

Soil Air CO₂ Concentrations in a Spruce-Fir Forest, Maine, USA¹

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ABSTRACT

Soil air CO₂ concentrations were measured in two soil depths (O and B horizon) by (1) the use of the Draeger direct reading chromatographic tubes and (2) syringe gas collections with gas chromatographic detection in a Spodosol supporting low elevation, commercial spruce-fir forest, Maine, USA. Mean soil air CO₂ concentrations(%) during the growing season of 1991 ranged from 0.11 in the O horizon by the Draeger method to 0.29 in the B horizon by the gas chromatographic method. Soil air CO₂ concentrations by the Draeger method were lower than those obtained using the gas chromatographic method for both soil horizons. However, data from the two methods were significantly ($p < 0.01$) correlated and paralleled each other relative to temporal patterns. Positive and highly significant correlations existed between soil air CO₂ concentrations and soil temperature, although correlation coefficients only ranged from 0.13 to 0.32, depending on the method and horizon chosen.

Key words : Draeger, forest soils, gas chromatography, soil air CO₂ concentration, soil temperature

적 요

미국 Maine 주 저지대 가문비나무-젓나무 경계림 지역의 spodosol 토양의 2개의 토층(O와 B층)에 서 토양공기 CO₂ 농도를 측정하였다. CO₂ 농도 측정은 Draeger 直讀 chromatography법과 가스주입 기를 이용한 gas chromatography 법의 두 가지 방법을 사용하였다.

1991년 생육기 동안의 토양공기 CO₂ 농도(%)의 평균값은 Draeger법으로 측정된 O층의 0.11로부터 gas chromatography법으로 측정된 B층의 0.29사이의 분포를 보였다. B층과 O층 모두에서 Draeger 법에 의한 토양공기 CO₂의 농도가 gas chromatography법으로 측정된 값보다 낮은 수치를 보였다. 두 방법에 의해 측정된 값들 상호간에는 두 층 모두에서 고도의 상관관계($p < 0.01$)를 보였으며, 시간 변화에 따른 변화 유형 역시 평행적인 관계를 보여 주었다. 토양공기 CO₂ 농도는 토양온도와 고도의 정의 상관관계를 보였는데 상관계수의 값은 선발된 측정방법 및 토층에 따라 0.13-0.32의 값을 나타 냈다.

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INTRODUCTION

Concerns for a forest decline in red spruce (*Picea rubens* Sarg.) forests at high elevations in the north-eastern United States have created a focus of interest on the effects of atmospheric deposition on carbon and nutrient dynamics (Johnson and Siccama 1983, Friedland 1989). Many scientists have also demonstrated that important relationships may exist between climate change and carbon and nutrient cycling (Long and Hutchin 1991, Rastetter et al. 1991). Soil CO₂ evolution has been used as an index of metabolic activity in soil, and can be utilized to study carbon cycling in ecosystems. However, previous studies have mostly focused on CO₂ evolution from the soil surface rather than from different soil horizons (Ewel et al. 1987, Singh and Gupta 1977, Hendrickson et al. 1989). The low elevation, commercial spruce-fir forest type represents the most extensive land use classification in Maine (Powell and Dickson 1984). Central Maine encompasses a regional ecotone between the northern boreal forest and the northern hardwood forest, this offers an unique opportunity for study of soil carbon dynamics in global climate change. Although there are numerous studies on methods of soil CO₂ evolution measurement (De Jong and Schappert 1972, Singh and Gupta 1977, Wagner and Buyanovsky 1983) and on quantifying soil CO₂ evolution in various ecosystems (Singh and Gupta 1977), few soil CO₂ evolution studies have been conducted in the low elevation, commercial spruce-fir forest (Fernandez and Kosian 1987, Fernandez et al. 1992). Furthermore, we are not aware of any studies that have compared methods of CO₂ measurement in soil air CO₂ evolution research.

The objectives of this study were to (1) quantify soil air CO₂ concentrations (2) compare two common soil air CO₂ measuring methods, and (3) examine the relationship between soil air CO₂ concentrations and soil temperature in a low elevation, commercial spruce-fir forest, Maine, USA.

METHODS

Study Site

This study was conducted at the Howland Integrated Forest Study (HIFS) site (45° 10' N, 68° 40' W), Maine, USA. The site is located approximately 30 km north of Orono, Maine. The HIFS site consists of two 0.2ha (40×50-m) plots (Tower and Lower sites) approximately 350m apart where intensive studies of nutrient cycling and global climate change effects are being conducted. The major forest type which occurs in the area is spruce-fir (*Picea rubens* Sarg. and *Abies balsamea* (L.) Mill, respectively) with white pine (*Pinus strobus* L.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.) (Lawrence and Fernandez, 1991). Little or no understory vegetation is present. Soils are classified as Aquic Haplorthods (Tower site) from the moderately well drained Skerry series, and as Aeric Haplaquods (Lower site) from the somewhat poorly drained Westberry series. Additional information on soil physical and chemical properties for the area is available from Fernandez and Struchtemeyer (1985), and information on soil solutions from the HIFS can be found in Lawrence and Fernandez (1991). Climate at the study site is cool, humid and predominantly continental. The growing season varies from 120 to 140 days (Fernandez and Struchtemeyer 1985). Winter temperatures frequently fall below 20°C and the snowpack is continuous from December through March, accumulating to a depth of one to two meters. Summer temperatures are cool, seldom exceeding 30°C (Fernandez et al. 1990). Mean annual precipitation for the past 10 years is 1060 mm, and mean January and July temperatures for the past 10 years are -8.9 and 20.1°C, respectively (NOAA 1981-1990).

Field Measurements

Soil air CO₂ concentrations were measured by the Draeger® direct reading chromatographic method (Buyanovsky and Wagner 1983) and syringe collections with gas chromatographic detection method (De Jong and Schappert 1972) in the O and B horizons. In 3 random locations outside the two plots, 3 mm inside diameter polycarbonate tubes were in-

stalled at 5 cm(O horizon) and 10 cm(B horizon) below the soil surface. Sampling tubes were open at both sides, with the lower 3 cm containing 18 holes drilled through the tubes. The top of the tubes were capped with a rubber septa. The direct Draeger method uses a hand-operated bellows pump that draws the gas sample through a 7 mm diameter and 10 cm long glass tube. The tube contains silica gel particles filled with a hydrazine compound and the redox indicator crystal violet. When saturated with CO₂, this indicator dye develops a blue color. For the gas chromatographic method, 10 ml purge of soil air was withdrawn from the tube with a gas tight syringe, followed by another 10ml which was used as a sample. The sample was placed in a 10 ml Vacutainer[®], with CO₂ determined by gas chromatography (thermal conductivity detector) (Anderson 1982). Measurements were taken every three weeks from May 7 through November 12, 1991. Of the ten sampling periods, samples for the Draeger methods were not taken on May 29, June 18 and November 12, 1991. Soil air temperatures were measured with a hand-held thermocouple each time soil air CO₂ concentrations were measured. Thermocouple wires were installed prior to the experiment by insertion into undisturbed soil to 5 and 10cm below the surface, after making a hole with a metal probe within 50 cm of the plastic soil sampling tubes.

Statistical Analysis

Mean soil air CO₂ concentrations and soil temperature were analyzed using a general linear model

procedure. Linear regression was also used to examine the relationship between soil air CO₂ concentrations and soil temperature. Unless otherwise indicated, a significance level of 0.05 was used. All statistical analyses were performed using the Statistical Analysis System(SAS, 1988).

RESULTS AND DISCUSSION

Descriptive statistics for soil air CO₂ concentrations are given in Table 1. Mean soil air CO₂ concentrations(%) ranged from 0.11 in the O horizon by the Draeger method to 0.29 in the B horizon by the gas chromatographic method. These values are somewhat lower than those reported for other forest sites in the region(Fernandez and Kosian 1987, Fernandez et al. 1992). We speculate that annual climatic differences(see below for the relationship between soil air CO₂ concentrations and soil temperature) and/or site characteristics would explain these differences. Many studies have reported differences in soil air CO₂ concentrations among horizons(Fernandez et al. 1992, Smirnov and Kirov 1986, Zabowski and Sletten 1991). In general, low soil air CO₂ concentrations in the O horizon are expected because of the large porosity of the forest floor resulting in rapid exchanges of air with atmosphere(Fernandez and Kosian 1987). Although soil air CO₂ concentrations were lower in the O horizons than the B horizon for both methods, the differences were not significant($p>0.05$) in this study. It is difficult to discern any pattern of soil air CO₂ concentrations among

Table 1. Mean soil air CO₂ concentrations(%) by the gas chromatography and Draeger methods of measurement during the growing season of 1991.

	Gas chromatography	Draeger
	O horizon	
Mean	0.245*	0.113*
S.D.	0.040	0.052
Range	0.197-0.340	0.053-0.2443
n	20	14
	B horizon	
Mean	0.292**	0.160**
S.D.	0.054	0.051
Range	0.210-0.416	0.103-0.267
n	20	14

* : significantly different at $p=0.0001$

** : significantly different at $p=0.0001$

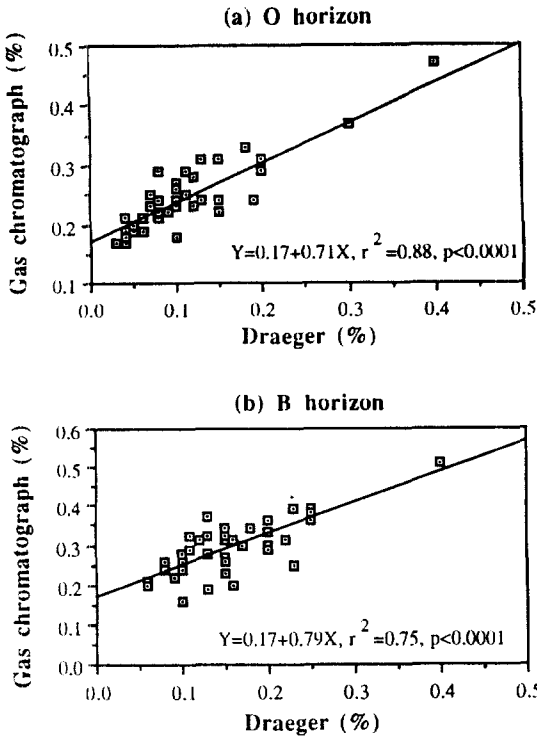


Fig 1. Relationship between soil air CO₂ concentrations measured with the gas chromatography and Draeger methods in (a) O horizon and (b) B horizon. Vertical bars are 1 standard deviations.

different soil horizons.

Mean soil air CO₂ concentrations by the Draeger method were significantly ($p<0.0001$ in both horizons) lower than those by the gas chromatographic method. The Draeger data correlated well with the gas chromatography data for both soil depths ($r^2=0.77, p<0.0001$ in the O horizon, $r^2=0.75, p<0.0001$ in the B horizon, respectively)

Temporal variations in soil air CO₂ concentrations were evident throughout the growing season. Temporal patterns at two soil depths were similar and parallel for data from both methods (Fig 2). Soil air CO₂ concentrations by the Draeger method were consistently lower than those by the gas chromatographic method throughout the growing season. Soil air CO₂ concentrations increased as soil temperature increased, showed the peak in mid summer, and decreased to the early growing season level in late fall for both soil horizons. Although we cannot truly

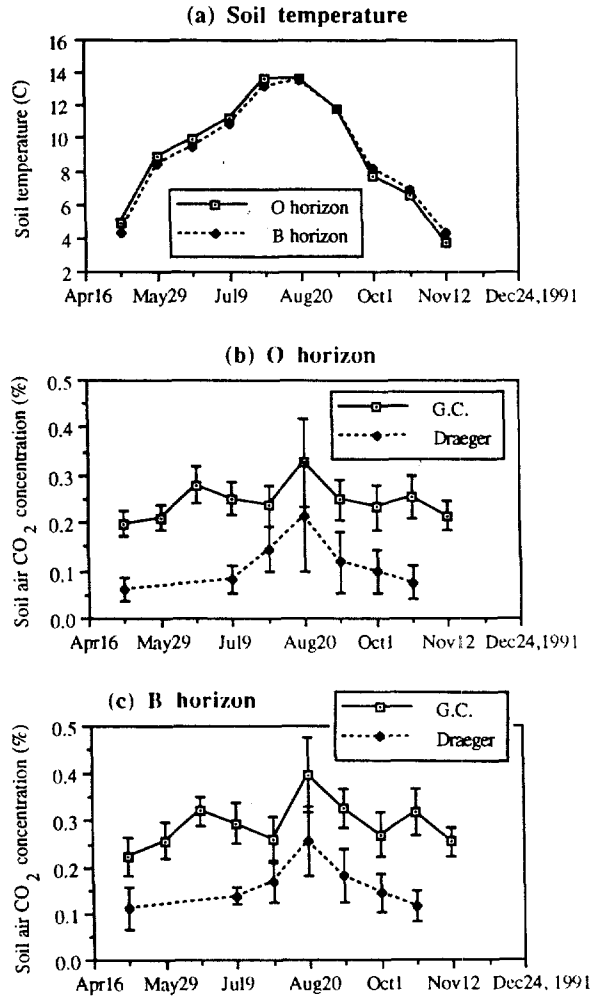


Fig 2. Seasonal (a) soil temperature and soil air CO₂ concentration in (b) O and (c) B horizons by the gas chromatography (G.C.) and Draeger methods during the growing season of 1991.

determine the number of peaks due to the missing samples for the Draeger method, we observed more than two seasonal peaks in soil air CO₂ concentrations by gas chromatography. Multiple-peaks in soil air CO₂ concentrations are consistent with previous findings (Castelle and Galloway 1990). However, it is not clear why the gas chromatography method showed a small peak in soil air CO₂ concentrations in late fall compared with the continuous decrease by the Draeger method. Figure 2a shows seasonal soil temperatures, which peaked to coincide with the

Table 2. Linear regression equations for the relationships between soil air CO₂ concentrations(%) and soil temperature(°C) by methods and soil horizon.

Horizon	Equation	r ²	p	n
Gas chromatography				
O	CO ₂ (%) = 0.189 + 0.006 temperature(°C)	0.13	0.0042	60
B	CO ₂ (%) = 0.210 + 0.009 temperature(°C)	0.21	0.0002	60
Draeger				
O	CO ₂ (%) = -0.001 + 0.012 temperature(°C)	0.27	0.0004	42
B	CO ₂ (%) = 0.049 + 0.011 temperature(°C)	0.32	0.0001	42

maximum soil air CO₂ concentration during the growing season. The soil temperatures recorded indicated that there was not a large thermal gradient between the O and B horizons. The largest difference between the O and B horizons was less than 0.5°C(Fig 2a).

There was a positive and significant correlation for both horizons between soil air CO₂ concentrations and soil temperature by both CO₂ measurement (Table 2). These results are consistent with previous studies in this region for spruce-fir and hardwood forests(Fernandez and Kosian 1987, Fernandez et al. 1992), and other soil air CO₂ research under a variety of forest settings(Castelle and Galloway 1990). In this study, correlation coefficients between soil air CO₂ concentrations and soil temperature ranged from 0.13 for the O horizon(gas chromatography) to 0.32 for the B horizon(Draeger), which are similar to those reported by Castelle and Galloway(1990) in Virginia but are not as strong as those found by Fernandez and Kosian(1987) and Fernandez et al. (1992) in other Maine forests. The coefficients were higher for the Draeger method than the gas chromatographic method.

No obvious explanation exists for the higher correlations between Draeger CO₂ data and soil temperature in this study. The question remains as to which method is recommended for research on forest soil CO₂ evolution, and certainly further research could be done to better address that question. However, we believe the gas chromatography CO₂ detection method is best to research on ecosystem carbon cycling and quantitative estimates of CO₂ flux from the soil. Presumably the gas chromatographic detection is more accurate since (1) the instrument has the capability of measuring concentration well below those found in this study, (2) gas chromatography is

a well established method in the scientific literature for measuring gas concentrations, and (3) the accuracy of the method can be verified using standard reference materials. However, when a qualitative evaluation of soil CO₂ evolution is all that is required, the Draeger method offers (1) an easy detection technique that can be completed in the field, (2) an inexpensive technique that does not require the purchase a costly gas chromatograph, (3) a technique that parallels the gas chromatographic data when temporal trends in CO₂ concentrations are encountered, and (4) a technique with nearly identical precision when compared to the gas chromatography technique. These evaluations should be viewed as preliminary. Further research should be carried out to quantify the accuracy of both techniques under controlled analytical conditions.

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