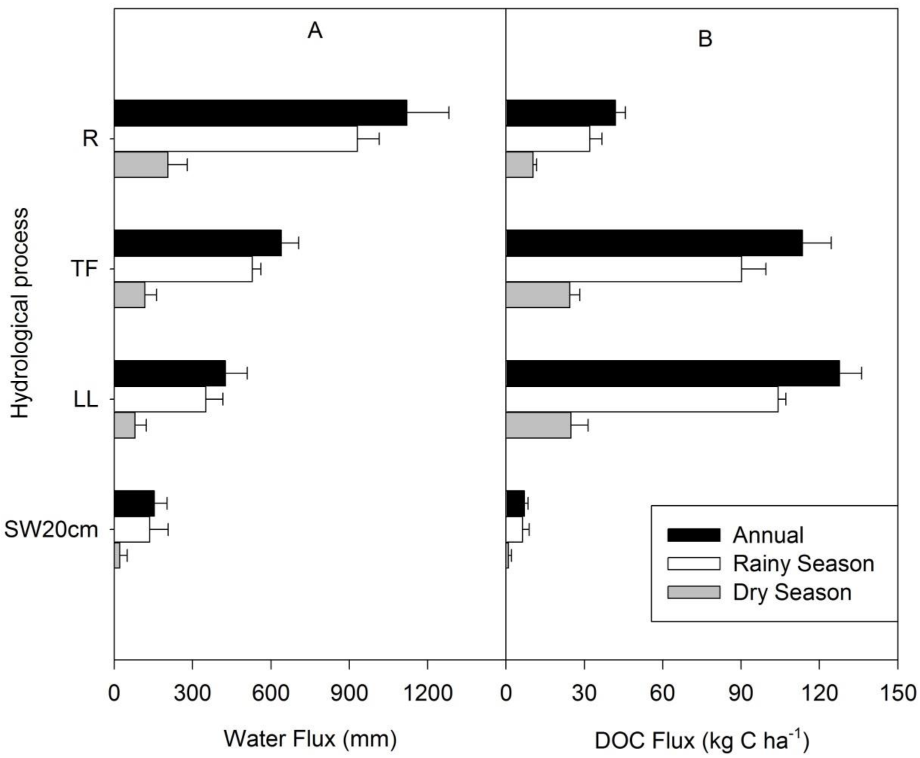
constant of the regression equation for standrised SRsoil respirations, and for soil temperature, soil water content, water flux, and DOC flux: Y = ax+be^{bx}, where Y is the standrised soil respiration rate, and x is standrised soil temperature, soil water content, water flux, or DOC flux.

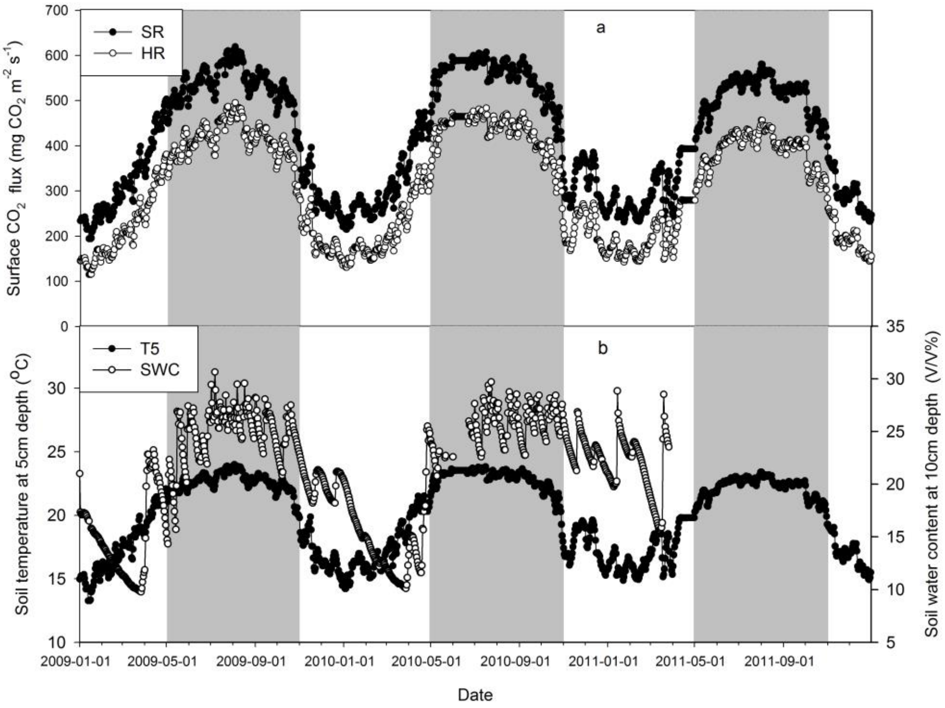
T indicates soil temperature at a depth of 5 cm, SWC indicates soil water content,TF indicates throughfall, LL indicates litter leachate, SW20 indicates soil water at a depth of 20 cm, LL- SW20cm indicates the difference between litter leachate and soil water at a depth of 20 cm, . T5 indicates soil temperature at a depth of 5 cm, SWC indicates soil water content.

Figure 1


A
B
Hydrological process
R
TF
LL
SW20cm
Annual
Rainy Season
Dry Season
0
300
600
900
1200
0
30
60
90
120
150
Water Flux (mm)
DOC Flux (kg C ha-1)

740

741 Figure 2



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