Comparison of different approaches for estimating carbon budgets in a managed grassland in Hokkaido, Japan

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Abstract

We estimated carbon (C) budgets of the fertilizer and manure plots established in a grassland of reed canary grass for two years in Southern Hokkaido, Japan. In the manure plot, beef cattle manure was applied at a rate of 43 - 44 Mg fresh matter (5.8 - 7.7 MgC/ha/yr), and a supplement of chemical fertilizer was also added to equalize the application rate of mineral nitrogen to that of the fertilizer plots. The harvesting of grass was carried out twice a year. The net ecosystem production (NEP) was estimated by biometric and micrometeorological approaches. The net biome production (NBP) was estimated as NEP + Manure application - Harvest. In addition, we measured changes in soil organic carbon (SOC) within the top 30 cm layer. All approaches showed that the manure application can increase C sequestration and is necessary to prevent the loss of C from the grassland. However, the meteorological NBP (-2.2 and 3.0 MgC/ha/yr in the fertilizer and manure plots, respectively) was higher than biometric NBP (-3.6 and 0.3 MgC/ha/yr) and changes in SOC (-4.3 and 1.3 MgC/ha/yr). This suggests that the meteorological method could possibly overestimate the NEP.

Key Words

Net ecosystem production, net biome production, soil organic carbon sequestration, grassland.

Introduction

Carbon dioxide (CO_2) concentrations in the atmosphere have increased at an annual rate of 1.9 ppmv from 1995 to 2005 (IPCC 2007). An understanding of the carbon (C) cycle through soil-plant ecosystems is essential to predict the effect of an increase in CO_2 on the earth. The net gain or loss of C from an ecosystem is defined as the net ecosystem production (NEP). NEP is estimated as the gain in C by plant (net primary production, NPP) minus C loss by heterotrophic respiration (RH). Recently, micrometeorological methods (e.g. eddy covariance, Bowen ratio/energy balance method) have been widely applied for measuring the NEP without any disturbance. However, the measurement using only meteorological methods is not sufficient to explain seasonal and yearly changes in C budgets or to forecast the change in the source or sink of C. A comparison with different approaches such as biometric method and direct soil sampling is considered to be helpful in estimating annual flux and understanding C stock and flow. The C budget in managed grasslands includes C input through manure application and C output through crop harvest and grazing as well as NEP. This budget, taking abiotic process into account, is defined as the net biome production (NBP), and is thought to be equal to changes in SOC (Schulze *et al.* 2000). In the non-grazing grasslands, the NBP is estimated using the following equation.

$$\text{NBP} = \text{NEP} + \text{Manure application} - \text{Harvest} \quad (1)$$

In Japan, livestock husbandry has been depending on enormous amounts of imported feed, and livestock excreta are in surplus. Therefore manure should be efficiently and appropriately returned to crop fields for an environmental-friendly agro-ecosystem, and it is expected to sequester the applied manure C in soils (Janzen *et al*. 1998). The objectives of this study were therefore to compare different approaches for estimating carbon budgets in a managed grassland, and to clarify the effect of manure application on C budgets.

Materials and methods

Study site

This study was conducted for two years in a managed grassland located on the Shizunai Experimental Livestock Farm, Field Science Center for the Northern Biosphere of Hokkaido University in Southern Hokkaido, Japan (42°26'N, 142°29'E). The mean annual precipitation is approximately 1365 mm and the mean annual temperature is 7.9 ˚C. The dominant species of the grassland are reed canarygrass (Phalaris arundinacea L.) and meadow foxtail (Alopecurus pratensis L.). The soil is classified as Thaptic Melanudands (Soil Survey Staff 2006).

Two experimental plots were set up on the study site, one for application of farmyard manure (manure plot), and the other for chemical fertilizer (fertilizer plot). The application rate of manure was 43 - 44 Mg fresh matter (5.8 - 7.7 MgC/ha/yr). At the manure plot, supplement of chemical fertilizer was also given to equalize the application rate of mineral nitrogen to that of fertilizer plot (164 - 184 kgN/ha/yr). The harvesting of grass was carried out twice a year; in late June and in mid August.

Biometric approach
The above-ground and below-ground biomass was measured by using a harvest method to estimate the NPP. Heterotrophic respiration from soil organic matter (RHs), dead plants (RHl) and manure (RHm) was measured by using the static closed chamber method. The biometric NEP was estimated using the following equation (Shimizu *et al*. 2009).

Biometric NEP = ANPP + BNPP - RHs - RHl - RHm (2)

The biometric NBP was estimated as the C budget of a field taking into account the harvest and manure applications as equation (1).

Micro-meteorological approach
The net ecosystem CO_2 exchange was measured continuously by an eddy-covariance method to estimate the meteorological NEP. The eddy covariance system, which consisted of a sonic anemometer (CSAT3, Campbell Scientific) and an open-path infrared gas analyzer (LI-7500, LI-COR), was installed at each plot with instruments to measure other meteorological variables. The eddy covariance data were post-processed on half-hourly basis following general procedures including half-hourly block averaging, the planar fit coordinate rotation (Wilczak *et al*. 2001), corrections for high-frequency spectral losses due to path-length averaging and horizontal separation between the sonic anemometer and the gas analyzer and for low-frequency spectral losses due to the block averaging (Massman 2000; 2001), corrections to sensible heat flux due to water vapour flux, and the density correction (WPL correction) (Webb *et al*. 1980). As quality control of the eddy covariance data, 10-Hz raw data were examined by quality control tests proposed by Vickers and Mahrt (1997). We did not apply u*-correction. Missing and rejected half-hourly CO_2 fluxes were filled by non-linear gap filling method. The meteorological NBP was estimated using equation (1).

Changes in SOC
The SOC stocks within the top 30 cm layer were measured in October 2006 and August 2008 to estimate changes in SOC. Sixteen soil cores (5 cm internal diameter) were collected from each plot at 0-15 cm and 15-30 cm depth. The soil samples were air-dried and weighted. A portion of the air-dried sample was dried at 105°C for 24 h to measure bulk density. The C content of air-dried sample was measured using N/C analyzer (SUMIGRAPH NC-1000, Sumika Chemical Analysis Service). SOC concentration (gC/kg) was converted to SOC content with depth (MgC/ha within specified depth) using measured soil bulk density.

Statistical analyses
Uncertainties were calculated using the following equation.

Uncertainty (%) = {(two-sided 95% confidence interval) / 2} / Means × 100 (3)

Results and discussion

The biometric NEP in 2005 and 2006 were 2.1±0.8 and 1.2±0.6 MgC/ha/yr for the fertilizer plot, and -1.5±1.1 and -0.9±0.9 MgC/ha/yr for the manure plot, respectively. The meteorological NEP in 2005 and 2006 were 2.6 and 3.6 MgC/ha/yr for the fertilizer plot, and 0.9 and 2.2 MgC/ha/yr for the manure plot, respectively. Both biometric and meteorological NEP were greater in the manure plot than in the fertilizer plot. However, the meteorological NEP were 0.5 - 3.1 MgC/ha/yr larger than the biometric NEP (Figure 1). Two-year averages of the biometric NBP in the fertilizer and manure plots were -3.6±1.3 and 0.3±1.6 MgC/ha/yr, respectively (Table 1). Two-year averages of the meteorological NBP in the fertilizer and manure plots were -2.2 and 3.0 MgC/ha/yr, respectively (Table 1). Changes in SOC within the top 30 cm layer were -4.3±12.5 and 1.3±10.3 MgC/ha/yr, respectively. All approaches show that the C was lost in fertilizer plot, but gained in manure plot. This result indicates that the harvest consumes the C, and that manure application is necessary to prevent the loss of C from the managed grassland. The C sequestration rate estimated by the difference between the fertilizer and manure plots ranged from 3.9 to 5.4 MgC/ha/yr. Jarecki and Lal (2003) have also reported that manure application increases C input to soil and consequently enhances SOC concentration. However, Poulton (1996) stated that the manure applications at the rate of 3 MgC/ha/every 4 years over many decades in a grassland at Rothamsted Experimental Station did not change SOC levels appreciably, because the SOC content of the grassland soil might have reached a steady state. In this study, the site might not be carbon saturated, thereby manure application may enhance SOC sequestration in soils.

The meteorological NBP was the highest among three approaches. We used open-path eddy covariance method for meteorological approach. Some studies have reported that the NEP measured by the open-path system might be systematically overestimated compared with the closed-path system (Anthoni *et al*. 2002; Hirata *et al*. 2007). Hirata *et al*. (2007) measured the NEP in a northern Japan larch plantation forest using open- and closed-path eddy covariance methods, and found that the NEP from open-path system was 3.9 - 4.3 MgC/ha/yr larger than that from closed path system. Recent studies have indicated that the heat flux from surface heating of an open-path instrument produced incomplete WPL correction (Ono *et al*. 2007). The literature values of biometric and meteorological NEP were plotted on Figure 1. The NEP from closed-path system was closer to the biometric NEP than that from open-path system. This suggests that meteorological method, especially open-path eddy covariance method, could possibly overestimate the NEP.

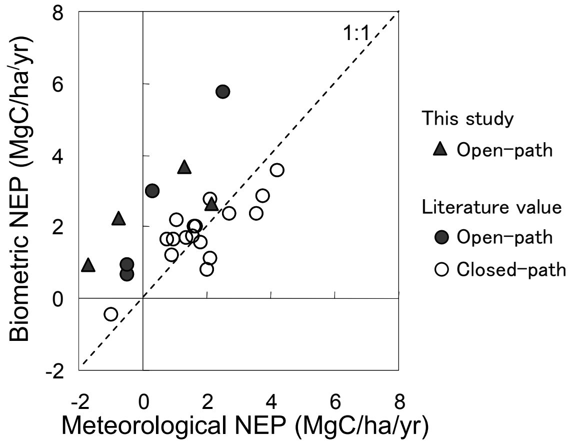

Figure 1. Biometric net ecosystem production (NEP) compared to meteorological NEP. Literature values are referred to Barford *et al.* (2001), Law *et al.* (2001), Ehman *et al.* (2002), Curtis *et al.* (2002), Gough *et al.* (2008), Hirata *et al.* (2008) and Kominami *et al.* (2008).

Table 1. Annual net biome production (NBP) and the changes in soil organic carbon (SOC) (MgC/ha/yr). Data represent means ± (uncertainties/100×means).

	Fertilizer plot	Manure plot
Biometric NBP		
2005	-3.3 (1.0)	-0.4 (1.2)
2006	-3.9 (0.7)	0.1 (1.1)
Average	-3.6 (1.3)	0.3 (1.6)
Meteorological NBP		
2005	-2.8	2.8
2006	-1.5	3.2
Average	-2.2	3.0
Changes in SOC		
0 - 15 cm	-1.8 (6.6)	1.8 (5.0)
15 - 30 cm	-2.5 (7.8)	-0.5 (6.6)
0 - 30 cm	-4.3 (12.5)	1.3 (10.3)

Conclusion

Carbon budgets in a managed grassland were measured using three different approaches. All approaches showed that manure application is necessary to prevent the loss of C from the grassland. However, meteorological approach could possibly overestimate the NEP.

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