Ecosystem Water-Use Efficiency in Inner Mongolia Temperate Grassland

Jiuyi Li

Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.

Mailing address: Institute of Geographic Sciences and Natural Resources Research, 11A, Datun Road, Chaoyang District, Beijing, 100101, China.

Abstract

Clarifying spatial variations in grassland ecosystem water-use efficiency (eWUE) will help our understanding of how grassland ecosystems water respond to climate change. However, a comprehensive understanding of the spatial variations of eWUE in Inner Mongolia temperate grassland is yet to be achieved. We investigated the spatial patterns of ANPP and eWUE along a precipitation gradient in the grassland. The ANPP increased exponentially with increasing mean annual evapotranspiration (MAE). The eWUE (eWUE\text{dry} and eWUE\text{wet}) increased linearly with increasing mean annual precipitation (MAP).

Keywords: Ecosystem water-use efficiency; Net primary productivity; Evapotranspiration; Chinese temperate grassland; Inner Mongolia

1. INTRODUCTION

Aboveground net primary productivity (ANPP), which is a key attribute of vegetation ecosystems, integrates different aspects of ecosystem structure and functioning in its value (Paruelo et al., 1999). Evapotranspiration (ET) is a strong predictor of patterns of ANPP across large regions (Webb et al., 1983). Ecosystem water-use efficiency (eWUE), the ratio of ANPP to ET, provides an effect integral measure for evaluating...
the response of ANPP to changes in ET. Examining the spatial variations in eWUE is useful for predicting the effects of climate change on vegetation productivity.

China has the second largest area of grassland in the world. The grassland covers nearly 40% of the country (Fan et al., 2008). Temperate grassland is the main grassland type. It has great significance for global climate change research and livestock production (Hu et al., 2007). Some researchers (Bai et al., 2008; Hu et al., 2010) have sought to improve our knowledge of the spatial pattern of precipitation use efficiency (PUE, the ratio of ANPP to precipitation) along a precipitation gradient in Chinese temperate grassland, but a comprehensive understanding of the spatial pattern of eWUE along the precipitation gradient is yet to be achieved. Compared with PUE, the eWUE provides further insight into the ecological structure and functioning in the grasslands.

In this study, we examined the spatial variations in ANPP and eWUE, along a precipitation gradient in the grassland of Inner Mongolia, which covers most of Chinese temperate grassland. This study attempts to address the following three research questions: (1) What is the shape of the ET–ANPP relationship in the grassland? (2) What is the spatial pattern of eWUE along the precipitation gradient?

2. MATERIALS AND METHODS

2.1 Study region

The study was conducted in the Inner Mongolia Autonomous Region (IMAR) in northern China. The IMAR has 78.8 million hectares of natural grasslands which account for 66% of the total land area. Inner Mongolia temperate grassland belongs to the arid and semiarid region, where precipitation is the principal climatic factor limiting plant growth. From east to west, mean annual precipitation (MAP) in the region decreases from 500 to 100 mm. The soil shifts from chernozems, chestnut, and meadow soil to calcic brown and desert soils from the wet northeast to the dry southwest along the gradient. The study region is the main region of temperate grassland in China. Vegetation changes progressively from meadow steppe in the east to typical steppe in the middle and desert steppe in the west with decreasing precipitation.

2.2 ANPP measurements

In this study, ANPP was estimated as the peak aboveground biomass during the growing seasons. This is popular method for estimating grassland ANPP. We collected ANPP data on a total of 57 zonal sites, which were fenced to prevent grazing. Two
sources were used: (1) Long-term observations. For this dataset (Sharing Information System of Grassland Resources in China), a total of 14 sites were selected from this data source. (2) Literature. A total of 43 sites were selected from this source.

2.3 Climatic factors

Zhou and Zhang (1995, 1996) proposed a model of annual ET. The model offers an approach for estimation of annual ET on the basis of annual precipitation (P) and radiation dryness index (RDI):

$$ET = \frac{P \times RDI \times (1 + RDI + RDI^2)}{(1 + RDI) \times (1 + RDI^2)}$$  \hspace{1cm} (1)

where ET is annual evapotranspiration, P is annual precipitation, and RDI is annual radiation dryness index. RDI is obtained using the model:

$$RDI = 0.629 + 0.237 \times \frac{PER}{P} - 0.00313 \times \frac{PER^2}{P^2}$$  \hspace{1cm} (2)

$$PER = BT \times 58.93 / P$$  \hspace{1cm} (3)

$$BT = \sum \frac{MMT}{12}$$  \hspace{1cm} (4)

where RDI is radiation dryness index, PER is annual potential evapotranspiration ratio, BT is annual biotemperature, P is annual precipitation, and MMT is monthly mean temperate (if MMT > 30°C, then MMT = 30°C; if MMT < 0°C, then MMT = 0°C).

We acquired annual precipitation, annual mean temperature, and monthly mean temperature, and interpolated the station-specific climate data.

3. RESULTS

The ANPP of the temperate grassland in Inner Mongolia increased exponentially with increasing mean annual evapotranspiration (MAE) ($ANPP = 15.61e^{0.01MAE}$, $R^2 = 0.59$, $p < 0.001$), implying an increasing eWUE with increasing MAE along the precipitation gradient (Fig. 1). Using long-term observation data, we also investigated the spatial variations in eWUE during the driest years (eWUE$_{dry}$, calculation from minimum precipitation and corresponding ANPP) and the wettest years (eWUE$_{wet}$, calculation from maximum precipitation and corresponding ANPP). Along the precipitation gradient, eWUE$_{dry}$ and eWUE$_{wet}$ all tended to increase with MAP ($p < 0.001$) (Fig. 2).
Fig. 1 Spatial relationship between aboveground net primary productivity (ANPP) and MAE.

\[ R^2 = 0.59 \quad P < 0.001 \]

Fig. 2 Spatial relationship between mean annual precipitation (MAP) and eWUE\textsubscript{dry} (eWUE in the driest year) and eWUE\textsubscript{wet} (eWUE in the wettest year).

\[ eWUE\textsubscript{dry} \quad R^2 = 0.35 \quad P < 0.001 \]
\[ eWUE\textsubscript{wet} \quad R^2 = 0.24 \quad P < 0.001 \]
5. CONCLUSIONS

Our study illustrated that ANPP increased exponentially with increasing MAE, and the eWUE increased linearly with increasing MAP along a precipitation gradient in Inner Mongolia temperate grassland. There were no constant spatial eWUE along precipitation gradient.

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REFERENCES


