Available online at www.sciencedirect.com
ScienceDirect
Agricultural and Forest Meteorology 146 (2007) 57–69
AGRICULTURAL AND FOREST METEOROLOGY
www.elsevier.com/locate/agrformet

Seasonal and interannual variation in water vapor and energy exchange over a typical steppe in Inner Mongolia, China

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Received 29 June 2006; received in revised form 20 October 2006; accepted 16 May 2007

Abstract

In this study, we conducted eddy covariance (EC) measurements of water vapor exchange over a typical steppe in a semi-arid area of the Inner Mongolia Plateau, China. Measurement sites were located within a 25-year-old enclosure with a relatively low leaf area index ($\sim$1.5 m^2 m^{-2}) and dominated by *Leymus chinensis*. Energy balance closure was (H + LE) = 17.09 + 0.69 × (Rn − G) (W/m^2; r^2 = 0.95, n = 6596). Precipitation during the two growing seasons of the study period was similar to the long-term average. The peak evapotranspiration in 2004 was 4 mm d^{-1}, and 3.5 mm d^{-1} in 2003. The maximum latent heat flux was higher than the sensible heat flux, and the sensible heat flux dominated the energy budget at midday during the entire growing season in 2003; latent heat flux was the main consumption component for net radiation during the 2004 growing season. During periods of frozen soil in 2003 and 2004, the sensible heat flux was the primary consumption component for net radiation. The soil heat flux component was similar in 2003 and 2004. The decoupling coefficient (between 0.5 and 0.1) indicates that evapotranspiration was strongly controlled by saturation water vapor pressure deficit (VPD) in this grassland. The results of this research suggest that energy exchange and evapotranspiration were controlled by the phenology of the vegetation and soil water content. In addition, the amount and frequency of rainfall significantly affect energy exchange and evapotranspiration upon the Inner Mongolia plateau.

Keywords: Eddy covariance; Evapotranspiration; Energy exchange; Decoupling coefficient; Soil water content; Typical steppe

1. Introduction

Of all the ecological processes related to carbon sequestration in terrestrial ecosystems, water and the energy balance are the most crucial (Dugas et al., 1999; Baldocchi et al., 1997). Many important ecosystem processes such as plant photosynthesis and vegetation productivity are associated with water vapor exchange. Latent heat and sensible heat fluxes have a significant affect on the weather and climate (Pielke et al., 1998; Wever et al., 2002). In turn, water and energy fluxes are influenced by the functional type of plants, weather, and physical properties of the soil (Baldocchi and Nancy Kiang, 2004). Consequently, it is important to investigate water vapor and energy exchanges in different ecosystems to better understand the mechanisms that control the carbon cycle and other ecosystem processes.

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0168-1923/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.agrformet.2007.05.005

The eddy covariance (ED) technique has been widely applied to measure the exchange of carbon, water vapor, and energy between the Earth's surface and atmosphere (Baldocchi, 2003). As part of the FLUXNET project (Steven et al., 2005), studies have recently been undertaken in a variety of ecosystems ranging from the tropics to the northern high latitudes; however, although some research has targeted grassland ecosystems in savanna areas and the Central Great Plains (Dugas et al., 1999; Frank and Dugas, 2001; Sims and Bradford, 2001; Suyker and Verma, 2001; Novick et al., 2004), few research projects have focused on the great steppes of Asia (Li et al., 2006). This omission represents a critical gap in our knowledge, as grasslands comprise approximately 32% of the Earth's natural vegetation (Adams et al., 1990) and grassland ecosystems record considerable annual fluctuations in gross primary production (Frank and Dugas, 2001). Recent studies have also documented the significantly asymmetric responses of grassland ecosystems to environmental change and pertinent biomass dynamics (Baldocchi et al., 2001; Wever et al., 2002).

Typical grassland areas in Inner Mongolia are an important and representative part of Eurasian temperate grasslands. The part of the steppe that developed under semi-arid continental temperate climate is the largest grassland in China (Fig. 1). Climate change in this region has been documented recently, with a gradually warming trend of wintertime air temperature and severe springtime droughts (Chen et al., 2003). Unfortunately, there is no detailed information regarding the exchange of water vapor and energy within this grassland ecosystem.

The objectives of the present study are to determine patterns of seasonal and annual variation in water vapor and energy fluxes within a typical grassland ecosystem.

Fig. 1. Distribution of typical steppe in China (after "China Grassland Resource", 1996).

A specific objective is to examine how biotic and abiotic variables affect water vapor and energy exchange in the studied grassland.

2. Methods

2.1. Site description

The experimental site is located within the Inner Mongolia Grassland Ecosystem Research Station in the Xilin river watershed of the Inner Mongolia autonomous region (43°32′N, 116°40′E, 1200 m a.s.l). The study site, which covers 400 × 600 m, has been fenced off since 1979 and is located upon a smooth wide plain that contains low hills. The tops of the low hills are 20–30 m above the surrounding plain, and the hills have slopes of $<5°$. The climate of the area is a semi-arid continental temperate steppe climate with a dry spring and humid summer. The average annual temperature is −0.4 °C, with a growing season of 150–180 d. The annual precipitation range is 320–400 mm, and rainfall is concentrated within the period from June to August.

The soil at the experimental site is a dark chestnut (Mollisol), and the soil depth is usually in excess of 100–150 cm (Wang and Cai, 1988). The A horizon extends to 20–30 cm depth, and there is no obvious $CaCO_3$ layer in the soil profile. The soil consists of 21% clay, 60% sand, and 19% silt. Of 86 species of flowering plants that belong to 28 families and 67 genera at the site, there are 11 grass species (Jiang, 1985). The xeric rhizomatous grass *Leymus chinensis* is the constructive species, and *Agropyron cristatum*, *Cleistogenes squarrosa*, and *Carex duriuscula* are the dominant species. The heights of grass clusters are 50–60 cm; coverage averages 30–40% but can reach as high as 60–70% during rainy years. Litter is able to accumulate within the enclosure because sheep are prevented from grazing in the area.

2.2. Above-ground biomass and LAI measurements

Above-ground biomass was determined by cutting the vegetation around the eddy covariance tower every 15 days during the period from May to September. Twenty quadrates of 1 × 1 m^2 were collected at the time of each cutting in 2003 and 2004 (interval: 2 weeks). Six quadrates of all samples were within the footprint of the tower. The above-ground parts of the vegetation were clipped to the ground surface and brought back to the laboratory for the measurement of dry matter. The clipped plant material was separated into live and standing-dead parts, which were then weighed as the