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The Effects of Plant Species and Water Table Height on Methane Transport in Wetlands

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The Effects of Plant Species and Water Table Height on Methane Transport in Wetlands

By

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Introduction

Globally, wetlands are the single largest natural source of methane (CH_4) to the atmosphere (Denmann et al., 2007). CH_4 is a potent greenhouse gas with a global warming potential ~23x greater than that of carbon dioxide (Ramaswamy et al., 2001) and wetland emissions of CH_4 are likely to increase significantly along with rises in global surface temperatures and atmospheric CO_2 concentrations (Gedney et al., 2004; Shindell et al., 2004). With the potential for dangerous positive feedback between a changing climate and wetland CH_4 emissions, there is an urgent need to further develop our understanding of methane dynamics in wetlands.

In wetlands, methane is produced by a specialized group of bacteria called methanogens in a process known as methanogenesis. Methanogenesis generally occurs in the oxygen-free environments typical of wetland soils. Methane production in wetlands can be a complex and highly variable process that is dependent on a multitude of environmental factors including temperature, water table height, vegetation, and the availability of easily degradable organic matter needed to support populations of methanogenic bacteria (Segers 1998, Joabsson et al. 1999; Moore and Roulet 1993, Yagi et al. 1990). Within wetlands, vascular plants often act as a major conduit for transporting methane produced in wetland soils to the atmosphere (Whiting and Chanton 1992). In one high latitude wetland dominated by sedges, plants served as a pathway for an average of 75% of the total CH_4 flux to the atmosphere (Schimel 1995). Another study conducted by Van der Nat and Middleburg (1998) found that 85% of the net methane flux in two tidal wetlands could be attributed to CH_4 venting from *Scirpus* and *Phragmites*.

This paper describes two complementary experiments in which methane flux from individual wetland plants was monitored. The first experiment was designed to explore species-specific differences in methane transport and took place in a greenhouse on the University of

Nebraska - Lincoln's east campus during the summer of 2013. The second experiment took place the following summer at a restored wetland near Dayton, OH and investigated the effect of water table height on plant-mediated methane transport and provided supporting data for the first experiment regarding species-specific differences in methane transport.

Materials and Methods

Site Description

The field site for this study is a recently restored wetland located near the city of Dayton, Ohio USA. The presence of hydric soil lenses at the site indicates that it was likely a natural wetland in the past; however the land is believed to have been under agricultural production for about the last one hundred years. Restoration activities took place between August 2011 and March 2012 and included the construction of an earthen berm around the northeast corner of the site, removal of tile drainage, and native vegetation and tree planting. The site is generally divided into three sections called the submerged zone, the transition zone, and the upland zone.

Mesocosm Study Design

The mesocosm experiment took place in a climate controlled greenhouse on the University of Nebraska – Lincoln’s east campus. In July 2013, thirteen Swamp Milkweed seedlings and thirteen Water Plantain seedlings were collected from the field site near the edge of the submerged zone and fifteen twelve-inch long intact soil cores were collected from the same area of the field site in six-inch diameter PVC sleeves. Upon returning to the University of Nebraska – Lincoln, the plants were maintained in the greenhouse for ~40 days allowing them time to recover and adapt to the greenhouse environment. During this time the soil cores were kept in their PVC sleeves and placed in five gallon buckets. The buckets were covered with lids but were not kept air-tight. In August 2013, 5 specimens of each species were selected and transplanted into randomly selected soil cores. An attempt was made to select plants of similar size and health. Fully assembled systems consisted of a five gallon bucket holding a soil core containing Swamp Milkweed, Water Plantain, or an unvegetated control for a total of 15 mesocosms. On August 28th, 2013, all mesocosms were filled with water to 2cm above the soil surface for the duration of the experiment. Gas sampling began on August 30th and took place weekly until October 4$^{th.}$

Field Study Design

The field study took place in July 2014 and was designed to complement the results of the mesocosm experiment by addressing the hydrologic variability present in areas where Swamp Milkweed and Water Plantain coexist. A handheld GPS unit was used to map the transitional zone where the habitats of Swamp Milkweed and Water Plantain overlap. Within this zone two 15m x 15m study sites, each containing ~10 plants of each species, were selected. The "wet" site was characterized by standing water covering 95% of the soil surface and was located in the northern part of the transitional zone closest to the submerged zone. The "dry" site had no standing water and was located in the southern part of the transitional zone further away from the submerged zone. At each site, 5 specimens each of Swamp Milkweed and Water Plantain were selected with an effort made to choose plants of similar size and health. No controls were used in the field study due to a lack of unvegetated soil. Three-and-a-half-inch tall PVC collars were driven into the ground around each plant as a base for the acrylic chambers used to sample methane fluxes. The plants and soil were allowed one week to recover from the disturbance caused by placing the collars before sampling began. Gas sampling took place over three consecutive days from July 14th – 16th.

Chamber Construction

Both the mesocosm experiment and the field study used sampling chambers of a similar design consisting of a clear acrylic cylinder with a sampling port and vent tube at the top that could be placed over the outside of a PVC collar. In the mesocosm experiment, the acrylic cylinder was permanently sealed at the top and the open end was designed to fit tightly around the outside of the PVC sleeve that contained the intact soil core. The water in the mesocosm created an effective seal around the bottom of the chamber. In the field study, the acrylic cylinder had a removable clear acrylic top and was designed to fit around the outside of the PVC collar which remained in the ground around the target plant for the duration of the experiment. The seams at the top and bottom of the sampling chambers in field study were made air-tight with latex bands.

Gas Sampling

The same gas sampling method was used in both the mesocosm experiment and the field study. Immediately after the sampling chamber was placed over the target plant, a 10mL syringe connected to the sampling chamber by a three-way stopcock and 2.4mm tygon tubing was pumped 10 times to facilitate mixing of the air in the headspace. To obtain a sample, 20mL of chamber air was flushed through a 6mL vial and then a 10mL sample of chamber air was injected into the vial. Samples were collected every ten minutes over a period of 40 minutes. Gas samples were analyzed for methane concentration using a gas chromatograph equipped with a FID. Flux rates were determined using the equations found in Standard Soil Methods for Long-Term Ecological Research (Robertson 1999).

Results

Mesocosm Experiment

Mesocosms planted with Swamp Milkweed had significantly higher methane emissions than those containing Water Plantain or no plants (Figure 1). Swamp Milkweed averaged ~ 1.1 mg CH_4-C m^{-2} hr^{-1}, Water Plantain averaged ~0.1 mg CH_4-C m^{-2} hr^{-1}, and Control cores averaged ~0.1 mg CH_4-C m^{-2} hr^{-1}. There was not a correlation between plant growth (e.g., plant height, number of leaves) and CH_4 emission. Potential methane production (PMP) (Figure 2) was measured at the end of the experiment. Swamp Milkweed sediment averaged ~ 1.7 mg CH_4-C $hr^{-1}(g.w.)^{-1}$, Water Plantain sediment averaged ~ 0.8 mg CH_4-C $hr^{-1}(g.w.)^{-1}$, and Control core sediment averaged ~ 2.2 mg CH_4-C $hr^{-1}(g.w.)^{-1}$. PMP from the Swamp Milkweed cores was not significantly different from either the control cores or those planted with Water Plantain; however, the difference in PMP between the Plantain cores and the control cores was outside the range of standard error. While no conclusions can be drawn solely from this data, it is possible that the Water Plantain created an unfavorable habitat for methanogens through radial oxygen loss. This would explain the lower PMP compared to Milkweed or control cores, as well as the low CH_4 emissions from the Plantain.

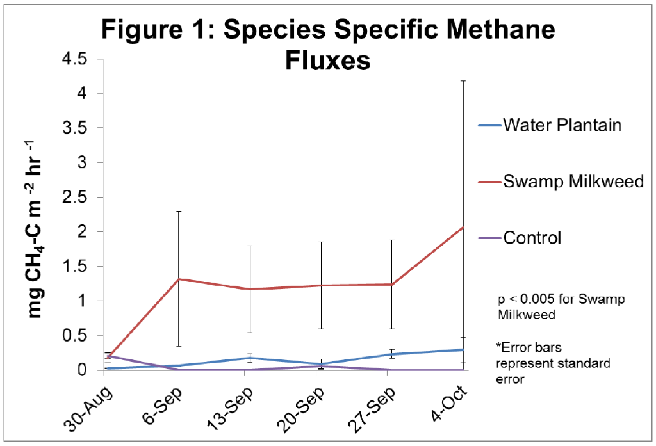

Fig. 1: Mesocosms planted with Swamp Milkweed demonstrated significantly higher CH_4 emission than either Water Plantain or Control mesocosms.

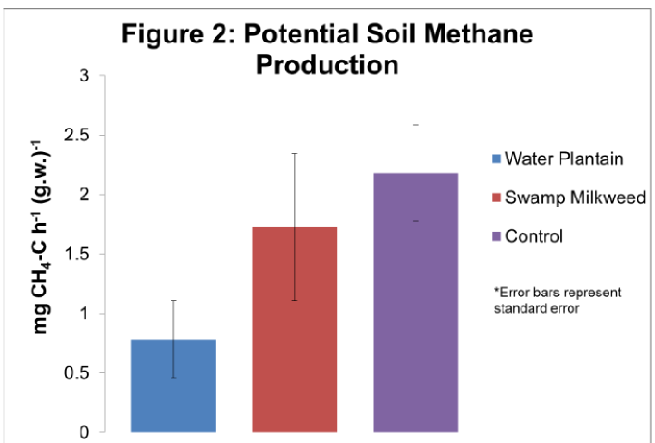

Fig. 2: Potential Methane Production (PMP) was measured at the end of the experiment. PMP from the Swamp Milkweed cores was not significantly different from either the control cores or those planted with Water Plantain, however, the difference in PMP between the Plantain cores and the control cores was outside the range of standard error.

Field Experiment

Over three days of sampling, the water table at the dry site was, on average, ~26cm below the soil surface. At the wet site, water levels were consistently at or above the soil surface (Table 1). Both Swamp Milkweed and Water Plantain were significant sources of CH_4 at the wet site; however CH_4 emission was not significantly different between the two species. At the dry site, Swamp Milkweed did not exhibit any significant CH_4 flux while Water Plantain acted as a net sink for CH_4. Water Plantain had an average flux of -0.2 mg CH_4-C m^{-2} hr^{-1} at the dry site and 0.8 mg CH_4-C m^{-2} hr^{-1} at the wet site (Figure 3). Swamp Milkweed had an average flux of ~0 mg CH_4-C m^{-2} hr^{-1} at the dry site and 0.9 mg CH_4-C m^{-2} hr^{-1} at the wet site (Figure 4). It is interesting to note that CH_4 emissions from Swamp Milkweed in the field are well within the range of emissions measured in the greenhouse, yet emissions from Water Plantain are much higher in the field compared to emissions observed in the mesocosm study.

Date	Dry Site	Wet Site
7/15/2014	20.8	0
7/16/2014	23.4	0
7/17/2014	33.2	0
Average=	25.8	0

Table 1: Depth (in cm) to water from soil surface.

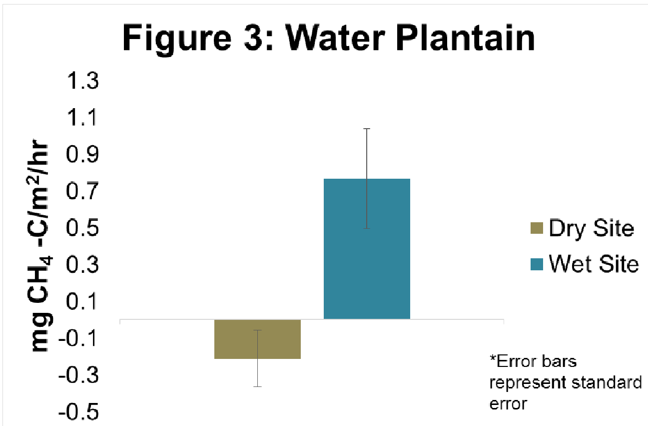

Fig. 3: Water Plantain was a source of CH_4 at the wet site and a sink for CH_4 at the dry site.

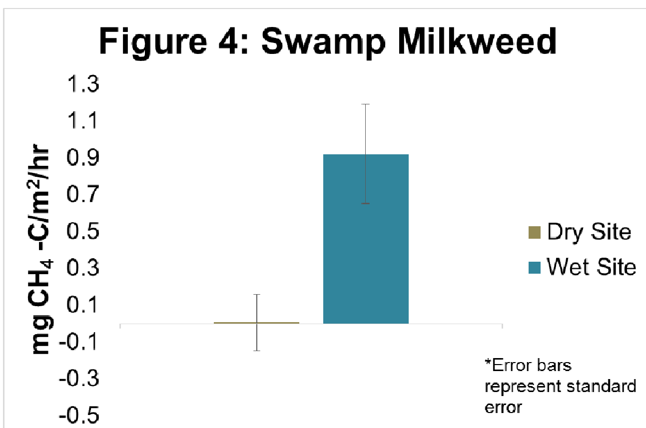

Fig. 4: Swamp Milkweed had a net flux of zero at the dry site, and was a source of CH_4 at the wet site.

Discussion

Although data from the mesocosm experiment showed that significantly more methane was emitted from Swamp Milkweed compared to Water Plantain, field data suggests that methane emissions from these two species may not be significantly different under saturated field conditions. Swamp Milkweed displayed nearly identical flux rates in the greenhouse and in the field when rooted in waterlogged soil; however, Water Plantain showed a much higher CH_4 flux under wet field conditions than in the mesocosm experiment. One possible explanation for this difference could be a phenomenon known as radial oxygen loss (ROL). ROL occurs when plants, either actively or passively, move oxygen from the atmosphere down to their roots for respiration. Some of this oxygen can leak into the rhizosphere creating an unfavorable habitat for methanogens, and thus, less methane production. Researchers have demonstrated significant variability in ROL both within and between some wetland plant species (Bezbaruah and Zhang 2004), but more data is needed to correlate CH_4 flux with ROL for this experiment.

Both species showed either net zero or negative flux rates when the water table was more than 20cm below the soil surface. Other experiments have reported similar results (Moore & Roulet 1993; Funk et al. 1994), and while no conclusions can be drawn from these two experiments regarding species-specific effects on methane transport, it does appear that methane flux is tightly correlated with water table height.

CH_4 dynamics in wetlands are highly complex and variable. Recognizing the hydrologic variability inherent in any wetland system and knowing how this heterogeneity affects plant-mediated methane transport is critical to developing our ability to accurately model methane flux through time and space for a given wetland.

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