Carbon dioxide exchange in a peatland ecosystem

N. J. Shurpali, S. B. Verma, and J. Kim
Department of Agricultural Meteorology and Center for Laser-Analytical Studies of Trace Gas Dynamics
University of Nebraska, Lincoln

T. J. Arkebauer
Department of Agronomy, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln

Abstract. Micrometeorological measurements of carbon dioxide exchange were made in an open peatland in north central Minnesota during two growing seasons (1991 and 1992). The vegetation at the site was dominated by Sphagnum papillosum, Scheuchzeria palustris, and Chamaedaphne calyculata. The objective of the study was to examine the diurnal and seasonal variations in canopy photosynthesis (P) and develop information on the net ecosystem CO2 exchange. The two seasons provided contrasting microclimatic conditions: as compared with 1991, the 1992 season was significantly wetter and cooler. Canopy photosynthesis was sensitive to changes in light, temperature, and moisture stress (as indicated by water table depth and atmospheric vapor pressure deficit). Under moderate conditions (temperature 18-28°C, vapor pressure deficit 0.7-1.5 kPa, and water table near the surface) during the peak growth period, midday (averaged between 1000-1400 hours) P values ranged from 0.15 to 0.24 mg m\(^{-2}\) s\(^{-1}\). Under high-temperature (30°-34° C) and moisture stress (water table 0.16-0.23 m below the surface and vapor pressure deficit 2.2-3.0 kPa) conditions, midday P was reduced to about 0.03-0.06 mg m\(^{-2}\) s\(^{-1}\). There was a high degree of consistency in the values of P under similar conditions in the two seasons. Seasonally integrated values of the daily net ecosystem CO2 exchange indicated that the study site was a source of atmospheric CO2, releasing about 71 g C m\(^{-2}\) over a 145-day period (May-October) in 1991. Over a similar period in 1992, however, this ecosystem was a sink for atmospheric CO2 with a net accumulation of about 32 g C m\(^{-2}\). These results are consistent with previous investigations on CO2 exchange in other northern wetland sites during wet and dry periods.

Introduction

Peat in northern wetlands contains about one third of the total world pool of carbon [e.g., Miller et al., 1983; Gorham, 1991]. The carbon sink/source strengths in these important ecosystems, however, are not well understood. Northern wetlands have been thought to be a net sink for atmospheric CO2 in the past [e.g., Oechel et al., 1993]. How these ecosystems will respond to future climatic perturbations is not known. Recent studies [e.g., Tans et al., 1990; Oechel et al., 1993] suggest a possible shift in the carbon balance of northern boreal and arctic ecosystems, from a sink to a source. However, these results can not readily be generalized to other regions.

Some information is available on carbon dioxide fluxes in arctic and subarctic peatlands [e.g., Coyne and Kelley, 1975; Billings et al., 1982; Armamento and Menges, 1986; Oechel and Billings, 1992]. However, very little is known about the carbon dioxide exchange in peatlands in other areas. Also, most of the prior studies have used chambers and are limited to small areas. Micrometeorological techniques have been recommended for measurement of large-scale fluxes of mass and energy. These techniques allow direct, continuous, and spatially integrated fluxes and cause minimal disturbance to the microenvironment being investigated. We know of only two short-term micrometeorological measurements of carbon dioxide flux in northern wetlands (Coyne and Kelley [1975], over a wet meadow tundra in Alaska, and Neumann et al. [1994], above a raised open bog at Lake Kinosheo in the southern Hudson Bay lowlands). Here, we report the results of a micrometeorological study conducted during two contrasting growing seasons (mid-May to mid-October 1991 and 1992) in a peatland in north central Minnesota. The primary objective of the study was to examine the diurnal and seasonal variations in canopy photosynthesis and net ecosystem CO2 exchange at this site.

Materials and Methods

Site

The study site, referred to as the Bog Lake Peatland, is located in the Chippewa National Forest, adjacent to the Marcel Experimental Forest (47°32′N, 93°28′W) in north central Minnesota. The vegetation is dominated by Sphagnum papillosum, a carpet-forming moss species. The most common emergent species are Scheuchzeria palustris (a triseeded arrow grass), Carex spp. (sedges), and Chamaedaphne calyculata (leather leaf). Other prevalent species include Rhynchospora alba (beak-rush), Sararacenia purpurea (pitcher plant), and 1- to 3-m tall, widely scattered Larix laricina (tamarack). The organic soil of the peatland consists primarily of Sphagnum-derived peat. The surface consists of a pattern of hummocks (microhills of 0.15-0.55 m) and hollows (microvalleys). The site provided at least 250-300 m of upwind fetch of open...
values were corrected for the effects of tube attenuation and water vapor following the method of Webb et al. [1980]. The use of metal intake tubing to draw air samples through the CO₂ flux was computed over 30-min averaging periods. The CO₂ flux was corrected for the variation in air density due to the transfer of energy in J mol⁻¹, and T₁ is the leaf temperature in degrees Celsius. Since these vascular plants grow in close proximity to the peatland from the instrument tower in the SSW through NNE (200°–390°) directions (Figure 1).

Micrometeorological Measurements

Fluxes of CO₂, latent and sensible heat, and momentum were made employing the eddy correlation technique. The eddy correlation system consisted of a closed path, differential, nondispersive, infrared CO₂ gas analyzer (model LI-6251, LI-COR Inc., Lincoln, Nebraska), one-dimensional sonic anemometers (Campbell Scientific, Logan, Utah), a three-dimensional sonic anemometer (Kaijo Denki Co., Tokyo, Japan), fine-wire thermocouples and krypton hygrometers (Campbell Scientific, Logan, Utah). The three-dimensional sonic anemometer and a fine-wire thermocouple were mounted at a height of 3.5 m above the peat surface. The rest of the instruments were mounted on a horizontal boom at a height of 2.5 m above the peat surface. Further details of the eddy correlation instruments and installation can be found in the works by Verma [1990], Verma et al. [1992], and Suyker and Verma [1993].

The CO₂ sensor was calibrated twice on each day of measurement. Eddy fluxes were obtained from covariances computed over 30-min averaging periods. The CO₂ flux was corrected for the variation in air density due to the transfer of water vapor following the method of Webb et al. [1980]. The use of metal intake tubing to draw air samples through the CO₂ sensor eliminated the need for the density correction term due to heat transfer [e.g., Leuning and Moncrieff, 1990]. Covariance values were corrected for the effects of tube attenuation [Suyker and Verma, 1993] and spatial separation of sensors [Moore, 1986]. The combined effect (tube attenuation and spatial sensor separation) was of the order of 10% for CO₂ flux for daytime conditions.

Supporting measurements included air temperature, humidity, horizontal wind speed, wind direction, and photosynthetically active radiation (Rₛ). Surface temperature was measured by an infrared thermometer (although the infrared thermometer was pointed toward an area dominated by moss, the measured values were assumed to represent the overall vegetation temperature). The daily water table position was recorded using a recording well installed near the instrument mast. The daily water table depth was measured relative to an “average” hollow surface referenced at 415.84-m altitude from the mean sea level. Peat temperature (at 0.1-m depth relative to an average hollow surface) was also monitored.

To evaluate the overall performance of the flux measurement system at a micrometeorological study site, it is worthwhile to investigate the tower footprint, examine the closure of the surface energy budget components, and develop information on aerodynamic characteristics, such as the drag coefficient. A footprint analysis [e.g., Gash, 1986; Scheupp et al., 1990] indicated that about 90% of the measured flux at a height of 2.5 m (under neutral and unstable conditions) should be from the peatland. Results on the surface energy budget closure and drag coefficient for this site, included in the work by Verma et al. [1992], are typical of observations on agricultural crops and prairie vegetation in reasonably flat terrain.

Soil Surface CO₂ Measurements

A closed gas exchange system [Norman et al., 1992] consisting of a 0.75 L dark chamber, attached to an infrared gas analyzer (model LI-6200, LI-COR Inc., Lincoln, Nebraska), was used to measure soil surface CO₂ flux (Fₛ). Details of these measurements are reported by Kim and Verma [1992]. An empirical relationship of the following type, developed from these measurements, was used in this study:

\[ Fₛ = \frac{(b₁ + b₂W)/(b₁ + 0.4b₂)}{a₃}(r-Ø)/Ø \] (1)

where W is the water table depth (in meters), T is peat temperature (in degrees Celsius) at 0.10-m depth, b₁ is a nondimensional constant, b₂ is a constant with units of m⁻¹, a₃ is the soil surface CO₂ flux at 10°C (g m⁻² d⁻¹), and a₄ is the temperature Q₁₀ coefficient. The soil surface CO₂ flux was about 5–15 g m⁻² d⁻¹ during midseason in 1991. In 1992, when the water table was higher and air temperature substantially cooler (see the next section for details), the midseason soil CO₂ flux was smaller (4–8 g m⁻² d⁻¹). These values of Fₛ include the contribution from moss dark respiration. We estimated this contribution by making soil CO₂ flux measurements at locations where the moss was clipped. Results indicated that the moss dark respiration during the midseason was about 1.5–3.0 g m⁻² d⁻¹ in 1991 and 1992.

Dark Respiration Measurements

Leaf level measurements at the study site were used to estimate the values of dark respiration of Scheuchzeria palustris and Chamaedaphne calyculata. The data were expressed by the following relationship:

\[ R₂₉₈ exp \left( E(T₁ - 25)/[298R(T₁ + 273)] \right) L \] (2)

where R₂₉₈ is the rate of dark respiration in μmol m⁻² s⁻¹ at 25°C (1 μmol m⁻² s⁻¹ = 0.044 mg m⁻² s⁻¹), E is the activation energy in J mol⁻¹, and T₁ is the leaf temperature in degrees Celsius. Since these vascular plants grow in close proximity to

Figure 1. Map showing the area upwind of the instrument tower.
moss, \( T_r \) was approximated by the moss surface temperature measured by an infrared thermometer discussed above. \( R \) (8.314 J \( \text{oK}^{-1} \text{ mol}^{-1} \)) is the gas constant. The values of \( R_A \) and \( E \) were estimated to be 3.0 \( \mu \text{mol m}^{-2} \text{s}^{-1} \) and 42,884 J \( \text{mol}^{-1} \) for Scheuchzeria palustris and 1.9 \( \mu \text{mol m}^{-2} \text{s}^{-1} \) and 27,552 J \( \text{mol}^{-1} \) for Chamaedaphne calyculata, respectively. The term \( L \) represents the leaf area index of the vascular plants. The leaf area was measured using a hand-held leaf area meter (model LI-2000, LI-COR Inc., Lincoln, Nebraska). The value of \( L \) reached up to 0.6. This value was approximately equally partitioned between the two dominant vascular species. Moss dark respiration was estimated as described in the previous subsection.

Calculation of Canopy Photosynthesis

During daytime, \( F_c \) (the atmospheric flux measured with eddy correlation sensors) is the sum of the net uptake of \( \text{CO}_2 \) by the vegetation (or canopy photosynthesis, \( P \)) and the soil surface \( \text{CO}_2 \) flux due to microbial respiration:

\[
F_c(\text{day}) = P + (1 - \alpha) R_s(\text{day})
\]

The term \( R_s \) includes only the contribution from \( \text{CO}_2 \) evolution due to microbial activity in the soil and root respiration. We used an average value of 0.7 for the term \( \alpha \), which is the fraction of \( R_s \) due to root respiration [e.g., Billings et al., 1977]. Equation (3) was used to compute canopy photosynthesis. On some days, \( F_c \) data during the early morning and late afternoon hours were missing. The missing \( F_c \) values were estimated by a canopy photosynthesis-light response relationship (5).

At night, \( F_c \) is the sum of \( R_s \) and the dark respiration (\( R_d \)) of the aboveground vegetation (vascular plants and moss):

\[
F_c(\text{night}) = R_s(\text{night}) + R_d(\text{night})
\]

Most of our \( \text{CO}_2 \) flux data are from daylight hours. Many nights were quite calm and did not allow accurate eddy flux measurements. The missing nighttime \( F_c \) values were estimated using the measurements of \( R_s \) and \( R_d \) in (4). A comparison of calculated and measured values, during the periods when the nighttime eddy correlation measurements were available, suggests that this approach is reasonable (Figure 2).

Results and Discussion

Microclimatic Conditions

The 1991 and 1992 seasons had contrasting microclimatic conditions. As compared with 1991, the 1992 season was wetter and cooler. The total precipitation and average temperature during May–October in 1991 were 452 mm and 14.9\(^{\circ}\)C, while in 1992 these values were 642 mm and 13.4\(^{\circ}\)C, respectively. The 30-year (normal) total precipitation and average temperature for the May–October period are 553 mm and 13.6\(^{\circ}\)C.

The water table fluctuated within the first 0.10 m below an average hollow surface from late May until the third week of July in 1991 (Figure 2a). There was a sustained drop in the water table (from 0.08 to 0.23 m below the surface) during late July until the end of August. During the remainder of the 1991 season, the water table fluctuated between 0.14 and 0.22 m below the surface. The water table was generally above the surface during most of the 1992 season, except for a brief dry spell during late May to mid-June, when the water table declined from 0.03 to 0.20 m below the surface (Figure 2b).

Canopy Photosynthesis

Sphagnum papillosum and vascular plants such as Scheuchzeria palustris and Chamaedaphne calyculata were the dominant species contributing to canopy photosynthesis in this peatland. Chamber measurements of photosynthesis (T. J. Arkebauer, manuscript in preparation, 1995) and aboveground dry matter sampling indicated that the relative contribution of Sphagnum papillosum to the total canopy photosynthesis was about 50% and the remainder was contributed by vascular plants. Canopy photosynthesis in this ecosystem is affected by factors including light, temperature, moss moisture content, and atmospheric
Figure 4. Canopy photosynthesis as a function of light ($R_p$) under (a) moderate conditions (temperature ≈ 20°-28°C, vapor pressure deficit ≈ 1.2-1.5 kPa, and water table 0.00-0.08 m below the surface) and (b) high-temperature (30°-34°C) and moisture stress (water table 0.21 m below the surface and vapor pressure deficit between 1.9 and 2.4 kPa). Data are fitted (nonlinear regression) with a rectangular hyperbolic relationship (see text for details).
spheric CO₂ flux $= 0.18 \text{ mg m}^{-2} \text{ s}^{-1}$ in a wet meadow tundra near Barrow, Alaska [Coyne and Kelley, 1975]; 0.15 mg m$^{-2}$ s$^{-1}$ in an open bog at Lake Kinosheo in northern Ontario, Canada [Neumann et al., 1994]; 0.1–0.2 mg m$^{-2}$ s$^{-1}$ in fen and bog sites at Lake Kinosheo, Ontario, Canada [Whiting, 1994]). Considerably higher values of midday atmospheric CO₂ flux, however, have been observed in agricultural crops (1.0–2.0 mg m$^{-2}$ s$^{-1}$ [Anderson and Verma, 1986; Baldocchi et al., 1983; Monteith et al., 1964]), in grasslands (0.6–1.3 mg m$^{-2}$ s$^{-1}$ [Kim and Verma, 1990]), and in deciduous and coniferous forests (0.4–1.0 mg m$^{-2}$ s$^{-1}$ [Jarvis et al., 1976; Verma et al., 1986]). These differences in CO₂ fluxes can be attributed to differences in plant photosynthesis and respiration rates and soil biological activities (e.g., root respiration, decomposition of organic matter).

**Seasonal variation.** Midday (averaged between 1000 and 1400 hours) $P$ during the 1991 season is plotted in Figure 6a. In the beginning of the growing season (middle to late May) the vascular canopy was just developing and the value of $P$ was small (0.04–0.07 mg m$^{-2}$ s$^{-1}$). The value of $P$ increased to 0.12 mg m$^{-2}$ s$^{-1}$ during the first week of June and ranged from 0.09 to 0.24 mg m$^{-2}$ s$^{-1}$ during the period from the second week of June to the third week of July. During this period, temperature (22ø–28øC) and vapor pressure deficit (0.8–1.2 kPa) were moderate, and the water table was close to the surface (0.00–0.07 m).

Following a peak (0.24 mg m$^{-2}$ s$^{-1}$) during the third week of July, $P$ declined to a low of 0.06 mg m$^{-2}$ s$^{-1}$ in the second week of August (day 227). The water table dropped continuously (from 0.06 to 0.23 m below the surface) from late July until the end of August. The reduced values of $P$ during the second week of August were associated with high temperature (30ø–34øC) and moisture stress (water table was 0.21 m below the surface, and vapor pressure deficit was between 1.9–2.4 kPa). This drop in $P$ was followed by 20 mm of precipitation on August 16 (day 229) and moderate temperature (18ø–22øC) and low vapor pressure deficit (0.7–1.0 kPa) during the third week of August. In this period, $P$ reached 0.23 mg m$^{-2}$ s$^{-1}$. The values of $P$ declined from 0.17 mg m$^{-2}$ s$^{-1}$ by the end of August to 0.05 mg m$^{-2}$ s$^{-1}$ in late September and 0.03 mg m$^{-2}$ s$^{-1}$ in the second week of October.

During late May in 1992 (Figure 6b), $P$ was low (0.01–0.04 mg m$^{-2}$ s$^{-1}$). These values are similar to those observed during this period in 1991. There was a dry spell beginning in the last week of May until the second week of June. Photosynthesis declined from 0.12 mg m$^{-2}$ s$^{-1}$ during the first week of June to 0.03 mg m$^{-2}$ s$^{-1}$ during the second week of June. These small values of $P$ (as compared with those in the corresponding period in 1991) were likely due to high-temperature (29ø–30øC) and moisture stress (water table was about 0.18 m below the
surface and vapor pressure deficit was between 2.5 and 3.0 kPa).

Ample rainfall (about 145 mm) raised the water table above the surface during the third week of June. Canopy photosynthesis increased to 0.20 mg m$^{-2}$ s$^{-1}$ by late June. Subsequent rainfall during the remainder of the season kept the water table at or above the surface. Canopy photosynthesis ranged from 0.13 to 0.23 mg m$^{-2}$ s$^{-1}$ during the period from the second week of July to the third week of August. In this period, temperature was moderate, ranging from 18$^\circ$ to 24$^\circ$C, and vapor pressure deficit was 0.5-1.4 kPa. These values of $P$ are comparable with those observed during the second week of June to the second week of July in 1991, when temperature, vapor pressure deficit, and water table conditions were similar. The values of $P$ ranged from 0.13 mg m$^{-2}$ s$^{-1}$ in early September to 0.03 mg m$^{-2}$ s$^{-1}$ in mid-October.

Daily Net Ecosystem CO$_2$ Exchange

The net daily exchange ($F$) of CO$_2$ between this ecosystem and the atmosphere was calculated by integrating $F_c$ data over 24-hour periods:

$$F = F_c(\text{day}) + F_c(\text{night})$$

A positive value of $F$ implies that the ecosystem is a sink for atmospheric CO$_2$. The seasonal distributions of $F$ in 1991 and 1992 (Figure 7) indicate significant day-to-day and interannual variations.

Early season. The value of $F$ was $-1.4$ g m$^{-2}$ d$^{-1}$ in late May 1991, and it ranged from $-5.5$ to $-3.6$ g m$^{-2}$ d$^{-1}$ during the same time in 1992. Peat decomposition and plant respiration exceeded canopy photosynthesis early in the season. During this period in 1992 the water table was lower, and peat temperature was higher, which caused greater release of soil CO$_2$, thus resulting in more negative values of $F$.

In the second week of June the value of $F$ was 0.9 g m$^{-2}$ d$^{-1}$ in 1991 and $-7.9$ g m$^{-2}$ d$^{-1}$ in 1992. This difference in $F$ was associated with the contrasting conditions that prevailed during this time in 1991 and 1992. Moderate temperature ($22^\circ$-$27^\circ$C), vapor pressure deficit (0.7-1.5 kPa), and high moss moisture content (water table 0.04-0.06 m below the surface) conditions favored high canopy photosynthesis and small soil CO$_2$ release during this period in 1991. On the other hand, higher temperature and vapor pressure deficit and lower moisture content (the water table was 0.16-0.18 m below the surface) in 1992 reduced $F$. In addition, the decrease in water table and high temperature resulted in a release of large amounts of soil CO$_2$ (about 10 g m$^{-2}$ d$^{-1}$) to the atmosphere during this time in 1992.

Midseason. During the first week of July to the first week of August, temperature ($18^\circ$-$28^\circ$C) and vapor pressure deficit (0.8-1.2 kPa) were generally moderate in both years. The water table elevations, however, were different. The water table dropped (0.00-0.14 m) below the surface during this time in 1991 (implying continued depletion of moss moisture content and hence decreasing photosynthetic rates and increasing soil CO$_2$ flux). In 1992 the water table was above the surface (resulting in low rates of soil CO$_2$ release). Accordingly, the values of $F$ indicated opposite trends during this period in the 2 years: $F$ declined from 4.4 to 1.4 g m$^{-2}$ d$^{-1}$ in 1991 and increased from 2.8 to 4.2 g m$^{-2}$ d$^{-1}$ in 1992.

In 1991 the drop in the water table continued until the end of August. During the middle of August in 1991 the water table was low (0.21 m below the surface). The increased aerated depth below the surface and high temperature caused a substantially greater soil CO$_2$ flux (about 13 g m$^{-2}$ d$^{-1}$) to the atmosphere. Also, high temperature ($30^\circ$-$34^\circ$C) and moisture stress conditions resulted in a significant reduction in photosynthesis. Hence the peatland was a source of CO$_2$ releasing 9.2 g m$^{-2}$ d$^{-1}$ during this time. During the same period in 1992, however, conditions were favorable for high photosynthesis and small soil CO$_2$ flux. Accordingly, the peatland was a sink for CO$_2$ during the middle of August with a peak CO$_2$ uptake rate of 4.9 g m$^{-2}$ d$^{-1}$ in the third week of August.

Late season. The photosynthetic rate declined toward the end of the season. Soil CO$_2$ release also decreased. In 1991 the water table was below the surface during the period from the end of August to mid-October, and the soil CO$_2$ flux exceeded the uptake by canopy photosynthesis. Thus the ecosystem remained a source of atmospheric CO$_2$. The magnitude of $F$ decreased toward the end of the season ($F$ ranged from $-8.1$ to $-1.5$ g m$^{-2}$ d$^{-1}$) from the second week of September and from $-2.5$ to $-0.7$ g m$^{-2}$ d$^{-1}$ during the first 2 weeks of October).

In 1992, however, moisture conditions were nonlimiting, and the ecosystem was a sink until mid-September ($F \approx 1.5$ g m$^{-2}$ d$^{-1}$). Toward the end of the season (mid-September to mid-October), due to rapid reduction in canopy photosynthesis, the values of $F$ ranged from 0.4 to $-2.9$ g m$^{-2}$ d$^{-1}$.

Seasonally integrated values. Integration of the daily net ecosystem CO$_2$ exchange indicated that this ecosystem released about 71 g C m$^{-2}$ over a period of 145 days (mid-May to mid-October) in 1991. As was discussed above, moisture stress conditions prevailed during the latter half of the growing season in this year, which reduced the uptake of CO$_2$ by the vegetation. The decrease in water table led to enhanced soil
aeration and increased release of soil CO₂. Wetlands have been reported to be possible sources of atmospheric CO₂ under moisture stress conditions. Billings et al. [1982] measured CO₂ exchange from intact cores from the wet coastal arctic tundra at Barrow, Alaska. They found that lowering the water table from the surface to 0.05 m below had a pronounced effect in reducing net carbon storage and concluded that greenhouse warming could change this ecosystem from a sink to a source. Oechel et al. [1993] made whole-ecosystem CO₂ flux measurements over five seasons at Toolik Lake, Alaska. They reported a net carbon loss to the atmosphere at all sites measured. They attributed the carbon loss at their sites to a decrease in the water table, enhanced drainage, and soil aeration. The average rate of annual CO₂ loss at their sites ranged from 34 to 156 g C m⁻² yr⁻¹. Whiting [1994] found that the open bog and interior fen sites near Lake Kinoseo, Ontario, released carbon to the atmosphere at rates between 9 and 21 g C m⁻², respectively, over a 153-day growing season. Measurements of CO₂ exchange by Grulke et al. [1990] also indicated a net loss of carbon (53.4 g C m⁻² yr⁻¹) from an upland tussock tundra site in Alaska.

The 1992 season was wetter and had conditions favorable for high photosynthesis and low rates of soil CO₂ release. Accordingly, this ecosystem was a sink for atmospheric CO₂ with a net accumulation of 32 g C m⁻² over a 145-day period (mid-May to mid-October). Previous investigations have reported wetland sites to be sinks for CO₂ during wetter periods. Coyne and Kelley [1975] measured a net seasonal uptake of 40 g C m⁻² yr⁻¹ over a wet meadow tundra site in Barrow, Alaska. Whiting [1994] estimated a net uptake of 6 g C m⁻² in a productive coastal fen site near Lake Kinoseo, Ontario, over a 153-day growing season. Neumann et al. [1994] reported an average daily net ecosystem exchange rate of 1.7 g CO₂ m⁻² d⁻¹ in an open bog at Lake Kinoseo during the month of July in 1990.

Summary and Conclusions

Carbon dioxide flux was measured during the 1991 and 1992 seasons in a Minnesota peatland. On days with moderate conditions, the canopy photosynthesis (P) data indicated a mid-morning peak. The subsequent decline in P was likely associated with increasing temperature and vapor pressure deficit in the afternoon hours. The light compensation was estimated to be 33 µmol m⁻² s⁻¹ under moderate conditions. This value is consistent with those reported for similar vegetation types in northern wetlands.

During the early part of the season (late May to early June), midday P ranged from 0.01 to 0.12 mg m⁻² s⁻¹. During the period from mid-June to mid-August, photosynthesis varied from 0.15 to 0.24 mg m⁻² s⁻¹ when temperature was moderate and the water table was close to the surface. Under high-temperature and moisture stress conditions, P declined to 0.03–0.06 mg m⁻² s⁻¹. Toward the end of the season (late September to mid-October), canopy photosynthesis decreased to small values (0.03–0.05 mg m⁻² s⁻¹).

The daily net CO₂ exchange showed significant day-to-day and year-to-year variations. During most of the 1992 season, moisture conditions were nonlimiting, and temperatures were moderate. Accordingly, canopy photosynthesis was high, soil CO₂ flux was small, and this ecosystem was a sink for atmospheric CO₂. Because of high temperatures and a low water table in the 1991 season, photosynthetic rates were low, and large amounts of soil CO₂ were emitted; hence the ecosystem was a source of atmospheric CO₂. These results indicate that the predicted higher temperature and lower water table elevations, due to greenhouse warming [e.g., Gorham, 1991], could significantly affect the net ecosystem CO₂ exchange in northern wetlands and, consequently, change them from sinks to sources of atmospheric CO₂.

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T. J. Arkebauer, Department of Agronomy, Institute of Agriculture and Natural Resources, University of Nebraska, P.O. Box 830817, Lincoln, NE 68583-0817.

J. Kim, N. J. Shurpali, and S. B. Verma, Department of Agricultural Meteorology and Center for Laser-Analytical Studies of Trace Gas Dynamics, University of Nebraska, P.O. Box 830728, Lincoln, NE 68583-0728.

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