

A chamber design for measuring net CO₂ exchange on rangeland

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Abstract

Net carbon exchange of terrestrial ecosystems will likely change as atmospheric CO₂ concentration increases. Currently, little is known of the annual dynamics or magnitude of CO₂ flux on many native and agricultural ecosystems. Remoteness of many ecosystems has limited our ability to measure CO₂ flux on undisturbed vegetation. Today, many plant ecologists have portable photosynthesis systems with which they make single-leaf photosynthesis measurements. Utility of this equipment is enhanced when canopy-level CO₂ flux is also measured. We designed a portable 1-m³ closed chamber for use in measuring CO₂ exchange in short statured vegetation with widely varied canopy structure. The design includes external ductwork equipped with doors which are used to open the chamber for ventilation with outside air between measurements. The chamber was tested on a Wyoming big sagebrush (*Artemisia tridentata* ssp. *Wyomingensis* Nutt.)/Thurber's needlegrass (*Stipa thurberiana* Piper) community using 10 plots equally divided between shrub and interspace. The ductwork and doors provided adequate ventilation to allow consecutive measurements of CO₂ flux without removing the chamber from the plot. The chamber could differentiate CO₂ flux between plots with sagebrush and those with grass only, even at relatively low fluxes. Net CO₂ uptake per unit ground area was greater ($P = 0.04$) on sagebrush-grass plots ($7.6 \pm 1.4 \mu\text{mol m}^{-2} \text{s}^{-1}$) than on interspace plots without sagebrush ($3.1 \pm 1.0 \mu\text{mol m}^{-2} \text{s}^{-1}$). Chamber and leaf temperature increased by an average of 0.5 and 1.2°C, respectively, during measurements.

Key Words: photosynthesis; respiration; carbon dioxide flux, sagebrush

There is renewed interest in evaluating terrestrial CO₂ fluxes and ecosystem productivity as a basis for understanding the global carbon cycle and ecosystem responses to increasing CO₂. At present, there is a significant "missing sink" in most global carbon budgets (Gifford 1994).

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Resumen

El intercambio neto de carbón de los ecosistemas terrestres probablemente cambiará conforme la concentración atmosférica de CO₂ se incrementa. Actualmente se sabe poco acerca de la dinámica anual o de la magnitud del flujo de CO₂ de muchos de los ecosistemas nativos y agrícolas. La localización remota de muchos de los ecosistemas ha limitado nuestra capacidad para medir el flujo de CO₂ en vegetación sin disturbio. Hoy, muchos ecólogos de plantas cuentan con sistemas portátiles para medir fotosíntesis, con los cuales hacen mediciones de fotosíntesis en una sola hoja. La utilidad de este equipo aumenta cuando el flujo de CO₂ a nivel de la copa también es medido. Nosotros diseñamos una cámara cerrada portátil de 1 m³ para utilizarla en la medición del intercambio de CO₂ en vegetación corta saturada con una estructura de copa muy variada. El diseño incluye ductos externos equipados con puertas que son utilizadas para abrir la cámara para ventilarla con aire del exterior entre mediciones. La cámara fue probada en una comunidad de "Wyoming big sagebrush" (*Artemisia tridentata* ssp. *Wyomingensis* Nutt.) / "Thurber's needlegrass" (*Stipa thurberiana* Piper) utilizando 10 parcelas divididas igualmente entre los arbustos y los espacios entre ellos. Los ductos y puertas suministraron una ventilación adecuada para permitir medidas consecutivas del flujo de CO₂ sin remover la cámara de la planta. La cámara pudo diferenciar el flujo de CO₂ entre parcelas con arbustos ("sagebrush") y con solo pasto, aun en flujos relativamente bajos. La toma neta de CO₂ por unidad de terreno fue mayor ($P = 0.04$) en parcelas con arbustos y zacate ($7.6 \pm 1.4 \mu\text{mol m}^{-2} \text{s}^{-1}$) que en los espacios sin arbustos ($3.1 \pm 1.0 \mu\text{mol m}^{-2} \text{s}^{-1}$). Durante las mediciones, la temperatura de la cámara y hoja se incrementaron en promedio 0.5 y 1.2°C respectivamente.

Schimel (1995) suggests there is "increasingly strong evidence for terrestrial sinks, potentially distributed between Northern Hemisphere and tropical regions, but conclusive detection in direct biomass and soil measurements remains elusive." More complete data on ecosystem CO₂ fluxes will help identify some of these missing sinks.

The temporal and spatial aspects of CO₂ flux and responses to increasing atmospheric CO₂ are also of interest. Modeled predictions of ecosystem-level responses to CO₂ provide interesting insights, but fall outside the realm

of traditional science because rigorous tests are not usually possible (Rastetter 1996). Traditional CO₂ response studies usually involve a short-term (< 2 yr) comparison of current ambient CO₂ concentration to about twice ambient levels. However, it is difficult to know if responses to an immediate doubling of CO₂ will approximate responses to the slow, long-term elevation of CO₂ (about 1.5 μmol mol⁻¹ yr⁻¹) that ecosystems actually will experience. An alternative approach is to study long-term responses of ecosystems to changes in climate and CO₂ as they occur (Rastetter 1996). Such an approach requires patience, but would be a useful complement to ongoing modeling and CO₂ enrichment work. The chamber approach can also be used in conjunction with soil respiration measurements to construct community or ecosystem carbon budgets (e.g., Norman et al. 1992). Chamber measurements are also a useful complement to larger-scale techniques for quantifying carbon fluxes (i.e. Bowen ratio or eddy correlation). One major advantage of the chamber technique is that comparisons of small-scale treatments are possible. Thus the effects of species composition, prescribed fire, grazing, etc. on carbon budgets can be investigated. This would be more difficult with larger-scale techniques because of the treatment size required.

Reicosky (1990) reviewed the use of closed transparent chambers in the field and discussed their advantages. Closed chamber techniques have been developed for ecosystem and crops research (Sebacher and Harris 1982, Wagner and Reicosky 1992, Pickering et al. 1993), and have proven to be a practical method when limitations of the design are taken into account.

Battery powered, portable photosynthesis systems have also been developed for single-leaf photosynthesis measurements. Recently, these systems have been used with passive closed chambers. Passive chambers do not maintain steady-state conditions by active dehumidification and cooling, whereas active closed chambers use equipment to cool and dehumidify the chamber air. Passive chambers have

successfully measured CO₂ flux in widely varied settings including native arctic ecosystems (Vourlitis et al. 1993) and peanut crops (Pickering et al. 1993). Vourlitis et al. (1993) utilized a LI-COR 6200 portable photosynthesis system (LI-COR, Inc., Lincoln, Nebr., USA¹) to measure CO₂ concentration within the chamber. They reported that the system, which included a base inserted into the turf, had minimal effect on ecosystem CO₂ flux.

One major difficulty with large passive closed chambers is that the chamber must be physically lifted from the plot between measurements to prevent excessive CO₂ depletion. Venting capability provided with the LI-COR 6200 works well on leaf cuvettes, but is inadequate for use on chambers such as the one discussed here. A chamber design which allows chamber ventilation without removal from the plot could greatly enhance the utility of closed systems.

The design presented here provides a new approach whereby air exchange through the chamber is accomplished using ductwork, a fan, and doors. These innovations permit the chamber to be operated as a closed system for measurement, and as an open system for ventilation. We designed the chamber for use on both shrub and grass dominated plots. The plot area (1 m²) is sufficient for whole-plant measurements, but small enough to characterize spatial variability, which is critical in assessing landscape productivity (e.g., Whiting et al. 1992, Gilmanov and Oechel 1995). This chamber is relatively inexpensive, easy to use, commercially available, and adaptable to a wide array of non-forested ecosystems, both native and agricultural.

Materials and Methods

Chamber Design

Air within closed chambers departs from ambient temperature and relative

humidity (RH) through time, but these changes can be minimized either by actively cooling and dehumidifying chamber air (e.g., Whiting et al. 1992), or by using a passive design that reduces sampling time (Wagner and Reicosky 1992). Our passive closed chamber system was designed to provide rapid measurement of carbon dioxide exchange rate (CER) in shrub and grassland communities. Minimized sampling time eliminated the need for additional equipment and weight compared with actively cooled and dehumidified chambers, which is a major advantage on remote sites.

The chamber was fabricated commercially (Bend Plastic Supply, Bend, Ore.) for about U.S. \$1,500 and has a mass of about 20 kg. The design incorporates upper and lower air channels (6 x 16 cm). These are attached on their inner surfaces to the 1 x 1 m Lexan[®] (6-mm thick) walls of the chamber (Fig. 1). The top of the 1m x 1m cube is open, and the front and sides have 60 x 60 cm openings, each of which is covered with plastic film (propafilm[®] C; ICI Americas, Inc., Wilmington, Del.). The openings minimize chamber mass thereby enhancing portability. Additionally, the film may help reduce heat buildup because it transmits about 70% in the 2.5–20 μm (thermal) wavelengths, while the Lexan walls are opaque to thermal radiation. The back wall is solid and provides a surface on which to mount sensors. Top, front, and side openings are closed by taping propafilm to the Lexan surfaces. A detachable Lexan duct is mounted directly to the upper and lower air channels on the back of the chamber. The duct has upper and lower doors, which can be opened to allow air exchange between inside and outside the chamber. A fan (rated at 11 m³ minute⁻¹) is mounted inside the duct on the lower air channel. The fan can circulate air through the chamber by 2 pathways: When the upper and lower doors on the duct are open, ambient air is blown into the bottom of the chamber through holes on the lower air channel. Air exits the 1-m³ chamber through holes in the upper air channel and leaves the upper channel through the upper door. Alternatively,

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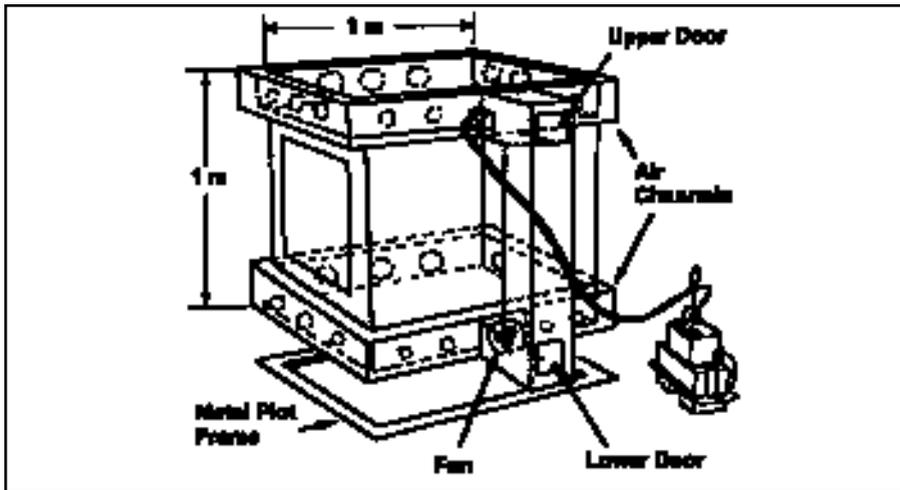


Fig. 1. Schematic drawing of a 1 m³ chamber, approximately to scale. The chamber is constructed of Lexan[®] and propafilm[®] C.

when both doors are closed the duct provides a closed loop whereby air circulates from the upper chamber, through the duct, to the lower chamber.

In the field, permanent study plots were established by pressing a 1-m² angle-iron frame into the soil. The vertical angle is pressed into the soil and seals the soil surface, while the horizontal angle provides a flat mounting surface for the chamber. Closed-cell foam mounted on the chamber's lower air channel provides a gas-tight seal between chamber and frame. Chamber mass is sufficient to compress the foam and close the joint between chamber and frame. Scale drawings of both chamber and frames are available from the authors. We use a small trailer and an all-terrain vehicle (ATV) to transport the chamber and associated equipment between plots.

CO₂ Sampling

Carbon dioxide exchange is estimated by operating the chamber with the fan on and the doors closed (i.e. as a passive closed system). The fan directs air into the chamber at the soil surface. Air then flows upward through the chamber into the upper air channel. A LI-6200 sensor head mounted on the upper end of the duct samples air exiting the upper air channel (Fig. 1). We used LI-COR equipment, however the chamber design should be adaptable to other commercially available portable photosynthe-

sis systems. Sensor tubing and cables are routed to a LI-6250 infrared gas analyzer and system console. The analyzer measures CO₂ concentration at 60 samples min⁻¹, providing rapid measurement of CO₂ concentration. Carbon dioxide exchange rate is then estimated from the rate of change in CO₂ concentration. Details regarding the IRGA and associated equipment were presented by McDermitt (1987). Chamber air temperature and humidity are measured at the sensor head, while leaf temperature is measured by a fine wire thermocouple attached to a leaf within the chamber, similar to Pickering et al. (1993). Alternatively, leaf temperature can be measured remotely by infrared thermometry. Incident PAR is measured by a quantum sensor mounted on the inside back wall of the chamber. Chamber shading is minimized by positioning the back wall away from the sun.

Chamber Volume

Chamber volume and mixing time were determined by injecting a known amount of pure CO₂ into the chamber during a data collection period. Total system volume was determined to be 1,020 ± 6 liters, including chamber, air channels, duct, tubing, and IRGA. Total volume is needed for calculating CER, and can be entered into the LI-COR system tables. Mixing time was considered to be the time required for CO₂ to stabilize after injection.

Approximately 10 seconds after injection, CO₂ concentration increased rapidly and stabilized at the new concentration in about 30 seconds (Fig 2a).

Field Testing

The chamber was tested at the Northern Great Basin Experimental Range (119° 43'W, 43° 29'N; 1,380 m elev.) approximately 67 km west of Burns, Ore. in a Wyoming big sagebrush (*Artemisia tridentata* Nutt. subsp. *Wyomingensis*) community. Understory species include Thurber's needlegrass (*Stipa thurberiana* Piper), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), Sandberg's bluegrass (*Poa sandbergii* Vasey.), bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) Smith), prairie lupine (*Lupinus lepidus* Dougl.), hawksbeard (*Crepis occidentalis* Nutt.) and longleaf phlox (*Phlox longifolia* Nutt.) Soils are coarse-to-fine sandy loam Holte-Milican complex.

Ten frames were inserted into the soil and sealed by packing soil against the frame as needed. Measurements were taken no earlier than 7 days after placing the frames. Five of the 10 frames were centered over a sagebrush plant, and 5 were randomly located in an adjacent interspace containing no sagebrush. The chamber was lowered onto the frame with the doors open, and the fan was immediately started. When the system was in place, the doors were closed, and a measurement was initiated about 30 seconds later. During each measurement, the LI-6200 software was programmed to compute 2 consecutive flux rates, which are referred to as observations in LI-COR manuals (LI-COR 1990). Each observation was programmed to end after a 5 μmol mol⁻¹ CO₂ change. Sampling time per observation varied from 15 to 90 seconds, depending on the CO₂ flux rate. At the end of the measurement period CER was calculated for each observation by the LI-6200 software, based on changes in CO₂ concentration and total system volume.

All reported flux rates are based on plot surface area (1 m²), not green leaf area. We are currently evaluating a protocol for estimating leaf area index in shrub plots.

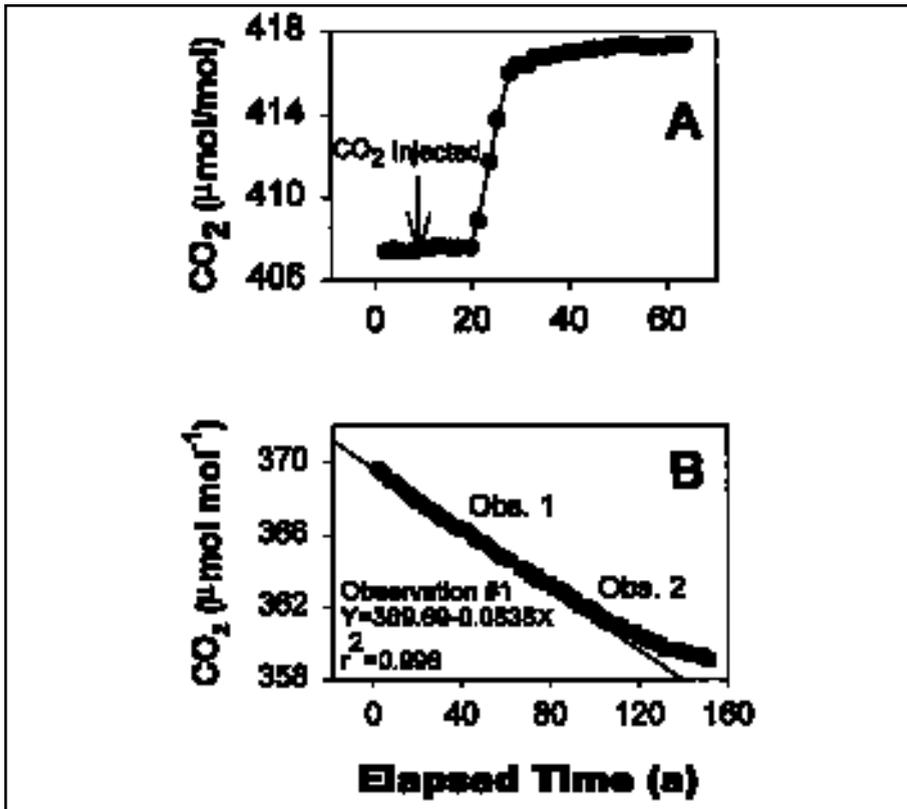


Fig. 2. Chamber CO₂ changes recorded during testing. (A) Mixing time of the chamber was determined by measuring time required to stabilize at the new concentration after injecting a known amount of CO₂. (B) Field data collected in full sun (1700 μmol m⁻² s⁻¹ over a grass/forb canopy on 25 May 1996. The solid line represents the least squares regression for data from observation 1.

Results

Chamber Leak Testing

The chamber was leak tested in the laboratory by flushing it with air from outside the building, thereby creating a 135 μmol mol⁻¹ gradient between the chamber interior (375 μmol mol⁻¹ CO₂) and room air (510 μmol mol⁻¹ CO₂). Chamber doors were closed, and the fan was operated at full speed. Following a 30-second settling time, chamber CO₂ concentration was recorded for 2 min. Carbon dioxide increase averaged 0.03 μmol mol⁻¹ sec⁻¹ (n = 5). In the field, gradients between inside and outside are at least 10- to 30-times less than this, and CO₂ changes caused by leakage should be proportionately lower.

Field Testing

Carbon dioxide exchange rate of the 10 field plots was measured on 25 May 1996, during peak growth, when tran-

spiration and CER are at seasonal maxima. Solar radiation measured inside the chamber averaged 1,655 μmol m⁻² sec⁻¹ and ranged from about 600 to 2,000

μmol m⁻² sec⁻¹, depending on cloud cover. During these measurements, air temperature, leaf temperature and RH inside the chamber increased about 0.5 ± 0.1°C, 1.2 ± 0.4°C and 8 ± 1%, respectively (n = 20).

Later, on 30 May, we evaluated the ability of the fan and ductwork to ventilate the chamber between consecutive measurements by measuring CER in full sun followed quickly by a measurement of plant and soil respiration. Between the light and dark measurements, the chamber doors were opened and the chamber was ventilated with ambient air for 2 min during which the cover was placed over the chamber. Chamber air temperature and leaf temperature differences between full sun and dark measurements reflect the effect of covering the chamber with a shroud, which reduces heating (Table 1). Relative humidity at the start of the dark measurement was within 1% of the previous starting value in full sun.

The profile of CO₂ concentration change during a measurement is illustrated in Figure 2b for an interspace plot. On this plot, the first observation spanned a 5 μmol mol⁻¹ CO₂ change, and lasted 60 seconds. The depletion of CO₂ was linear with time, with a slope of -0.08 ± 0.001 μmol mol⁻¹ sec⁻¹ (r² = .996, df = 29). The second observation lasted 90 seconds. The

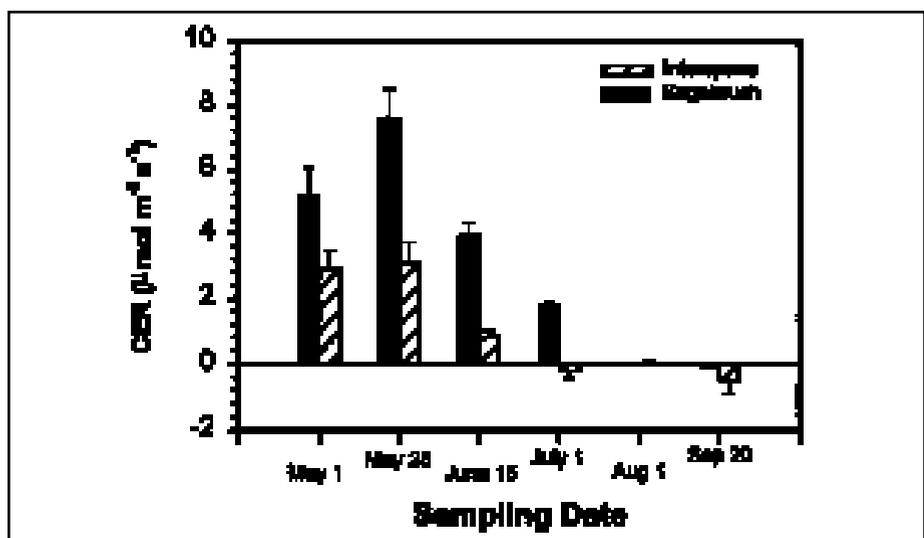


Fig. 3. Seasonal profiles of CO₂ exchange rate (CER) over sagebrush and interspace plots during 1996. Data are presented on a ground area basis and vertical bars represent 1 SE.

Literature Cited

Table 1. Chamber air and leaf temperature initial conditions and associated SE measured on 5 sagebrush plots on 30 May. The range of each variable is the change recorded during the measurements. Full sun (light) measurements were separated from covered chamber (dark) measurements by about 2 min, during which the chamber remained affixed to the plot, and ambient air was circulated through the open chamber doors. For time, range is the length of the measurement.

Variable	Light			Dark		
	Starting value		Range \bar{x}	Starting value		Range \bar{x}
	\bar{x}	SE		\bar{x}	SE	
Chamber PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	1601	5	10	—	—	—
Air temperature ($^{\circ}\text{C}$)	20.7	0.6	0.3	20.1	0.6	0.2
Leaf temperature ($^{\circ}\text{C}$)	21.2	1.4	1	17.4	0.6	0.5
Relative humidity (%)	51	1.7	3.4	50.1	2	6.8
Carbon dioxide (μmol^{-1})	360	2	5.3	366	1	5.1
Measurement time (s)			13			50

slope was linear ($-0.06 \pm 0.001 \mu\text{mol mol}^{-1} \text{sec}^{-1}$; $r^2 = .98$, $df = 45$), but was significantly ($P < 0.05$) less than for the first observation. Visual inspection of the figure shows that depletion rate slowed after about 90 seconds (about 2 min after door closure), likely because of increased humidity and lowered CO_2 concentration.

We were able to separate CER on shrub and interspace, even though rates in this area are low, and plant cover is variable. Seasonally, CER averaged $0.27 \mu\text{mol mol}^{-1} \text{sec}^{-1}$ on sagebrush plots, twice the rate measured on interspace plots ($P = 0.04$). During the period of maximum growth, mean CER on shrub plots was $7.6 \pm 1.4 \mu\text{mol m}^{-2} \text{sec}^{-1}$ versus $3.1 \pm 1.0 \mu\text{mol m}^{-2} \text{sec}^{-1}$ over interspace plots (Fig. 3). Even though CER on these plots was not large, we easily distinguished between shrub and interspace during this critical period of active growth.

Discussion and Conclusions

The chamber described here was designed to provide estimates of instantaneous CER on undisturbed rangeland, without incorporating specialized air conditioning equipment. The duct and fan arrangement allows the chamber to be ventilated without removing it from the frame. This arrangement facilitates measurement of CER in full sunlight, followed immediately by measurements of plant and soil respiration after covering the

chamber with an opaque cloth. Based on measured CO_2 exchange in both sagebrush and interspace plots, precision is good. Standard errors of CER within a measurement period were generally less than 1% of the least squares slope for that measurement. Temperature increases were small, while humidity increases were somewhat larger. Both appeared to have only slight effect on CER during the first 60 seconds. We found that if chamber measurements were kept under 2 min and chamber conditions remained close to ambient, linear curves provided a good fit for CO_2 flux data. In cases where quadratic relationships occur, other approaches for analysis are available, and are discussed elsewhere (Reicosky et al. 1990). Cloud cover changes are always a problem, however if the measurement is split into more than 1 observation, cloud effects can be delineated. The chamber is sufficiently portable that 2 persons equipped with an ATV and trailer can easily set up and take a measurement within 10 minutes, even in remote areas. This arrangement allows wide separation of plots for treatment comparisons or characterization of spatial variation. The chamber we have described is easy to use, relatively inexpensive, and adaptable to a wide range of field conditions.

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