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Soil carbon dioxide fluxes in established switchgrass land managed for biomass production

D.K. Lee, J.J. Doolittle*, V.N. Owens

Plant Science Department, South Dakota State University, SNP215, Box 2140C, 1110 Rotunda Lane North, Brookings, SD 57007, USA

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Abstract

Switchgrass (*Panicum virgatum* L.) grown for biomass feedstock production has the potential to increase soil C sequestration, and soil CO_2 flux in grassland is an important component in the global C budget. The objectives of this study were to: (1) determine the effects of N fertilization and harvest frequency on soil CO_2 flux, soil microbial biomass carbon (SMBC), and potentially mineralizable carbon (PMC); and (2) evaluate the relationship of soil CO_2 flux with soil temperature, soil moisture, SMBC, and PMC. Two N rates (0 and 224 kg ha^{-1}) were applied as NH_4NO_3 and cattle (*Bos Taurus* L.) manure. Switchgrass was harvested every year at anthesis or alternate years at anthesis. The data were collected during growing season (May–October) 2001–2004 on switchgrass-dominated Conservation Reserve Program (CRP) land in east-central South Dakota, USA. Manure application increased soil CO_2 flux, SMBC, and PMC during the early portion of the growing season compared with the control, but NH_4NO_3 application did not affect soil CO_2 flux, SMBC, and PMC. However, seasonal variability of soil CO_2 flux was not related to SMBC and PMC. Estimated average soil CO_2 fluxes during the growing periods were 472, 488, and 706 g CO_2–C m^{-2} for control, NH_4NO_3–N, and manure-N plots, respectively. Switchgrass land with manure application emitted more CO_2, and approximately 45% of the C added with manure was respired to the atmosphere. Switchgrass harvested at anthesis decreased soil CO_2 flux during the latter part of the growing season, and flux was lower under every year harvest treatment than under alternate years harvest. Soil temperature was the most significant single variable to explain the variability in soil CO_2 flux. Soil water content was not a limiting factor in controlling seasonal CO_2 flux.

Keywords: Soil CO_2 flux; Switchgrass; Soil temperature; Soil carbon; Microbial biomass; N fertilization

1. Introduction

Grasslands covering large areas of the earth's surface (Shantz, 1954) and containing high soil organic carbon (SOC) (Carpenter-Boggs et al., 2003; Arshad et al., 2004; Bronson et al., 2004) are a potential sink or source of carbon. Switchgrass (*Panicum virgatum* L.) is a highly productive, perennial warm-season tallgrass in the North America prairie (Weaver, 1968). The high under- and above-ground biomass production make switchgrass a potentially valuable bioenergy crop with the potential to increase soil C sequestration (McLaughlin and Walsh, 1998; McLaughlin et al., 2002).

Soil respiration (e.g., carbon dioxide flux from soil surface) negatively influences soil C sequestration (Paustian et al., 2000). Soil CO_2 fluxes add almost 10% of the CO_2 concentration in the atmosphere each year, and the flux is 10 times larger than CO_2 released from fossil fuel burning (Raich and Tufekcioglu, 2000). Total global CO_2 emission from soils is recognized as one of the largest fluxes in the global C cycle, and small changes in the magnitude of soil CO_2 fluxes could have a large impact on CO_2 concentration in the atmosphere (Schlesinger and Andrews, 2000). Knowledge of the factors controlling soil C sequestration and soil CO_2 fluxes is essential for understanding the changing global C cycle.

Seasonal changes in soil CO_2 flux are affected by agronomic management practices such as fertilization, grazing, and clipping or harvesting (Bremer et al., 1998; Rochette and Gregorich, 1998; Ma et al., 2000a; Frank

*Corresponding author. Tel.: +1 605 688 8616; fax: +1 605 688 4452.
E-mail address: james.doolittle@sdstate.edu (J.J. Doolittle).

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et al., 2002). Agricultural management practices affect soil CO_2 flux by changing the soil environment (e.g., soil moisture, soil temperature, and C/N ratio of substances). These soil environmental characteristics can have a significant impact on soil microbial activity and the decomposition processes that transform plant-derived C to soil organic matter (SOM) and CO_2 (Franzluebbers et al., 1994, 1995b). Previous research has shown that soil CO_2 flux rates are strongly related to soil temperature and soil moisture conditions (Linn and Doran, 1984; Franzluebbers et al., 1995b; Boone et al., 1998; Davidson et al., 2000; Mielnick and Dugas, 2000; Frank et al., 2002).

Nitrogen fertilization and harvest management are important management practices for switchgrass biomass production (Sanderson et al., 1999; Muir et al., 2001; Vogel et al., 2002). Clipping or harvest management in grasslands reduces soil surface CO_2 flux by removal of photosynthetic tissue (Bremer et al., 1998; Ma et al., 2000a). Other studies have demonstrated that fertilization, particularly *N* addition, enhance SOC accumulation in annual cropping systems (Campbell et al., 1991; Paustian et al., 1997; Halvorson et al., 1999; Grant et al., 2001). However, Ma et al. (2000b) reported that *N* fertilizer and harvest frequency during switchgrass establishment did not change the SOC content over a 2–3 yr period. Using manure as a *N* source could replace mineral fertilizer in switchgrass biomass production systems, and minimize possible environmental problems which could normally occur in an annual cropping system (Sanderson et al., 2001). Janzen et al. (1998) reported that manure application had benefits such as C accumulation in soils and nutrient recycling. Manure application has been shown to have a significant positive impact on soil CO_2 flux in annual cropping systems (Gregorich et al., 1998; Rochette and Gregorich, 1998; Rochette et al., 2000, 2004). However, little is known about soil CO_2 fluxes and C sequestration as affected by N fertilization and harvest management in established monoculture grasslands, like some conservation reserve program (CRP) lands, managed for biomass feedstock production.

The goal of our research was to determine optimum management practices for converting switchgrass CRP land into bioenergy crop production, while maintaining soil quality gained from CRP management, and maximizing C sequestration. Objectives of this study were to: (1) determine the effects of N fertilization (using NH_4NO_3 or manure application) and harvest frequency (every year or alternate years) on seasonal changes in soil CO_2 flux, soil microbial biomass C (SMBC), and potentially mineralizable C (PMC); and to (2) evaluate the relationships between soil CO_2 flux and soil temperature, soil water content, SMBC, and PMC.

2. Materials and methods

This study was conducted from May 2001 to October 2004 on CRP land located in Moody County, SD (96°41′W longitude and 44°10′N latitude). Average (30-y) annual temperature is 6.3 °C and average annual precipitation is 602 mm (Todey, 2005). Average daily temperature during the growing season (May–October) is 10.5 °C and maximum daily temperature is 22.2 °C in July. Monthly precipitation during the growing season of 2001–2004 is shown in Fig. 1. Average precipitation and soil moisture content at a depth of 0–10 cm during the growing season from 2001 through 2004 was 65% of annual precipitation and 0.33 cm cm^{-3}, respectively. The soil at the site is an Egan silty clay loam (fine-silty, mixed, superactive, mesic Udic Haplustolls) and selected soil chemical and physical properties are shown in Table 1. Switchgrass was planted at this site in 1975 and has been enrolled in CRP since 1990. Detailed records for years in which these stands were harvested for hay (emergency CRP release) or burned were unavailable; however, to our knowledge none of the herbage was routinely removed during the life of stand. Existing aboveground switchgrass biomass was mowed at a 10–15 cm height and removed from the site in the fall of 2000. Treatments were initiated in the spring of 2001. Phosphorus (2.5 g m^{-2}) was broadcast across the entire experimental area during spring 2001 to bring soil fertility to recommendation (Brejda, 2000). The experimental design consisted of a 3 × 2 factorial arrangement of treatments (fertility × harvest frequency) within a rando-

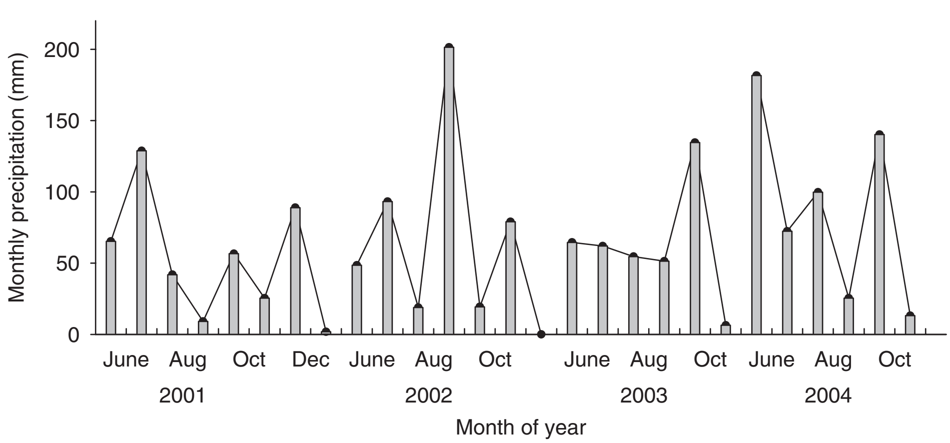

Fig. 1. Monthly precipitation during the growing season from 2001 through 2004 on switchgrass land Moody County, South Dakota (Todey, 2005).