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Seasonal variations of the water budget in typical grassland ecosystems in China

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ABSTRACT

Regional droughts may become more frequent this century as a result of anthropogenic global climate change. Thus, it is becoming critically important to evaluate the water budget accurately in terrestrial ecosystems. The water budget, which represents an important index for drought, is widely used to characterize water cycle processes in terrestrial ecosystems and to inform management decisions regarding regional water resources. As a vital component of the terrestrial biosphere, grassland ecosystem plays crucial role in regional carbon sinks and sources especially that located in the Qinghai-Tibet Plateau. In this study, based on water balance method, seasonal variations of water budget were analyzed using flux data obtained from eddy covariance measurements from 2004 to 2011 in an alpine meadow in Damxung (DX), an alpine shrubland in Haibei (HBGC), and a *Leymus chinensis* grassland in Inner Mongolia (NMG). We found that seasonal variations of water budget were quite different among the three ecosystems. The average water budget were (-81.48 ± 76.56) mm, (-35.97 ± 81.70) mm, and (-53.05 ± 56.91) mm for DX, HBGC, and NMG, respectively. Water surplus happened from June to August in DX with an amount of (52.04 ± 68.15) mm, while water deficit existed during the other months of the year with an amount of (-133.51 ± 42.62) mm. There was little evidence of water deficit in HBGC at the yearly scale. However, seasonal water surplus occurred from May to September with an average of (30.11 ± 67.47) mm and water deficiency were noted during the other months of the year with an average of (-66.08 ± 25.87) mm. Due to lack of precipitation in NMG, water deficiency occurred from January to March, and the amount of deficiency during this time period was (-18.01 ± 17.95) mm. Although precipitation was ample from April to October, water deficiency still occurred in NMG as a result of high evapotranspiration (i.e., the deficiency was approximately (-39.99 ± 70.49) mm). In addition, the water budget and net ecosystem productivity showed consistent trends during the study period. Net ecosystem productivity was relatively higher from June to August when there were ample precipitation and water surplus than that of months with water deficit. Further studies need to be done in the future to address the complex influence of rain intensity and soil water balance on ecosystem productivity.

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1. Introduction

Moisture is the main factor affecting the productivity of ecosystem in arid and semi arid area [1,2]. Not only can the researches on the water budget benefit the reasonable allocation and management of regional water resources, but also provide important ecological information for the study on vegetation growth and material production [1–3]. At present, the academic circles generally believed that together with the effects of natural and anthropogenic processes of material production on global energy balance, the change of surface radiation and temperature can affect the process of water cycle by changing the water vapor content in the air under the influence of global climate change [4–7], which make the water budget of the ecosystem at regional scale showing a complex change.

About the methods for evaluating ecosystem water budget, some studies adapted the climate moisture index (CMI), expressed by the difference or ratio between precipitation and potential evapotranspiration [1,8–15], and some based on the difference between the actual and potential evapotranspiration to characterize the extent of water budget [16–22]. The potential evapotranspiration used in the above methods represents the energy status of the vegetation growing environment and the maximum evaporation capacity of water.

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To a certain extent, the water budget calculated by these methods represents a climatic potential. Water budget can be reflected more accurately the actual water supply and demand by calculating the difference between the actual input and output water of the ecosystem in a certain period of time, which might be more significant for analyzing vegetation productivity.

As an important part of terrestrial ecosystem, grassland ecosystem acts as significant carbon sinks/sources of atmospheric greenhouse gases [23], and plays an important role in regulating the climate and environment changes [24,25]. Since the unique locations, the temperate grasslands in arid and semi-arid regions and the alpine meadow in the Qinghai-Tibet Plateau have often been chosen to study the response of vegetation to climate change in grassland ecosystem [26]. Most studies of water balance in grassland ecosystem analyze the impact of climate change on soil moisture based on the long-term observation data obtained from meteorological station [27–31]. While, the others analyze the temporal and spatial variations of ecosystem water budget at regional scale based on observation data of meteorological station [12, 32] or remote sensing data [33,34]. To some extent, Meteorological data and remote sensing data can give a better analyze of the water budget of vegetation. However, the lack of direct observation of the actual evapotranspiration of ecosystem can make some deviation in the actual water supply and demand of vegetation. The water vapor flux observed by the eddy covariance technique provides the possibility for accurate analysis on the water budget at different time scales (including day, seasonal, and years). Therefore, this paper selected three sites of ChinaFLUX, including an alpine meadow ecosystem in Damxung (DX), an Alpine Meadow Ecosystem in Haibei (HBGC) and a *Leymus chinensis* grassland ecosystem in Inner Mongolia (NMG), and analyzed the seasonal variations of water budget in the three typical grassland ecosystems using the data of water vapor flux data observed during the period of 2004 to 2011.

2. Materials and methods

2.1. Site description

This study selected the alpine meadow ecosystem in Damxung (DX), the alpine meadow ecosystem in Haibei (HBGC) and the *Leymus chinensis* grassland ecosystem in Inner Mongolia (NMG) from ChinaFLUX and analyzed the seasonal variations of water budget. The site descriptions of the three ecosystems are shown in Table 1.

2.2. Observation and data processing

2.2.1. Observation of flux and micro-meteorological data

Eddy covariance techniques can calculate the turbulent flux by measuring and calculating the covariance of the physical quantity fluctuation (such as temperature, CO_2 and H_2O) and the vertical wind velocity fluctuation. In the process of observation and calculation of flux, there is a solid theoretical foundation with almost no assumptions [37]. Unified eddy covariance observation system and conventional meteorological factor measurement system of ChinaFLUX were used in this study. The eddy covariance observation system composed of a three dimensional ultrasonic anemometer (CSAT3, Campbell Scientific, USA) and an infrared CO_2/H_2O analyzer (Li-7500, Li-Cor Inc., USA) is installed at a height of 2.2 m from the ground. The three-dimensional ultrasonic anemometer measures three-dimensional wind velocity and air temperature. The infrared gas analyzer measures atmospheric concentrations of CO_2 and H_2O. The sampling frequency is 10 Hz, and all variables are given 30 min average values after processing.

The conventional meteorological elements measuring system mainly consists of the radiation sensor, air temperature and humidity sensor (model HMP45C, Vaisala Inc.), canopy infrared temperature sensor (IRTS-P, Apogee Inc.) and air pressure sensor (CS105, Vaisala Inc.), which are installed at 1.2 m height above the ground. Soil moisture was measured primarily with time domain reflector (TDR) (model CS615-L, Campbell Scientific). Soil moisture in DX and NMG are recorded at three depths of 0.05, 0.2 and 0.50 m, while in HBGC the depths are 0.2 and 0.4 m. The conventional meteorological factors and soil moisture were recorded with a datalogger (Model CR23X, Campbell Scientific) and the average values were calculated by 30 min time step [36,37].

2.2.2. Methods for evaluating water budget

According to the water balance equation of ecosystem [38,39], water budget can be defined as the difference between the water input (W_i) and water output (W_o) within a certain period, which is equivalent to the change of water storage in the ecosystem.

$$\Delta W = W_i - W_o$$

For a relatively flat terrain like grassland, it can be neglected that a small amount of water flow into and out of adjacent areas, and the water infiltration from soil that exceeds the capacity of plant to use. As a result, precipitation and snow (P) are the main water input items of the ecosystem, and evapotranspiration (ET) is the main water output item of the ecosystem. Thus, ecosystem water budget can be written as,

$$D = P - ET$$

where D is water budget (mm), P is precipitation (mm), ET is evapotranspiration (mm). When $D > 0$, it indicates water surplus in the ecosystem, while when $D < 0$, it indicates water deficit in the ecosystem.

2.3. Data processing

In this study, the data of carbon, water vapor flux, and the relevant micrometeorological factors are collected from eddy covariance observation of ChinaFLUX from 2004 to 2011. Monthly values of the seasonal

Table 1
General information of the three typical grassland ecosystems of ChinaFLUX.

Site	DX	HBGC	NMG
Location	30°24′36″N,91°04′48″E	37°39′55″N,101°19′52″E	43°33′11″N,116°40′31″E
Elevation (m)	4333	3293	1187
Climate	Plateau Monsoon Climate	Plateau Continental Climate	Continental Semi-Arid Temperate Grassland Climate
Mean annual temperature (°C)	1.3	−1.6	−0.4
Mean annual precipitation (mm)	476.8	560	350–450
Vegetation	Alpine *Kobresia* Meadow	*Potentilla fruticosa* shrub grassland	*Leymus chinensis* meadow
Soil type	Alpine meadow soil	Dark fertile frozen soil	Chestnut soil
Observation period	From July 2003	From October 2002	From April 2003
References	[35,36]	[30,36]	[28,35,36]

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