Geoderma 315 (2018) 11–19

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Plot-scale spatial variability of methane, respiration, and net nitrogen mineralization in muck-soil wetlands across a land use gradient

Joseph B. Yavitt[a,*], James C. Burtis[a], Kurt A. Smemo[a,b], Maryann Welsch[a]

[a] Department of Natural Resources, Cornell University, Ithaca, NY 14853-3001, USA
[b] Department of Environmental Studies and Sciences, Skidmore College, Saratoga Springs, NY 12866, USA

ARTICLE INFO

Editor: M. Vepraskas

Keywords:
Agricultural impact
CH_4 production
Greenhouse gases
Geostatistics
Spatial heterogeneity
Wetland restoration

ABSTRACT

Spatial patterns of soil microbial activity are central to understanding greenhouse gas dynamics in wetlands. Because agriculture reduces spatial heterogeneity in soil properties, we examined the hypothesis that soil microbial activity in natural wetlands would show a high degree of spatial autocorrelation when distances between samples were small; however, in wetlands that were disturbed by agriculture these spatial patterns would occur across larger sampling distances or disappear due to homogenization. We examined the hypothesis via methane (CH_4) dynamics, respiration (as carbon dioxide (CO_2) production), and net nitrogen (N) mineralization in muck soils from a natural wetland dominated by sedges (*Carex lacustris*) either with or without grey alder (*Alnus rugosa*). The disturbed wetland had corn production or restoration with either reed canary grass (*Phalaris arundinacea*) or purple loosestrife (*Lythrum salicaria*) growing for about 10 years. Rates of anaerobic CH_4 production ranged from 0.1 to 12,370 nmol kg^{-1} s^{-1} with the largest rates in the natural wetland with alder; the Reed Canary Grass site exhibited extremely slow rates of CH_4 production. Oxic CH_4 consumption occurred only in soils from the natural wetland, with no activity in soils from the Corn site and the two Restored sites. Rates of CO_2 production ranged from −76 to 388 nmol kg^{-1} s^{-1} under anoxic conditions and from 0.1 to 402 nmol kg^{-1} s^{-1} under oxic conditions, with the highest rates in natural wetland surface soils. Despite broad spatial variation in rates across all sites, spatial patterns of CH_4, respiration, and net N mineralization displayed limited spatial dependence, with autocorrelation at distances < 8 m only in the Purple Loosestrife site. The results suggest that large sample sizes are needed to characterize the high variability present in microbial activity and greenhouse gases in muck soils, but explanation(s) for spatial variability remain elusive.

1. Introduction

To increase food supply, natural wetlands have been and will continue to be utilized for agriculture (Zedler, 2003). Because agriculture alters the soil via tillage, types of crops, irrigation, fertilization and other activities, microorganisms that inhabit soil are affected to varying extent (Thiele-Bruhn et al., 2012). The impacts have the potential to escalate and affect concentrations of atmospheric greenhouse gases given the crucial role that wetland microbes play as sources (and sinks) for several of the gases (Maljanen et al., 2004). Although there has been considerable research on wetland agriculture and gas dynamics (cf., Kasimir-Klemedtsson et al., 1997; Maljanen et al., 2010), a remaining challenge is knowing spatial variability and patterns of soil microbial activity, to make accurate estimates of greenhouse gas emissions, and to inform models that are being used for forecasting future emissions (Bridgham et al., 2013).

We start with the premise that muck soils in natural wetlands exhibit a moderate degree of spatial heterogeneity. Mucks are largely the reworked residue of plant and microbial litters (Sokołowska et al., 2005). Over time, the bulk soil supports less microbial activity. As a result, input of fresh leaf and root litter is key to maintaining the greatest rates of respiration and methane (CH_4) production (Walker et al., 2016), and thus differences in litter quality among different plant species are largely responsible for soil spatial heterogeneity (Williams and Yavitt, 2010; Yavitt and Williams, 2015). Unfortunately, the distribution of plant species alone cannot predict variation in soil microbial activity, as variations in water flux though the soil matrix influences redox as well as the distribution of reactants and products in microbial and chemical reactions that drive soil gas dynamics (Holden, 2005).

Agriculture affects microbial activity in muck soils in several ways, but the outcome is uncertain. For example, agricultural management includes periods when plant cover is removed, and thus surface muck is exposed to wind erosion (Zobeck et al., 2013). Consequently, over time,

* Corresponding author.
E-mail addresses: jby1@cornell.edu (J.B. Yavitt), ksmemo@Skidmore.edu (K.A. Smemo).

https://doi.org/10.1016/j.geoderma.2017.11.038
Received 21 June 2017; Received in revised form 12 November 2017; Accepted 26 November 2017

soil from deep in the profile becomes exposed at the surface (Fenstermacher et al., 2016). This should reduce variation in microbial activity as microorganisms must rely on a uniform poor-quality soil (Elder and Lal, 2008). Because tillage aerates the soil, this should decrease rates of anaerobic CH_4 production and anaerobic respiration. On the other hand, microbial activity could benefit, as the deep soil tends to be nitrogen (N) rich (Kuhry and Vitt, 1996), and the availability of N helps to fuel microbial activity.

Inevitably, crop production on muck soils declines (Stephens et al., 1984), paving the way for restoration in a post-agricultural landscape. Although wetland restoration has many facets (Moreno-Mateos et al., 2012), it is a slow process, taking years to decades (Yu et al., 2017). As a result, soil microbial activity is restored via fresh plant litter being added to the old surface. If this occurs in patches associated with individual plants (Callaway et al., 2003), microbial activity would again show spatial variability. Given these possible outcomes, we examined the hypothesis that agricultural disturbance in wetlands increases the distance at which spatial autocorrelation in soil microbial activity occurs relative to natural wetlands due to slow recovery upon wetland restoration.

We assessed these predictions related to spatial variability and dependence of CH_4, respiration (as carbon dioxide (CO_2) production), and net N mineralization for natural, agricultural, and post-agricultural restored wetlands. We focused on sapric muck soils. By collecting multiple soil samples in a geostatistical design (Trangmar et al., 1986), we were able to quantify spatial variability as well as spatial dependence, i.e., autocorrelation between adjacent samples as a function of distance. Overall, we found considerable variability in rates among samples taken within a specific site. However, we also found surprisingly limited spatial dependence regardless of wetland management.

2. Materials and methods

2.1. Study sites

Muck soils were collected from wetlands within 40 km of Ithaca in central New York State. Climate in the region is characterized by warm, humid summers and cold, snowy winters. The region has a mean annual temperature of 8.1 °C, with average temperatures of −4.8 °C in January and 20.4 °C in July. The total annual precipitation is 947 mm. The regional vegetation is mixed hardwood forest that has recovered from logging in the late 1800s and early 1900s (Stover and Marks, 1998).

The undisturbed (natural) wetland was Michigan Hollow (local name; 42°21′N, 76°28′W), a 15-ha sedge-dominated site. Wetlands like Michigan Hollow were common in the lowest parts of valleys, although many were drained for agriculture in the late 1800s. Michigan Hollow was not used for agriculture based on the uneven surface topography that would have been flattened by tillage. The central part of the wetland has a stand of lake sedge (*Carex lacustris* Willd.) that developed over an abandon beaver pond in the 1970s (Bernard and Macdonald, 1974). The edge of the wetland has sedge and scattered alder trees (*Alnus rugosa* L.). Soil is a sapric Carlisle muck (Euic, mesic Typic Haplosaprists), about 1 m deep, and very poorly drained. It has developed over a moraine of lake sediment (USDA – NRCS, 2016a).

The disturbed wetland, with on-going agriculture and wetland restoration, was Martens Tract (local name: 42°58 N, 76°42 W), a 99-ha site within the northern portion of the Montezuma Wildlife Management Area, near Savannah, New York, USA. Prior to agriculture, the natural wetland was likely a swamp forest dominated by red maple (*Acer rubrum* L.) with open sedge (*Carex* sp.) meadows (Vogelmann, 1972). The wetland was drained for agriculture (corn, potato farming) in the 1930s. As agricultural productivity declined, the practice was abandoned in part of the site in 1989. The water table fluctuates in response to seasonal flooding from snowmelt, followed by gradual water-level drawdown associated with the adjacent New York State Barge Canal and Seneca River. Soil is a sapric Martisco Muck, which is a fine-silty, mesic, Histic Humaquept (USDA – NRCS, 2016b). The agricultural field had corn (*Zea mays* L.) with added nutrient fertilizer. Closer to the river was a restored site dominated by purple loosestrife (*Lythrum salicaria* L.), whereas on the opposite side of the Corn site, furthest from the river, was a planted stand of reed canary grass (*Phalaris arundinacea* L.).

2.2. Experimental design and soil sampling

The overall experimental design examined natural versus agricultural disturbance. We could not consider three levels (natural, agriculture, restored) because the agriculture treatment was not replicated. Therefore, we combined agriculture and restored wetlands. Sampling in the field consisted of two 20 m × 20 m sampling plots in the natural wetland and three similar sized plots in the disturbed wetland. In Michigan Hollow, one plot was in the area dominated by lake sedge (hereafter: Sedge) and the other was in an area with sedge and alder (hereafter: Alder). In the Sedge site, the peat soil was deeper than in the other sites. In Martens Tract, one plot was in a cultivated area (hereafter: Corn) and two were in restored sites (hereafter: Purple loosestrife and Reed canary grass).

Each plot had five parallel rows of base points set 4 m apart from each other beginning 2 m from the plot edge. Along each row there were 8 base points set on a 2.5-m spacing beginning 2 m from the plot edge. At each of the base points we placed a 1-m short transect in a randomly assigned cardinal direction (N, NE, E, SE, S, SW, W, NW) and located three additional sample points at 0.1, 0.2, and 1 m away from the base point. This gave a total of 160-sampling points at spatial scales from 0.1 m to > 20 m.

At each sampling point, we collected a soil sample using a Russian style peat core (Aquatic Research Instruments, Inc., Hope, ID, USA) that had a 10-cm-diameter barrel. The cores sampled the top 0 to 0.15 m of the soil. In the Sedge site, the peat soil was deeper and we also collected a second soil sample from the 0.15 to 0.3-m depth interval. Samples were placed in plastic bags, sealed with no air space, and stored on ice for no > 2 h for transport to the laboratory.

On the same day as collection, a 40-g (wet weight) portion was transferred immediately to a 230-mL sterile mason jar. The portions were not sieved, although large roots were excluded. The jars were sealed with a lid that had a septum through it to facilitate sampling gas concentrations in the headspace. The jar headspace was evacuated and replaced with O_2-free N_2. This gas-exchange procedure was repeated three times to establish an anoxic environment. The jars were incubated at 17 °C without shaking. At approximately 12-h intervals for 2 days we sampled concentrations of gases in the headspace. To sample gases, a syringe filled with 10 mL of O_2-free N_2 was injected into the jar, pumped several times to mix gases thoroughly, before a 10 mL sample was taken with the same syringe. After the 2-day incubation, the jar headspace was evacuated and flushed with room air containing 100 μmol CH_4 mol^{-1} to establish oxic conditions for CH_4 consumption. The jar was incubated again at 17 °C without shaking. We sampled concentrations of CH_4 and CO_2 in the headspace at approximately 12-h intervals for 2 days as described above, except that room-air was added to maintain oxic conditions.

Gas samples were analyzed by gas chromatography (Perkin-Elmer; Sigma 3B, Wellesley, MA, USA) with a 3-m Porapak-Q column with 80/100 mesh (Alltech, Deerfield, IL, USA) maintained at 50 °C to separate gases. The gas chromatograph had a thermal conductivity detector for CO_2 and a flame ionization detector for CH_4. We estimated gas production rates from linear regression of concentrations versus time, and express rates per kilogram of dry soil.

Two separate portions per collection were extracted in 2 M KCl to determine concentrations of extractable ammonium (NH_4^+) and nitrate (NO_3^-). The extracts were stirred and allowed to settle for 24 h before being filtered and stored for < 1 week at 4 °C before analyses.