Agriculture, Ecosystems and Environment 134 (2009) 234–242

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Impact of reduced tillage and cover cropping on the greenhouse gas budget of a maize/soybean rotation ecosystem

T.K. Bavin [a,*], T.J. Griffis [a], J.M. Baker [b], R.T. Venterea [b]

[a] Department of Soil, Water, and Climate, University of Minnesota-Twin Cities, 439 Borlaug Hall, 1991 Upper Buford Circle, St. Paul, MN 55108, USA
[b] USDA-ARS, Department of Soil, Water, and Climate, University of Minnesota-Twin Cities, 439 Borlaug Hall, 1991 Upper Buford Circle, St. Paul, MN 55108, USA

ARTICLE INFO

Article history:
Received 5 March 2009
Received in revised form 10 July 2009
Accepted 14 July 2009
Available online 14 August 2009

Keywords:
Reduced tillage
Cover cropping
Ecosystem respiration
Soil respiration
Nitrous oxide fluxes
Methane fluxes

ABSTRACT

Agricultural ecosystems have been viewed with the potential to sequester atmospheric carbon dioxide (CO_2) by increasing soil organic carbon (SOC) through reduced tillage and cover cropping practices. There remains considerable uncertainty, however, regarding the carbon (C) sink/source potential of these systems and few studies have examined C dynamics in conjunction with other important greenhouse gases. The objective of this study was to evaluate the impact of an alternative management scenario (reduced tillage and cover cropping) on ecosystem respiration (R_E) and nitrous oxide (N_2O) and methane (CH_4) fluxes in a maize (*Zea mays* L.)/soybean (*Glycine max* L.) rotation ecosystem in east-central Minnesota, United States. The control treatment was managed using fall tillage with a chisel plow in combination with a tandem disk, and the experimental treatment was managed using strip tillage and a winter rye (*Secal cereale*) cover crop. Over the two-year study period (2004–2005), cumulative R_E was 222.7 g C m^{-2} higher in the alternatively managed treatment as a result of increased decomposition of the cover crop residue. N_2O fluxes were similar in both treatments during the 2004 growing season and were 100.1 mg N m^{-2} higher in the conventional treatment during the 2005 growing season after nitrogen (N) fertilization. N fertilization and fertilizer type were the dominant factors controlling N_2O fluxes in both treatments. CH_4 fluxes were negligible in both treatments and often below the detection limit. Cumulative growing season N_2O losses in the control and experimental treatments, which totalled 38.9 ± 3.1 and 26.1 ± 1.7 g C m^{-2} when converted to CO_2 equivalents, were comparable to the annual estimates of net ecosystem CO_2 exchange in both treatments. This study further supports that N_2O losses are an important component of the total greenhouse gas budget of agroecosystems. It also suggests that spring cover cropping, without residue removal, has limited C sequestration potential. The results from this study, however, may not necessarily represent equilibrium conditions in the experimental treatment. Rather, they are a measure of the transient response of the system after tillage conversion and cover crop addition. It is expected that the soil microbes will continue to adjust to the reduction in tillage and increased C inputs. Therefore, continued, long-term monitoring is needed to confirm whether the results are representative of equilibrium conditions.

1. Introduction

The intensive management of agricultural soils has resulted in the depletion of soil carbon (C) stocks and has increased atmospheric carbon dioxide (CO_2) levels. Reversing this trend by increasing the C sink potential of agricultural soils could help to offset some of the rise in atmospheric CO_2 concentrations. It has been suggested that conservation tillage (Lal and Bruce, 1999; Lal, 2003, 2004) and cover cropping during fallow periods (Baker and Griffis, 2005) could increase the amount of C sequestered in agricultural soils. A review of soil organic carbon (SOC) studies from West and Post (2002) concluded that conservation tillage could, on average, sequester 0.60 ± 0.14 t C ha^{-1} y^{-1}. Several recently published studies, however, have found little to no difference in SOC in conventional and reduced-tillage systems (Dolan et al., 2006; Venterea et al., 2006; Baker et al., 2007; Blanco-Canqui and Lal, 2008).

While SOC measurements allow researchers to estimate soil C gains and losses, they provide little information about the dynamic exchange processes. If management strategies are to be improved to increase C uptake, then a comprehensive understanding of how C cycles through agroecosystems needs to be developed. In addition to SOC measurements, soil respiration (R_S), ecosystem

* Corresponding author at: Dept. of Soil, Water, and Climate University of Minnesota – Twin Cities 1991 Upper Buford Circle Soil Science Room 331 St. Paul, MN 55108, USA. Tel.: +1 651 587 2807.
E-mail address: bavi0001@umn.edu (T.K. Bavin).

0167-8809/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2009.07.005

respiration (R_E), and net ecosystem CO_2 exchange (F_N) measurements are needed to examine how C is cycled between terrestrial ecosystems and the atmosphere. Recent observations of F_N in conservation tillage maize/soybean systems have shown little or no C gains (Baker and Griffis, 2005; Verma et al., 2005). In contrast, Hollinger et al. (2005) reported a net C gain of 90 g m^{-2} y^{-1} in a conservation tillage maize/soybean system. However, Dobermann et al. (2006) have argued that weed growth could have been the main cause of the increased C sequestration. A better understanding of how R_S and R_E contribute to C losses in agricultural systems would help to explain the large variation observed in budget estimates and could provide insight regarding how to better manage these pools for C sequestration.

While much attention has focused on understanding how conservation tillage will impact C sequestration, understanding the potential impact on nitrous oxide (N_2O) and methane (CH_4) emissions is also critical given that the global warming potential (i.e. how much a given mass of gas contributes to global warming) of N_2O and CH_4 are 296 and 23 times larger than that of CO_2 over a 100 year period, respectively (Ramuswamy et al., 2001). A number of studies have reported that conservation tillage systems have higher N_2O emissions when compared to conventionally tilled systems (Robertson et al., 2000; Mummey et al., 1998; Ball et al., 1999). Interpreting the impact of tillage on N_2O emissions, however, can be complicated by nitrogen (N) fertilization. Venterea et al. (2005, 2009) have shown that fertilizer type can have a large impact on N_2O emissions. Similarly, McSwiney and Robertson (2005) and Wagner-Riddle et al. (2007) have shown that fertilizer application rates also influence N_2O fluxes and can potentially be reduced by using best management practices (BMPs). Therefore, understanding the connection between N fertilization and tillage is critical when investigating the impact of tillage on N_2O losses.

It has also been argued that conservation tillage may increase CH_4 oxidation rates as a result of improved soil structure, which allows for greater rates of CH_4 diffusion into the soil profile (Smith et al., 2001). Current research, however, has found no significant difference in CH_4 uptake/loss between conventional and conservation tillage systems (Venterea et al., 2005; Robertson et al., 2000).

The goal of this research, therefore, was to improve the understanding of how C cycles through maize/soybean agroecosystems in east-central Minnesota, United States, and to evaluate whether an alternative management strategy (reduced tillage and cover cropping) has a significant impact on CO_2, N_2O, and CH_4 losses. Two key questions were addressed: (1) are R_S, R_E, N_2O and CH_4 fluxes different in a conventionally tilled and reduced-tillage system with spring cover cropping? and (2) what factors are responsible for the differences in R_E, R_S, N_2O, and CH_4 fluxes?

2. Materials and methods

2.1. Site description

Research was conducted in two adjacent fields at the University of Minnesota Rosemount Research and Outreach Center, MN (44°45′ N, 93°04′ W). The soils at the site are a Waukegan silt loam (fine-silty over skeletal mixed, superactive mesic Typic Hapludoll) consisting of a silt loam surface layer 0.5–1.8 m thick overlying a layer of sand and gravel >20 m thick. The FAO classification is Chernozem. The field site has been under cultivation for the past 125 years; however, prior to cultivation, it consisted of an upland dry prairie (Griffis et al., 2005). The two fields are directly adjacent to each other with a road separating them. Both fields were managed using a maize *(Zea mays* L.)/soybean (*Glycine max* L.) rotation, with soybeans planted in 2004 and maize planted in 2005. The southernmost field was tilled conventionally using fall tillage with a chisel plow used in combination with a tandem disk and was designated as the control treatment. The northern field was tilled using an alternative technique consisting of strip tillage and a cover crop of winter rye (*Secale cereale*) and was designated as the experimental treatment. Tillage intensity in the experimental treatment was reduced in 2001 when chisel plowing was replaced with strip tillage and the cover crop was changed from oats (*Avena sativa*) to winter rye in 2003. The soybeans were planted into the rye and the rye was killed with a herbicide approximately ten days later. At the beginning of the growing season in 2005, anhydrous ammonia was knifed into the soil in the control treatment and urea was broadcast on the experimental treatment at a rate of 112 kg actual N per hectare.

2.2. Micrometeorological flux measurements

F_N was measured in both fields using the eddy covariance (EC) approach. The EC system consisted of a 10 m mast instrumented with a 3D sonic anemometer-thermometer (CSAT3, Campbell Scientific Inc., Logan, UT) and an open-path infrared gas analyzer (Li7500, LiCor, Lincoln, NE) located in the center of both the control and experimental treatments. Raw signals (sonic temperature, wind fluctuations, water vapor, and carbon dioxide concentrations) were recorded at 10 Hz and the mean covariances were computed over 30 min intervals.

Ancillary measurements at each tower included: (1) net radiation (NR Lite Net Radiometer, Kipp & Zonen, Netherlands; also computed by summing the downwelling and upwelling short and longwave radiation components); (2) soil heat flux and soil temperature; (3) soil water content; and (4) leaf area index (LAI). Downwelling and upwelling long and short wave radiation were measured using up and downward-facing pyranometers and pyrgeometers, respectively (Eppley Laboratories, Newport, RI). Soil heat fluxes were measured using soil heat flux plates (Huskeflux, the Netherlands and REBS, Seattle, WA) installed at 10 cm and corrected caliorimetrically. Soil temperature and volumetric water content were measured at 8 depths ranging from 0.05 to 1 m using copper-constantan thermocouples (Omega Engineering, Stamford, CT) and time-domain reflectometry (TDR 100, Campbell Scientific, Logan, UT). Soil and radiation measurements were made at 30 or 60 s intervals and averaged over 30 min. Soil water content measurements were made every 30 min. A more detailed site description can be found in Baker and Griffis (2005).

A quality control procedure similar to that used by the CarboEurope community was used to assess all half-hourly fluxes. Three parameters were used to evaluate the fluxes: (1) the integral turbulence parameter (α); (2) the stationarity parameter (β); and (3) a coordinate deviation parameter (ε) (Foken and Wichura, 1996; Thomas and Foken, 2002; Gockede et al., 2004; Foken et al., 2004). A quality parameter was also added in which fluxes were flagged if over 10% of the 10 Hz measurements were deemed to be outliers. These quality control criteria were then used to assign individual quality flags and were grouped to get a final quality flag for assessing the fluxes (Foken et al., 2004). Fluxes with final flag values between 1 and 3 were considered of high quality and used for further analysis in this study.

Nighttime fluxes were first screened using a box-plot filter that used a centered window to examine 10, non-overlapping, half-hourly time periods. Fluxes within the 10-point window that were greater than 25% of the inner quartile range were removed assuming that EC measurements usually contain approximately 20% random error (Wilson et al., 2002; Massman and Lee, 2002). The box-plot filter was used in addition to the CarboEurope method because a few outliers still remained after applying the methodology.