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Dynamics of total organic carbon (TOC) in hydrological processes and its contributions to soil organic carbon pools of three successional forest ecosystems in southern China

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Abstract: The dynamics of total organic carbon (TOC) in hydrological processes are important for understanding carbon cycling in forest ecosystems. TOC was monitored in precipitation, throughfall, stemflow, litter leachate and runoff in subtropical climax forest ecosystem-monsoon evergreen broad-leaved forest (MBF), and its two successional forests of natural restoration-mixed *Pinus massonniana*/broad-leaved forest (PBF), and *Pinus massoniana* forest (PF) at Dinghushan Nature Reserve (DNR) in southern China for 3 years (from April, 2002 to May, 2005). The major results and conclusions are as follows: TOC concentrations and fluxes of throughfall (DTF), stemflow, and litter leachate in PF were higher than those in MBF and PBF. TOC concentrations in dry season were higher than that in rainy season, while TOC fluxes were in opposite situation. The contributions of different hydrological processes to forest SOC pools decreased in the order: litter leachate >DTF >stemflow. Forest canopy and litter appeared to be important sources for TOC. Therefore, large TOC fluxes imported to soils with small amount of outputs by runoff may result in SOC accumulation. The net inputs of organic carbon to soil profile from the hydrological processes in MBF, PBF and PF were (27.1 ± 1.65) $g\cdot m^{-2}\cdot a^{-1}$, (28.9 ± 2.79) $g\cdot m^{-2}\cdot a^{-1}$, (30.2 ± 2.65) $g\cdot m^{-2}\cdot a^{-1}$, respectively. This part of carbon is usually negligible because it is only a small proportion of SOC. However, this part of carbon could be imported into the soil through infiltration. Through soil filtration and adsorption, carbon should be distributed in soil evenly, which is helpful to long-term preservation of SOC.

Key words: Dinghushan; forest succession; hydrological processes; TOC concentrations; TOC fluxes

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Total organic carbon (TOC) can be divided into two compositions: dissolved organic carbon (DOC) and particulate organic carbon (POC). The majority of TOC is dissolved in aquatic ecosystems. On average, DOC accounts for 97% of TOC in Finnish catchments [1].

Increasing concerns about climate change evoked interest in the role of DOC in the global C balance[2]. DOC is an important component of forest ecosystem carbon and nutrient cycling, which contains a range of organic compounds, from simple sugars to complex fulvic and humic acids[3-5]. Concentration and composition of DOC change due to biotic and abiotic processes as it moves through the ecosystem [3, 5].

Although DOC import to and export from forest ecosystems is small compared to other C fluxes, the internal DOC cycle plays an important role in nitrogen (N) and phosphorus (P) dynamics, and acts as a major control on soil formation processes, mineral weathering and pollutant transport [6-9].

There have been a number of studies on the dynamics of DOC concentration and flux [3-4, 6, 9, 10-18]. Whereas, little attention has been given to the question of how DOC concentrations, fluxes and chemistry vary with the successional development of a forest stand [9].

DOC is often considered as the most labile portion of organic matter in soil and as a negligible part in soil organic carbon (SOC). However, recent evi-

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dences show that this view is invalid [2, 19]. The laboratory incubation experiments indicate that the mean residence time of DOM from the Oa horizon increased from <30 years in solution to >90 years after sorption to the subsoil [2] (Kalbitz and Kaiser, 2008). DOC movement into the mineral soil constitutes 22% of the annual C inputs below 40 cm in a coniferous forest[19]. Radiocarbon measurements of field-collected DOC interpreted with a basic transport-turnover model indicate that DOC transported and subsequently absorbed has a mean residence time of 90~150 years [19]. Besides, as water percolates downward through the soil profile, DOC distributes evenly, which is also helpful to long-term preservation of SOC. What is more, large internal DOC fluxes in soil relative to small outputs into aquatic ecosystems may result in mineralization or stabilization, thus, accumulation in the soil [20].

The objectives of this study were: (1) to determine TOC concentrations and fluxes from precipitation to runoff in three successional forest ecosystems, and (2) to examine TOC contribution to forest SOC pools in the hydrological processes.

1 Materials and methods

1.1 Site Description

The studied vegetations are lower subtropical climax vegetation-monsoon evergreen broad-leaved forest, and its successional series of restoration-coniferous and broad-leaved mixed forest and *Pinus massoniana* forest. The natural successional sequence of these three forest types is *Pinus massoniana* forest-coniferous and broad-leaved mixed forest-monsoon evergreen broad-leaved forest. They represent the main forest types at Dinghushan Nature Reserve (DNR) at the altitudes from 250 m to 300 m.

The DNR (112°30'39"~112°33'41" E, 23°09'21"~23°11'30" N) is located in the central part of Guangdong Province in southern China. It is the first natural reserve in China with a long history of protection, with an area of 1 133 hm^2. The region is characterized by a typical south subtropical monsoon climate, with annual average precipitation of 1 927 mm, of which nearly 80% falls in the warm humid season (April-September) and 20% in the cool dry season (October-March). The annual mean temperature is 20.9 ℃ and the relative humidity is 80%. Mean annual runoff coefficient varies between 0.455 and 0.492. The soils, with serious natural acidification and pH 4.1-4.9, are classified as hydration lateritic. The forest coverage is about 85% of total area in DNR [21].

The *Pinus massoniana* forest (PF), over 60 years old[22], consisting of *Pinus massoniana* mainly and lower subtropical pioneer plants occasionally, is the representative forest at the early-successional stage. Its aboveground part can be divided into an arbor layer with open canopy and a well-developed shrub and grass layer. The biomass of this community is 12 200 $g·m^{-2}$ approximately [21, 24]. The soil of this community is lateritic soil about 80 cm deep, developed from sandy shale [21].

The mixed *Pinus massonniana*/broad-leaved forest (PBF), over 70 years old[22], which originated from artificial or natural *Pinus massoniana* forest after invasion by broad-leaved trees, is the representative forest type at the mid-successional stage. Its aboveground vertical structure can be divided into four layers: two arbor layers, one shrub layer and one grass layer. In addition, there are many other interlayer plants (i.e. liana and epiphyte). The biomass of this community is about 26 000 $g·m^{-2}$ [21, 23]. The soil is lateritic soil about 30~60 cm, developed from sandy shale [21].

The monsoon evergreen broad-leaved forest (MBF), over 400 years old [22] (Tang et al., 2006), is the regional climax of vegetation. Its aboveground vertical structure can be divided into five layers: three arbor layers, one shrub layer and one grass layer. In addition, there are many other interlayer plants (i.e. liana and epiphyte). Among its floristic composition, evergreen plants are absolutely dominant and most of them are tropics and subtropics. The biomass of this community is about 38 000 $g·m^{-2}$ [23]. The soil of this community is hydration lateritic soil, about 30 cm, developed from sandy shale [21].

1.2 Sample collection and calculation

Precipitation data were obtained from a weather station located on a low grass-covered hilltop near the south-eastern corner of the reserve, at an elevation of 100 m above sea level. Samples of precipitation were collected in the APS-2B. Dust fall automatic precipitation sampler from March, 2002 to May, 2005.

Throughfall in the three vegetation communities was collected by cross-shaped troughs (two for each site) with a horizontal area of 0.75 m^2 and 1.25 m^2 and was measured using a fluviograph. Six trees adjacent to each site where throughfall was monitored were selected for stemflow measurement, to represent tree species present in each forest type. An open PVC tube was wrapped in a downward spiral around the tree bole and led to a tipping bucket rain gauge for measurement of stemflow.

Litter leachate was collected with self-made 50 cm×50 cm×6 cm tempered glass dishes beneath the forest floor layer. The glass dishes were installed laterally from soil pits by inserting them into soils and connected to glass bottles below them.

Runoff samples were taken from above the weirs of the related watersheds on the same day when samples of precipitation, throughfall, stemflow and litter leachate were collected.

These water samples were collected after each precipitation. They were filled in 125 ml brown glass bottles, added with sulfuric acid to make pH values less than 2, and transported in a cooler to the analytical laboratory at South China Botanical Garden. Then they were frozen and stored under 0 ℃ until analysis.

Calculation equations are described as follows:

Litter leachate (mm)=throughfall (mm)×the percentage of litter cover (%)–litter evaporation (mm)

Throughfall (directly reaching the ground surface without passing through forest litter) (DTF) (mm) = throughfall (mm) – throughfall (mm) × the percentage of litter coverage (%)

Increment of SOC from the hydrological processes($g \cdot m^{-2}$)=TOC in stemflow ($g \cdot m^{-2}$) + TOC in DTF ($g \cdot m^{-2}$) + TOC in litter leachate ($g \cdot m^{-2}$) – TOC in runoff ($g \cdot m^{-2}$)

2 Results

2.1 TOC concentrations and fluxes

Due to the hydrological processes from precipitation to the runoff, TOC concentrations changed due to the leaf washing and litter leaching. Table 1 shows the results of TOC from April, 2002 to May, 2005.

TOC concentrations were low in precipitation, averaged (3.65±0.59) $mg \cdot L^{-1}$ and increased as the precipitation passing through the forest canopy, with means of (16.0±1.9), (19.5±3.3) and (19.9±1.4) $mg \cdot L^{-1}$ in MBF, PBF and PF, respectively (Table 1). Throughfall TOC concentration in MBF was significantly ($p<0.05$) lower than these in other two forest types. TOC fluxes in precipitation amounted to 51.810 $kg \cdot hm^{-2} \cdot a^{-1}$, but increased in throughfall to 187.659, 220.109, 216.070 $kg \cdot hm^{-2} \cdot a^{-1}$ in MBF, PBF and PF, respectively (Table 1).

Table 1 Concentrations and fluxes of TOC in hydrological processes in three successional forests

	TOC concentration/($mg \cdot L^{-1}$)	TOC flux/($kg \cdot hm^{-2} \cdot a^{-1}$)
Precipitation	3.65±0.59	51.810
MBF		
Stemflow	21.4±4.0	4.663
Throughfall	16.01±1.9	187.659
DTF	16.01±1.9	28.152
Litter leachate	25.5±1.6	246.983
Runoff	1.95±0.23	8.707
PBF		
Stemflow	20.9±4.0	5.910
Throughfall	19.51±3.3	220.109
DTF	19.51±3.3	37.410
Litter leachate	28.3±3.2	255.187
Runoff	1.87±0.14	9.318
PF		
Stemflow	45.6±7.3	4.566
Throughfall	19.92±1.4	216.070
DTF	19.92±1.4	43.176
Litter leachate	31.7±3.5	261.876
Runoff	1.73±0.12	7.220

TOC concentration of stemflow in PF ((45.6±7.3) $mg \cdot L^{-1}$) was significantly ($p<0.001$) higher than in MBF and PBF ((21.4±4.0) and (20.9±4.0) $mg \cdot L^{-1}$) (Table 1). TOC fluxes of stemflow were small, with means of 4.663, 5.910 and 4.566 $kg \cdot hm^{-2} \cdot a^{-1}$ in MBF, PBF and PF, respectively (Table 1).

TOC concentrations were highest in litter leachate, with the mean values of （25.5±1.6）,（28.3±3.2） and （31.7±3.5） $mg \cdot L^{-1}$ in MBF, PBF and PF, respectively. There were significant differences ($p<0.05$) in TOC concentrations between MBF and PF. TOC fluxes of litter leachate were 246.983, 255.187 and 261.876 $kg \cdot hm^{-2} \cdot a^{-1}$ in MBF, PBF and PF, respectively(Table 1).

TOC concentrations were low in runoff, averaged (1.95±0.23), (1.87±0.14) and (1.73±0.12) $mg \cdot L^{-1}$ in MBF, PBF and PF. TOC outputs of runoff were 8.707, 9.318 and 7.220 $kg \cdot hm^{-2} \cdot a^{-1}$ in MBF, PBF and PF, respectively (Table 1). There were no significant differences of TOC concentrations in runoff among the three forest types.

TOC concentrations and water volumes of throughfall, stemflow and litter leachate in the three forest types showed similar monthly dynamics (Fig.1). TOC concentrations showed a downward trend from

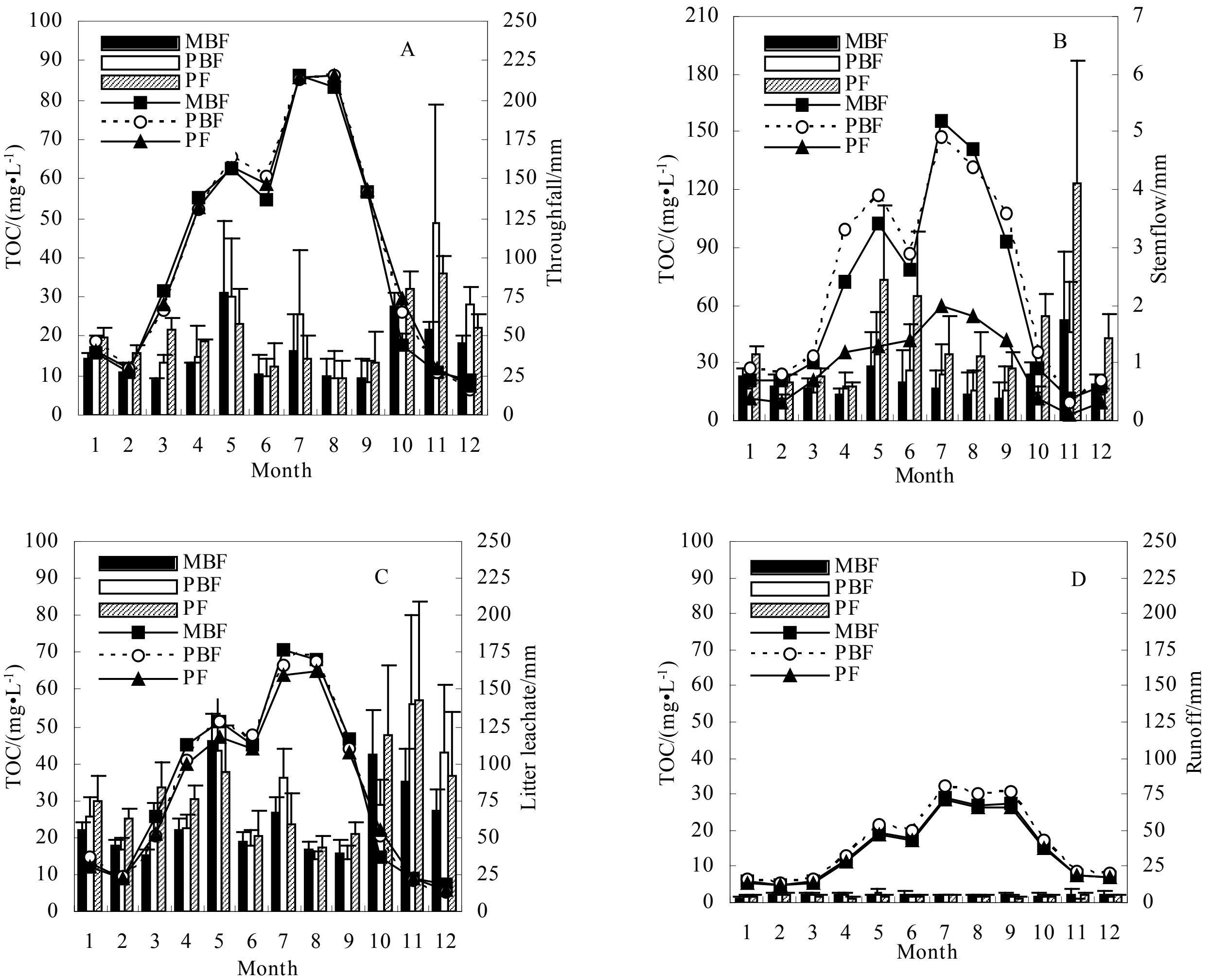

Fig. 1 Dynamics of TOC concentrations and volumes of throughfall, stemflow, litter leachate and runoff in the three forests

May to September and then increased from the beginning of the dry season in October.

2.2 TOC import to and export from SOC pools

Figure 2 shows TOC fluxes of DTF, stemflow, litter leachate and runoff in the three forest types.

Based on Figure 2, we can see that TOC of litter leachate imported to soil was the largest contributor to SOC pools in all of the hydrological processes. The second contributor was TOC in DTF. Although stemflow TOC concentrations were much higher than those of others, the TOC fluxes were so small that they contributed much less to SOC increments.

2.3 SOC increment from hydrological processes

SOC obtained from the hydrological processes showed similar patterns in the three forests throughout the year, corresponding with the distribution pattern of precipitation (Fig. 3). SOC increment in rainy season (April-September) was larger than that in the dry season (October-March). However, SOC increment in June was smaller than that in other months during the rainy season.

The net SOC increments to soil profile from the hydrological processes in MBF, PBF and PF were (27.1±1.65), (28.9±2.79) and (30.2±2.65) $g \cdot m^{-2}$, respectively.

3 Discussions and Conclusions

3.1 TOC concentrations and fluxes

Precipitation is an important TOC source for sub-tropical forest ecosystems[25]. TOC concentrations and fluxes in precipitation in Dinghushan averaged (3.65±0.59) $mg \cdot L^{-1}$ and 51.810 $kg \cdot hm^{-2} \cdot a^{-1}$, respectively. During the same period, DOC concentration in precipitation was 3.53 $mg \cdot L^{-1}$[26], accounting for 96.7% of TOC concentrations in precipitation. TOC concentration in precipitation in Dinghushan was lower than that in the montane rain forest of Ecuador in South America (TOC concentration was 4.114 $mg \cdot L^{-1}$)[27] and Guandaushi forests in central Taiwan

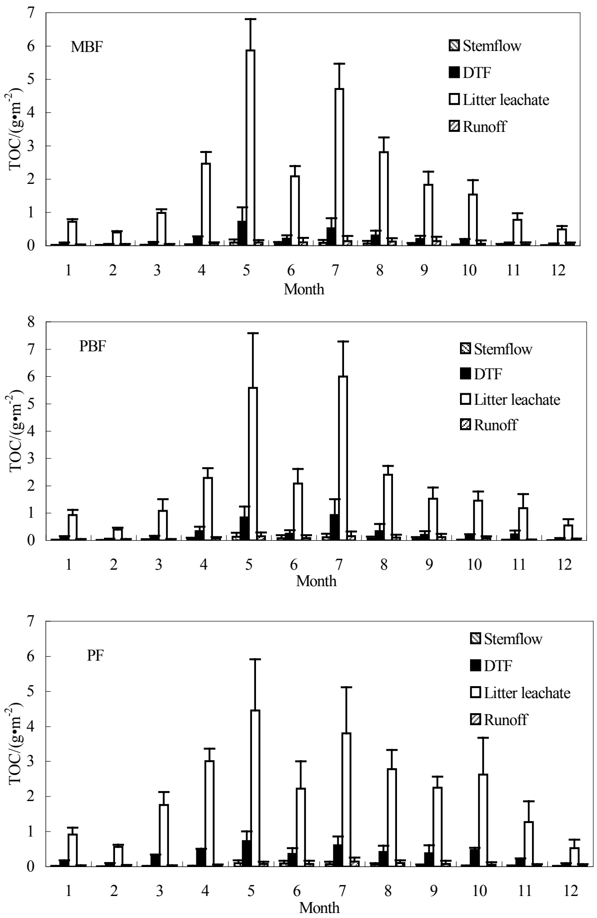

Fig.2 TOC import to and export from SOC pools in the three forests

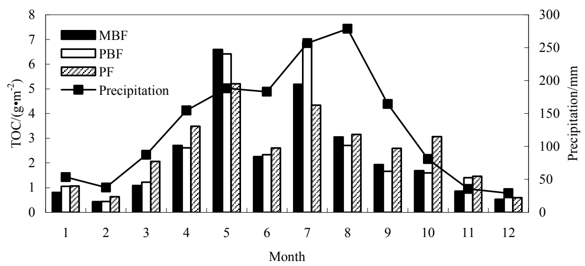

Fig.3 SOC increment from hydrological processes in the three forest types

(DOC concentration was 4.7 mg·L^{-1}) [18], but higher than that of the Luquillo Mountain tropical forests (1.0 mg·L^{-1}) [3] and other forests [4, 10-15]. TOC flux in precipitation amounted to 51.810 kg·hm^{-2}·a^{-1}, which was lower than that in Guandaushi forests in central Taiwan (DOC flux of precipitation was 142.8 kg·hm^{-2}·a^{-1})[18], higher than that in these forests as reported in the studies [3,10,13]. The phenomena implied that suspended substance in atmosphere was significant in Dinghushan.

TOC concentration and flux of throughfall in MBF were lower than those in the other two forest types. Throughfall chemistry is mainly affected by latitude, elevation, seasonality, proximity to the sea, species composition, forest age and local land-use[28], and it also depends on the following process: nutrients input to the canopy; the evapotranspiration of interception; leaching of plant tissue exudate; leaf washing; branch absorption of solution ions, and solid particles or aerosol[29]. PF and PBF have high-fat needles, which are easy to adsorb dust and aerosol in the atmosphere, resulting in higher TOC concentrations than that in MBF. Furthermore, the canopy coverage of MBF is up to 93%[30]. The MBF has a complex canopy structure, of which the vertical structure can be divided into 5 layers. After multi-level interception, absorption and adsorption, throughfall volume in MBF was less than that in PF and PBF (Fig.1 A).

TOC concentration of stemflow in PF was significantly (p<0.001) higher than that in MBF and PBF. TOC fluxes of stemflow were 4.663, 5.910 and 4.566 kg·hm^{-2}·a^{-1} in MBF, PBF and PF, respectively. TOC concentration and flux in stemflow can be influenced by the residence time of the water retained in barks [18] and the bark morphology[12]. The bark of PF has a rougher fibrous multi-layer and loose texture which could retain stemflow longer, making organic matter easily to interact with water. Dry deposition is another factor influencing TOC concentration[18]. What is more, the volume of stemflow was much smaller in PF than that in the other two forests (Fig.1 B). This is the reason why TOC concentration of stemflow in PF was the highest whereas TOC flux of stemflow in PF was the smallest among the three studied forest types.

TOC concentration and flux in litter leachate in PF were higher than those in the other two forests. This result is consistent with the result by Currie et al[13]. TOC concentrations and fluxes were considerably affected by tree species, tree biomass, litter degradation stages and forest floor carbon throughout the development of forest ecosystems[9, 31]. The standing crop, carbon content and carbon stock of litter layer in PF were the highest of the three forest types[32]. And the volume of litter leachate was larger in PF than the other two (Fig.1 C), thus TOC flux of litter leachate was the largest among three forest types.

TOC concentrations and fluxes of runoff were very small in all three forest types, with no significant differences among them. Results were consistent with other reports[11, 18].

Monthly variations of TOC concentrations showed similar dynamic patterns in throughfall, stemflow and litter leachate (Fig.1). TOC concentration showed a downward trend from May to September due to leaf leaching and leaf washing[3, 18]. From the beginning of the dry season (October), a great deal of particulate organic carbon accumulated on leaf surface owing to little precipitation and so TOC concentrations in throughfall, stemflow and litter leachate gradually increased, reaching the peak value in November. There was obvious seasonality of TOC concentrations in the hydrological processes. TOC concentrations in the dry season (October- next March) were higher than that in the wet season (April-September).

Generally, the mean and monthly TOC concentrations and fluxes in MBF were lower than those in PBF and PF. TOC variation becomes small with forest successional stage.

3.2 TOC import to and export from SOC pools

TOC fluxes increased from precipitation to a maximum in the forest litter and thereafter decreased in the runoff, indicating that forest canopy and forest floor were large TOC sources to soil SOC pools.

The litter layer was the major source of TOC in forest ecosystems. Litter leachate TOC is the main contributor to SOC pools [6, 9, 17, 33-35]. In our study, observations showed that evaporation of litter accounts for 3%, 5% and 5% of throughfall in MBF, PBF and PF, respectively. And litter coverage was 82%, 78% and 75% in MBF, PBF and PF. So, the litter layers were leached by the majority of throughfall, and the organic matter adhering to the litter surface was brought into the soil through leaching. Thus, TOC amount of litter leachate imported into soil was the largest contributor to SOC pools through hydrological processes.

Forest canopy is another TOC source because it increased TOC concentrations and fluxes about two to five times as much as in precipitation. Precipitation passing through the canopy was known to dissolve slightly soluble and soluble organic acids both from the foliage itself and from dry deposition accumulated on foliar surface[35]. In this study, TOC fluxes in DTF accounted for 10.4%, 12.9%, and 14.3% of the total carbon increment in MBF, PBF and PF, respectively. Although stemflow TOC concentrations were higher than those in throughfall and litter leachate, the small volumes of stemflow meant that TOC fluxes of stemflow formed only a small portion of SOC increments.

The main exports of TOC in forest ecosystem were runoff and soil erosion. However, there was no soil erosion during the research period. Compared to other hydrological processes, TOC flux in runoff was much smaller, which was consistent with other reports [11, 18]. It indicates that soil absorption and adsorption for TOC were significant in Dinghushan.

Therefore, large TOC fluxes imported to soils with small amount of outputs by runoff may result in SOC accumulation.

3.3 SOC increment from hydrological processes

Figure 3 shows the SOC increment in rainy season (April -September) was larger than that in the dry season (October- next March). Although TOC concentrations in rainy season were low, the great amount of water led to more carbon into soils. However, SOC increment in June was smaller than that in the other months during the rainy season. This was mainly due to the fact that litter amount in these forests was the smallest in June [21], which resulted in low TOC concentrations and fluxes of litter leachate (Fig. 3).

The net SOC increments to soil profile from the hydrological processes were (27.1±1.65), (28.9±2.79), (30.2±2.65) $g \cdot m^{-2} \cdot a^{-1}$ in MBF, PBF and PF, respectively, suggesting a strong TOC sorption capacity of the soil. The organic carbon mainly came from the aboveground input, which existed in almost all forest soil layers. However, there was not much concern about it. This part of carbon could be imported into the soil through infiltration. Through soil filtration and adsorption, carbon should be distributed in soil evenly, which was helpful to long-term preservation of SOC.

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References:

[1] KORTELAINEN P, MATTSSON T, FINER L, et al. Controls on the export of C, N, P and Fe from undisturbed boreal catchments, Finland[J]. Aquatic Sciences, 2006, 68: 453-68.

[2] KALBITZ K, KAISER K. Contribution of dissolved organic matter to carbon storage in forest soils[J]. Journal of Plant Nutrition and Soil Science, 2008, 171: 52-60.

[3] MCDOWELL W H, LIKENS G E. Origin, composition, and flux of dissolved organic carbon in the Hubbard Brook Valley[J]. Ecological Monographs, 1988, 58: 77-195.

[4] DALVA M, MOORE T R. Source and sinks of dissolved organic carbon in a forested swamp catchment[J]. Biogeochemistry, 1991, 15: 1-19.

[5] GUGGENBERGER G, ZECH W. Dissolved organic carbon controls in acid forest soils of the Fichtelgebirge (Germany) as revealed by distribution patterns and structural composition analyses[J]. Geoderma, 1993, 59: 109-129.

[6] MICHALZIK B, MATZNER E. Dynamics of dissolved organic nitrogen and carbon in a Central European Norway spruce ecosystem[J]. European Journal of Soil Science, 1999, 50: 579-590.

[7] NEFF J C, ASNER G P. Dissolved organic carbon in terrestrial ecosystems: synthesis and a model[J]. Ecosystems, 2001, 4: 29-48.

[8] MATTSON T, KORTELAINEN P, RAIKE A. Export of DOM from boreal catchments: impacts of land use cover and climate[J]. Biogeochemistry, 2005, 76: 373-394.

[9] PEICHL M, MOORE T R, ARAIN M A, et al. Concentrations and fluxes of dissolved organic carbon in an age-sequence of white pine forests in Southern Ontario, Canada[J]. Biogeochemistry, 2007, 86: 1-17.

[10] MOORE T R, JACKSON R J. Dynamics of dissolved organic carbon in forested and disturbed catchment, Westland, New Zealand.2. Larry River[J]. Water Resources Research, 1989, 25: 1331-1339.

[11] EDMONDS R L, THOMAS T B, BLEW R D, et al. Biogeochemistry of an old-growth forested watershed, Olympic National Park, Washington[J]. Water Resources Bulletin, 1995, 31: 409-419.

[12] INAGAKI M, SAKAI M, OHNUKI Y. The effects of organic carbon on acid rain in a temperate forest in Japan[J]. Water, Air and Soil Pollution, 1995, 85: 2345-2350.

[13] CURRIE W S, ABER J D, MCDOWELL W H., et al. Vertical transport of dissolved organic C and N under long-term N amendments in pine and hardwood forests[J]. Biogeochemistry, 1996, 35: 471-505.

[14] QUIDEAU S A, BOCKHEIM J G. Biogeochemical cycling following planting to red pine on a sandy prairie soil[J]. Journal of Environmental Quality, 1997, 26: 1167-1175.

[15] MCDOWELL W H. Internal nutrient fluxes in a Puerto Rican rain forest[J]. Journal of Tropical Ecology, 1998, 14: 521-536.

[16] KAISER K, GUGGENBERGER G, HAUMAIER L, et al. Seasonal variations in the chemical composition of dissolved organic matter in organic forest floor layer leachates of old-growth Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) stands in northeastern Bavaria, Germany[J]. Biogeochemistry, 2001, 55: 103-143.

[17] MICHALZIK B, KALBITZ K, PARK J H, et al. Fluxes and concentrations of dissolved organic carbon and nitrogen-asynthesis for temperate forests[J]. Biogeochemistry, 2001, 52: 173-205.

[18] LIU C P, SHEU B H. Dissolved organic carbon in precipitation, throughfall, stemflow, soil solution, and streamwater at the Guandaushi subtropical forest in Taiwan[J]. Forest Ecology and Management, 2003, 172: 315-325.

[19] SANDERMAN J, AMUNDSON R. A comparative study of dissolved organic carbon transport and stabilization in California forest and grassland soils[J]. Biogeochemistry, 2008, 89: 309-327.

[20] KAISER K, GUGGENBERGER G. The role of DOM sorption to mineral surfaces in the preservation of organic matter in soils[J]. Organic Geochemistry, 2000, 31: 711-725.

[21] ZHOU GUOYI, ZHOU CUNYU, LIU SHUGUANG, et a1. Belowground carbon balance and carbon accumulation rate in the successional series of monsoon evergreen broad-leaved forest[J]. Science in China: Series D, 2006, 49(3): 311-321.

[22] TANG XULI, LIU SHUGUANG, ZHOU GUOYI, et a1. Soil-atmospheric exchange of CO2, CH4, and N2O in three subtropical forest ecosystems in southern China[J]. Global Change Biology, 2006, 12: 546-560.

[23] 彭少麟, 张祝平. 鼎湖山针阔叶混交林的第一性生产力研究[J]. 生态学报, 1994, 14(3): 300-305.
PENG Shaolin, ZHANG Zhuping. Studies on the biomass, primary productivity and energy use efficiency of the mixed forest in Dinghushan[J]. Acta Ecologica Sinica, 1994, 14(3): 300-305.

[24] PENG S L, ZHANG Z P. Studies on the biomass, productivity and energy use efficiency of the zonal in Dinghushan[J]. Science in China: Series B, 1994, 24(5): 497-502.

[25] LIKENS G E, EDGERTON E S, GALLOWAY J N. The composition and deposition of organic carbon in precipitation[J]. Tellus, 1983, 35B: 16-24.

[26] 刘艳. 鼎湖山森林生态系统3种主要林型水文学过程中DOM浓度和通量研究[D]. 北京: 中国科学院研究生院, 2005: 26-27.
LIU Yan. Concentrations and fluxes of dissolved organic matter during forest hydrological processes of three main forest types in Dinghushan[D]. Beijing: Graduate School of Chinese Academy of Sciences, 2005: 26-27.

[27] WILCKE W, YASINI S, VALAREZO C, et al. Change in water quality during the passage through a tropical montane rain forest in Ecuador[J]. Biogeochemistry, 2001, 55: 45-72.

[28] LEVIA D F, FROST E E, 2003. A review and evaluation of stemflow literature in the hydrologic and biogeochemical cycles of forested and agricultural ecosystems[J]. J Hydrol, 274: 1-29.

[29] 李凌浩, 林鹏, 何建源, 等. 森林降水化学研究综述[J]. 水土保持学报, 1994, 8(1): 84-96.
LI Linghao, LIN Peng, HE Jianyuan, et al. Review on the study of forest precipitation chemistry[J]. Journal of Soil Water Conservation, 1994, 8(1): 84-96.

[30] 闫俊华. 鼎湖山主要生态系统的水热过程研究及脆弱性初探[D]. 广州: 中国科学院华南植物研究所, 2001: 66-68.
YAN Junhua. Studies on water-heat processes and frangibility of the dominating ecosystems in Dinghushan[D]. Guangzhou: South China Institute of Botany, Academia Sinica, 2001: 66-68.

[31] DON A, KALBITZ K. Amounts and degradability of dissolved organic carbon from foliar litter at different decomposition stages[J]. Soil Biology and Biochemisty, 2005, 37: 2171-2179.

[32] 方运霆, 莫江明, 彭少麟, 等. 森林演替在南亚热带森林生态系统碳吸存中的作用[J]. 生态学报, 2003, 23(9): 1685-1694.
FANG Yunting, MO Jiangming, PENG Shaolin, et al. Role of forest succession on carbon sequestration of forest ecosystems in lower subtropical China[J]. Acta Ecologica Sinica, 2003, 23(9): 1685-1694.
[33] HONGVE D. Production of dissolved organic carbon in forested catchments[J]. Journal of Hydrology, 1999, 224: 91-99.
[34] MOORE T R. Dissolved organic carbon in a northern boreal landscape[J]. Global Biogeochemical Cycles, 2003, 17(4) doi: 10.1029/2003GB002050.
[35] STARR M, UKONMAANAHO L. Levels and characteristics of TOC in throughfall, forest floor leachate and soil solution in undisturbed boreal forest ecosystems[J]. Water, Air, and Soil Pollution: Focus 4: 2004: 715-729.

鼎湖山森林演替序列水文过程中总有机碳（TOC）变化规律及其对土壤碳平衡的贡献

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摘要：森林水文过程中的总有机碳转运对土壤有机碳平衡起着重要的作用，但我们对于水文过程对碳平衡的贡献机理所知甚少。本研究针对鼎湖山季风常绿阔叶林演替序列不同森林生态系统(马尾松林、针阔混交林和季风常绿阔叶林(简称季风林))的大气降水、穿透水、树干流、凋落物淋洗水以及地表径流中的总有机碳（TOC）进行了三年（2002 年 4 月—2005 年 5 月）观测，以此来分析水文学过程中 TOC 的变化规律和水文学过程对不同成熟度森林生态系统土壤有机碳积累的贡献。每场雨后进行水样的采集，采集的水样装入棕色玻璃瓶中，加硫酸至 pH 值小于 2，放置于实验室冰箱冷藏待测。TOC 用日本岛津公司生产的 5000A 型 TOC-Ⅴ分析仪测定。研究结果及推论如下：鼎湖山森林水文学过程中 TOC 浓度和总量变化呈现规律性的变化。大气降水中的 TOC 浓度和总量分别为（3.65±0.59） $mg \cdot L^{-1}$ 和 51.810 4 $kg \cdot hm^{-2} \cdot a^{-1}$，大气降水是鼎湖山森林生态系统水文循环过程中 TOC 的主要来源。穿透水(DTF)中 TOC 浓度和总量均为：松林>混交林>季风林，其中季风林 TOC 浓度显著低于其他两种林型。松林树干流的 TOC 浓度显著高于混交林和季风林。凋落物淋洗水 TOC 浓度和总量大小依次均为：松林>混交林>季风林，且三林型间存在显著差异($p<0.05$)。径流中 TOC 浓度和总量均较小，且无明显差异。在湿季 5 月份，穿透水、树干流、凋落物淋洗水的 TOC 浓度呈现下降趋势。干季（10 月）开始以后，穿透水、树干流、凋落物淋洗水中的 TOC 浓度又逐步回升。地表径流中 TOC 浓度干湿季变化趋势不明显。干季中各水文学分量 TOC 浓度大于湿季，但 TOC 总量呈现相反趋势。在森林水文学过程中，凋落物淋洗水所携带的有机碳量是土壤有机碳输入的最大项，季风林、混交林、松林中 TOC 总量分别为 246.983 $kg \cdot hm^{-2} \cdot a^{-1}$，255.187 $kg \cdot hm^{-2} \cdot a^{-1}$ 和 261.876 $kg \cdot hm^{-2} \cdot a^{-1}$；其次是直接到达土壤表面的穿透水，季风林、混交林、松林中 TOC 总量分别为 28.152 $kg \cdot hm^{-2} \cdot a^{-1}$，37.410 $kg \cdot hm^{-2} \cdot a^{-1}$ 和 43.176 $kg \cdot hm^{-2} \cdot a^{-1}$；树干流中有机碳浓度虽高，但总量很微小，季风林、混交林、松林中 TOC 总量分别为 4.663 $kg \cdot hm^{-2} \cdot a^{-1}$，5.910 $kg \cdot hm^{-2} \cdot a^{-1}$ 和 4.566 $kg \cdot hm^{-2} \cdot a^{-1}$，所以对土壤有机碳收入贡献不大。径流所携带的 TOC 总量很小，季风林、混交林、松林中分别为 8.707 $kg \cdot hm^{-2} \cdot a^{-1}$，9.318 $kg \cdot hm^{-2} \cdot a^{-1}$，7.220 $kg \cdot hm^{-2} \cdot a^{-1}$。由此可知，水文过程输入土壤的 TOC 总量远大于径流所带走的 TOC 总量，导致了水文过程中的 TOC 存留在土壤中，对土壤有机碳（SOC）的积累起着重要作用。季风林、混交林和马尾松林土壤每年通过水文学过程净输入的有机碳量分别为（27.1±1.65） $g \cdot m^{-2}$，（28.9±2.79） $g \cdot m^{-2}$ 和（30.2±2.65） $g \cdot m^{-2}$。水文学过程中的这部分有机碳由于占总有机碳比例较小往往被忽视，但是正是由于水分在土壤中的下渗使得有机碳的分布趋于均匀，这将更加利于 SOC 的积累和保存。
关键词：鼎湖山；森林演替；水文过程；TOC 浓度；TOC 总量