United States Department of Agriculture

Forest Service

Southern Research Station

Research Paper SRS-13

Assessing the Vegetation History of Three Southern Appalachian Balds through Soil Organic Matter Analysis

Jennifer D. Knoepp, Larry L. Tieszen, and Glen G. Fredlund

Goat Bald

Jarrett Bald

Rocky Bald

The Authors:

Jennifer D. Knoepp, Research Soil Scientist, USDA Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory, 3 160 Coweeta Lab Road, Otto, NC 28763; **Larry L. Tieszen,** Professor, Department of Biology, Augustana College, Sioux Falls, SD 57 197; **Glen G. Fredlund,** Associate Professor, Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI 53201.

September 1998

Southern Research Station
P.O. Box 2680
Asheville, NC 28802

Assessing the Vegetation History of Three Southern Appalachian Balds through Soil Organic Matter Analysis

Jennifer D. Knoepp, Larry L. Tieszen, and Glen G. Fredlund

Abstract

The history of Southern Appalachian grassy balds has long been a topic of speculation. Two types have been identified: those completely covered by grass and those occupied by a mixed-hardwood overstory with a grassy herbaceous layer. Three areas historically known as balds were identified in the Wine Spring Ecosystem Project Area. Each is currently under a different management regime. The objective of this assessment was to determine the vegetative history of these balds through soil organic matter (SOM) analysis. Soil was collected from each horizon through the profile on the bald sites using a nearby forest for reference. The $\delta^{13}C$ values were determined for the green vegetation, litter, and soils of the bald sites and reference forests. Samples were selected for determination of phytolith and charcoal content and for ^{14}C dating. The $\delta^{13}C$ value of plant tissues varies with photosynthetic pathway and plant type, providing a distinctive signature in SOM. Significant shifts in SOM $\delta^{13}C$ values with depth in the profile would suggest changes in site vegetation. Organic matter analysis indicated that two of the bald sites were never completely covered by grass without a woody component. The third bald may have undergone a vegetative shift in more recent times. Data also suggest that a vegetative shift may have occurred on two of the reference forest sites.

Keywords: Carbon dating, grassy bald, hardwood, prescribed burn, soil organic matter, Southern Appalachians.

Introduction

The origin of Southern Appalachian balds has been a subject of speculation since botanical inventories were conducted in the 1930's (Camp 1931, Camp 1936, Wells 1937). Balds are distinguished by high elevation and general lack of forest cover. Some are characterized as heath balds, with ericaceous shrubs being the dominant vegetation. Grassy balds, on the other hand, have grasses dominating the herbaceous layer, and include both those completely covered by grass and those with a sparse, mixed-hardwood overstory and grassy herbaceous layer. Historically, the latter type often had a completely grassy center (Lindsay 1976). Suggestions about the origins of the grassy balds include proposals that they represent natural plant communities maintained by frequent fire, or are a result of clearing by aboriginal peoples or early settlers for grazing (Fink 193 1, Wells 1936). Following extensive logging in the 1920's and 1930's, the Federal Government acquired land in the Southern Appalachians for the national forests and the Great Smoky Mountains National Park. Since then fiie has been excluded from the balds, and grazing has ceased. This has allowed the surrounding woody vegetation to encroach on these areas. The balds are maintained in an open condition as both wildlife areas and scenic vistas, which requires vegetation management including prescribed burning and clearing by hand and mechanical means (Lindsay and Bratton 1979).

The carbon $\delta^{13}C$ isotope signature present in soil organic matter (SOM) has been used to document vegetation changes over time (Andreux and others 1992, Balesdent and others 1993, Dzurec and others 1985, Mariotti and Peterschmitt 1994, Schwartz and others 1986, Tieszen 199 1, Vitorello and others 1989, Volkoff and Cerri 1987) and to reconstruct paleoenviromnents (Cerling 1992, Krishnamurthy and DeNiro 1982, Sukumar 1993). Plant tissue $\delta^{13}C$ values fall into modal groups based on their photosynthetic pathway. Plants that fix CO, by the C_4 (Hatch-Slack) mechanism have $\delta^{13}C$ values ranging from - 17 to -9‰, while those that use the C_3 (Calvin cycle) mechanism are significantly more negative: -32 to -20‰ (O'Leary 1988, Tieszen 1994). As a result, the isotopic value of SOM pools represents the vegetation that produced the SOM (Parton and others 1987).

Soil phytolith content and composition can also be used to test the relative stability or longevity of grassy areas. Opal phytoliths are silicaceous formations produced in leaf material. Grasses produce large quantities of very distinctive, densely silicified, short-cell phytoliths. Trees and shrubs, on the other hand, produce significantly fewer, less densely silicified phytoliths in a variety of shapes that are more susceptible to breakage and dissolution. These differences are reflected in the soil phytolith content. Soils from stable grasslands have substantially higher opal phytolith content than do woodland soils (Jones and Beavers 1964). Soil phytolith content can be used to determine the dominance of grassy vegetation and the long-term stability of a grassy patch.

The objective of this research was to determine the vegetative history of three Southern Appalachian ridge tops designated as balds. All three areas are within the Wine

Spring Creek Ecosystem Management Area and are currently under different management regimes. The SOM $\delta^{13}C$ values were examined to determine if a $\delta^{13}C$ signal shift indicated major changes in vegetation, such as encroachment of grassy areas by woody vegetation or the presence of C_4 grasses. Changes in the $\delta^{13}C$ values with depth in the soil profile were evaluated and compared with those in nearby forests. Soil chemical analysis was conducted to confirm that these sites had never been used for agriculture. Soil samples from balds and forests were analyzed for phytolith and charcoal content to estimate differences in grass populations and fire history. Soil samples from several depths on each bald were also ^{14}C dated.

Site Description

The Wine Spring Creek Ecosystem Management Project Area in the Nantahala National Forest in western North Carolina contains three high-elevation ridge locations historically known as balds. They are Goat Bald (GB), Jarrett Bald (JB), and Rocky Bald (RB). These areas are currently under different management regimes, but until 1980 all were occupied by an oak/mixed-hardwood overstory with grassy herbaceous layers before management. The elevation at GB and JB is 1500 meters (m); RB is at 1595 m. Sites are nearly level and occupied by soils in the Wayah series--coarse-loamy, mixed, frigid Typic Haplumbrepts.

Goat Bald has been managed as a wildlife opening since 198 1. In 198 1 and 1986, prescribed burns were conducted to promote grass production. All woody vegetation, including stumps, was mechanically removed in 1987. Following clearing, land managers planted a mixture of cool season grasses. The site was burned again in 1990. In 1992, a *Quercus rubru* L. (red oak) stump was located adjacent to the bald, probably representing an individual that was dominant before the site was cleared. Ring counts showed it to have been approximately 180 years old when felled.

Jarrett Bald also is managed as a wildlife opening. In 1986, all woody vegetation was cut and left in place. Sprouting woody vegetation was periodically hand cut. Prescribed burns were conducted in 1981 and in 1987. In 1992, cross-sections from stumps of the apparent dominant and codominant Q. *rubru* were cut. Their ages when felled were 210 and 98 years, respectively. Two *Betula alleghaniensis* Britton (yellow birch, a fire-intolerant species) stumps were also identified and cross-sectioned; they were about 40 years old when cut in 1987.

Rocky Bald has not been disturbed by humans in recorded history. Q. *rubru* dominates the overstory. The ages of two dominant individuals were determined by coring and were found to be more than 100 years. Codominant species were ***Betula lenta*** L. (black birch) and ***Acer rubrum*** L. (red maple) ranging from 45 to 50 years old.

Reference forests used for comparison of $\delta^{13}C$ values were at the Coweeta Hydrologic Laboratory, about 15 kilometers (km) from the Wine Spring Creek Project Area. The sites were three south-facing areas that, in side-slope, cove, and ridge landscape positions, represent three forest communities within the Coweeta basin. The mixed oak-hardwood community, which is dominated by Q. ***prinus*** L. (chestnut oak), with Q. *coccineu* Muenchh. (scarlet oak), Q. ***alba*** L. (white oak), Q. *velutina* Lam. (black oak) plus *A.* ***rubrum*** and ***Carya*** spp. (hickory) present, is on the side-slope position. The cove-hardwood community, which includes *Liriodendron tulipiferu* L. (yellow-poplar), *A.* ***rubrum***, and Q. *rubra*, is found in mesic cove areas. The oak-pine community, dominated by Q. *coccinea* and ***Pinus rigida*** Mill. (pitch pine), is on xeric, south-facing ridges. The slope and ridge sites had been undisturbed since the 1920's, but the cove site was clear-cut harvested in 1977. All three community types were sampled at low and high elevations, approximately 870 m and 1100 m, respectively. Soils on all sites are classified as either the Fannin series, a fine-loamy, micaceous, mesic Typic Hapludult; or the Chandler series, a coarse-loamy, micaceous, mesic Typic Dystrochrept.

Materials and Methods

Sample Collection

A transect extending from the elevational center of the bald toward the surrounding forest was established for soil and vegetation sampling on GB, JB, and RB. Transect establishment allowed examination of the possibility that hardwood vegetation had encroached on a completely grassy bald. Three or four 1 -m^2 quadrats along the transect were chosen to represent the vegetation occupying each bald. A complete vegetation inventory was conducted, and percent cover of each species was determined within each quadrat before sample collection. Vegetation inventory and samples were taken to characterize the quadrat from which soil samples were taken, not to confirm differences between balds. The plant materials collected from each quadrat were green graminoids (G); green forbs (F); litter, dead but identifiable plant material (L); and humus, unrecognizable organic material (H). All samples were dried and ground to pass a 40-mesh sieve.

Two soil cores were collected within each quadrat using a 2.5centimeters (cm) diameter, 60-cm-long core sampler with a slide hammer attachment. For each core, the soil profile was described; and the soil was sampled and composited by horizon for each quadrat. Due to slight differences in horizon designations among quadrats, ANOVA testing was conducted on similar depth/horizon increments to determine differences among bald sites. Roots were removed from each soil horizon and sorted into two groups, ≥ 2 millimeters (mm) and ≤ 2 mm in diameter. Roots and soils were treated with 1N HCl at room temperature and shaken to remove carbonates, which were occasionally present. Samples were then evacuated, centrifuged, and rinsed with deionized water before being ground.

Reference forest soil samples were collected from soil pits. Two pits were dug for each community type in the reference forests, one at 870 m (low elevation) and one at 1100 m. Each soil pit was cl m wide and up to 1 m deep. Soil profiles within the pits were described in two locations 1 m apart. Soil samples were collected from each horizon, one at each description point throughout the profile. Horizons ≥ 20 cm deep were sampled in 10-cm increments. Leaf litter samples were collected from the dominant woody vegetation at each site: oak leaves (0) from the mixed oak site; oak leaves (0) and pine needles (P) from the xeric ridge site; and oak leaves (0), tulip poplar leaves (T), and black locust leaves (B) from the cove site. Forest floor samples were also collected and included the litter layer (L), fermentation layer (F), and humus layer (H). All samples were dried and ground to pass a 40-mesh sieve.

Soil samples from each bald were composited by horizon for chemical characterization. Soil cation concentrations were determined in dilute, double-acid extracts. Five grams of air-dried soil was shaken for 30 minutes with 25 milliliters (mL) 0.05 M H_2SO_4 and 0.5 M HCl. Samples were then centrifuged and supematant analyzed for cation concentration using an atomic absorption spectro-photometer. Soil pH measurements were taken in a 1: 1 soil to 0.1 M $CaCl_2$ slurry, using a single pH electrode.

Isotopic Analyses

Vegetation and soil samples were analyzed for C and N by combustion (1.5 milligrams [mg] for vegetation, 5 to 20 mg for soil) on the Carlo Erba 1500 CN analyzer. Sample CO, from elemental analysis was then cryogenically purified and analyzed for carbon isotope ratios on a VG SIRA 10 isotope ratio mass spectrometer (Tieszen and Fagre 1993). The $\delta^{13}C$ values were calculated by the following standard equation:

$$\delta^{13}C = \frac{(Rs - RP)}{(Rp)} * 1,000,$$

where
Rs = ratio of ^{13}C to ^{12}C in the sample;
Rp = ratio of ^{13}C to ^{12}C in PDB standard.

The error associated with instrument precision, sample preparation, and analysis is ≤ 0.2‰. Quality control procedures included running periodic sample duplicates and an internal standard after every 10th sample.

Soil samples from representative horizons of each bald were decarbonated and radiocarbon-dated at Geochron Inc. by conventional or American Meteorological Society counting methods.

Phytdith Analyses

Eight grams of air-dried soil were used for phytolith extraction, except where limited by sample size. Samples were treated with 20 mL HCl (37 percent) to oxidize carbonates, followed by repeated washing with distilled H_2O. Sodium hexametaphosphate ($(NaPO_3)_6$), 0.01 M, was used to deflocculate clays and oxidize colloidal organic material, which was removed by repeated settling and decanting. Then samples were treated with H_2O_2 (30 percent) in a boiling water bath to oxidize residual organic material. Clay and colloidal materials released by this process were then decanted. Biogenic silicates were isolated from the soil mineral fraction by flotation with a $ZnBr_2$ solution at 2.35 specific gravity, repeated three times. The supematant was filtered through a 5-μm pore membrane to ensure that no phytoliths were lost. The isolated fraction was washed, air-dried, and stored. The air-dried, extracted fraction (specific gravity ≤ 2.35) was weighed and expressed as a percentage of the original air-dried soil sample.

Two or more slides per extracted sample were mounted using a glycerin solution. Glycerin allows the rotation of micro fossils under the cover-slip for more accurate classification. Slides were systematically scanned at 630X magnification using a Leitz Laborlux-S microscope. Rapid, point-count estimates were made for at least five fields of view. All objects greater than 5-μm were classified, including: (1) non-biogenic silicates, (2) irregular phytolith fragments, (3) large, dense arboreal phytolith forms, (4) grass short-cell phytolith forms, (5) other phytolith forms (elongate, bulliforms, trichomes, etc.), and (6) charcoal. So few large, dense arboreal phytolith forms were isolated that relative frequencies could not be calculated. The percentage of grass short-cell form, relative to the total phytolith sum, was calculated for each sample. Data reported are percent phytolith by weight recovered, and short-grass phytolith content as the percent total phytolith of each sample.

Statistical analyses of bald $\delta^{13}C$ values were conducted using ANOVA procedures in SAS (SAS Institute 1985). A one-way ANOVA test was used to determine significant differences in $\delta^{13}C$ among vegetation, litter, and soil horizons for each bald. A two-factor ANOVA test was used to examine interactions between bald and soil depth/horizon. Matching soil horizons within the soil profile were analyzed using General Linear Models procedures (SAS Institute 1985) to determine differences between $\delta^{13}C$ values for reference forest and bald soils. Significant differences between means were determined using Tukey's mean separation test (SAS Institute 1985).

Results and Discussion

Neither SOM $\delta^{13}C$ values, nor phytolith and ^{14}C data suggest that a major vegetation shift occurred on the three balds. There was no evidence that these sites ever included a significant C_4 grass component; however, RB showed an increase of ≥ 2‰ in SOM $\delta^{13}C$ values within the soil profile, possibly due to some changes in vegetation composition. On the other hand, $\delta^{13}C$ data from the reference forests suggest that some major vegetation shifts may have occurred. As table 1 shows, the bald sites vary substantially in herbaceous plant species composition due to differences in management.

Goat Bald was dominated by cool season grasses. Jarrett Bald was dominated by a variety of forbs and very few graminoids. Rocky Bald had Q. ***rubra*** and ***A. pennsylvanicum*** seedlings and an extensive cover of ***Carex pennsylvanica***, which occasionally formed nearly pure swards beneath a closed tree canopy. Thirty percent of plant species found in the quadrat inventory were listed in historical plant inventories conducted on balds in this area of the Blue Ridge province in the 1930's (table 1) (Wells 1937). Current or historical plant inventories showed no evidence of C_4 plant species. The similar ages of dominant overstory trees, > 100 to 180 years, and fire sensitive understory trees, 40 to 50 years, suggest the three balds had a common history of woody plant occupation and fire frequency.

The relationship between vegetation and SOM $\delta^{13}C$ composition was similar among all quadrats on all bald sites, dispelling the hypothesis that they ever had a grassy center, lacked a forest component, or that trees are on the site due to encroachment. Soil organic matter $\delta^{13}C$ values were more positive than the plant compartments (fig. 1). Soil and green vegetation differences were most marked on RB, where values for graminoids and forbs were the most negative (-28.9‰), and the soil from lower horizons was most positive (-23.4 ‰). The pattern at JB was intermediate. Bulk root $\delta^{13}C$ values were 1‰ to 4‰ more negative than SOM at the same depth.

Soil profiles in each quadrat along the transect from bald center to forest edge were similar on all three balds (table 2). There was no evidence that these areas had ever been used for agriculture. Distinct surface horizons were present on all bald sites. Lime application during grass establishment was evident in A horizon soils on GB, where the pH is 5.8 and Ca and Mg levels are high. However, the effects of lime were evident only in the surface 12 cm, suggesting that the area was never plowed. Soils from all balds were slightly acidic, with pH values ranging from 4.0 to 4.7 (table 2). Carbon content of the A horizon soils on all balds was quite high. Soil carbon was greatest at RB (11 .O percent) and significantly lower (7.7 and 6.6 percent, respectively) for GB and JB, (F = 10.047 and p = .008). Carbon-to-nitrogen (C:N) ratios ranged from 10 to 25 and differed significantly among balds but not with soil horizon. Soils from JB had the highest C:N ratios (mean = 2 1.4), compared with soils from GB (mean = 16.0) and RB (mean = 16.5).

Vegetation $\delta^{13}C$ values differed significantly among balds (F = 13.59, p = 0.0001) and plant components (F = 2.63, p = 0.0 18) (fig. 1). Rocky Bald plant compartments were significantly more negative than the other balds at ≤ -28‰. This may have been due to increased assimilation of soil-respired CO, because plants on RB were beneath a closed overstory canopy. Rocky Bald also showed a significant difference among plant compartments. The graminoid and forb $\delta^{13}C$ values were more negative than values in the litter and humus layers, perhaps due to input from the overstory vegetation. ANOVA testing showed that root $\delta^{13}C$ values did not change with soil depth on any of the bald sites.

Reference forests showed the same pattern as bald sites, with SOM $\delta^{13}C$ values more positive than the plant components (fig. 2). Unlike the balds, differences in forest site $\delta^{13}C$ values for plant components were not significant. Only oak leaf $\delta^{13}C$ values were significantly more negative than other plant components, including the litter and humus layers. As

Table l-Average percent cover of each plant species present in the quadrant (1 m^2) sampled for vegetation material and soil cores on Goat Bald, Jarrett Bald, and Rocky Bald

Species	Location		
	Goat Bald	Jarrett Bald	Rocky Bald
	- - - - - - - - - - - - Average percent cover - - - - - - - - - - - - -		
Herbaceous			
Anemone quinqifolia			2
Carex pennsylvanica			37
Carex spp."			0.25
Dactylis glomerata"	26		
Danthonia compressa"	3.75		
Diasporum lanuginosum			1.25
Fern		5	
Festuca rubra	3.75		
Fragaria virginiana"		5	
Hedyotis crassifolia	3.75	41	41
Hedyotis purpurea	3.75	0.25	
Honeysuckle	1.25		
Legume	.25		
Luzula acuminata			10
Lysimachia quadrifolia[a]	2.5	10	
Monarda clinopodkf			1.25
Panicum spp."	.25	3.75	
Potentilla simplex	30		
Potentilla canadensis[a]	5		
Prenanthes trifoliata			>0
Ranunculus hispidus		21.25	
Smilax herbacea			.25
Solidago arguta[a]		2.75	2.5
Thelypteris novoboracensis			7.5
Tiarella cordifolia			.25
Woody			
Acer pensylvanicum			1.25
Quercus alba			1
Quercus rubra"			.25
Rhododendron calendulaceum		3.75	1.25
Rubus spp."	3.75	1.25	

[a] Included on a species list for balds in what is now the Wine Spring Ecosystem Management Area as described by Wells (1937)

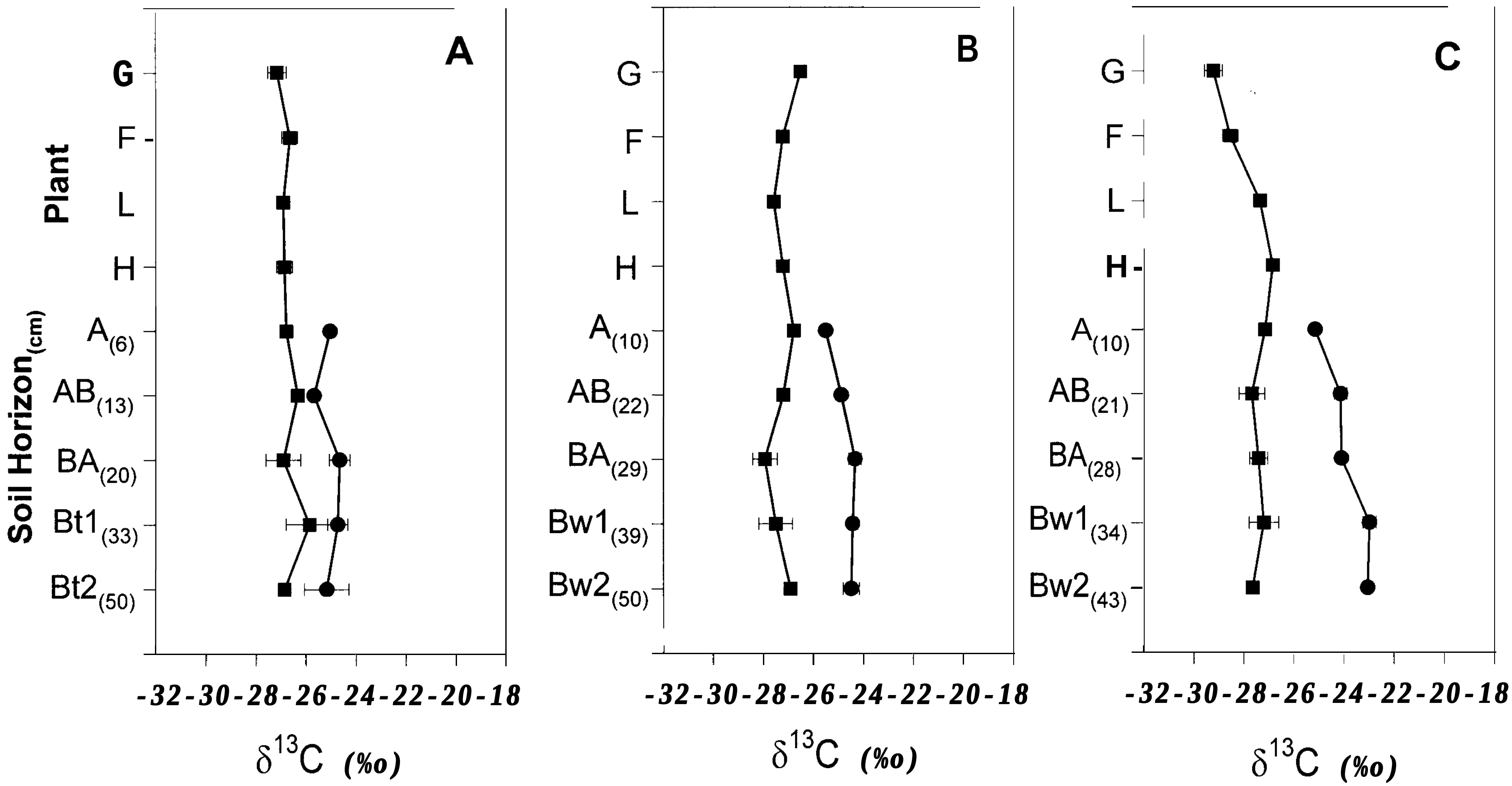

Figure I-Mean (bars = SE.) carbon isotope values ($\delta^{13}C$) for SOM (●) and roots (■) at each sample point through the profile and mean isotopic values for plant compartments on grassy bald sites. Bald sites presented are Goat Bald (A), Jarrett Bald (B), and Rocky Bald (C). Plant components: green graminoids (G) and green forbs (F). Organic horizon components: litter (L) and humus (H). Soil horizon designations represent a general profile description and average depth for each site.

Table 2-Soil profile description and chemical characterization for soils from Goat Bald, Jarrett Bald, and Rocky Bald

Horizon[a]	Carbon[b]	C:N[b]	pH[c]	Ca[c]	Mg[c]	K[c]	P[c]
	Percent	Ratio			*mg kg⁻¹*		
Goat Bald							
A (4cm)	7.66 (0.7)	17.3 (1.1)	5.84	1302	689	41	2.3
A2 (9cm)	5.90 (0.8)	18.2 (2.6)	4.61	282	120	22	1.4
AB (12cm)	3.62 (0.2)	18.2 (2.3)	4.73	221	102	18	.9
BA (20cm)	1.45 (0.1)	16.1 (0.8)	4.37	28	13	14	1.1
Bwl(33 cm)	.43 (0.1)	13.1 (0.7)	4.28	13	7	11	.8
Bw2 (44 cm)	.20 (0.06)	11.3 (0.1)	4.31	12	10	14	1.3
BC (44 cm)[d]	.17[d]	10.8[d]	4.38	7	6	6	3.0
Jarrett Bald							
A (7 cm)	6.57 (0.6)	18.1 (0.3)	4.32	152	36	120	1.7
A2 (17 cm)	4.48 (0.4)	20.7 (1.4)	4.42	50	11	56	1.1
A3 (19cm)	3.72 (0.3)	20.4 (1.0)	4.54	92	27	155	8.2
AB 1(24 cm)	2.29 (0.2)	19.6 (0.9)	4.42	17	5	36	3.7
AB2 (27 cm)	2.48 (1.0)	21.9 (2.3)	4.41	21	5	34	3.7
BA (31 cm)	1.48 (0.4)	22.3 (3.7)	4.51	8	3	16	2.3
B1 (42cm)	.40 (0.05)	22.2 (2.9)	4.41	7	8	14	2.2
B2 (54 cm)	.17 (0.01)	22.9 (8.9)	4.43	6	8	16	.6
Rocky Bald							
Al (5 cm)	10.99 (0.8)	16.0 (0.5)	4.00	111	42	90	1.5
A2 (15 cm)	7.29 (0.6)	18.8 (0.7)	4.19	28	21	123	1.0
A3 (20 cm)	5.58 (0.9)	18.9 (0.8)	–	16	12	28	.5
AB (24cm)	4.72 (0.7)	18.4 (0.6)	4.29	11	6	18	.5
BA (30cm)	1.92 (0.5)	16.0 (1.4)	4.43	8	4	12	5.1
B1 (35 cm)	1.30 (0.2)	15.1 (0.5)	4.42	9	4	10	1.6
B2 (43 cm)	1.27[d]	16.4[d]	4.50	7	3	9	.7

[a] Horizon designations are presented with average (n = 3 for GB and RB n = 4 for JB) bottom depth in parentheses.

[b] Percent C and C:N ratios presented with standard errors in parentheses, sample numbers as “a.”

[c] Soil Ph, Ca, Mg, K, and P determinations were made on one composited sample per horizon for each bald.

[d] n = I.

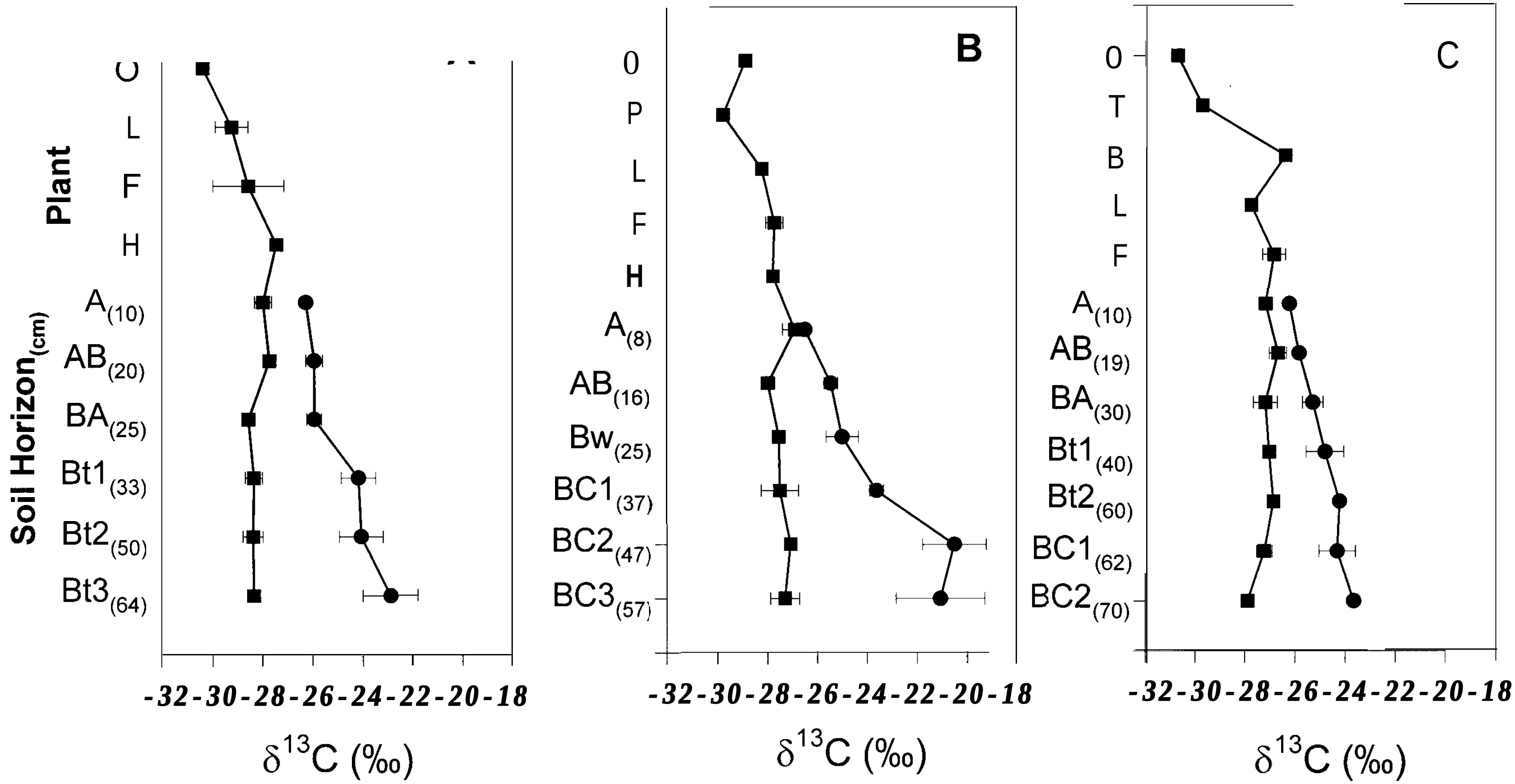

Figure 2. Mean (bars = S.E.) carbon isotope values ($\delta^{13}C$) for SOM (●) and roots (■) at each sample point through the profile and mean isotopic values for plant compartments on reference forest sites. Sites presented include mixed oak (A), xeric ridge (B), and mesic cove (C). Plant components: mixed oak, oak leaves (0); xeric ridge, oak leaves (0); pine needles (P); mesic cove, oak leaves (O), tulip poplar leaves (T), black locust leaves (B). Organic horizon components: L (litter) = Oi, F (fermentation layer) = Oe, and H (humus) = Oa. Soil horizon designations represent a general profile description and average depth for each community type.

on the balds, reference forest root $\delta^{13}C$ values did not vary within the soil profile. However, differences between root and SOM $\delta^{13}C$ were much greater in the forests than on the bald sites, reaching up to 6‰ in the BC horizon on the xeric ridge site.

Soil organic matter $\delta^{13}C$ values differed significantly among sites and soil horizons on balds and reference forest sites (table 3). Most showed a significant decrease in SOM $\delta^{13}C$ with depth in the profile (figs. 1 and 2). The exceptions were GB and the cove site, where horizon effect p-values were 0.74 and 0.09, respectively. Rocky Bald soils showed the greatest enrichment with depth of the bald sites, with an increase of ≥ 2‰ within the profile. Soil organic matter $\delta^{13}C$ increases, relative to profile depth, were greater in reference forests than on the balds, ranging from 2‰ for the cove site to 5‰ for the xeric ridge. Changes in $\delta^{13}C$ of this magnitude suggest that some vegetative changes have taken place. C_4 plant species may have been present on the xeric ridge and mixed-oak site, both south-facing slopes, resulting in less negative SOM $\delta^{13}C$ values.

Some ^{13}C enrichment of SOM through the profile can be accounted for by the incorporation of anthropogenically depleted ^{13}C into SOM pools. Fossil fuel use, agricultural practices, and deforestation have released ^{13}C-depleted carbon into the atmosphere. This has resulted in atmospheric $\delta^{13}C$ values that are about 1.5‰ more negative than they were a century ago. Von Fischer and Tieszen (1995) studied a Puerto Rican forest system and found that recently fixed carbon, e.g., green vegetation and litter, is incorporated into SOM pools with rapid turnover rates. Those SOM pools that turn over more slowly have $\delta^{13}C$ values that become more positive deeper in the profile. Many researchers studying forest soils have found increases of 1.4 to 2.0‰ between the litter layer, surface soils, and subsurface horizons deep in the profile (Goh and others 1976; Melillo and others 1989; Nadelhoffer and Fry 1988; Schleser and others 198 1). Under deciduous forests in New Zealand, Goh and others (1976) found a 1.4 to 1.5‰ enrichment between the surface and soils at a 75 cm depth. Schleser and others (198 1) studied some German forests where deeper soils were enriched 2‰ relative to surface soils. North American forests also have exhibited enrichment within the soil profile. Soils under oak forests in Wisconsin were enriched by 1.6‰ between the top 10 cm of mineral soil and the deeper soils (Nadelhoffer and Fry 1988). A pine forest soil in Massachusetts was enriched 1.6‰ between the forest floor and SOM at 45 cm (Melillo and others 1989).

Tieszen and Pfau (1995) examined changes in vegetation over time using changes in $\delta^{13}C$ values with soil depth. They documented woodland intrusions on grasslands with a substantial C_4 component in loess hill areas of the grassland-forest transition zone. In this study, the SOM $\delta^{13}C$ values on the bald sites did not lead to firm conclusions concerning the balds' vegetative history. This is largely due to the absence of C_4 grasses. However, RB and the reference forest soils show greater enrichment with depth than can be accounted

Table 3—Two-factor ANOVA for soil organic matter carbon isotope value as a function of bald or forest and horizon as described in the soil profile"

Source	df	Sum of squares	F-value	Prob >F
Bald	2	5.59	11.26	<0.00 1
Horizon	5	10.85	8.75	<.001
Bald X horizon	8	6.13	3.09	.008
Error	43	10.67		
Forest	2	9.31	3.56	.037
Horizon	8	114.14	10.90	<.001
Forest X horizon	8	8.98	.86	.558
Error	43	56.29		

"This table presents the analysis of all soil profile designations across all balds or reference forests.

for by anthropogenic enrichment, suggesting that a vegetative shift took place on these sites sometime in the past. Balesdent and others (1987) showed that the C_3 signal of forest SOM was completely replaced by the C_4 signal of maize after 23 years of cultivation. However, this took place only in the surface soil. The C_3 signal was still evident at greater depths in the profile, SOM turnover rates decreased with depth in the profile due to lower biological activity and increased clay content. This is typical in soil profiles that have a Bt horizon, which is the case with most soils sampled in this study.

The incorporation of recently fixed or modem C in the SOM on the bald sites is evident in the ^{14}C data presented in table 4. These data showed that modem C was >50 percent at all depths sampled. Many samples possessed substantial bomb radiocarbon; for example, the GB A-horizon soils, where the modem C was >100 percent. The samples from JB illustrate a profile where ^{14}C age increased with depth, and even the surface carbon was premodem. Radiocarbon dating showed the deepest soil sample, from between 37 and 48 cm, to be 4,945 years B.P. Carbon at RB, however, was more recent than at JB and GB. This may reflect recent C input at greater depth by trees on the site.

Total phytolith content of surface soils suggested no significant difference between bald and reference forest soils (table 5). However, the morphological composition of phytolith assemblages suggested a slight difference between bald and forest soils. Upper soil horizons from balds had a slightly greater percentage of grass phytoliths than do forest soils, but the difference was not significant. A significant decline in total phytolith content occurred with depth in most of the bald soil profiles. Deeper soil horizons from the balds had a greater percentage of grass phytoliths. This could have resulted from the long-term grass component present on the bald sites and the dissolution and decay of less hardy arboreal morphotypes over time. The dissolution of arboreal phytoliths was supported by the overall decrease in phytolith content with depth. Counts showed substantial amounts of charcoal in the bald soils at depths down to 20 cm in the profile. This supported the tree-age data, suggesting that bald sites had the same fire and vegetative histories.

Conclusions

Examination of SOM $\delta^{13}C$ values through the profile on three balds in the Southern Appalachians suggested a slight vegetative shift may have occurred on Rocky Bald. These data and the ages of dominant and codominant trees suggest the sites probably had the same fire history. There was no evidence that any of the bald sites were ever grassy without a woody vegetation component, or that woody vegetation

Table &Carbon-l4 dates for selected soil horizons from one sample for each bald[a]

Site-horizon	Carbon	Age (S.E.)	Modem (S .E.)	Method
	Percent		*Percent*	
RB-Al	10.9	Modem	101.3 (1.8)	Conventional
RB-AB 1	4.5	Modem	105.7 (3.1)	Conventional
RB-BA	2.4	365 (310)	95.5 (3.7)	Conventional
RB-B2	1.3	Modem	100.8 (4.4)	Conventional
JB-Al	8.41	275 (160)	96.7 (1.9)	Conventional
JB-AB 1	4.00	1575 (700)	82.2 (7.1)	Conventional
JB-BA	2.28	2790 (440)	70.7 (3.9)	Conventional
JB-B2	.18	4945 (70)	53.6 (0.5)	AMS
GB-A 1	8.99	Modem	113.0 (1.4)	Conventional
GB-B 1	1.31	128 (390)	85.2 (4.2)	Conventional

RB = Rocky Bald; JB = Jarrett Bald; GB = Goat Bald; S.E. = Standard Errors.
‘Data presented include percent C, age of C, percent C that is modern, and method of determination. Values in parenthesis for age and percent modern are standard errors.

Table S-Total percent phytolith (g phytolith x g soil^{-1}×100), percent grass short cell phytolith (g grass phytolith x g phytolith^{-1}×100) content, and relative abundance of charcoal for bald and reference forest soils (all values presented are means of all samples analyzed)

Soil horizon—depth	Phytoliths”	Grass phytoliths	Charcoal[b]—abundance
	- - - - - - - - - - Percent - - _ _ _ _ - - _ _		
Balds			
A1[c] (0-10 cm)	0.94 (.14)	3.52 (.90)	5
A2/AB[d] (IO-20 cm)	.63 (.06)	5.58 (.51)	3
Forest			
Al (O-10 cm)	.99 (.17)	2.79 (.39)	2

[a] Standard errors in parentheses.
[b] Presented as mean of ranked values where 1 = absent; 5 = abundant.
[c] A1 horizon n = 6.
[d] A2/AB horizon includes all soils above the B horizon n = 14.

encroached on a grassy bald center. Neither modern nor older SOM $\delta^{13}C$ data suggest these sites ever had a substantial C_4 grass component. Phytolith and charcoal analyses showed that the bald sites had both a greater grass component and higher charcoal content than reference forests. Changes in $\delta^{13}C$ with depth in the soil profile differed between bald and reference forest sites. Interestingly, SOM $\delta^{13}C$ data from two of three reference sites indicated that a major vegetative shift had occurred.

Acknowledgment

This research was supported by the US. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station (now Southern Research Station), through cooperative agreements 29- 1067 and 29-798. We thank Wayne Swank for supporting study in this area, Steven McNulty and David Wedin for their helpful reviews of this manuscript, Chad McMurtry and Michael Pfau for field assistance, Joe von Fischer and Donovan DeJong for early data analysis, Mike Chapman for the isotopic analyses, and Lee Reynolds for plant identification and logistic support.

Literature Cited

Andreux, F.; Cerri, C.; Vose, P.B.; Vitorello, V.A. 1992. Potential of stable isotope, ^{15}N and ^{13}C, methods for determining input and turnover in soils. In: Harrison, A.F.: Ineson, P.; Heal, D.W.. eds. Nutrient cycling in terrestrial ecosystems, [Place of publication unknown]: [Publisher unknown]: 259-275.

Balesdent, J.; Mariotti, A.; Guillet, B. 1987. Natural ^{13}C abundance as a tracer for studies of soil organic matter dynamics. Soil Biology and Biochemistry. 19: 25-30.

Balesdent, J.; Girardin, C.; Mariotti, A. 1993. Site-related ^{13}C of tree leaves and soil organic matter in a temperate forest. Ecology. 74: 1713-1721.

Camp, W.H. 193 I. The grass balds of the Great Smoky Mountains of Tennessee and North Carolina. Ohio Journal of Science. 3 I: 157-164.

Camp, W.H. 1936. On Appalachian trails. Journal of New York Botanical Garden. 37: 249-265.

Cerling, T. 1992. Use of carbon isotopes in paleosols as an indicator of the p(CO_2) of the paleoatmosphere. Global Biogeochemical Cycle\. 6: 307-3 14.

Dzurec, R.S.: Boutton, T.W.; Caldwell, M.M.; Smith, B.N. 1985. Carbon isotope ratios of soil organic matter and their use in assessing community composition changes in Curlew Valley, Utah. Oecologia. 66: 17-24.

Fink, P.M. 1931. A forest enigma: one of nature's mysteries of the Southern Appalachians. American Forester. 37: 538.

Goh, K.M.; Rafter, T.A.; Stout, J.D.; Walker, T.W. 1976. **The** accumulation of soil organic matter and its carbon isotope content in a chronosequence of soils developed on aeolian sand in New Zealand. Journal of Soil Science. 27: **89**- 100.

Jones, RL.; Beavers, A.H. 1964. Variation of opal phytolith content among some great soil groups in Illinois. Soil Science Society of America Journal. 28: 71 I-712.

Krishnamurthy, R.V.; **DeNiro,** MJ. 1982. Isotope evidence for Pleistocene climatic changes in Kashmir, India. Nature. 298: 640644.

Lindsay, MM. 1976. History of the grassy balds in Great Smoky Mountains National Park. Research/Resources Management Report No. 4. Gatlinburg, TN: U.S. Department of Interior, National Park Service, Southeast Regional Office, Uplands Field Research Laboratory.

Lindsay, M.M.; **Bratton,** S.P. 1979. Grassy balds of the Great Smoky Mountains: their history and flora in relation to potential management. Environmental Management. 3: 417-430.

Mariotti, A.; Peterschmitt, E. 1994. Forest savanna ecotone dynamics in India as revealed by carbon isotope ratios of soil organic matter. Oecologia. 97: 475480.

Melillo, J.M.; Aber, J.D.; Linkiis, A.E.; Ricca, A.; Fry, B.N. 1989. Carbon and nitrogen dynamics along the decay continuum: Plant litter to soil organic matter. In: Clarholm, M.L. Bergstrom, eds. Ecology of arable land. Kluwer Academic Publishers: 53-62.

Nadelhoffer, K.J.; Fry, B. 1988. Controls on nitrogen-15 and carbon-13 abundances in forest soil organic matter. Soil Science Society of America Journal. 52: 1653-1660.

O'Leary, M.H. 1988. Carbon isotopes in photosynthesis. Bioscience. 38: 328-335.

Parton, WJ.; **Schimel,** D.S.; Cde, C.V.; **Ojima,** D.S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Science Society of America Journal. 51: 1173-l 179.

SAS **Institute Inc. 1985.** SAS user's guide: statistics. Version 5 edition. Cary, NC.

Schleser, G.H.; **Pohling,** R.; **Kerpen,** W. 198 1. Die verteilung der stabilen kohlenstoftisotope 13C/12C in einem pseudogley unter wald. Z. Pflanzenemaehr. Bodenk.144: 149-155.

Schwartz, D.; Mariotti, A.; Lanfranchi, R.; Guillet, B. 1986. ^{13}C:^{12}C ratios of soil organic matter as indicators of vegetation changes in the Congo. Geoderma. 39: 97-103.

Sukumar, RR 1993. A delta ^{13}C record of late quaternary climate change from tropical peats in Southern India. Nature. 364: 703-706.

Tieszen, L.L. 1991. Natural variations in the carbon isotope values of plants: Implications for archaeology, ecology, and paleoecology. Journal of Archaeological Science. 18: 227-248.

Tieszen, L.L. 1994. Stable isotopes on the Plains: Vegetation analyses and diet determinations. In: Owsley, D.W.; Jantz, R.L., eds. Skeletal biology in the Great Plains: a multidisciplinary view. Smithsonian Press: 261-282.

Tieszen, L.L.; **Fagre,** T. 1993. Carbon isotopic variability in modern and archaeological maize. Journal of Archaeological Science. 20: 25-40.

Tieszen, L.L.; **Pfau,** M.W. 1995. Isotopic evidence for the replacement of prairie by forest in the Loess Hills of eastern South Dakota. In: D.C. Hartnett, ed. Proceedings of the fourteenth North American Prairie Conference: Prairie Biodiversity. Kansas State University: Manhattan, KS. 153-165.

Vitorello, V.A.; Cerri, C.C.; Andreux, F.; Feller, C.; Victoria, R.L. 1989. Organic matter and natural carbon-13 distribution in forested and cultivated oxisols. Soil Science Society of America Journal. 53: 773-778.

Volkoff, B.; **Cerri,** C.C. 1987. Carbon isotopic fractionation in subtropical Brazilian grassland soils: comparison with tropical forest soils. Plant and Soil. 102: 27-3 1.

Von Fischer, J.C.; **Tieszen,** L.L. 1995. Carbon isotope characterization of vegetation and soil organic matter in subtropical forest in Luquillo, Puerto Rico. Biotropica. 27: 138-148.

Wells, B.W. 1936. Origin of the Southern Appalachian grass balds. Science. 83: 283.

Wells, B.W. 1937. Southern Appalachian grass balds. Elisha Mitchell Science Society. 53: l-25.

[redacted]

Knoepp, Jennifer D.; Tieszen, Larry L.; Fredlund, Glen G. 1998. Assessing the vegetation history of three Southern Appalachian balds through soil organic matter analysis. Res. Pap. SRS-13. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 12 p.

The history of Southern Appalachian grassy balds has long been a topic of speculation. Two types have been identified: those completely covered by grass and those occupied by a mixed-hardwood overstory with a grassy herbaceous layer. Three areas historically known as balds were identified in the Wine Spring Ecosystem Project Area. Each is currently under a different management regime. The objective of this assessment was to determine the vegetative history of these balds through soil organic matter (SOM) analysis. Soil was collected from each horizon through the profile on the bald sites using a nearby forest for reference. The $\delta^{13}C$ values were determined for the green vegetation, litter, and soils of the bald sites and reference forests. Samples were selected for determination of phytolith and charcoal content and for ^{14}C dating. The $\delta^{13}C$ value of plant tissues varies with photosynthetic pathway and plant type, providing a distinctive signature in SOM. Significant shifts in SOM $\delta^{13}C$ values with depth in the profile would suggest changes in site vegetation. Organic matter analysis indicated that two of the bald sites were never completely covered by grass without a woody component. The third bald may have undergone a vegetative shift in more recent times. Data also suggest that a vegetative shift may have occurred on two of the reference forest sites.

Keywords: Carbon dating, grassy bald, hardwood, prescribed burn, soil organic matter, Southern Appalachians.