Research paper

The Turnover of Soil Organic Matter and the Flux of Soil Carbon Dioxide at Guandaushi Forest Ecosystem

Chen-Chou Lee[1] Chen-Chung Tan[1] Daw-Ren Wu[2]

【**Abstract**】The soil organic matter is a major constituent of the primary production of ecosystem. The soil nutrient contents and soil respiration were monitored at Guandaushi Forest Ecosystem Research Station, Taiwan to understand the fate and role of soil organic matter in carbon cycle of ecosystem. The sampling sites were located at route cross of the watershed of Guandaushi Creek. The amounts of soil carbon, nitrogen, and the other nutrient contents were analyzed in laboratory and soil respiration rate was determined in the field. The amount of total carbon ranges from 220 to 550 g C m^{-2} in litter layer, and 18.2 to 41.4 kg C m^{-2} in soil pedon. The amounts of the total nitrogen are 4.5-13.9 g N m^{-2} and 1.62-3.74 kg N m^{-2} in litter and soil layer, respectively. The C/N ratios of litter and soil layer are 32-79 and 11.3-15.7. The soil respiration rates varied with season. The soil carbon dioxide efflux ranges from 1.24 to 2.35 kg C m^{-2} yr^{-1}. The belowground carbon stock of soil was estimated 16.9 to 39.5 kg C m^{-2}. The estimated turnover rate of soil organic matter ranged from 19.3 to 51.1 years.

【**Key words**】Soil organic matter, CO_2 flux, forest ecosystem.

研究報告

關刀溪森林生態系土壤有機質週轉率與土壤呼吸通量

李振州[1] 譚鎮中[1] 吳道仁[2]

【**摘要**】土壤有機質是生態系初級生產量的主要組成，本文闡述台灣中部關刀溪森林生態系之土壤有機質與土壤呼吸量之境況，以瞭解土壤有機質在生態系之碳循環中的角色與變化。在穿越集水區不同林分的人行步道上劃設的採樣點，分別取樣並帶回分析其中有機碳與氮等營養含量，以及現場量測土壤表面二氧化碳的釋放速率。落葉層中總碳含量從 220 到 550 g C m^{-2}，而土壤層則為 18.2 到 41.4 kg C m^{-2}；總氮含量則分別為 4.5～13.9 g N m^{-2} 與 1.62～3.74 kg N m^{-2}，進一步計算其碳氮比，落葉層為 32～79，土壤層為 11.3～15.7。土壤呼吸量隨季節變化，累計各樣點的長期觀測結

1. Department of Soil and Environmental Sciences, NCHU.
中興大學土壤環境科學系
2. Chung-Hwa College of Medical Technology, Tainan, Taiwan, ROC.
中華醫事學院

果，土壤二氧化碳的釋放量爲 1.24 到 2.35 kg C m^{-2} yr^{-1}。因此地下部的土壤碳儲量估計至少爲 16.9 到 39.5 kg C m^{-2}，以異營性呼吸量佔總呼吸量 50% 計算，土壤有機質的周轉率估計至少爲 19.3～51.1年。

【關鍵字】土壤有機質、二氧化碳通量、森林生態系

I. Introduction

The terrestrial ecosystem is a very large sink of carbon in the world (Ciais and Tans, 1995), and to understand carbon metabolism of terrestrial ecosystem is critical, because it play essential role on the stage of global carbon cycle. The total soil of World contains an estimated 1550 Pg C in surface matter (Eswaran *et al.*, 1993). The soil carbon is the second large pool of global carbon cycle and more than twice of the amount of carbon in the atmosphere (Schimel, 1995). The decomposition rates of soil organic matter and soil carbon stock have definite key relation of belowground primary production. Significantly, soil respiration is one major pathway of flux from ground earth into atmosphere. To quantify the soil carbon dioxide efflux and storage capacity of carbon in pedon are the main pathway for resulting forest ecosystem production (Schlesinger and Andrews, 2000). The biological activities in natural ecosphere are depended on the nutrient circumstance and structure of ecosystem. In the meanwhile, forest system can also modulate the indigenous climate and global ecosystem. The interactive effects of carbon dioxide efflux and climate change are between every ecosystem simultaneously. The global natural system is complicate and unpredictable, and so need to be familiar to ecosystem from regional researches, i.e., Long Term Ecological Researches (LTERs). The Guandaushi forest ecosystem is one of the representatively ecosecure areas in central Taiwan and funded by National Science Council since 1994. Carbon and nitrogen cycles are two major research topics in the long term ecological research project. This paper describes the principal nutrient circumstance and soil carbon dioxide efflux in this research site.

II. Materials and Methods

The study area was located on the Hwei-suen Experimental Station, one of the Forest Stations of National Chung-Hsing University in central Taiwan (c.a. 24° 04' N latitude, 120° 04' E longitude). Temperature averages about 21℃ and precipitation averages about 2600mm annually. Summer is normally wet season. The climate type is humid with ranging from subtropics and cool-temperate. The watershed was designated to be the Guandaushi Experimental Forest Station as showed in Fig.1. Elevations of sampling sites range from 1132 m above sea level in entrance of route to 1708 m on Shiau-tzu Peak (1417m in average elevation). The Fagaceae and Lauraceae are the main plant communities, and a representatively subtropical mixed hardwood forest (Lu and Ou, 1996). There are China-fir (*Cunninghamia lanceolata*) plantation, natural hardwood, and secondary hardwood in the Guandaushi forest watershed, respectively.

The sampling sites were distributed among three different stands along the trail to the peak of

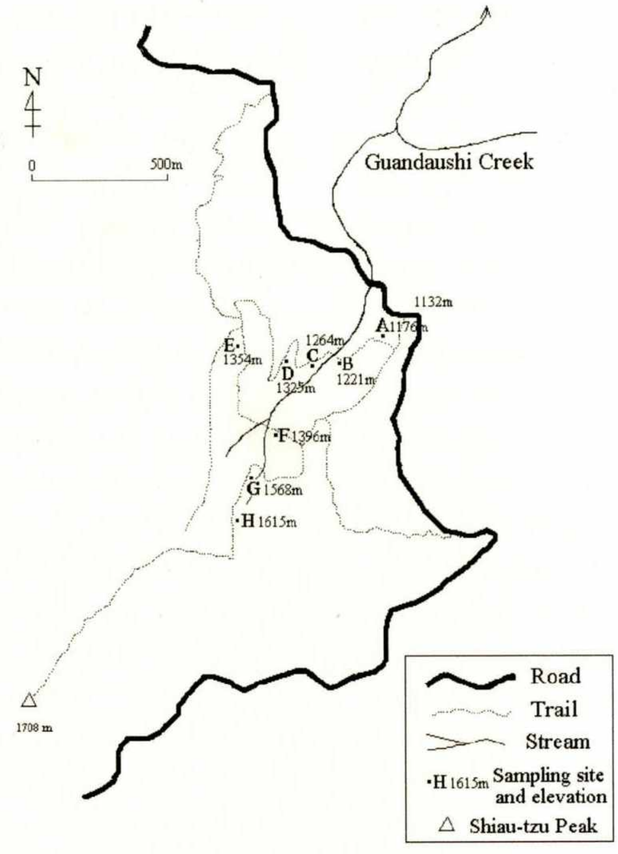

Fig. 1. Sampling sites along the track and stand areas in watershed of Guandaushi experimental station.

Shiau-tzu mountain. Several methods for measuring soil surface CO_2 flux had been applied in publications. The classical method with a static closed chamber and passive absorption of CO_2 in an alkali trap were widely used. However, the method is time consuming. Cause of accuracy and convenience, the dynamic chamber method is gradually in place of the passive absorption (Jensen *et al.*, 1996). The soil surface CO_2 efflux was measured monthly by the dynamic system at all sites in this study. The measuring system consisted of a chamber coupled to a portable infrared gas analyzer (SRC-1 and EGM-1, respectively, PP System, U.K.). The soil respiration rates were determined by infrared gas analysis method (Norman *et al.*, 1997; Rochette *et al.*, 1997), using an environmental gas monitor (EGM-1, PP system) with a closed chamber. The soil carbon dioxide efflux was integrated with periodical respiration rate estimates from surface of the soil, eventually.

Sampling sites from A to H along the path passed through the three different stands, China-fir (*Cunninghamia lanceolata*) plantation (site A, D, E), natural hardwood (site G, H), and secondary hardwood (site B, C, F), respectively. These sites are at core area in watershed of Guandaushi creek, as showed in Fig. 1. The soil profiles were observed by drilled a hole in 1 square meter area as deep as possible. The soil depths in varied stands were diverse from 80 to 150 cm. The soil pedon in lower elevation or gentle ascent were thicker than the others. Soil description and classification were made in field with standard methods of Natural Resources Conservation Service, USA (Soil Survey Staff, 1992). Litter and soil samples were collected from different depths of pedon at each site. The total carbon contents were estimated by colorimetric method and nitrogen contents were determined by concentrated sulfuric acid digestion and Kjedahl method (Jones, 1990; Spark, 1996). The K, Ca, Mg and available P were extracted by double acid and determined by inductively coupled plasma atomic emission spectrometry (ICP-AES, JY50P, Jobin Yvon, France). Total carbon and total nitrogen contents were analyzed for each horizon at each site, and the total amount in the pedons was calculated as follow:

Total C in pedon on area basis = Σ 〔(Total C on dry weight basis)$_i$ $\times$ (Bulk density)$_i$ $\times$ (Depth)$_i$ 〕,where i is the ith horizon from the top of the pedon.

III. Results and Discussion

The soils of Guandaushi forest ecosystem are derived from three parent materials, sandstone, shale and slate. The soil description of representative pedons, from natural hardwood and China-fir plantation, were showed in Table 1 and 2, respectively. They are two typical soils in the study area. The pedon of natural hardwood was above a weir and accumulated by collapsed soils (Table 1). The rock still lasting to collapse constantly. There were a lot of partly weathering shingle and gravel. The content of stones increased gradually from layer A to Bw, and however decreased in layer 2BC (60-80 cm depth). The tendency of stone amounts suggests that they were developed from different sources. The pedon was well drainage; and had many amounts of medium roots and many pores. It was classified to Dystrochrepts by the characteristics, i.e., orhric epipedon in upper level (0-25 cm depth), cambric horizon in 25-60 cm depth, acidic, pH values rose gradually with depth from 3.91 to 5.16 between layer A and 2BC, saturation degree of salts were less than 60%, and so forth (Soil Survey Staff, 1992).

Table 2 was the pedon description of China-fir plantation. The A1 and A2 layers were in dark brown and brown colors, respectively. However, the black organic matters were scattering in the layer, and irregularly contacted with boundary of layer Bw. It is suggestion that the new layer A was covered on the old one by disturbance after plantation. The pedons was also belonging to Dystrochrepts.

The soil properties of each site were showed in Table 3. The soil in every site was acidic, pH ranged from 3.3 to 4.3. The content of soil organic matter (SOM) in China-fir (150-213 g kg^{-1}) was less than in natural hardwood except site A. The elevation of secondary hardwood was higher than natural hardwood. It was probably caused of slower decomposition rate under lower temperature. Furthermore, the contents of P, K, Ca, and Mg in soil at site F were extremely high, as that, the canopy of a huge tree sheltered the sampling site. The leaching of salts from soil was less than other sites, and so that the mineral nutrient contents were significant higher.

The soils of site B, C, D were damper than the others as their crown density were higher and

Table 1. Soil profile description at natural hardwood site.

Location	No. 3 district of Hui-Sun Experimental Forest
Elevation	1130 m
Landform	Side slope of hill shoulder with stream
Slope	East, very steep, concave
Rock	Disappear
Fragments	Much lithic
Vegetation	Extremely dense cover (>75%) hardwoods
Drainage	Well
Erosion	Medium / heavy
Parent material	Colluviums by shale and sandstone mixed-up
2-0cm (Oi)	Undecayed, scattering of withered fallen leaves and twigs from hardwoods.
0-15cm (A)	Dark brown (7.5YR2.5/2, moist), silty loam, common flat partly weathering shingle and many flat partly weathering gravel, strongly developed fine aggregately blocks and moderately developed large subangular blocks; very fragile, non-sticky, non-plasticity, numerous pores, many very fine porous, numerous fine lignified roots, many medium lignified roots, few coarse lignified roots, clear smooth boundary.
15-25cm (BA)	Dark brown (7.5YR4/3, moist), silty clay loam, many flat partly weathering shingle and gravel, moderately developed medium subangular blocks and strongly developed fine aggregately blocks; fragile, slightly sticky, slightly plasticity, common pores, common very fine pores, many medium lignified roots and few coarse lignified roots, clear smooth boundary.
25-60cm (Bw)	Brown yellow (7.5YR5/8, moist), silty clay loam, immense partly weathering angular sandstone blocks and many flat partly weathering shale shingle, moderately developed medium subangular blocks and strongly developed fine aggregately blocks; fragile, slightly sticky, slightly plasticity, common pores, common coarse and very fine pores; many fine lignified roots, few medium and coarse lignified roots, clear smooth boundary.
60-80cm (2BC)	Brown yellow (7.5YR4/6, moist), silty clay loam, many angular and flat partly weathering sandstone-shale shingle and gravel, moderately developed medium subangular blocks and fine aggregately blocks; fragile, slightly sticky, slightly plasticity, common pores, common fine and coarse pores; medium fine lignified roots, few medium and coarse lignified roots.

Table 2. Soil profile description at China-fir site.

Location	No. 3 district of Hui-Sun Experimental Forest
Elevation	1160 m
Landform	Summit of hill shoulder
Slope	North, slightly ripple, convex
Rock	Disappear
Fragments	Disappear
Vegetation	China-fir plantation and fern, common cover
Drainage	Well
Erosion	Slightly
Parent material	Slate, shale and sandstone mixed-up, in-place deposits
2-0 cm (Oi)	Undecayed, scattering of leaves and twigs from China-fir and other plants.
0-5 cm (Al)	Dark brown (7.5YR3/2, moist), silty clay loam, large moderately developed subangular blocks, compact, slightly sticky, slightly plasticity; few pores, common fine pores, many fine and coarse lignified roots, clear smooth boundary.
5-15 cm (A2)	Brown (7.5YR4/4, moist), silty loam, medium moderately developed subangular blocks, fragile, slightly sticky, slightly plasticity; common coarse pores, many fine and common medium lignified roots, clear smooth boundary.
15-40 cm (Bw)	Brown yellow (7.5YR4/6, moist), silty clay loam, medium moderately developed subangular blocks, fragile, slightly sticky, slightly plasticity; many pores, many very fine pores, many fine and common medium lignified roots, clear irregular boundary.
40-80 cm (BC)	Brown yellow (7.5YR5/8, moist), silty clay, common flat moderately weathering slate shingles and gravels, medium moderately developed subangular blocks and fine aggregately blocks; fragile, common or many pores, many very fine pores, common medium pores, common fine and medium lignified roots.

near the stream. The soil moisture was contributed to humification of carbon input. Therefore, the soil organic carbon content at these sites was higher than those at the other sites. The amounts of nutrients, carbon and nitrogen, C/N ratio of litter and soil are showed in Table 4. The carbon content of litter and soil ranged from 221 to 546 g C m^{-2}, and from 18,160 to 41,400 g C m^{-2}, respectively. The nitrogen content of litter and soil ranged from 4.5 to 13.9 g N m^{-2}, and from 1621 to 3741 g N m^{-2}, respectively. The C/N ratios of litter ranges from 26 to 79 and 11.3 to 15.7 for soil.

The differences of soil C/N ratios among A

Table 3. Some soil properties in A horizon of study area.

Site	Stand[a]	Elevation (m)	OM[b] (g kg^{-1})	TN[c] (g kg^{-1})	pH	Texture[d]	Bray-1 P (mg kg^{-1})	Exch. K	Exch. Ca	Exch. Mg
									(cmol(+) kg^{-1})	
A	C	1176	213	9.9	3.76	L	7	2.23	1.55	1.32
B	N	1221	176	11.1	4.08	L	27	3.05	5.85	1.77
C	N	1264	246	11.0	3.75	L	6	2.26	0.85	1.15
D	C	1325	165	10.6	3.82	SiL	5	1.51	0.63	0.86
E	C	1354	150	7.3	3.78	SiL	6	0.15	0.55	0.86
F	N	1396	320	20.4	3.66	L	17	5.03	15.68	4.53
G	S	1568	325	16.2	3.45	L	7	2.82	2.93	3.33
H	S	1615	290	12.4	3.58	SL	9	3.64	5.35	3.58

a: C: China-fir, N: natural hardwood, S: secondary hardwood.
b: Organic matter.
c: Total nitrogen.
d: L: loam, SiL: silty loam, SL: sandy loam.

to H sites were only slightly, indicating that organic matter in the soils were relatively stable. The C/N ratio of litter was more diverse than the soil. Nevertheless, they could be separated into two groups. The sites in conifer, A, D, E had higher C/N ratio than in hardwood. This means soil nutrient of conifer was less efficient than hardwood (Johnson *et al.*, 2001; Russell, 2002).

The soil carbon and tree stands are the main storage pool of a forest ecosystem. As much of carbon in terrestrial ecosystems is stored in soil organic matter, changes in the carbon content of soils by different land use and vegetation types, that is need to figure out (van Noordwijk *et al.*, 1997). The carbon dioxide flux ranges from 1,239 to 2,352 g C m^{-2} year^{-1} (Table 4). The differences of the CO_2 fluxes were not significant among different stands. However, in evidence, excepting of carbon dioxide flux, total residue carbon of soil in hardwood is higher than China-fir, indicating soil sequestering of carbon by hardwood were larger than China-fir. Evermore, forestation is an important way to sequestering carbon from atmospheres (Nabuurs *et al.*, 1997). In this case, the quantities of carbon sequestration by hardwood would be potential than conifer. Consequently, the China-fir is likely not to be the best choice for carbon budget in soils.

The soil carbon dioxide efflux is contributed by microbial respiration, root respiration, and rhizosphere respiration. The autotrophic respiration is mainly from plant roots (Raich, 1992). Although it is difficult to distinguish heterotrophic respiration within the soil carbon dioxide efflux the ratios of heterotrophic respiration were estimated previously (Lee *et al.*, 2003) from 33 to 50%. In addition, the turnover time of soil organic matter were calculated and ranged from 19.3 to 84.4 years. The turnover time and soil organic carbon (SOC) of site D, E are much less than the others because of the SOC in natural hardwood or secondary hardwood is

Table 4. Total carbon, total nitrogen contents, C/N ratios of litter and soil, and turnover time of soil organic carbon at Guandaushi forest soils.

Site*	Litter			Soil			Soil CO_2 flux	Turnover time** of SOC
	C (g C m^{-2})	N (g N m^{-2})	C/N	C (g C m^{-2})	N (g N m^{-2})	C/N	(g C m^{-2} yr^{-1})	(year)
A	480	10.0	48	25200	2295	13.4	1239	40.7-67.1
B	332	12.9	26	37040	3741	11.3	1449	51.1-84.4
C	415	12.0	34	41400	3450	15.7	2352	35.2-58.1
D	283	5.9	48	20550	1834	13.0	2127	19.3-31.9
E	356	4.5	79	18160	1621	13.2	1581	23.0-37.9
F	546	13.9	39	31720	2910	13.2	1720	36.9-60.9
G	465	13.9	33	28210	2172	15.1	1679	33.6-55.4
H	221	6.6	32	24020	1849	15.6	1931	24.9-41.0

*China-fir: site A, D, E; Hardwood: site B, C, F, G, H.

**Turnover time of soil organic carbon was estimated with assumption of 50 and 30% of heterotrophic respiration, respectively.

higher than China-fir generally. Nevertheless, SOC of site B, C is more twice than D, E, although these sites are near central land of the watershed. It is suggested that the vegetation model is one main reason (Russell, 2002; Schroth *et al.*, 2002). The China-fir is a simple plantation around the watershed, so that suggested organic matter input to soils is less diverse than natural hardwood. Consequently, the refresh rates of soil organic matter by microbial decomposition are low in china-fir. The soil organic matter is a potentially important source and sinks for the greenhouse gas CO_2 (Steffen *et al.*, 1998). Forestation is thought to be a useful method for sequestering atmospheric carbon dioxide (Dixon *et al.*, 1994; Schimel, 1995). However, the carbon sequestration of hardwood in soil is more longevous and valuable than conifer in our study. The community diversity of China-fir plantation is lower than the other stand type in the watershed (Lu and Ou, 1996). Multistrata forests had advantages over monocultures, as they allowed more long-term biomass accumulation, complete occupation of the soil (Schroth *et al.*, 2002). The suggestion may be useful for the authority of forest management to govern plantation in the future, especially in carbon sequestering and trade issues.

Soil CO_2 fluxes changed seasonally from Jun 1995 to Apr 1997 as showed in Fig. 2. The soil carbon dioxide flux is contribution of root respiration, microbial decomposition of soil organic matter. Despite carbon inputs to the soil, carbon sequestration was limited by decomposition (Richter *et al.*, 1999). Thus, we discriminate it to autotrophic and heterotrophic respiration, respectively. They also represent the biological activity of organic matter decomposition of belowground part. These sources of respiration were depended on soil moisture and temperature. There were some climate events in estimation of soil respiration, as dry seasons lasting more than three month and unexpected rainstorm (Yu and Chung, 1999). The relationship between CO_2 flux and the environmental factors in the study sites need further investigation.

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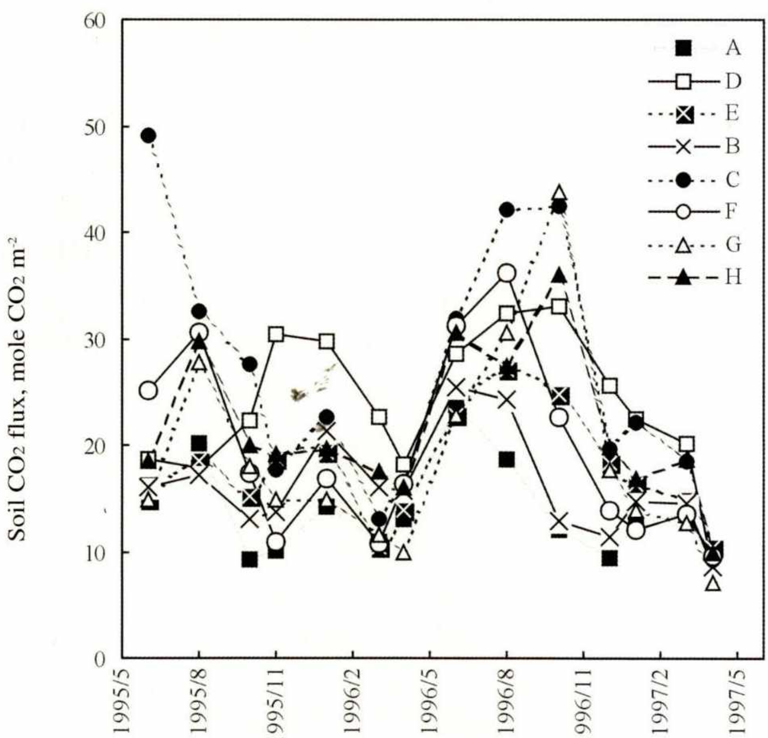

Fig. 2. Soil CO_2 flux from April 1995 to Jan 1997 of Site A to H in Guandaushi Experimental Forest Station.

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