

A Modified Soil Diffusion Chamber for Gas Profile Analysis

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ABSTRACT

Gas concentration gradients in soil profiles can provide important information on the timing and location of gas production and consumption. High spatial variation complicates both determination of soil gas profile concentration or gradient and calculation of the gaseous flux from soil. A modified diffusion chamber is introduced in this paper with advantages of gas sampling at multiple depths at a single location, easy installation and less maintenance. Field measurement using both original chamber (requiring multiple installations at various depths) and the modified chamber techniques showed comparable soil CO₂ and CH₄ profile gradients.

SOIL GAS fluxes to the atmosphere represent an integration of heterogeneous biological activities in the vertical column of the soil, but they may not represent actual gas production in the soil. Some of the gases produced can be consumed in movement through the soil profile, such as carbon dioxide (CO₂) reduction to methane (CH₄), CH₄ oxidation to CO₂, and nitrous oxide (N₂O) reduction to nitrogen gas (N₂). Determining the gas concentration in soil profiles helps to identify the location of sources and sinks in soils. Accurately sampling soil gases is essential for understanding soil microbial activities, vertical distribution of gases and their movement in the soils, and estimating the gas effluxes according to their concentration gradients.

Techniques for obtaining soil gas samples vary according to what is being studied and field conditions. A soil gas-sampling probe can be used to withdraw gases from soil pore spaces (Burton and Beauchamp, 1994; Mosier and Hutchinson, 1981). This device cannot be used in flooded soils. Also the gases that are collected may not represent the point sampled because of gas mixing from other soil depths and/or even from the atmosphere. A diffusion technique, however, can be used in any soil conditions once gases reach equilibrium between inside a diffusion chamber and surrounding soils of the same depth (Fang and Moncrieff, 1998; Kammann et al., 2001). This procedure has a particular advantage under flooded conditions where little soil atmosphere is available for sampling. A typical soil diffusion chamber developed in this Institute consists of a polyvinyl chloride (PVC) cap (5 cm in diam., approximately 70 mL in volume) connected to a three-way stopcock valve that is above soil/water surface for sampling (Faulkner et al., 1989). The opening of the cap is located at a designated depth of the soil (e.g., 20 cm). The cap and valve are

connected with a gas impermeable Tygon plastic tube of desired length (Fig. 1 embedded diagram). In application, the chambers are left in field for at least 2 wk to allow equilibrium between the gas inside the chamber and the soil. After purging approximately 5 mL of gas from the tube, a gas sample (e.g., 20 mL) is withdrawn from the chamber using a gas-tight syringe. Then, an equivalent amount of air (e.g., 25 mL) is recharged to the chamber to maintain sufficient gas within the chamber for the next sampling. Proper sealing between the cap, plastic tube, and valve is critical. Otherwise, the chamber space will become filled with water under flooded conditions, resulting in no gas present for sampling. Detail information on construction and application of such a diffusion chamber can be found in previous publications (Faulkner et al., 1989; Yu et al., 2006). Unlike other diffusion methods using a membrane (Schipper and Reddy, 1995; Yu et al., 2004) or silicon tubing (Jacinthe and Groffman, 2001), there is no physical boundary to separate the gas phase and surrounding soil/water in such a diffusion chamber. The gas, just as soil air, has direct contact with the surroundings, and remains trapped (because of no pathway for leakage) in the chamber under flooded conditions. Accuracy of soil gas profile analysis largely depends on the equilibrium established between sampling devices and soil surroundings, thus the direct contact mechanism provided by this diffusion chamber is probably the best option.

The above chamber design (Faulkner et al., 1989) has two limitations: (1) gas sampling at multiple depths in a soil profile requires multiple chambers installed at different locations. Gas samples obtained using this procedure may not represent gas dynamics in the individual soil profile, due to large spatial variations under field conditions; (2) the exposed plastic tube is vulnerable to weather and destructive wild animals, causing leaking and/or clogging. In this paper, we introduce a modification of this diffusion chamber technique which eliminates such limitations.

CONSTRUCTION DETAILS

Figure 1 shows the design diagram, including materials and relative scales of individual parts, assembling order and a complete modified diffusion chamber with openings for measuring gas at the 10-, 20-, 30-, and 40-cm soil depths in the soil profile at one location. A single PVC pipe (45 cm long, 4.5 cm and 4 cm for o.d. and i.d., respectively) divided by four silicon rubber septa (4 cm in diam. of the smaller end, 4 cm high) forms the four diffusion chambers (approximately 75 mL each). Eight holes (1.4 cm in diameter) are drilled in symmetry at each of the desired depths with an accumulative area close to that of the open bottom of the pipe, which result in all chambers having the same contact surface (12.5 cm²)

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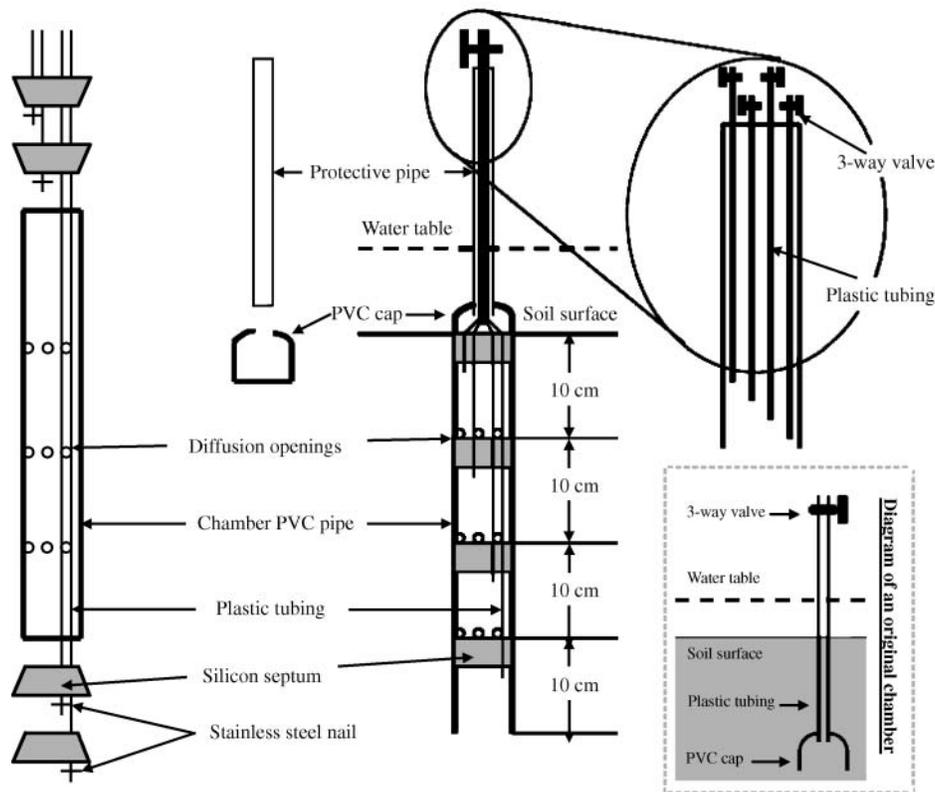


Fig. 1. Diagram of a modified diffusion chamber. Assembling order is demonstrated from left to right of the diagram. A diagram of an original diffusion chamber (which requires multiple installations at different depths) is embedded (bottom right corner).

with surroundings. The septum is previously drilled one (for 40 cm chamber), two (for 30 cm chamber), three (for 20 cm chamber), and four (for 10 cm chamber) holes, respectively. The diameter of the hole in the septa is slightly smaller than that of a sampling Tygon plastic tubing (0.5 and 0.3 cm for o.d. and i.d., respectively). Each chamber has only one opening in the sampling tube for a desired length. A small stainless steel nail (0.1 cm in diam., 1 cm long) is poked through the sampling tube close to the septum to prevent the tube from being pulled out of the septum during assemblage (the nail does not interfere with gas sampling). The other end of the sampling tube is later connected to a three-way stopcock valve for gas sampling following field installation. During assembly, it is convenient to place the bottom two rubber septa (to form 30- and 40-cm chambers) into place first, because the greater number of tubes passing through the top two septa (the 10 and 20 cm chambers) makes it difficult to adjust their positions. A metal rod or a screwdriver may be needed to hold the septa in place (through the holes in the chamber PVC pipe) when adjusting the tube position. Lubricating the tubes and septa with water or petroleum jelly may be necessary during assemblage, because of tight contacts to ensure necessary sealing. A hole is drilled on the top PVC cap (5 and 4.5 cm for o.d. and i.d., respectively) to fit the o.d. (2.5 cm) of a protective PVC pipe (length according to actual application) through which four sampling tubes can pass. After covering the top of the chamber pipe with the cap through which the four sampling tubes are pulled through, the

assembly process is complete. The protective PVC pipe is installed following field installation. A good seal between the cap and chamber pipe, and between the cap and protective pipe is not critical.

FIELD INSTALLATION AND OPERATION

To prevent clogging of chambers openings during field installation, each chamber is filled with water and kept frozen in a freezer (with the device in an upside down position). One must ensure that there is no leakage of water in the chambers at this stage. The chambers are transported frozen to the field in a cooler filled with ice. A hole is bored with a bucket auger that is slightly smaller than the o.d. of the chamber pipe to a desired depth (e.g., 40 cm) and then the device is placed in the hole. Using this procedure, good contact between the device and surrounding soils is ensured. All sampling plastic tubes are pulled through the protective pipe. The protective pipe is then pushed through the cap, leaving none of the sampling tubes exposed. Each sampling tube is trimmed just above the protective pipe, labeled for the appropriate sampling depth and connected tightly to a three-way valve.

After the ice melts, chamber air space is created under dry field conditions, but will remain filled with water under flooded field conditions. It is suggested for all soil conditions the chambers be charged with air for at least its volume before the first gas sampling. A gas sample (e.g., 20 mL) can be collected once equilibrium is reached

in each chamber after purging the gas in the sampling tube (about 5 mL). Then, the same amount of air (e.g., 25 mL) is recharged to fill the chamber space with air for next sampling event. For convenient purpose, ambient air is used to recharge the chambers after sampling. In flooded soils where oxygen (O_2) concentration is low, the introduction of ambient air will result in a longer equilibration time. If more frequent sampling is needed, N_2 can be used as an alternative, which requires a portable N_2 supply.

Such a modified diffusion chamber technique ensures gas samples from different depths come from a single location in a relatively undisturbed soil profile. The procedure also has an advantage of allowing for multiple chambers be installed at one time over a short period of time. In actual field measurement (as described in the

next section), the device has performed satisfactorily for 2.5 yr without maintenance or replacement.

APPLICATION

The modified device was tested in a coastal-forested swamp, located in the Jean Lafitte National Historic Park and Preserve (N 29° 48.2', W 90° 06.7'), Louisiana (USA). Average soil total C and N contents were 9.19 and 0.68% for 0 to 10 cm, 2.30 and 0.19% for 10 to 20 cm, 1.38 and 0.12% for 20 to 30 cm, and 1.05 and 0.07% for 30 to 40 cm of the soil, respectively. Average soil pH in the 40-cm profile was 7.1 (SD = 0.3, $n = 4$). More information on the study site was reported in another work (Yu et al., 2006). Four replicate plots (more than 20 m apart) were selected in the study site.

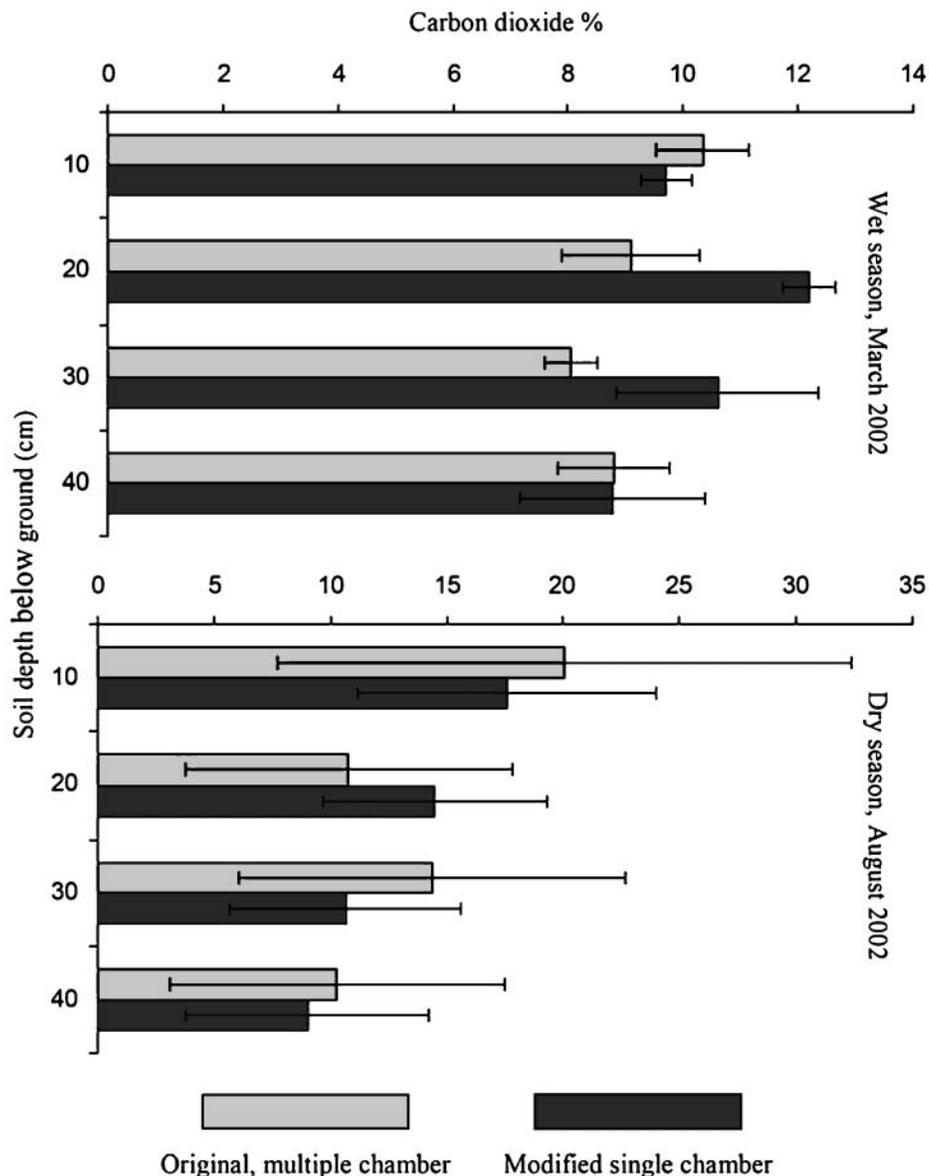


Fig. 2. Comparison of carbon dioxide concentration measurement in soil profile using two different chamber techniques. Data represent mean values with standard deviations denoted by error bars ($n = 4$).

At each plot, an original diffusion chamber (as described above) was installed at depths of 10, 20, 30, and 40 cm, respectively. With an objective of replacing the existing system, a modified chamber with openings at the same depth as the original chamber was installed in an adjacent location in each plot.

Carbon dioxide and CH₄ concentration in the 40-cm soil profile was determined. A Tremetrics 9001 gas chromatograph (GC) instrument (Tremetrics, Eden Prairie, MN) equipped with a flame ionization detector was used to analyze CO₂ and CH₄ concentration in the samples. The GC also contained a methanizer catalyst column that reduced CO₂ to CH₄ for detection by flame ionization detection. Gas analyses were calibrated using certified standards of known concentration (Scott Specialty Gases, Inc., Plumsteadville, PA).

Comparison between the original and modified chambers was made in a wet (March) and dry (August) sea-

son in 2002. There was no specific CO₂ and CH₄ profiles pattern among the different hydrological seasons, different plots, and different sampling systems. On average, concentrations of CO₂ (Fig. 2) and CH₄ (Fig. 3) tended to be higher in the surface soil layers. The results show a large profile variation in CO₂ and CH₄ in the soil between the replicate plots, especially in the dry season. Results suggest that the modified chamber yields gas concentration profiles that are similar to profiles determined by the original multi-chamber technique. The results also show large differences in the gas concentration between two adjacent vertical subchambers of the modified technique, indicating a good seal between the chambers required for capturing the unique gas signature at a certain depth.

Despite the variations of gas profile in the soil, both sampling techniques show the same magnitude of soil CO₂ and CH₄ concentration and distribution at the study

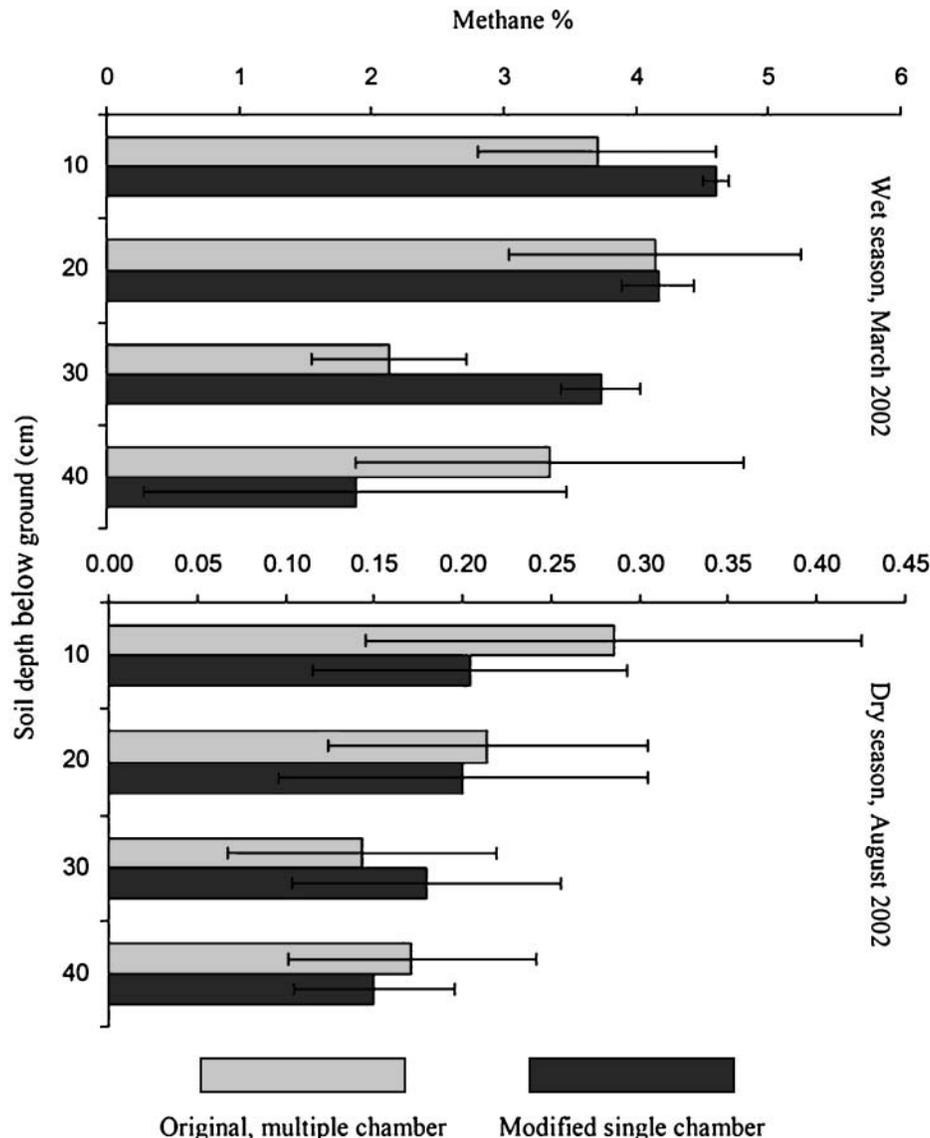


Fig. 3. Comparison of methane concentration measurement in soil profile using two different chamber techniques. Data represent mean values with standard deviations denoted by error bars ($n = 4$).

site with no significant difference ($n = 16$, four depths). Mean CO_2 concentration in the top 40 cm soil was 9.1 and 10.3% in the wet season ($P = 0.21$), and 13.7 and 12.6% in the dry season ($P = 0.76$) using the original chamber and modified technique, respectively (Fig. 2). Mean CH_4 concentration was 3.3 and 3.6% in the wet season ($P = 0.74$), and 0.20 and 0.19% in the dry season ($P = 0.60$) using the original chamber and modified technique, respectively (Fig. 3). We conclude that the modified chamber technique yields comparable results of soil gas profile with the original chamber. The much higher soil CH_4 concentration found in the wet season was mainly due to lower redox (E_H) conditions that are favorable for CH_4 production (Yu and Patrick, 2003; Yu et al., 2006). The modified sampling technique was as successful as the original one for determining changes of CO_2 and CH_4 concentration at different seasons, making it adequate as an alternative technique with multiple advantages. Analyzing soil gas at a single location in the profile allow for examining the soil as a three-dimensional body for gas production, transport, and storage. Such analysis aids in resolving discrepancies in predicted and measured gas efflux and provide a link to soil microbial processes and surface gas emissions.

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