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Response of ecosystem CO_2 exchange to biomass productivity in a high yield grassland

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ABSTRACT

We measured the biomass production and ecosystem carbon CO_2 exchange in a high yield grassland dominated by *Miscanthus sinensis*. The experimental grassland is managed by mowing once a year in winter every year and the harvested biomass on the ground is left to become the humus. The maximum aboveground and belowground biomasses were 1117 and 2803 g d.w. m^{-2} in our grassland. Although the high potential of our grassland for biomass production led to higher carbon uptake than with other types of grassland, the large biomass contributed to a higher respired carbon loss. Biomass increase led to a linear increase in ecosystem respiration. Over the 3 years, RE_{10} increased with increasing aboveground biomass. The potential gross primary production at a photosynthetic photon flux density of 2000 μmol m^2 s^{-1} logarithmic increased with LAI. These responses of CO_2 exchange to biomass production suggest this grassland behaved as weak CO_2 sink or near carbon neutral (−78 and 17 g C m^{-2} $year^{-1}$) in current management.

1. Introduction

The need to mitigate the impact of rising atmospheric CO_2 concentrations on the global climate has been attracting much attention. Information on the carbon budgets of regional ecosystems can improve our understanding of an ecosystem's functioning and its potential response to the climate system. For temperate grasslands in Asia, a positive correlation has been shown between summer precipitation, temperature and aboveground biomass productivity (Ni, 2004). High productivity is expected in the temperate grasslands where high precipitation associated with the Asian summer monsoon occurs.

The East Asian giant perennial grass *Miscanthus* has attracted attention as a high-yielding plant for temperate regions, since it requires low inputs of nitrogen and can achieve high yields—in excess of those of other C_4 forages in temperate climates (e.g., Clifton-Brown et al., 2004). Some studies of *Miscanthus*-type grasslands have focused on their large productivity (Kayama et al., 1972; Shoji et al., 1990). Most of the grasslands in Japan are regarded as semi-natural grasslands that are maintained by human activities such as grazing, mowing, and burning management (Numata, 1969; Takahashi and Naito, 2006).

Recent studies have shown that most grassland ecosystems also show large interannual variability in the annual net ecosystem exchange (NEE) of CO_2, and some even show a near-zero or negative annual uptake (Jaksic et al., 2006; Lawton et al., 2006). There is a need for long-term field measurements to estimate and control of ecosystem carbon CO_2 exchange of the grassland. However, little information has emerged on the ecosystem carbon CO_2 exchange and seasonal patterns of productivity of high yield grassland over several years.

Our objectives were: (1) to determine how *Miscanthus*-type grassland ecosystems respond to climatic and biological factors; and (2) to address seasonal variations in the production and ecosystem carbon CO_2 exchange of a *Miscanthus*-type grassland. An understanding of variations in the response of the ecosystem carbon CO_2 exchange to biomass productivity is important in characterizing high yield grasslands. We focus on the ecosystem carbon CO_2 exchanges during 3 years of continuous measurements over a *Miscanthus*-type grassland. We expect that this information will improve our understanding of the ecosystem carbon CO_2 exchange of high yield grasslands and will encourage the management of land in ways that mitigate carbon emissions.

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Nomenclature

GPP	gross primary production ($gC\,m^{-2}\,d^{-1}$)
GPP_{2000}	GPP at a PPFD of 2000 $\mu mol\,m^{-2}\,s^{-1}$ ($gC\,m^{-2}\,d^{-1}$)
IRGA	infrared gas analyzer
LAI	leaf area index ($m^2\,m^{-2}$)
NEE	net ecosystem CO_2 exchange ($gC\,m^{-2}\,d^{-1}$ or $gC\,m^{-2}\,year^{-1}$)
$NEE_{daytime}$	daytime NEE ($gC\,m^{-2}\,d^{-1}$)
NEE_{night}	night-time NEE ($gC\,m^{-2}\,d^{-1}$)
PPFD	photosynthetic photon flux density ($mmol\,m^{-2}\,d^{-1}$)
Q_{10}	multiplier of the respiration rate for a temperature increase of 10 °C
RE	ecosystem respiration ($gC\,m^{-2}\,d^{-1}$)
RE_{10}	ecosystem respiration at an air temperature of 10 °C ($gC\,m^{-2}\,d^{-1}$)
SWC	Volumetric soil water content ($m^3\,m^{-3}$)
VPD	vapor pressure deficit (kPa)
u^*	friction velocity

2. Materials and methods

2.1. Site description

The measurements were carried out in an experimental grassland (lat. 36°06′N, long. 140°06′E, 27.0 m above sea level) at the Terrestrial Environment Research Center, University of Tsukuba, Japan, from 2001 to 2003. Annual rainfall was between 1118 and 1225 mm, and the annual mean temperature is 14.1 °C in the 3 years (Shimoda et al., 2005). The area is dominated by marine humid climate. The grassland is circular, with a diameter of 160 m (20 000 m^2; Fig. 1). The experimental site was established in April 1975 by clear-felling of a red pine (*Pinus densiflora*) forest with the aim of monitoring the long-term vegetation dynamics of grasslands, and the facility has been used for meteorological and biometric field experiments over the past 25 years. The grassland is managed by mowing once a year in winter every year, and let the harvested biomass on the ground became the humus. Biomass and leaf area index (LAI) have been estimated every month throughout the growing season since 1993 (Saigusa et al., 1998). The results show that C_3 species such as *Solidago altissima* (Compositae) grow in spring, whereas C_4 species such as *M. sinensis* and *Imperata cylindrica* (Gramineae) predominate during late summer and autumn. Among these species, *M. sinensis* showed the highest growth in aboveground biomass during the growing season. Its biomass occupied approximately 60% of the total aboveground biomass (Shimoda et al., in press). The soil is a volcanic ash (brown *Kuroboku* soil) that is widely distributed over central Japan. Field water capacity and porosity were 72% and 70% in the upper 10 cm, and bulk density and total organic carbon ratio in the surface upper 20 cm were 0.83 $g\,cm^{-3}$ and approximately 1.5% (Hamada et al., 1998).

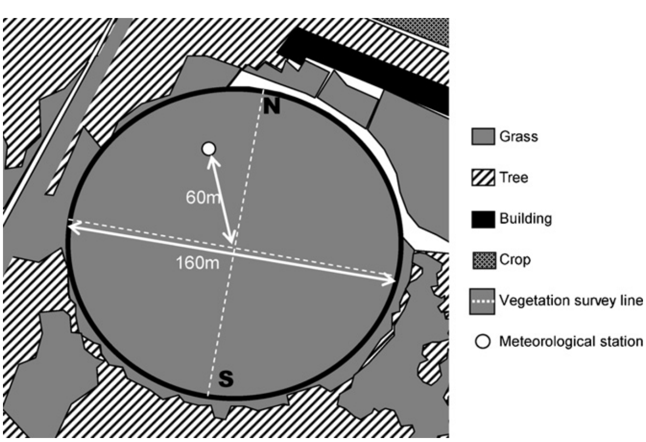

Fig. 1. Location of the experiment field, showing meteorological station and vegetation survey lines. This site is surrounded by pine forest and Lab buildings of Terrestrial Environment Research Center (TERC), University of Tsukuba.

The typical wet condition occurs from May to July and September. Average rainfall between 1991 and 2000 was more than 100 mm from April to July and September. The small rainfall in July 2001 (10.0 mm) and September 2003 (20.5 mm) were abnormal in this site (Shimoda and Oikawa, 2008). Volumetric soil water content had been rapidly depleted from about 0.50–0.26 $m^3\,m^{-3}$ by July 2001 and to 0.32 $m^3\,m^{-3}$ in August 2002, but it remained above 0.40 $m^3\,m^{-3}$ for all of 2003.

2.2. LAI and aboveground biomass measurements

Vegetative coverage percentage was measured by establishing 80 quadrats (2 m × 2 m) in the grassland every month during the growing season. Line transects for the vegetation survey set at north-south and west-east (Fig. 1). Monthly harvested specific species biomasses were obtained by points of the three sub-quadrats (0.5 m × 0.5 m). We assumed the relationship of each species between vegetative coverage percentage and the aboveground biomass or LAI and at sub-quadrats can extend to the relationship at field scale. Aboveground biomass was determined as dry weight after oven-drying. LAI was measured with an automatic area meter (AAM-7, Hayashi Denkoh, Tokyo, Japan). The root biomass was estimated by collecting soil core (6 cm diameter) to 50 cm depth at 25 points in 2003. The ratio of dominant aboveground biomass to belowground biomass was gained using the harvest at highest growth in August 2003. The roots were washed in tap water, oven dried (70 °C), and weighted. To determine the maximum belowground biomass we used the known belowground to aboveground biomass ratios of the dominant species, i.e. 2.8 for *M. sinensis*, 2.5 for *S. altissima*, and 3.7 for *I. cylindrica* (Liu et al., 2004). From the vegetative cover and the aboveground to belowground biomass ratio, we then estimated the maximum belowground biomass.

2.3. Micrometeorological measurements

To ensure an adequate flux source area for meteorological measurements in the direction of the prevailing wind, micrometeorological data were collected 60 m NNE of the center of the circular grassland. Rainfall was measured by rain gauge (B-011–00, Yokogawa, Tokyo, Japan). Air temperature, humidity and volumetric soil water content (SWC) were measured at a frequency of 10 Hz and stored as 5-min averages on a datalogger (CR23X, Campbell Scientific, Logan, UT, USA). SWC was measured by time domain reflect meters (TDR CS615, Campbell Scientific, USA) with three sensors inserted at a depth of 0–0.15 m under the soil surface. Photosynthetic photon flux density (PPFD) was sampled at 5-s intervals and stored as 5-min averages on a datalogger (Thermodac EF 5001A, ETO Denki, Tokyo, Japan).

The flux system used from January 2001 to July 2003 consisted of a three-dimensional supersonic anemometer (DAT600, Kaijo, Tokyo, Japan) and an open-path infrared gas analyzer (IRGA; E009B, Advanet Inc., Okayama, Japan) at height of 2.0 m. In May 2003, another open-path IRGA (LI-7500, Li-Cor, Lincoln, NE, USA) was added. The data from these sensors were sampled at a frequency of 10 Hz and stored on a datalogger (CR23X). The anemometer and IRGA provided a digital output of fluctuations in vertical wind speed (w') and either CO_2 density (c') or water vapor density (q'). The cospectral gap scale was examined by studying MR cospec-