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The effect of clipping on methane emissions from *Carex*

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Abstract. The purpose of this study was to estimate the resistance to methane release of the above-ground portion of *Carex*, a wetland sedge, and to determine the locus of methane release from the plant. Measurements conducted on plants clipped to different heights above the water level revealed that the methane flux from clipped plants was on the order of 97% to 111% of control (unclipped) values. The greatest increase was observed in the initial flux measurement after the plants had been clipped to a height of 10 cm. Subsequent measurements on the 10 cm high stubble were similar to control values. When the ends of plants which had been clipped to 10 cm were sealed, the methane flux was reduced to 65% of control values. However, sealing had no effect on the flux from plants which were clipped at 15 cm and higher, indicating that virtually all methane was released on the lower 15 cm of the plants as they emerged from the water. The results indicate that the above-ground portions of *Carex* at our study site offered only slight resistance to the passage of methane, and that the main sites limiting methane emission are below-ground, at either the porewater-root or root-shoot boundary. We hypothesize that the transitory increase in flux associated with clipping was due to the episodic release of methane held within the plant lacunae. The buildup of CH_4 partial pressure within lacunal spaces overcomes the resistance to gas transport offered by aboveground parts.

Introduction

Emergent aquatic plants serve as conduits for gas exchange between the atmosphere and the anaerobic sediments in which they are rooted (Dacey 1981). In the process of transporting oxygen belowground to support root respiration, plants transport methane, an important greenhouse gas (Cicerone & Oremland 1988), to the atmosphere. Because CH_4 emission rate from plants has not been affected by manipulations which have varied such factors as CO_2 partial pressure, illumination, transpiration rate and photosynthetic rate, researchers have concluded that CH_4 release is independent of stomatal aperture (Seiler et al. 1984; Nouchi et al. 1990; Chanton et al. 1992; Whiting & Chanton 1996). Nouchi et al. (1990) concluded that rice emits methane from the culm, through micropores, which are different from stomata. Harden

and Chanton (1994) reached similar conclusions for *Pontederia cordata* and *Sagittaria lancifolia* and showed that methane release from these plants occurs from the petiole shortly after it emerges from the water.

Alternatively, Knapp and Yavitt (1992), in a study of gas emission from *Typha latifolia*, presented evidence that methane emission from green leaves was controlled by stomatal conductance. Morrissey et al. (1993) suggested that reductions in stomatal conductance can limit emissions from *Carex* by as much as a factor of two. Schimel (1995) reported that methane emissions increased to 160% of control values when *Carex aquatilis* was clipped to heights of 5 cm, and concluded that the transport of CH_4 through leaves and stomata was the rate limiting step in CH_4 release from this plant in the Arctic ecosystems he studied.

In this work, we report a clipping experiment performed on *Carex* to extend the observations of Schimel (1995) to a boreal ecosystem. Our purpose was to estimate the resistance of different parts of the plant to methane release and to determine the locus of methane emission from the plant. We hypothesized that if CH_4 release was limited by passage through leaves and stomata, methane emission rates would increase dramatically as we clipped the plants closer and closer to the water surface.

Methods

This experiment was conducted in a fen in northern Alberta, Canada (54.6° N, 113.4° W, 110 km north of Edmonton). This fen was chosen for its accessibility and its nearness to the University of Alberta's Meanook Biological Research Station. The fen is semi-enclosed by willow and spruce, and similar to the many other fens in the area. The portion of the fen where this study was conducted is dominated by *Carex aquatilis* and *Carex rostrata* at a height of about 80 cm. The year before this experiment was initiated a boardwalk was constructed at the site from which measurements were made.

Carex plants were enclosed in 20 cm diameter clear Plexiglas chambers with interior fans to circulate air. The bottom of the chambers rested below the water surface; water depth within the chamber varied between 3 and 20 cm, depending on the water level of the fen (Table 1). The chamber was shaded to regulate air temperature. Experiments or tests are designated in Table 1. Each letter represents work done a particular day, and the values in parentheses following the letters represent the number of replicate chambers run that day. The heading across the top indicates the manipulation performed, sequentially running from left to right. For example, in test A, three chambers were run and after measuring a control flux, fluxes were measured on clipped plants at 60, 40, 20, 10 (twice) and 5 cm, and the next day at 10 cm, 5 cm

and on the plants clipped below the water surface. As a second example of how to interpret the table, in test K, after three replicate control fluxes on three replicate chambers (9 measurements total), plants were clipped directly to 20 cm and the three chambers measured three times each. The values in Table 1 represent the ratio of the flux following the manipulation relative to the control flux before manipulation (clip flux/control flux).

For each specific test, the open topped chamber was aired for fifteen minutes and then sealed with plastic wrap and a heavy duty rubber band. Samples of chamber air were taken every four or five minutes with a 30 mL syringe; in all tests five to seven samples were collected over 16 to 30 minutes for each flux measurement, except in tests J and O. During test J two flux measurements were calculated from 10 samples. The first five samples were taken at one minute intervals; the second five samples were pulled at five minute intervals once the first set had been taken. The first sample on each set of plants was drawn within two minutes of clipping. The chambers were not vented between the two sets of sample collections. Flux measurements were calculated separately from each set of five syringes. Test O was similar to test J but fourteen samples were taken at 0.5 minute intervals over 6.5 minutes; the first sample was drawn within four minutes of clipping. Groups of four consecutive samples were used to calculate running flux averages within the 6.5 minutes monitored.

After flux measurements were made the plants were clipped to the next height (as indicated in Table 1) or white petroleum jelly was used to seal the end of their clipped leaves. Measurements commenced within thirty minutes of the plants being clipped or sealed. Petroleum jelly placed on the clipped ends of the cut plants covered no more than 0.5 cm of the leaf blade itself. Leaf ends were sealed about 1.5 h after the initial clipping.

Flux measurements were repeated in most runs. Within twelve hours of collection, methane samples were quantified on a flame ionization gas chromatograph equipped with a poropac Q column. Except for the short term flux experiments (J and O), methane exhibited linear increases within the chambers and fluxes were calculated by linear regression. Some experiments were carried out over a two day period, as indicated in Table 1. Tests A through E were done in 1994; the rest of the tests took place during 1996.

Results and discussion

Plant transport accounted for over 97% of the methane transported from the fen. When plants were clipped below the flood-water surface, methane emission rates were only 3% or less of control values (Table 1, test A, H "below water" heading). Apparently methane oxidation at the soil-water inter-

Table 1. Methane emission rates from plots clipped to the heights indicated, expressed relative to control (unclipped) rates (clip flux/control flux). The number of replicate chambers is shown next to the test number in parentheses. Chambers with error estimates on control fluxes (footnote below) were run three times, so the reported values for these tests are the mean value of 9 determinations on 3 chambers. At 10 cm, measurements were repeated on half hour intervals. ± values are standard deviations.

Test # (n)	Starting date	Water depth (cm)	Same day as control																				One day later					
			60cm	±	40 cm	±	20 cm	±	15 cm	±	10 cm – 1	±	10 cm – 2	±	10 cm – 3	±	<5 cm	±	<5 cm	±	Below water	±	10 cm	±	<5 cm	±	Below water	
A(3)	12-Jul-94	12	1.08	0.01	1.10	0.06	1.05	0.02			1.16	0.02	1.07	0.00									1.09	0.03	1.05	0.05	0.01 ± 0.0	
B(E)	13-Jul-94	12					1.01	0.03			1.04	0.01					1.12	0.04										
C(1)	18-Jul-94	12									1.26		1.10															
D(1)	7-Aug-94	2					1.19																0.67	(0.05)				
E(1)	7-Aug-94	2			0.99		0.99				1.07																	
F(3)	12-Jun-96	9									1.06	0.03	0.99	0.05	0.95	0.04							0.85	0.02				
G(3)	20-Jun-96	17									1.08	0.06	1.02	0.04	0.99	0.03												
H(3)	2-Jul-96	13	1.00	0.05	0.96	0.06	0.95	0.96			0.94	0.06	0.92	0.07			1.05	0.09	0.97	0.10	0.02	0.00						
I(3)	7-Jul-96	10									1.18	0.04	1.09	0.04	1.02	0.05												
J(3)	18-Jul-96	11									1.18	0.09	0.96	0.03	1.04	0.06												
K(3)	29-Jul-96	11					1.00	0.04																				
L(3)	30-Jul-96	11							1.03	0.06																		
M(3)	1-Aug-96	9							1.10	0.03																		
N(4)	9-Aug-96	19							1.01	0.02																		
O(1)	15-Aug-96	19									1.13																	
P(1)	15-Aug-96	19															1.05											
		Mean	1.04		1.01		1.04		1.05		1.11		1.02		1.00		1.07		0.97		0.02		0.87		1.05		0.01	
		Standard error	0.04		0.03		0.03		0.02		0.03		0.02		0.02		0.03		0.00		0.00		0.10		0.00			

Control flux values in mg $m^{-2}d^{-1}$ were as follows: Test A, 905, 1265, 772; B 958, 804, 720; C 1302 (13); D 1185 (62); E 400; F 137 (6), 112 (3), 149 (3); G 194 (3), 270 (2), 191 (6); H 321 (2), 152 (7), 280 (4); I 131 (5), 158 (4), 237 (6); J 249 (3), 124 (3), 356 (7); K 512 (33), 287, 193 (5); L 368 (5), 450 (2), 386 (6); M 458 (10), 300 (1), 437 (7); N 268 (10), 296 (3), 351 (6) 492 (2); O 363 (2), 520 (10)
Values in parentheses represent standard deviation of 3 replicate flux determinations on a chamber.

face attenuated the flux of methane supported by diffusion from porewater (Happell et al. 1994).

Clipping plants at heights above the surface of the flood-water increased the methane emission rate by at most 26%. Mean values for each height ranged from 97% to 111% of control values (Table 1). Replication of fluxes on individual chambers was 6% of the mean value or better. The greatest increase was observed in the initial flux measurement after the plants had been clipped to a height of 10 cm. Subsequent measurements on the 10 cm high stubble were consistently lower (tests A, C, F, G, I, J, Table 1). The largest increase occurred when the plants were cut directly to 10 cm height instead of incrementally (test C, I, J). However when plants were clipped incrementally in experiments A and B, the largest increase in flux was still at 10 cm height. Frequent sampling immediately after clipping to 10 cm revealed an initially high rate that decreased quickly over time (Table 2). We suggest that these variations were due to the episodic release of methane held within the plant lacunae upon clipping. As will be discussed below, any resistance to gas transport offered by aboveground parts was overcome by the buildup of CH_4 partial pressure within lacunal spaces. Clipping to 5 cm produced effects similar to clipping at 10 cm.

Measurements on the 10 cm stubble after 24 hours (denoted "one day later" Table 1) were similar to or less than the values for the control fluxes. Diurnal measurements have indicated little change in *Carex* methane emission rates from unmanipulated plants from day to day (Whiting & Popp 1995, unpublished data).

Sealing the clipped ends with petroleum jelly caused the methane flux to decrease relative to control values on average 35% for plants clipped to 10 cm above the surface water. Plants clipped to 15 and 20 cm did not show a similar decrease (Figure 1). These observations suggest that methane exits the plant from the lower 15 cm, consistent with results for rice (Nouchi et al. 1990) *Pontederia* and *Sagittaria* (Harden & Chanton 1994). Schimel (1995) reported a decrease in flux when *Carex* stubble were similarly sealed.

Overall our results suggest that the leaves and stomata of the *Carex* at our sampling site play a limited role in attenuating methane release. We hypothesize that the *Carex* we studied released methane at the point where the leaves bundle or sheath, but not from the leaf blade itself. In our experiment the removal of leaves and stomata generally increased methane emission by only about 10%, and this increase was transitory. To the extent that leaves and stomata do attenuate methane emission, they cause the methane concentration within the plants' internal air spaces (lacunae) to increase, steepening the concentration gradient between the plant's internal gas spaces and the atmosphere. The increase in the concentration gradient overcomes the resis-

Table 2a. Chambers were placed immediately after clipping and the first sample drawn within three minutes. During the first five minutes, samples were taken at one minute intervals (10 cm-a). Subsequent samples were drawn at five minute intervals (10 cm-b). Fluxes are reported relative to control values, Table 1.

Test #	10 cm-a	10 cm-b
J-1	1.15	1.03
J-2	1.35	0.94
J-3	1.05	0.92

Table 2b. Chambers were placed immediately after clipping and the first sample drawn within four minutes. Samples were drawn at thirty second intervals over a period of 6.5 minutes. Fluxes are reported relative to control rates, Table 1. Rates were calculated from each four consecutive samples.

Time interval	Relative flux	
	O-1 (10 cm)	O-2 (<5 cm)
0.0–1.5 min	1.26	1.13
0.5–2.0	1.17	1.12
1.0–2.5	1.18	1.11
1.5–3.0	1.21	1.08
2.0–3.5	1.26	1.05
2.5–4.0	1.08	0.99
3.0–4.5	1.04	1.03
3.5–5.0	1.06	1.05
4.0–5.5	1.16	1.05
4.5–6.0	0.97	1.02
5.0–6.5	0.99	0.97

tance of leaves and stomata to gas transport and so the flux stays relatively constant. When plants are clipped at 10 cm, the internal methane is released causing an immediately higher flux. However, the gradient between the plant's internal gas spaces and the atmosphere quickly resets, keeping the flux relatively constant, and similar to control values. As the resistance to gas transport is reduced by clipping, the concentration gradient becomes less (i.e. the internal methane concentration becomes lower, while the atmospheric methane concentration remains constant), thus flux stays relatively constant.

We further hypothesize that methane release from *Carex* may be affected by the water level of the fen (how high the water rises on the plants) and by the height and maturity of the *Carex*. *Carex* leaves are bundled tightly at the base of the plant and surrounded by a thin sheath. The length of this

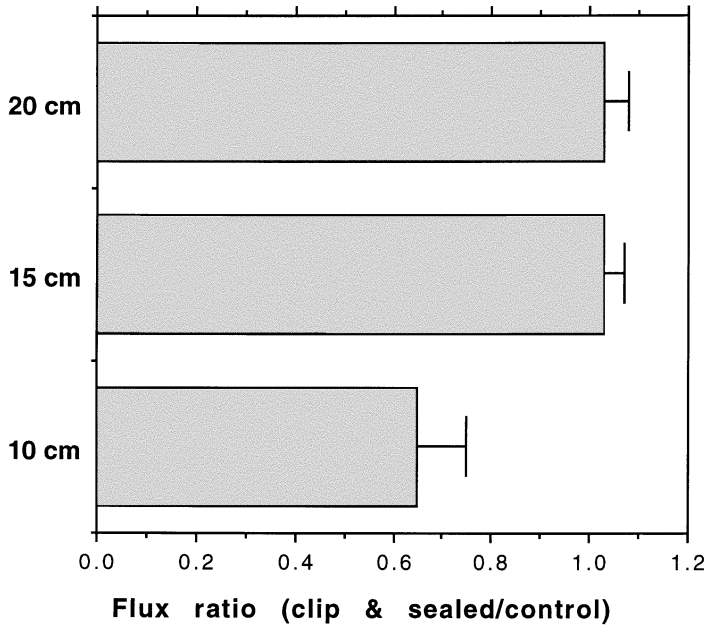

Figure 1. Methane emission rates from plants clipped at the indicated height and sealed with petroleum jelly approximately 90 minutes after clipping. Fluxes are reported relative to control rates given in Table 1. Error bars represent standard error.

sheathed bundle and how high the flood-water rises on it may affect the locus of methane emission.

Changing water levels can affect methane emission by covering the areas from which methane exits. If methane can exit from anywhere along the leaf blades, then variable water levels would have little effect on methane emission of clipped and sealed plants. The methane would simply exit from farther up the leaf blades. If, however, methane is emitted primarily from only the lower part of the plant, or where the leaves emerge from the sheath, then methane emissions of clipped and sealed plants would be affected by water level variations. There was some indication of a lessening of the effect of the clip and seal treatment at higher water levels, but there was an insufficient number of measurements to define a significant trend. Water level variations could also explain the discrepancy between our results and those of Schimel (1995).

In conclusion, our results differ from those of Schimel (1995) and indicate that at our Boreal study site, methane emission from *Carex* must be regulated for the most part belowground, by the transport of methane from porewaters to the internal gas spaces of the plant or at the root/shoot boundary. This result has been found in most other plant species as discussed by Schimel

(1995). It appears that control of CH_4 emission from *Carex* varies from site to site possibly due to variations in leaf sheath/bundle morphology. Clearly additional study of this regional variability is warranted.

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