SHORT-TERM DECLINE IN SOIL CARBON DIOXIDE CONCENTRATIONS UPON BURNING OF SECONDARY VEGETATION IN THE KARST OF BELIZE

MICHAEL DAY

Department of Geography, University of Wisconsin-Milwaukee,
P.O. Box 413, Milwaukee, Wisconsin 53201, USA.

Abstract

A series of forty soil carbon dioxide measurements were taken in hillslope soils at a single 0.5 hectare site in the karst of the Cayo District, Belize immediately prior to and following the burning of the secondary vegetation during March of 1984. All measurements were made with a Draeger probe at a soil depth of approximately 20 cm. The secondary growth had been cut, but not burned, prior to the first set of measurements, which indicated a mean soil CO_2 concentration of 1.5 % (n=10). The plot was burned the following day, on which no measurements were possible. Measurements the day after the burn produced a drastically reduced mean soil CO_2 level of 0.1 % (n=10), suggesting the virtual cessation of biological respiration within the soil. Measurements on the following two days indicated a gradual recovery of soil CO_2 levels, with mean soil CO_2 contents of 0.3 % (n=10) and 0.9 % (n=10) respectively, the latter following a brief rain shower. These measurements indicate that soil CO_2 levels in tropical karstlands may vary considerably over short time periods, particularly as a result of human activities, and they suggest that studies of carbonate rock dissolution in tropical karst should take into account the potential for both short- and long-term variations in soil CO_2 levels.

Introduction

Soil carbon dioxide, which is essentially the product of subsurface biological respiration, is an important short-term storage component in global carbon cycling and also exerts a critical influence on subsoil carbonate dissolution in karst landscapes. As such, variations in soil carbon dioxide contents are important indicators of changes in biological respiration levels in the soil and useful surrogate measures of soil-atmosphere carbon flux. Moreover, they are valuable indicators of changing potential for subsoil carbonate dissolution in karstlands.

Soil carbon dioxide is produced essentially by organic decomposition and the respiration of soil biota, which are influenced by soil environmental conditions, such as temperature, moisture content and pH (*Miotke, 1974, Ford and Williams, 1989*). Burrowing animals, soil microorganisms, aerobic litter decay and plant root respiration all contribute to soil CO_2 accumulation, which is most effective in damp soils with textures and structures which hamper rapid gas diffusion to the atmosphere (*Miotke, 1974, Ford and Williams, 1989*). Soil CO_2 levels generally increase with soil depth and temperature, and may vary seasonally and diurnally.

In karstlands, soil CO_2 levels are an important indicator of potential subsoil carbonate dissolution activity because CO_2 dissolution by percolating water increases carbonate dissolutional capability, or aggressivity (*Miotke, 1974; Smith and Atkinson, 1976,* *Gunn and Trudgill, 1982; Ford and Williams, 1989*). The partial pressure of CO_2 both in the soil and in the unsaturated zone directly influences the rate of carbonate dissolution (*Smith and Atkinson, 1976; Atkinson, 1977; White, 1988*). Soil CO_2 levels in karstland soils typically range from 0.1 % to 11 % (*Miotke, 1974, Ford and Williams, 1989*).

Based on worldwide variations in measured soil CO_2 levels, *Brook et al* (1983) constructed a controversial world model of soil carbon dioxide which suggested that actual evapotranspiration (AET) was the best predictor of soil PCO_2 and that soil PCO_2 levels in tropical areas were generally higher than those in other areas. About 50 % of variation in the partial pressure of soil CO_2 was explained by temperature, 20 % by precipitation, and the balance by seasonal water availability and organic growth factors. Although the effects of long-term changes in soil CO_2 levels, for example as a consequence of global environmental change, have been considered in such contexts (*Yonge, 1997; Yuan and Liu, 1998*), there has been little recognition of the potential impact on karst of short-term variability, for example as a result of transient human activities.

By contrast, there have been numerous studies of the short- and medium-term impact of human activities on soil chemistry and biology, particularly in the context of „slash and burn" agriculture in the tropics (e.g. *Jordan, 1987, Kotto-Same et al, 1997*). Overall, cutting and burning results in a marked increase in soil nutrient leaching losses, and in the loss of forest system carbon, particularly from the above-ground tree biomass; this accelerated carbon flux, in turn, contributes to atmospheric CO_2 accumulation and change (*Kotto-Same et al, 1997*). Despite leaching losses, soil nutrient stocks are not depleted as long as there is a supply of decomposing organic matter on the soil surface (*Jordan, 1987*). Similarly, the soil organic matter is a relatively stable carbon pool, with relatively high rates of carbon reaccumulation (*Kotto-Same et al, 1997*).

That notwithstanding, burning of tropical forests has a marked short-term impact on carbon flux to the atmosphere. The magnitude of CO_2 pulses from direct burning emissions per unit area in tropical forests has been calculated to be ten times that of boreal areas (*Auclair and Carter, 1993*), and burning may increase soil CO_2 fluxes by an order of magnitude, although they may decline to preburn levels within a few *days (Zepp et al, 1996*). Soil CO_2 effluxes may not be immediately impacted by fire, possibly being maintained at preburn levels by microbial decomposition of labile compounds released as a result of the fire (*Burke et al, 1997*). By contrast, in years after burning there may be a significant reduction in soil CO_2 flux, with recovery to preburn levels taking several years (*Burke et al, 1997*). Similar impacts have been demonstrated in tropical karstlands, including Belize (*Furley, 1987; Furley and Newey, 1979; Cooper, 1989*). Typically, clearance resulted in changes in soil organic contents, pH, nutrient cation levels and soil physical properties.

The Study Area

The study was undertaken in the Hummingbird karst of the eastern Cayo District in the Central American country of Belize (*Fig. 1*). The Hummingbird karst is part of a broader karst belt in central Belize that is known as the Boundary Fault karst (*Miller, 1996*). These karstlands, their geomorphology and landuse have been described in detail previously (*Day, 1987b, 1991, 1993; Day and Rosen, 1989; Miller, 1987, 1996*). The study

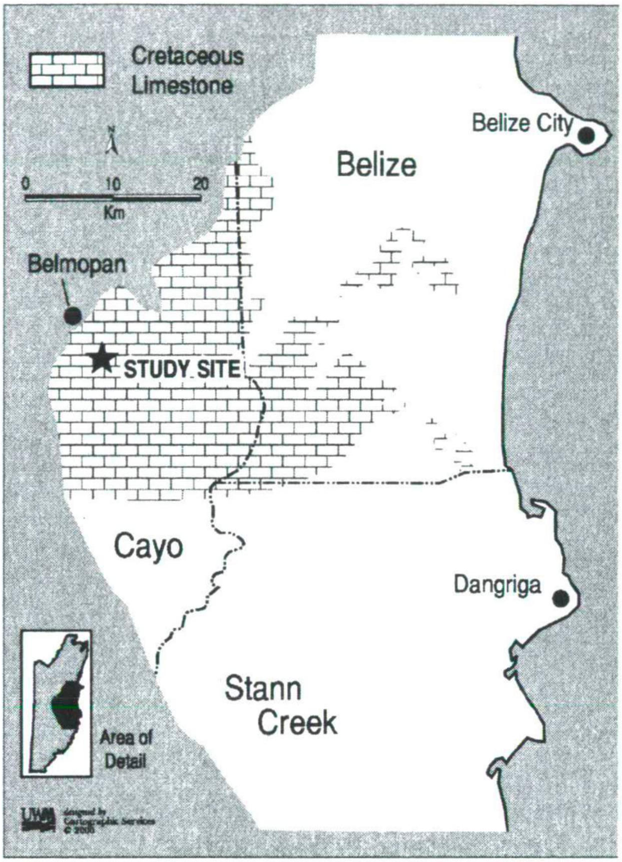

Fig. 1 Hummingbird karst of the eastern Cayo District in the Central American country of Belize

area is broadly that described by *Day* (1986, 1987a) and by *Furley and Newey* (1979), located in an area of polygonal karst approximately 7 km south of the Belizean capital city of Belmopan (*Fig. 1*). The site of the soil CO_2 measurements is a southeast-facing 0.5 hectare plot on the lower slopes of a residual hill which attains about 35 m in height. Overall slope angle is about 30 degrees. Area soils are reddish brown rendzinas or mollisols, with some vertisols, derived from the carbonates. Most are rubbly clay loams with a blocky structure and variable drainage. Upper slopes are xeric, and soil moisture generally increases downslope. Soil depth locally exceeds 50 cm in joints and solutional pockets, but is generally less; soil is absent on steeper slope segments, with thickness generally increasing downslope. Vegetation consists of mixed secondary forest (bush) containing a wide variety of deciduous and semi-evergreen trees, shrubs, vines and herbaceous plants, and rich in calcicolous species (*Furley and Newey, 1979*). The forest has suffered both pre-and post-European clearance, plus the ravages of hurricanes and wildfires (*Furley and Newey, 1979; Furley, 1987*). Mean annual temperature is about 25 degrees Centigrade, with mean annual rainfall of approximately 2300 mm. A marked dry season extends typically from January through May (*Walker, 1973; Furley and Newey, 1979*).

Forest Burning in the Belize Karst

Milpa, or „slash and burn" agriculture is common in the Belize karst and is generally associated with the short-term cultivation of corn, beans and squash, although other crops may be involved (*Bliss et al, 1987*). Small areas of secondary forest are cleared using axes and chainsaws to cut larger trees and machetes to clear vines, saplings and shrubs. Some larger, desirable trees, particularly the Cohune Palm (Orbignya cohune) may be left to provide shade or fruit. Cutting usually takes place during the dry season, typically in January or February but sometimes as late as March or April. Burning of the plant debris follows a period of drying, typically lasting from one to four months. Burning eliminates smaller branches, making the field more accessible, may kill weed seeds and affect soil bacteria, and provides a nutrient-rich ash (*Jordan, 1987*). Planting follows, usually within weeks after burning and just prior to the onset of rains at the end of the dry season. The site may be cultivated for a single season or for several years, depending largely on competition from weed species (*Kellman and Adams, 1970*) and is then abandoned to fallow.

Methodology

A series of forty soil CO_2 measurements were taken in the study site hillslope soils immediately prior to and following the burning of the secondary vegetation on March 17, 1984. The secondary growth had been cut, but not burned, prior to the first set of 10 measurements, which were made on the morning of March 16. The plot was burned the following day, on which no measurements were possible. Subsequent sets of ten measurements were taken the morning of the day after the burn (March 18) and on the mornings of the following two days (March 19 and 20). Measurements were not made systematically at exactly the same locations, rather the ten measurements each day were made at different locations within the site of the burn. All measurements were made with a Draeger probe (*Miotke, 1974*) at a soil depth of approximately twenty centimeters, thus avoiding problems of comparison between different soil depths.

Results

The first set of measurements, prior to the burn, indicated a mean soil CO_2 concentration of 1.5 % (n=10) (*Table 1*). Measurements the morning after the burn produced a drastically reduced mean soil CO_2 level of 0.1 % (n=10), within the soil, and measurements on the following two days indicated a gradual recovery of soil CO_2 levels, with mean soil CO_2 contents of 0.3 % (n=10) and 0.9 % (n=10) respectively, the latter following a brief rain shower on the evening of March 19.

Table 1 Soil Volume % CO_2, 20cm Depth, Belize, March 1984.

Date	3/16	3/17	3/18	3/19	3/20
Mean	1.62	n.a.	0.13	0.33	0.92
s	0.35	n.a.	0.07	0.12	0.20
n	10	n.a.	10	10	10

Discussion and Conclusion

In general, the ranges of soil CO_2 levels measured are not remarkable for tropical karst soils (*Miotke, 1974; Day, 1978; Brook et al, 1983*). The preburn mean level of 1.5 % is not atypical for Caribbean and Central American tropical karst soils at depths of 20 cm (*Day, 1978*), indeed it is modest, probably as a consequence of the effective diffusion of CO_2 from the soil during the dry season. The much-reduced soil CO_2 levels recorded on the day after the burn suggest a temporary soil CO_2 impoverishment perhaps reflecting an evacuation into the atmosphere of pre- existing CO_2 from the soil during the fire and/or a dramatic decline of biological respiration within the soil during and immediately following the burning. The slow recovery on subsequent days, particularly after a brief rain shower on March indicates that the soil CO_2 impoverishment was transient, lasting probably less than a week. In comparable studies elsewhere, *Zepp et al* (1996) recorded net soil CO2 fluxes rising by an order of magnitude immediately after burning of savanna sites, but returning to preburn levels within a few days. Similarly, *Kotto-Same et al* (1997) reported that soils had relatively high rates of carbon reaccumulation after burning. The recovery of soil CO_2 levels after the rain on March 19 mimics the stimulation by moisture of soil respiration and CO_2 fluxes in other settings (*e.g. Hao et al, 1988; Zepp et al, 1996*). The results give no indication of the impact of burning on soil CO_2 fluxes and concentrations beyond the immediate postburn period. Although it appears that recovery is rapid, it is possible that impacts may persist for several years (*Burke et al, 1997*). These measurements indicate that soil CO_2 levels in tropical karstlands may vary considerably over short time periods, particularly as a result of human activities such as forest clearance and burning, and they suggest that studies of soil CO_2 influence on carbonate rock dissolution in tropical karst should take into account the potential for both short-and long-term variations in soil CO_2 levels.

Acknowledgements

Fig. 1 was prepared by staff of the Cartographic Services Laboratory at the University of Wisconsin-Milwaukee. For their assistance in Belize, I am grateful to *Mike Neal, Pat Gaertner* and *Norm Stewart*. For valuable insights into soils and human impacts in Belize and elsewhere, I acknowledge the contributions of *Dr Peter Furley*, of the University of Edinburgh. A preliminary version of this paper was presented at the 1998 International Geological Union Correlation Program 379 meeting in Bowling Green, Kentucky; for their resulting comments I thank *Chris Groves, Phil Reeder* and *Julia James.*

References

Atkinson, T C, 1977. Carbon dioxide in the atmosphere of the unsaturated zone: an important control of groundwater hardness in limestones. Journal of Hydrology, Vol. 35, 111-123.

Auclair, A N D and Carter, T B, 1993. Forest wildfires as a recent source of CO2 at northern latitudes. Canadian Journal of Forest Research, Vol. 23(8) 1528-1536.

Bliss, E, Day, M J, Gruszczynski, G, Lewis, D H, Rosen, C J, Stewart, N R, Tilton, D and Urich, P B, 1987. Agriculture. In: Environment and Resources in the Hummingbird Karst of Central Belize. Department of Geography, University of Wisconsin-Milwaukee, Occasional Paper 2, 68-102.

Brook, G A, Folkoff, M E and Box, E O, 1983. A world model of carbon dioxide. Earth Surface Processes and Landforms, Vol.8, 79-88.

Burke, R A, Stocks, B J, Zepp, R G, Tarr, M A and Miller, W L, 1997. Effect of fire on soil-atmosphere exchange of methane and carbon dioxide in Canadian boreal forest sites. Journal of Geophysical Research, Vol. D102(D24), 29289-29300.

Cooper, A, 1989. The impact of forest clearances on soil properties. 53-70 in Ecology and Environment in Belize, ed. D M Munro, Department of Geography, University of Edinburgh.

D A B, 1996. Effects of moisture and burning on soil-atmosphere exchange of trace carbon gases in a southern African savanna. Journal of Geophysical Research, Vol. 101(D19), 23699-23706.

Day, M J (ed) 1987b. Environment and Resources in the Hummingbird Karst of Central Belize. Department of Geography, University of Wisconsin-Milwaukee, Occasional Paper 2.

Day, M J and Rosen, C J, 1989. Human impact on the Hummingbird Karst of central Belize. 201-214 in Resource Management in Limestone Landscapes: International Perspectives, ed D S Gillieson and D I Smith, Australian Air Force Academy, Canberra. Day, M J, 1991. Resource use in rural tropical karstlands:

Day, M J, 1978. The morphology of tropical humid karst with particular reference to the Caribbean and Central America. Unpublished PhD thesis, University of Oxford.

Day, M J, 1986. Slope form and process in cockpit karst in Belize. 363-382 in New Directions in Karst, ed. K Paterson and M M Sweeting, Geobooks, Norwich.

Day, M J, 1987a. Slope form, erosion and hydrology in some Belizean karst depressions. Earth Surface Processes and Landforms, Vol. 12(5), 497-505.

Day, M J, 1993. Resource use in the tropical karstlands of central Belize. Environmental Geology, Vol. 21(3), 122-128.

Day, M J, 1996. Conservation of karst in Belize. Journal of Cave and Karst Studies, Vol. 58(2), 139-144.

Ford, D C and Williams, P W, 1989. Karst Geomorphology and Hydrology, Unwin Hyman, London.

Furley, P A and Newey, W W, 1979. Variations in plant communities with topography over tropical limestone soils. Journal of Biogeography, Vol. 6, 1-15.

Furley, P A, 1987. Impact of forest clearance on the soils of tropical cone karst. Earth Surface Processes and Landforms, Vol. 12, 523-529.

Gunn, J and Trudgill, S T, 1982. Carbon dioxide production and concentrations in the soil atmosphere: a case study from New Zealand volcanic ash soils. Catena, Vol. 9, 81-94.

Hao, W M, Scharffe, D, Crutzen, P J and Sanhueza, E, 1988. Production of N2O, CH4 and CO2 from soils in the tropical savanna during the dry season. Journal of Atmospheric Chemistry, Vol. 7(1), 93-105.

Jordan, C.F.(ed), 1987. Amazonian Rain Forests: Ecosystem Disturbance and Recovery. Springer-Verlag, Berlin.

Jordan, C.F., 1985. Nutrient Cycling in Tropical Forest Ecosystems. Wiley, New York.

Kellman, M C and Adams, C D, 1970. Milpa weeds of the Cayo District, Belize. Canadian Geographer, Vol. 14(4), 323-343.

Kotto-Same, J, Louis, Z, Woomer, P L and Appolinaire, M, 1997. Carbon dynamics in slash and burn agriculture and land use alternatives of the humid forest zone in Cameroon. Agriculture, Ecosystems and Environment, Vol. 65(3), 245-256.

Miller, T, 1987. Fluvial and collapse influences on cockpit karst of Belize and eastern Guatemala. 53-57 in Karst Hydrology: Engineering and Environmental Applications, ed. B F Beck and W L Wilson, A A Balkema, Rotterdam.

Miller, T, 1996. Geologic and hydrologic controls on karst and cave development in Belize. Journal of Cave and Karst Studies, Vol.58(2), 100-120.

Miotke, F-D, 1974. Carbon dioxide and the soil atmosphere. Abhandlungen zur Karst und Hohlenkunde, Reihe A, Heft 9, 49pp, Munich.

Smith, D I and Atkinson, T C, 1976, Process, landforms and climate in limestone regions. 367-409 in Geomorphology and Climate, ed. E Derbyshire, Wiley, London.

The Hummingbird Karst, Belize. 31-38 in Proceedings of the International Conference on Environmental Changes in Karst Areas, ed U Sauro, A Bondesan and M Meneghel, Department of Geography, University of Padova.

Walker, S H, 1973. Summary of climatic records for Belize. Land Resources Division, Overseas Development Administration, Supplementary Report 3, HMSO, London.

White, W B, 1988. Geomorphology and Hydrology of Karst Terrains. Oxford University Press, Oxford.

Yonge, C J, 1997. Climate change: the karst record - a conference review. Cave and Karst Science, Vol. 24(2), 65- 75.

Yuan, D and Liu, Z (eds), 1998. Global Karst Correlation (IGCP 299). Science Press Beijing

Zepp, R G, Scholes, M C, Miller, W L, Burke, R A and Parsons,