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Labile soil carbon pools in subtropical forest and agricultural ecosystems as influenced by management practices and vegetation types

S. Hu [a,*], D.C. Coleman [b], C.R. Carroll [b], P.F. Hendrix [c], M.H. Beare [b,1]

[a] *Department of Integrative Biology, University of California, Berkeley, CA 94720, USA*
[b] *Institute of Ecology, University of Georgia, Athens, GA 30602, USA*
[c] *Institute of Ecology and Department of Crop and Soil Sciences, University of Georgia, Athens, GA 30602, USA*

Abstract

Carbon storage in agricultural and forest soils has attracted attention recently due to its potential as a substantial carbon sink. Labile soil C pools are especially important because they are more vulnerable to climatic change and disturbance and play vital roles in nutrient cycling. Southern Appalachian forest soils and those from conventional tillage (CT), no-tillage (NT) and fescue sods at three sites in the Georgia piedmont were analyzed for total C, total N, carbohydrates, and microbial biomass C. The sizes of soil labile C pools (carbohydrates and microbial biomass) and their contributions to the total soil C pool differed significantly among ecosystems. The highest carbohydrate contents and microbial biomass C were found in forest soils, but agricultural soils had a significantly higher proportion of the soil organic matter present as carbohydrates and as microbial biomass. This difference probably reflects the quality of soil organic matter. Soil microbial biomass C was more sensitive to changes in management regimes than soil carbohydrates. Management practices significantly affected organic C, carbohydrate contents, microbial biomass C and organic C turnover rates in agricultural soils, whereas differences in the quality of organic input due to different vegetation types substantially influenced soil labile C pools in forest soils. High mannose-to-xylose ratios in highly sandy agricultural soils indicate that plant-derived materials are rapidly metabolized by microorganisms and that organic C protection in sandy soils is largely dependent on reducing microbial access through effective residue management such as surface placement. © 1997 Elsevier Science B.V.

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1. Introduction

* Corresponding author. Tel.: +1-510-642-1054; fax: +1-510-643-6264; e-mail: sh68hu@socrates.berkeley.edu
1 Present address: Institute for Crop and Food Research, Canterbury Agriculture and Science Centre, Private Bag 4704, Christchurch, New Zealand.

The maintenance of soil organic matter (SOM) is desirable for long-term land use because of the multiple beneficial effects of organic matter on nutrient status, water holding capacity and physical structure (Jenny, 1980). Recent attention has focused on or-

ganic C storage of soils because of concerns over increases in atmospheric CO_2 levels and global warming. It was estimated that net annual release of C as CO_2 from fossil fuel combustion is 5.3×10^{15} g yr^{-1} whereas detrital production is about 60×10^{15} g yr^{-1} and decomposition at 50–60×10^{15} g yr^{-1} (Post et al., 1990). A slight imbalance between detrital production and decomposition could have important influences on the global C budget (Johnson, 1992). It has been suggested that CO_2 accumulation in the atmosphere could be reduced by conserving and sequestering C into soil ecosystems through appropriate management of forest and agricultural systems (Barnwell et al., 1992; Johnson, 1992; Wofsy et al., 1993).

Modelling experiments have been conducted to predict feedbacks of the carbon cycle to increased temperature (Jenkinson et al., 1991; Townsend et al., 1993; Raich and Potter, 1995). However, uncertainties are evident because of a lack of information on the effects of numerous crucial variables on soil organic C dynamics. One of these variables is the effect of soil organic matter quality on decomposition. Most experiments on temperature controls over soil respiration only tested the response of a very labile pool of SOM (Townsend et al., 1993). Since the very labile pool only consists of a small part of total SOM, and the highly recalcitrant organic matter is resistant to decomposition and has a turnover time of thousand years (Parton et al., 1987; Hsieh, 1992), the response of an intermediately labile pool of carbon, between the very labile pool and the highly recalcitrant pool, to altered temperature and moisture regime will determine soil C balance (Townsend et al., 1993).

Labile pools of soil organic matter are especially important because they control ecosystem productivity in the short term, and could be most affected by altered temperature and soil moisture regimes resulting from climate change (Zak et al., 1993). Soil microbial biomass C and microbial biomass C to total organic C ratios have been suggested as useful measures for monitoring organic matter dynamics (Powlson et al., 1987; Sparling, 1992). Soil carbohydrates, which comprise about 5–25% of soil organic matter, are readily degradable components of SOM and the major energy sources for microorganisms (Cheshire, 1985). They are presumably an im-

portant part of the intermediate labile pool. In soil systems, carbohydrates exist in various forms, from simple sugars or oligosaccharides to humic-polysaccharide complexes (Folsom et al., 1974; Cheshire et al., 1992). The relative composition of carbohydrates can provide information on the origin of carbohydrates (Folsom et al., 1974; Hu et al., 1995a) and the relative size of the carbohydrate pool could also be an important measurement of SOM decomposability. However, information on the size of the soil carbohydrate pool and its response to changes in management regimes is very limited (Roberson et al., 1991; Hu et al., 1995a).

This study was designed to (1) document the size of labile C pools (carbohydrates and microbial biomass) in Southern Appalachian forest and agricultural soils of the Southeastern United States, and (2) evaluate the influences of management practices on the size of soil labile C pools.

2. Methods and materials

2.1. Description of experimental sites

Soil samples were collected on Southern Appalachian forest and agroecosystems in the Georgia piedmont (at three sites), which represent a range of landscape positions and soil types. Study sites were located at the Dawson field near Watkinsville (GA, USDA-ARS Southern Piedmont Conservation Research Center), the Horseshoe Bend Experimental Area (HSB, U. of GA, Athens), the Bledsoe Farm (Griffin, UGA Agric. Experimental Station) and Coweeta Forest (Coweeta Hydrological Lab., NC; US Forest Service) (Table 1).

The HSB soil is a well-drained sandy clay loam with 66% sand and 21% clay in the Hiwassee series (clayey, kaolinitic, thermic, Rhodic Kanhapludult). The Griffin site is a sandy loamy Ultisols. Both HSB subplots and Griffin plots, which were initiated in 1989, had treatments of fescue sod, no-tillage, and conventional tillage, with replications of each treatment. The conventional plots were moldboard-plowed, disk-harrowed and rotary-tilled twice each year and planted with sorghum (*Sorghum bicolor* L. Moench) in summer, and kept fallow at HSB and planted with crimson clover (*Trifolium incarnatum*

Table 1
Management practices or vegetation types, and soil series or group and texture of studied ecosystems

Site	Soil series or group	Texture	Sand (%)	Vegetation types or management practices
HSB				
Subplots	Ultisol (Hiwassee)	Loamy sand	66	Fescue sods, NT, and CT (2 yr)[a]
Mainplots	Ultisol (Hiwassee)	Loamy sand	66	Long-term NT and CT[a]
Griffin	Ultisol (Cecil)	Sandy loam	56.5	Fescue sods, NT, and CT (2 yr)[a]
Watkinsville[b]				
WKS	Ultisol (Cecil)	Sandy loam	79	NT (2 yr)
WKC	Ultisol (Pacolet)	Sandy clay loam	54	NT (2 yr)
Coweeta[c]				
WS1	Ultisol	Sandy loam	ND[d]	White pines
WS27	Inceptisol	Sandy loam	ND	Northern hardwood forest dominated by red oak (*Quercus rubra*)
WS55	Ultisol	Sandy loam	ND	*Rhododendron maximum and Quercus prinus / Liriodendron tulipifera*

[a]CT = Conventional Tillage, NT = No-Tillage.
[b]WKS = Watkinsville Sandy Soil, WKC = Watkinsville Clayey Soil.
[c]WS1 = Watershed 1, WS27 = Watershed 27, WS55 = Watershed 55.
[d]ND = not determined.

L.) at Griffin in winter. No-tillage plots were treated as conventional-tillage plots except they were not plowed.

The HSB main conventional (CT) and no-tillage (NT) plots were initiated in 1978 and have been under continuous treatment since then (Groffman et al., 1986; Beare et al., 1992). Summer crops of either soybean (*Glycine max* L.: 1980, 1981, 1985) or grain sorghum (*Sorghum bicolor* L. Moench: 1978, 1979, 1982–1984, 1986–1991) have been followed by a cover crop of winter rye (*Secale cereale* L.: 1978–92).

The Dawson field was recently leased by USDA Agricultural Research Service for research on soil renovation under conservation management and has been under intermittent fallow, pasture and conventional row crop cultivation for over 100 yr. It is characterized by low organic matter content and various soil textures resulting from erosion (Table 1). The sampled site included toposequences of Cecil and Pacolet soils of slight, moderate and severe erosion (Beare and Bruce, 1993). Soils have low carbon content and poor soil structure resulting from erosion (Bruce et al., 1990). Samples for the current study were collected at the two extreme sides of the field: sandy or clayey sites, with 4 plots on each site.

The Coweeta Hydrological Lab. is located in the Nantahala Mountain Range of western North Car-

olina within the Blue Ridge Physiographic Province, latitude 350/03 N, longitude 83°25′ W (Swank and Crossley, 1988). The laboratory comprises two adjacent, east-facing, bowl-shaped basins: Coweeta Basin and Dryman Fork Basin. The 1626 ha Coweeta Basin has been the primary site for watershed experimentation. Soils within the laboratory fall within two orders: Inceptisols and older developed Ultisols. In the present study, soil samples were collected from three watersheds, e.g., watersheds 1, 27 and 55.

Watershed 55 is at a low elevation (about 760 m) and is used for riparian studies. The watershed stream has distinct north-facing slopes with dense stands of *Rhododendron maximum* and south-facing slopes containing sparse and patchy stands of *R. maximum* intermixed with *Liriodendron tulipifera* and *Quercus prinus*. Soils are mildly acidic Ultisols (pH = 5.5).

Watershed 1 was burned in April, 1942. All trees and shrubs within this hardwood watershed were killed with chemicals in 1954 and re-treated as necessary for three consecutive growing seasons. White pine was planted in 1957 after all trees and shrubs were cut and burned in 1956–57. This watershed has a similar elevation to Watershed 55.

Watershed 27 is one of the watersheds with an elevation of 1061 m at the bottom weir and 1454 m at its top. The soil is an Inceptisol. This watershed is

one of eight watersheds which have remained relatively undisturbed since the establishment of the laboratory and serve as controls in paired watershed experiments (Hewlett, 1971). The vegetation type is a northern hardwood dominated by red oak (*Quercus rubra*). The vegetation on this watershed was partially defoliated by a fall cankerworm infestation lasting from 1972 to 1979.

2.2. Soil sampling

2.2.1. Experiment 1

Soil cores (2–6) with a diameter of 5.8 cm were collected in November 1991 from each field replicate at Griffin, the HSB subplots, Watkinsville, and Watershed 27, Coweeta, sectioned into 0–5 and 5–15 increments and composited by depth. Three sampling locations (top, middle, and bottom of the watershed) were chosen for Watershed 27 at Coweeta, and six cores were collected and combined at each location.

2.2.2. Experiment 2

Soil cores (3–6) of 5.8 cm diameter were collected in February 1992 from each field replicate of the HSB mainplots, and Watersheds 1 and 55, Coweeta, sectioned into 0–5 and 5–15 increments and composited by depth. For Watersheds 1 and 55 at Coweeta, 3 sampling locations (top, middle, and bottom of the watersheds) were chosen and 6 soil cores were sampled at each location.

Coarse organic matter and plant roots were removed manually. Soil aggregates were dispersed physically. A subsample from each field sample was obtained, freeze-dried and ground for total C, N and carbohydrate analyses. Remaining soils were kept at 4°C until used for microbial biomass determination.

2.3. Determination of total C, N, carbohydrates and microbial biomass

Soil C and N contents were measured by a Carlo–Erba C/N Analyzer, with two replicates for each sample. Soil carbohydrates were determined by slightly modifying the method of Cheshire et al. (1992). Briefly, ground soil samples (200 mg) were hydrolyzed in 12 M H_2SO_4 at 22°C for 16 h followed by 1 M H_2SO_4 at 100°C for 6 h. The hydrolysates were reduced and acetylated, and the alditol

acetates in acetone were determined on a gas chromatograph equipped with a flame ionization detector (FID) on a 15 m fused silica capillary column of SP2330, using myo-inositol as an internal standard (Hu et al., 1995a,b). Five major simple sugars (i.e., arabinose, glucose, galactose, mannose and xylose) were identified and their sum was considered as total carbohydrates. Percentages of organic carbon present as carbohydrates ($C_{carb}/C_{org} \times 100$) were also calculated. The ratio of mannose to xylose (M/X) was calculated and used to evaluate the relative contribution of plant-derived or microbe-derived carbohydrates to the total soil carbohydrate pool (Hu et al., 1995a,b).

Microbial biomass C was determined by the chloroform fumigation-extraction method (Vance et al., 1987). A 20 g (dry wt. equivalent) moist soil sample was fumigated with chloroform for 48 h and extracted with 60 mL 0.5 M K_2SO_4, shaken for 30 min and filtered (No. 42 Whatman paper). Extracts were then analyzed using a Shimadzu (Shimadzu Scientific Instruments, Columbia, MD) total organic carbon (TOC-500) analyzer (Hu et al., 1995b). Microbial biomass C was calculated from the total dissolved organic carbon by using a K_{EC}-factor of 0.33 (Sparling and West, 1988). The microbial biomass C to total organic C ratios (C_{mic}/C_{org}) were calculated since they were considered to be a more sensitive index than organic C alone for monitoring SOM dynamics (Sparling, 1992).

2.4. Statistical analyses

One-way analyses of variance (ANOVAs) were used to compare the effects of tillage practices or sites on C, N, carbohydrates and microbial biomass. Fisher's protected LSD procedure was used to separate the means of dependent variables which were significantly affected by treatment. Both C_{mic}/C_{org} and C_{carb}/C_{org} were used as indicators of the relative size of labile C pools.

3. Results

3.1. Total C, total N and C/N ratios

Total organic C of forest soils was 2–25 fold higher than that of the agricultural soils (Table 2).

Table 2
Total soil carbon (mg C g^{-1} soil), nitrogen (mg N g^{-1} soil) and C/N ratios of studied ecosystems[a]

Site	Total C[b]		Total N[b]		C/N ratio	
	0–5 cm	5–15 cm	0–5 cm	5–15 cm	0–5 cm	5–15 cm
HSB subplots						
CT	8.3a	4.0a	0.75a	0.43a	11.02a	9.19a
NT	13.1a	4.6a	1.15a	0.48a	11.36a	9.39a
Fescue	14.7a	5.0a	1.44a	0.54a	10.19a	9.16a
HSB mainplots						
CT	12.7b	8.7a	0.94b	0.80a	13.54a	10.89a
NT	23.8a	8.0a	2.03a	0.75a	11.74b	10.58a
Griffin						
CT	23.9a	21.5a	1.54a	1.56a	15.46a	13.88b
NT	34.1a	21.4a	2.47a	1.43a	13.97a	14.97ab
Fescue	30.3a	19.5a	2.16a	1.24a	14.01a	15.85a
Watkinsville						
WKS	6.2b	4.6b	0.49b	0.36b	12.68a	13.03a
WKC	11.8a	7.8a	1.15a	0.61a	12.67a	12.87a
Coweeta						
WS1	60.1b	15.3c	1.50c	0.50c	39.74a	30.32a
WS27	155.5a	108.2a	10.0a	6.47a	15.60c	16.73c
WS55	69.0b	31.0b	2.77b	1.33b	24.85b	23.38b

[a] All the abbreviations refer to Table 1.
[b] Values are averages of the analyses from three or four field replicates ($n = 3$ or $n = 4$).
Means of treatments at each site within a column that have the same letter are not significantly different at $P = 0.05$ (LSD of one way ANOVA).

Among the forest soils, Watershed 27 at the higher elevation contained much higher organic C (155.5 mg C g^{-1} in 0–5 cm soils and 108.0 mg C g^{-1} in 5–15 cm soils, respectively) than Watershed 1 (60.1 and 15.3 mg C g^{-1} soil, respectively) and Watershed 55 (69.1 and 31.0 mg C g^{-1} soil, respectively). With respect to agricultural soils, there was a significant effect of experimental sites on organic C content in surface soils (0–5 cm), with the highest at Griffin and the lowest at Watkinsville. In the HSB mainplots, organic C and N in the CT soil were significantly lower than in the NT soil after 14 yr of continuous treatment. Organic C and N in the CT soils were not significantly different from those in their respective fescue or NT soils at the HSB subplots and at Griffin over the short term. Soil texture had significant influences on soil organic C and N.

At Watkinsville, organic C and N concentrations (11.8 mg C g^{-1} soil and 1.15 mg N g^{-1} soil) at the clayey site were about twice as high as those at the sandy site (6.2 mg C g^{-1} soil and 0.49 mg N g^{-1} soil), although the same management practices had been used for over 100 yr. Nitrogen followed a similar pattern as organic C, but the difference in organic N between agricultural soils and forest soils was much smaller than the difference in organic C. The difference in the quality of organic matter as measured by C/N ratios was significant between forest soils and agricultural soils, the highest C/N ratio (39.7) being under pine trees (Watershed 1) and the lowest (11.0) being in the HSB soils (Table 2).

3.2. *Total soil carbohydrate and microbial biomass*

In general, the size of soil labile C pools was significantly larger in forest soils than in agricultural soils. Soil carbohydrates were significantly different between forest and agricultural soils, the highest being 2968 μg carbohydrates g^{-1} soil in Watershed 27 and the lowest being 198 μg carbohydrates g^{-1} soil in the Watkinsville sandy soils (Table 3). Significant differences in microbial biomass C in surface soils were found among ecosystems (Table 3), the highest being 1326 μg C g^{-1} soil in Watershed 55 and the lowest being 248 μg C g^{-1} soil in CT soils of the HSB subplots. Microbial biomass C under pine trees (Watershed 1) was significantly lower than that under *R. maximum* and *Q. prinus/L. tulipifera* (Watershed 55), even though both contained similar organic C and had similar elevations.

For surface soils (0–5 cm) of agricultural systems, the concentrations of carbohydrates were significantly different among three experimental sites, the lowest being at 198 μg carbohydrates g^{-1} soil in the Watkinsville sandy soils and the highest being at 2225 μg g^{-1} soil in NT soils at Griffin (Table 3). In the HSB mainplots, carbohydrates were significantly lower in conventional (CT) soils (364 μg g^{-1}) than the no-till (NT) soils (752 μg g^{-1}). However, no significant short-term (2 yr) effects of management practices on soil carbohydrates were observed at the HSB subplots. Slightly (but not significantly) higher carbohydrate concentrations (2225 μg g^{-1}) were found in NT soils as compared to fescue and CT soils (1546 and 1450 μg g^{-1}, respectively) in Grif-

fin, which may reflect the difference in tillage and organic matter input since clover was planted in NT and CT plots. At Watkinsville, the clayey site (1088 μg g^{-1}) had significantly higher carbohydrate content than the sandy site (198 μg g^{-1}) ($P < 0.05$) in the surface soil. For the 5–15 cm soils, a significant difference was only observed in the Watkinsville soils, where clayey soils had a higher carbohydrate concentration than sandy soils (Table 3).

Mannose to xylose ratio (M/X) was highest (8.6) in the sandy soil at Watkinsville and lowest in the clayey soil (1.4) (Fig. 1). The M/X ratios of HSB soils (3.3) were also higher than those of soils at Griffin and clayey soil at Watkinsville. The M/X
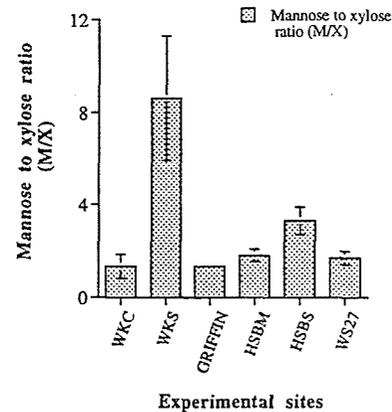

Fig. 1. Mannose to xylose ratios of soils at experimental sites studied. Values are mean ± 1 SE. HSBS = all the subplot CT, NT and fescue soils from HSB; HSBM = HSB mainplot soils; GRIFFIN = all the CT, NT and fescue soils from Griffin; WKC = Watkinsville clayey soils; WKS = Watkinsville sandy soils. WS27 = Watershed 27 at the Coweeta Hydrological Lab.

ratio was significantly correlated to the percentage of sands of tested soils ($P < 0.05$) (Fig. 2).

Soil microbial biomass C was more sensitive than soil carbohydrates in response to changes in management regimes. In the surface soils, microbial biomass C under conventional tillage practice for just two yr was significantly lower than that in NT or fescue soils both at HSB and Griffin (Table 3). Long-term conventional tillage also reduced soil microbial biomass. Soil microbial biomass C in CT soils of the

Table 3
Total soil carbohydrates and microbial biomass of studied ecosystems[a]

Soil system	Total carbohydrates[b]		C_{mic} (μg C g^{-1} soil)[c]	
	0–5 cm	5–15 cm	0–5 cm	5–15 cm
HSB subplots				
CT	507a	240a	248b	213a
NT	782a	232a	707a	157a
Fescue	508a	290a	721a	203a
HSB mainplots				
CT	364b	349a	345b	226a
NT	752a	329a	719a	208a
Griffin				
CT	1450a	897b	317b	310a
NT	2225a	1863a	1081a	431a
Fescue	1546a	946ab	1029a	397a
Watkinsville				
WKS	198b	178b	ND[d]	ND
WKC	1088a	1024a	ND	ND
Coweeta				
WS1	ND	ND	804b	367b
WS27	2968	2525	1672a[e]	
WS55	ND	ND	1326a	599a

[a]Abbreviations refer to Table 1.
[b]Unit, μg carbohydrates g^{-1} soil. Values are averages of the analyses from three or four field replicates ($n = 3$ or $n = 4$). Means of treatments at each site within a column that have the same letter are not significantly different at $P = 0.05$ (LSD of one-way ANOVA).
[c]C_{mic} = Microbial Biomass C.
[d]ND = not determined.
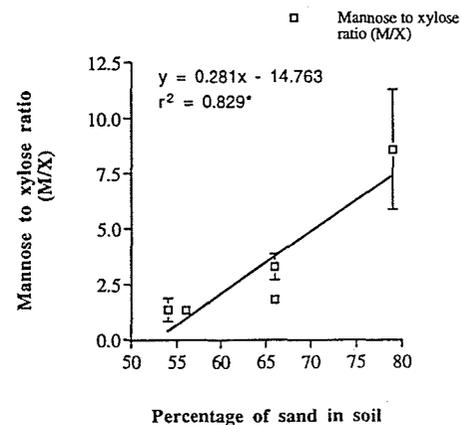[e]The value was the average of both soil layers.

Fig. 2. Relationship between mannose-to-xylose (M/X) ratios and sand concentrations of agricultural soils. Values of mannose-to-xylose ratios are mean ± 1 SE. *$P < 0.05$.

HSB mainplots was significantly lower ($<100\%$) than NT soils in the mainplots and the neighboring subplots, although the former contained similar total organic C to fescue and NT subplots (Table 2). Site effects were evident with larger microbial biomass C in Griffin than in HSB soils. No significant treatment effects on microbial biomass C were observed for the 5–15 cm soils.

3.3. Carbon present as carbohydrates and microbial biomass C

The relative size of soil labile C pools was significantly different among the ecosystems. Agricultural soils, in general, contained a relatively higher percentage of organic C present as labile C pools (C_{carb}/C_{org} and C_{mic}/C_{org}) than forest soils (Figs. 3 and 4). Clayey soils at Watkinsville had the highest proportion of the soil organic matter present as carbohydrates (11.2%), while forest soils of Watershed 27 and sandy soils at Watkinsville were the lowest ones (3.2% and 4.1% respectively) (Fig. 3). Long-term cultivation significantly reduced C_{carb}/C_{org} in the HSB mainplots both in CT and NT soils.
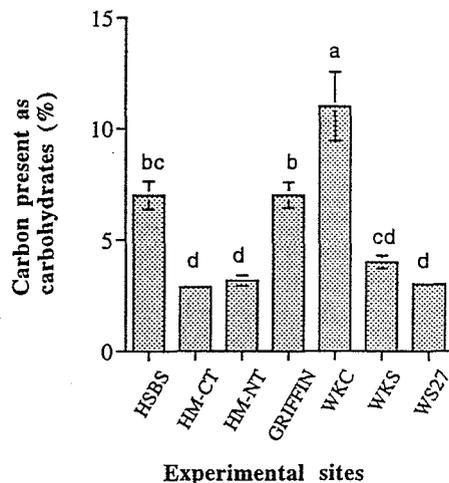

Fig. 3. Percentage of soil carbon present as carbohydrates. Values are mean ± 1 SE. HSBS = all the subplot CT, NT and fescue soils from HSB; HM-CT = HSB mainplot CT soils; HM-NT = HSB mainplot NT soils; GRIFFIN = all the CT, NT and fescue soils from Griffin; WKC = Watkinsville clayey soils; WKS Watkinsville sandy soils; WS27 = Watershed 27 at the Coweeta Hydrological Lab.
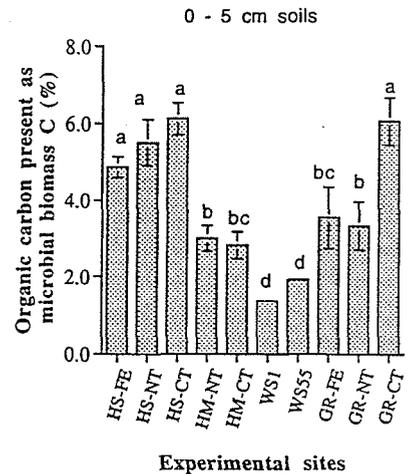

Fig. 4. Percentage of total organic carbon present as microbial biomass C (0–5 cm soils). Values are mean ± 1 SE. HS-FE = HSB subplot fescue soils; HS-NT = HSB subplot NT soils; HS-CT = HSB subplot CT soils; HM-NT = HSB mainplot NT soils; HM-CT = HSB mainplot CT soils; GR-FE = Griffin fescue soils; GR-NT = Griffin NT soils; GR-NT = Griffin CT soils. WS1 = Watershed 1 at the Coweeta Hydrological Lab; WS55 = Watershed 55 at the Coweeta Hydrological Lab.

C_{mic}/C_{org} ratios varied significantly among different soil ecosystems (Fig. 4). In the surface soils, the highest C_{mic}/C_{org} ratios were found in HSB subplot fescue and NT soils at 4.86% and 5.49%, respectively, which were significantly higher than those in CT and NT soils of the HSB mainplots, and Griffin fescue and NT soils. High C_{mic}/C_{org} were recorded in CT soils of both the HSB subplots and Griffin two yr after the fescue sods were plowed (Fig. 4). Forest soils had significantly lower C_{mic}/C_{org} ratios than cultivated soils. Soils in Watershed 1 under pine trees had the lowest at 1.36%. In the 5–15 cm soils, the differences in C_{mic}/C_{org} were less significant except for fescue and CT soils of the HSB subplots, which had a higher proportion of C in microbial biomass at 4.87% and 5.32%, respectively.

4. Discussion

Our results indicate that management practices and vegetation types exert profound influences on labile soil C pools. Relative sizes of labile C pools in

various ecosystems and their response to disturbance (e.g., tillage) could have important implications in understanding soil organic C stability in a changing climate. Different soil C pools have different lifetimes in soils (Parton et al., 1987; Hsieh, 1992) and labile C pools are most sensitive to temperature and moisture changes (Zak et al., 1993; Trumbore et al., 1996). About 30–50% of organic C in temperate soils is contained in highly recalcitrant organic-mineral complexes with a turnover time of thousand yr in temperate soils, while organic C in tropical soils (0–22 cm) is much more labile and the majority of that organic C has residence times of 10 yr or less (Trumbore, 1993). Most of the remainder exists in more labile forms with a turnover time of decades, forming an intermediate labile pool (Parton et al., 1987; Townsend et al., 1993). Carbohydrates could be an important component of this intermediate C pool. The response of labile C pools to altered temperature and moisture regime will be the most important factor determining the future soil C balance. Trumbore et al. (1996) suggested that a change of 0.5°C in temperature can cause soils to become significant sources or sinks of atmospheric CO_2 because the fast-cycling C pools are very sensitive to temperature changes.

Meanwhile, microbial biomass, the living part of SOM, is a more sensitive measure of a change in SOM because of its short turnover time of 1–2 yr (Powlson et al., 1987). Although the absolute C amount in microbial biomass is small, the microbes are the most important labile C pool since they are vital for soil organic C dynamics and nutrient cycling. Low C_{mic}/C_{org} ratios suggest that substrate availability for microorganisms is low, but provide no information on whether the low availability was resulted from low substrate quality or from low accessibility because of physical barriers (e.g., clayey protection of plant materials). The C_{carb}/C_{org} ratios can provide information on the chemical composition of SOM. Therefore, C_{carb}/C_{org} and C_{mic}/C_{org} ratios can provide complementary information on substrate availability.

In the present study, high C_{mic}/C_{org} in the fescue sods are consistent with results of other studies (Sparling, 1992). High organic matter input could be the driving factor resulting in higher microbial biomass C in pasture because grasses allot as much as 40–85% of photosynthetic products below ground through roots and mycorrhizae (Fogel, 1985; Whipps, 1990). C_{mic}/C_{org} ratios in pasture had been reportedly stimulated by organic C input in previous studies (Sparling, 1992). Extensive infection of roots with VAM mycorrhizae may also contribute, since external mycelium could be as high as 50 m g^{-1} soil in grasslands (Tisdall and Oades, 1979; Miller, 1986). Low percentages of C present as carbohydrates and low C_{mic}/C_{org} ratios in forest soils indicate that substrate availability for soil microorganisms was relatively low, which may explain why only a small fraction of soil organic matter is metabolized by soil microorganisms, although forest floor and mineral soils may contain 60% of the C and 95% of N within the forests (Zak et al., 1993). A significantly lower microbial biomass C in Watershed 1 than in Watershed 55 reflects the importance of the quality of organic matter input (rather than total organic C) in determining the size of the microbial biomass C pool.

Significant differences in carbohydrate composition between the sandy site and the clayey site at Watkinsville indicated that in the long term, soil texture has a dominant influence on soil C retention under conventional management regimes. Carbohydrates are readily degradable by microorganisms, but can last for much longer due to their association with clay and humic substances (Cheshire et al., 1992), and physical protection within soil matrices. Since mannose is predominantly of microbial origin and xylose is largely of plant origin, the mannose-to-xylose ratio provides information on the origin of carbohydrates (Folsom et al., 1974; Hu et al., 1995a,b). Significantly lower mannose-to-xylose ratios and higher percentages of C present as carbohydrates in the clayey site highlights the importance of protection of soil matrices, especially the clay component, on organic C. These results are in agreement with other findings that there were decreased decomposition and greater stabilization of organic carbon in soils of high clay contents (Van Veen and Paul, 1981; Nowak and Nowak, 1990; Skjemstad et al., 1996). Retention of soil organic C in low clay soils will rely on residue management practices effectively reducing microbial access such as surface residue placement (Holland and Coleman, 1987) and reducing disturbance (e.g., no-tillage). In the future,

influences of soil texture on soil C turnover should be given more consideration while modeling the C storage in agricultural soils.

For forest soils, substrate availability for microorganisms could be an important factor regulating the soil organic C turnover since high C/N ratios and high concentrations of carbon-based secondary compounds such as lignin and tannins lay the foundation for a self-reinforcing loop in which the decomposition of litter retards the release of nutrients (Vitousek, 1982). High C/N ratios and low labile carbon pools could be valuable characteristics which can be used to promote soil C accumulation in forest systems, provided that low nutrient cycling rates do not limit the primary production.

In conclusion, tillage significantly reduced microbial biomass C and carbohydrate concentrations, although carbohydrates were less sensitive than microbial biomass C to tillage in a short-term. Under conventional management regimes, retention of soil organic C and its labile pools, in particular, were largely dependent on the clay content of soils. Substrate quality (as shown in absolute and relative size of labile soil C pools) should be addressed when predicting the future soil C balance because labile C pools are most sensitive to temperature and moisture changes.

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