Agriculture, Ecosystems and Environment 172 (2013) 35–41

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

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

Nitrogen fertilization effects on pasture photosynthesis, respiration, and ecosystem carbon content

R. Howard Skinner*

USDA-ARS, Pasture Systems and Watershed Management Research Unit, Building 3702, Curtin Road, University Park, PA 16802, USA

ARTICLE INFO

Article history:
Received 3 October 2012
Received in revised form 4 April 2013
Accepted 11 April 2013

Keywords:
Ecosystem respiration
Gross primary productivity
Pastures
N fertilization
Eddy covariance

ABSTRACT

Some studies have shown that increasing N fertility can increase soil C sequestration, whereas others suggest that N fertilization has no effect on sequestration. Increasing N fertilization typically increases annual photosynthetic C uptake (gross primary productivity or GPP) and forage yield but also increases ecosystem respiration (Re), such that net ecosystem exchange (NEE) can increase, remain unchanged, or decrease depending on the relative impact of the fertilizer application on these two competing processes. Nitrogen fertilization also affects other inputs and outputs to the systems such as forage removal and manure deposition. A nine-year study monitoring carbon dioxide flux at two pasture sites examined in detail the effects of N fertilization rate on NEE, GPP and Re under a range of environmental conditions. High N fertility (>200 kg N ha^{-1} yr^{-1}) increased yield over a low N fertility site (<100 kg N ha^{-1} yr^{-1}) by 38%. As expected, forage yield was significantly correlated with GPP (P = 0.01), but also with Re (P = 0.003). No significant relationship existed between NEE and either GPP or Re. A nearly 1:1 relationship existed between GPP and Re over a wide range of environmental and fertilizer input conditions. For the high-N pasture, the net loss of C from the ecosystem increased under increased N fertilization because of the greater forage yield and subsequent removal of harvested C. Increasing N fertilizer application rate did not increase soil C sequestration in this temperate pasture system.

Published by Elsevier B.V.

1. Introduction

Grasslands have the potential to help mitigate global climate change by sequestering significant amounts of C in the soil, thereby reducing atmospheric CO_2 concentrations. Estimates of C sequestration following conversion of cropland to grassland range from 0.11 to 3.04 Mg C ha^{-1} yr^{-1} (Conant et al., 2001). Overall, mean C sequestration rates for temperate grasslands in North America and Europe are typically positive but small (Jones and Donnelly, 2004; Janssens et al., 2005). However, my previous research has shown that two mature pastures in the northeastern US with more than 40 years of perennial cover and managed with limited fertilizer inputs (0–100 kg N ha^{-1} yr^{-1}) were a net source of CO_2 to the atmosphere (Skinner, 2008). Others have suggested that the C sequestration potential of soils managed to promote C accumulation tends to saturate over time as these ecosystems reach equilibrium between C uptake and loss (Smith, 2004).

Studies of European grasslands suggest that intensively managed grasslands with high fertilizer inputs sequester more C than low input, extensive pastures (Soussana et al., 2007). Increasing N fertility has also been shown to increase soil C sequestration under switchgrass (Ma et al., 2000; Lee et al., 2007), and in a literature review, Schnabel et al. (2001) concluded that fertilizing pasture soils with low inherent fertility generally increased productivity and soil organic C. Similarly, Conant et al. (2001) suggested that a number of management practices, including fertilization, should promote C sequestration in grasslands.

In contrast with grasslands, many studies of cropping systems have found that N fertilization has no effect on C sequestration (Van Kessel et al., 2006; Khan et al., 2007; Coulter et al., 2009; Poirier et al., 2009). The lack of sequestration could generally be explained by the stimulatory effects of N on respiration rates (Dijkstra et al., 2006) and subsequent increased decomposition of crop residues (Khan et al., 2007). For example, in an experiment with cheatgrass (*Bromus tectorum*, L.), N fertilization almost doubled total plant biomass, but also caused a similar increase in soil respiration (Verburg et al., 2004). Peichl et al. (2011) also observed increased gross primary productivity (GPP) and ecosystem respiration (Re) with increased N fertilizer application in Irish pasture systems, such that NEE did not change. Consequently, the net effect of N fertilization on C sequestration is a function of the relative change in the magnitude of C inputs vs. outputs. Modeling work by van den Pol-van Dasselaar and Lantinga (1995) suggested that N applications in the range of 100–250 kg N ha^{-1} yr^{-1} provided the best balance between uptake and decomposition leading to the greatest increase in C sequestration. In agreement with the

* Tel.: +1 814 863 8758; fax: +1 814 863 0935.
E-mail address: howard.skinner@ars.usda.gov

0167-8809/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.agee.2013.04.005

modeling results, Soussana et al. (2004) suggested that enhanced C sequestration would result from reduced intensification of highly fertilized grasslands and from moderate intensification of nutrient poor grasslands.

A close relationship usually exists between ecosystem C input and output. Annual GPP was highly correlated with annual Re with a slope near unity for intensively managed humid-temperate grasslands in Ireland (Peichl et al., 2011). They also found significant seasonal correlations between GPP and Re for spring, summer, and autumn. Peaks in GPP were often accompanied by simultaneous or slightly delayed peaks in Re, which were interpreted as an indication of dependence of Re on GPP. Both shading and clipping of plant canopies can cause a reduction in soil respiration (Craine et al., 1999), and Bahn et al. (2008) concluded that assimilate supply affected soil respiration on daily to annual timescales. They later found a diurnal signature in the influence of GPP on soil respiration (Bahn et al., 2009).

Because the two pastures examined in this study had traditionally received relatively low annual N applications, and had previously been found over a number of years to be net sources of CO_2 to the atmosphere, a study was initiated to determine if increasing N fertility at one of the sites could cause it to switch from a C source to sink. In addition, effects of N fertilizer application on GPP and Re were quantified to identify potential mechanisms that might be responsible for any observed N effects on C sequestration.

2. Materials and methods

2.1. Site description and management

The study was conducted on two pastures (designated high-N and low-N as explained below) at the Pennsylvania State University Haller Research Farm located about 10 km northeast of State College, Pennsylvania (40.9° N; 77.8° W). The soil was a Hublersburg silt loam (Typic Hapludault) with 3–8% slopes. When measured in 2004, soil C content in the top 0–20 cm was 2.28 and 2.07% in the high- and low-N pastures, respectively. A complete description of the study site can be found in Skinner (2008). In short, eddy covariance systems were installed on two permanent pastures that had been traditionally cut once in the spring for hay then rotationally grazed three to four times per year by beef cattle (*Bos taurus* L.). Both pastures had been sown to perennial forage species since the university purchased the farm in 1968. Carbon dioxide fluxes were monitored from 1 January 2003 to 31 December 2011.

Management decisions regarding the timing and method of harvests were controlled by the Penn State University, Dairy and Animal Science Department, and varied from year to year based on pasture growth, weather constraints, equipment availability, and demands for the cattle by other research projects. During the experimental years, pastures were harvested three to six times per year between mid-May and mid-November. Pastures were subdivided into approximately 0.5 ha paddocks and each paddock was typically grazed for 3–4 d by 10–25 mixed-breed cows, cow/calf pairs, or heifers depending on the amount of available forage and availability of cows. Pastures were periodically cut for hay when forage availability on the farm exceeded demand by the grazing animals. Hay harvests most often occurred in May and June when biomass yield was high. Averaged across years, 80% of harvested biomass was removed by grazing in the high-N pasture, whereas, 36% was removed by grazing animals in the low-N pasture which was more frequently cut for hay.

Nitrogen fertilizer treatments are summarized in Table 1. For the first five years of the study, a grass-based pasture that would eventually receive the high N fertility treatment after 2008, typically received N fertilizer as urea twice each year in the spring and fall at an average annual rate of 83 kg N ha^{-1} yr^{-1}. The legume content of this pasture averaged less than 5% of harvested biomass. The other, low-N, pasture was initially dominated by alfalfa which accounted for about 50% of aboveground cover in 2003 and thus was not fertilized in 2003 and 2004. No attempt was made to quantify the amount of N fixed by the alfalfa. By 2005, the amount of alfalfa had been reduced to about 5% of harvested biomass and the pasture was dominated by cool-season grasses. The amount of alfalfa in the low-N pasture recovered somewhat in 2007 and averaged about 20% of biomass for the remainder of the study. The low-N pasture received spring (2005 and 2007) or spring and fall (2006) fertilizer applications, but at lower rates than the high-N pasture.

Table 1
Summary of N fertilization treatments for two pastures in central Pennsylvania. Application dates are shown in parentheses.

Year	High-N pasture	Low-N pasture
kg N ha^{-1}		
2003	90 (4/22, 9/1)	0
2004	90 (4/20, 8/20)	0
2005	101 (4/14, 8/29)	56 (4/14)
2006	90 (3/31, 5/25, 8/31)	56 (4/12, 9/7)
2007	45 (4/26, 8/16)	20 (4/23)
Mean	83	26
2008	250 (6/4, 9/9)	250 (6/4, 9/9)
2009	208 (4/14, 6/18, 8/27)	29 (8/11)
2010	203 (4/7, 5/24, 8/23)	28 (8/16)
2011	208 (5/10, 8/13, 9/2)	34 (9/14)
Mean	217	85

By 2007, it was clear that productivity was low on both pastures, and that they were acting as net sources of CO_2 to the atmosphere (Skinner, 2008). At that time a decision was made to increase N fertilizer rate on one of the pastures to determine if increased fertility could change the pasture from a C source to a sink. From 2008 through 2011, the high-N pasture received between 203 and 250 kg N ha^{-1}, generally split among three applications with the exception of 2008 when only two applications occurred. Due to a misunderstanding with the farm manager, the low-N pasture also received 250 kg N ha^{-1} in 2008. From 2009 to 2011, the low-N pasture received an average of 30 kg N ha^{-1} yr^{-1}, applied in the fall. As in the initial 5-year period of the study, exact fertilizer rates and timing of application were determined by the farm manager.

2.2. Flux measurements

Pasture-scale CO_2 fluxes were quantified using a Campbell Scientific[1] eddy covariance CO_2 flux system featuring a LI-7500 open path CO_2/H_2O analyzer and CSAT3 3-D sonic anemometer (Campbell Scientific Inc., Logan, UT). This system uses micrometeorological techniques to monitor biosphere–atmosphere exchanges of CO_2 by correlating fluctuations in vertical wind velocity with CO_2 density. Data were collected continuously at 10 Hz and averaged over 20-min intervals. The open-path CO_2/H_2O analyzer and CSAT3 3-D sonic anemometer were placed at a height of 1.75 m above the soil surface in the center of 7 ha (high-N) and 9 ha (low-N) pastures, providing >200 m fetch in the direction of the prevailing winds. Neighboring pastures located in directions other than those of the prevailing winds also contained cool-season grasses so that features such as roads, tree lines, and farm buildings that could interfere with obtaining good estimates of pasture CO_2 flux were

[1] Mention of a specific brand name is for identification purposes only and does not constitute endorsement by the USDA-ARS at the exclusion of other appropriate sources.