Journal of Forestry Research (2009) 20(1):23–26
DOI 10.1007/s11676-009-0004-4

RESEARCH PAPER

Responses of biomass to the addition of water, nitrogen and phosphorus in Keerqin sandy grassland, Inner Mongolia, China

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Abstract: The effects of water, nitrogen and phosphorus on productivity of sandy grassland were investigated with a fully factorial experiment to find out the main factors limiting natural restoration of grassland productivity in the southeastern Keerqin sandy land. In total, eight treatments were designed as water addition (W), nitrogen fertilizer addition (N), phosphorus fertilizer addition (P), water + nitrogen fertilizer addition (WN), water + phosphorus fertilizer addition (WP), nitrogen fertilizer + phosphorus fertilizer addition (NP), water + nitrogen fertilizer + phosphorus fertilizer addition (WNP) and control (CK). Each treatment was replicated six times and randomly assigned to 48 plots (4 m × 4 m) that were separated by a 2-m buffer. Results show that restoration of productivity is only limited by nitrogen factor for sandy grassland of Keerqin sandy land and not limited by water and phosphorus. Relative to CK plots, the biomass and the aboveground net primary productivity (ANPP) of all the plots added with nitrogen fertilizer were significantly enhanced ($P < 0.05$) in 2005 growing season. Grass root mass is dominant in underground biomass. The present study possibly underestimates net primary productivity of grassland in northern China, due to limitation of underground biomass measurements.

Keywords: belowground biomass; carbon cycle; factorial analysis; function group; Keerqin sandy land

Introduction

Abundant data indicate that the growth and reproduction of photosynthetic biota as well as large-scale ecosystem primary production are frequently limited by supplies of nitrogen or phosphorus in terrestrial environment (Walker & Syers 1976; Vitousek & Howarth 1991). In arid and semi-arid regions, changes of precipitation in amount and timing can affect the structure and function of ecosystems. It has been suggested that, in these ecosystems, soil moisture mediates the influence of other environmental factors, including elements of anthropogenic global change such as nitrogen deposition, at several scales of organization (Weltzin et al. 2003). As one of the most widespread ecosystem types, grassland plays an important role in research of global change. The ratio of total biomass of grassland to forest biomass in China is 1/4, much higher than that of the world, suggesting a greater contribution of grasslands to China's carbon pool (Piao et al. 2004). Estimates of biomass and net primary productivity (NPP) are fundamental to understanding carbon storage and the biogeochemical dynamics of terrestrial ecosystems.

NPP is defined as the total photosynthetic gain, less respiratory losses, of vegetation per unit ground area. For natural vegetation, this is often expressed on an annual basis. For a given period of measurement, NPP is equal to the change in both aboveground and belowground plant mass plus any losses over this period due to death and subsequent decomposition, herbivory and exudation/volatilization (Long et al. 1989). However, many earlier estimates of grassland NPP ignored both turnover and belowground production, and they were based on aboveground peak 'standing crop' only (i.e. total clipped live and dead matter). Even the coordinated studies of the International Biological Programme (IBP) Grassland Biome in the late 1960s and early 1970s were based mainly on aboveground biomass changes, with relatively few estimates of belowground productivity (Scurlock et al. 2002). Grassland underground biomass is an essential object in grassland ecology research. It plays an important role in both physiological function and carbon storage (Hu et al. 2005). Thus, it is necessary to research the effects of different study methods on estimating the NPP of grasslands and to veraciously evaluate the importance of grasslands in regional and global carbon circle using the long-term measured biomass data, especially the data of belowground biomass (Wang et al. 2008). Plant species also differ in the capacity of their roots to respond

Foundation project: This paper is supported by the Knowledge Innovation Program of the Chinese Academy of Sciences (KZCX1-YW-08-02-02), the National Basic Research Program of China (2007CB106803), and the National Science & Technology Pillar Program in the Eleventh Five-year Plan Period (2006BAC01A12; 2006BAD26B0201-1).

Received: 2008-07-19; Accepted: 2008-10-18

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Responsible editor: Hu Yanbo

to unpredictable soil-nutrient enrichment (Jackson & Caldwell 1989).

The aim of this research was to analyze the effects of adding water or nitrogen or phosphorus on aboveground and below-ground biomass of sandy grassland in Keerqin sandy land.

Study area and methods

Study area

This study was conducted in a permanent grassland site at Daqinggou ecological station (42°58′N, 122°21′E, 260 m above sea level) in the south-eastern part of the Keerqin sandy land, Inner Mongolia, China. Historically, this area was a pastoral zone, but now it is mainly an agropastoral ecotone. The area is a semi-arid region with sandy soils, low precipitation (450 $mm \cdot a^{-1}$) (Fig. 1), and high potential evaporation (1780 $mm \cdot a^{-1}$). The average annual temperature is 6°C, relative air humidity is 59%; and the average annual frost-free period is 154 d (Yu et al. 2006). Soil has developed on wind-deposited sands and is characterized by coarse texture and loose structure with greater proportion of sands; thereby, the contents of essential soil nutrient (C, N, and P) are rather low (Table 1). This site naturally was restored from cropland to grassland in 2000. The vegetation of this site was dominated by *Pennisetum flaeccidum* and *Artimisia scoparia*.

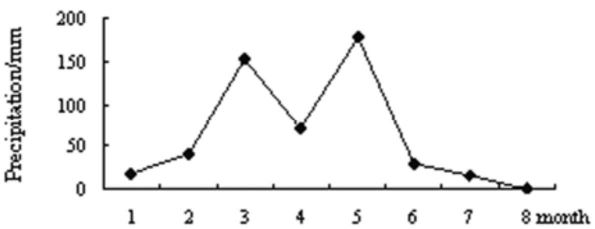

Fig. 1 Pattern of precipitation in 2005 at Daqinggou ecological station in the south-eastern part of the Keerqin sandy land, Inner Mongolia, China

Table 1. General characteristics of topsoil (mean ± standard error of nine measurements) * at Daqinggou ecological station in the south-eastern part of the Keerqin sandy land, Inner Mongolia, China

Soil layer	Bulk density ($g\ cm^{-3}$)	pH	Organic matter ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Total P ($g\ kg^{-1}$)
0–10cm	1.48±0.02	7.48± 0.04	6.57±0.31	0.57± 0.01	0.09±0.01
10–20cm	1.50± 0.01	7.43± 0.05	6.55±0.39	0.56±0.02	0.09± 0.00
20–30cm	1.57±0.02	7.84±0.08	5.68±0.43	0.49±0.02	0.09±0.00

Notes: *---- A paired *t*-test indicated that the difference in each property between two layers was not significant.

Methods

In 2004, one field experiment was designed in Daqinggou ecological station to study the effects of manipulation of water (80 mm), nitrogen (20 $g \cdot m^{-2} \cdot a^{-1}$), and phosphorus, P_2O_5, (10 $g \cdot m^{-2} \cdot a^{-1}$) on key ecosystem processes in sandy grassland of southeastern Keerqin sand lands by a fully factorial experiment. In total, eight treatments were designed, including water addition (W), nitrogen fertilizer addition (N), phosphorus fertilizer addition (P), water + nitrogen fertilizer addition (WN), water + phosphorus fertilizer addition (WP), nitrogen + phosphorus fertilizer addition (NP), water + nitrogen + phosphorus fertilizer addition (WNP), and control (CK). Each treatment was taken in six replications and randomly assigned to 48 plots (4 m × 4 m for each) that were detached by 2-m buffer.

In 2005, adding water (40 mm) was carried out from May 1 to May 28. Urea and NaH_2PO_4 were chosen as experimental fertilizer, and they were dissolved and sprayed on May 1 and June 20. Biomass was measured on June 1, July 15 and September 1, respectively. Three sub-plots (0.2 m × 0.5 m) were randomly set up in each plot for collecting aboveground and belowground plant body, standing dead matter and litterfall. Samples were sorted into grass and forb and dried by oven at 80°C.

The differences among any variables studied during growing season of the year 2005 and general characteristics of topsoil between plots were tested (*t*-test) by SPSS (13.0) for Windows statistical software.

Results

The biomass of sandy grassland with adding nitrogen fertilizer was higher than that without nitrogen fertilizer treatments on July 15 and September 1 (Fig. 2a). Date of biomass peak occurrence was different in different treatments, the biomass peaks of W, N, P, WN and WP treatments were on September 1 and those of NP, WNP and CK treatments were on July 15. The dynamics of aboveground net primary productivity was similar to biomass in all treatments except for W and CK treatments, resulting from the difference of root mass (Fig. 2b). Belowground biomass fluctuations in different treatments were not accordant (Fig. 2c), but grass root mass was significantly more than forb root mass (Fig. 2d).

Discussion

Our study shows that nitrogen was the only limiting factor for biomass and ANPP in this sandy grassland. This result is different from that of other temperate grasslands. The analysis of climate-productivity correlations implied that aboveground productivity is more controlled by rainfall, whereas belowground and total productivity is more influenced by temperature in the temperate grasslands of northern China (Ni 2004). To accurately estimate biomass of grasslands, we require long-term data on aboveground and belowground biomass, the masses of standing dead matter and litterfall, and the rates of decomposition and turnover.

In order to reduce plot disturbance during sampling roots, the advanced methods should been adopted to study root mass in situ. Kucke et al. (1995) compared the four commonly used direct field methods for estimating root mass, i.e., core method, core-break method, trench profile wall method, and root extraction method. They concluded that core-break method and trench profile methods delivered no reliable data for comparing rooting intensities between soils and between different crops. Newer and more sophisticated techniques such as automated imaging analyses (Dowdy et al. 1998), portable minirhizotron, color scanner system (Pan et al. 1998), and image analysis (Kimura et al. 1999) are also used for the estimation of root growth, mass and length measurements. However, these have not been widely accepted due to the requirement of expensive equipment and/or special skills.

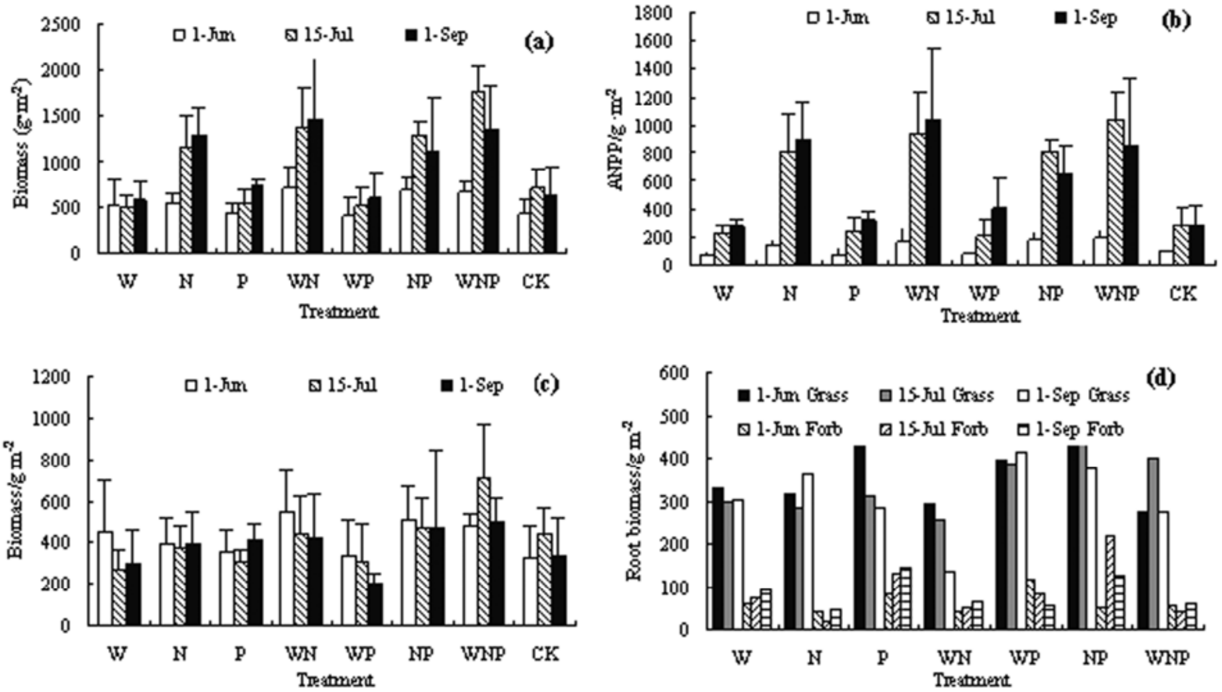

Fig. 2 Dynamics of biomass (a), aboveground net primary productivity (ANPP) (b), belowground biomass (c), root mass of grasses, and forbs (d) in 2005. Note: W---water addition, N---nitrogen fertilizer addition, P---phosphorus fertilizer addition, WN---water + nitrogen fertilizer addition, WP---water + phosphorus fertilizer addition, NP---nitrogen + phosphorus fertilizer addition, WNP---water + nitrogen + phosphorus fertilizer addition, and CK---control.

Table 2. Factorial analysis of biomass, aboveground net primary productivity (ANPP) and belowground biomass in 2005

	Date		W	N	P	W×N	W×P	N×P	W×N×P
Biomass	1-Jun	F	1.147	11.616	0.014	0.131	1.848	0.860	0.096
		Sig.	0.295	0.002*	0.907	0.720	0.187	0.363	0.759
	15-Jul	F	1.567	87.520	0.930	6.926	1.685	3.274	0.017
		Sig.	0.223	0.000*	0.344	0.015*	0.207	0.083	0.898
	1-Sep	F	0.185	22.267	0.055	1.026	0.000	0.534	0.072
		Sig.	0.671	0.000*	0.816	0.321	0.991	0.472	0.791
Aboveground net primary productivity	1-Jun	F	0.228	26.208	0.670	0.755	0.008	1.292	0.388
		Sig.	0.637	0.000*	0.421	0.393	0.931	0.267	0.539
	15-Jul	F	1.323	108.866	0.077	3.218	0.233	0.495	0.038
		Sig.	0.261	0.000*	0.784	0.085	0.634	0.488	0.874
	1-Sep	F	1.130	28.742	0.433	0.445	0.177	2.206	0.003
		Sig.	0.298	0.000*	0.517	0.511	0.678	0.150	0.955
Belowground biomass	1-Jun	F	0.913	3.870	0.015	0.013	1.873	0.374	0.017
		Sig.	0.349	0.061	0.903	0.911	0.184	0.546	0.896
	15-Jul	F	0.489	9.620	1.543	4.802	2.389	4.487	0.000
		Sig.	0.491	0.005*	0.226	0.038*	0.135	0.045*	0.988
	1-Sep	F	0.470	4.182	0.241	1.378	0.439	0.460	0.444
		Sig.	0.499	0.052	0.628	0.252	0.514	0.504	0.512

Note: df = 7; significance differences at $P < 0.05$ are indicated by the asterisk (*).

By using SPSS 13.0 software, factor analysis was taken for biomass, ANPP, and underground biomass (Table 2). Interaction was not found for biomass between three factors (water, nitrogen, and phosphorus) except that biomass was significantly increased by the interaction of water and nitrogen on July 15. Biomass and ANPP were found marked increasing in the treatment of nitrogen fertilizer addition when being sampled on June 1, July 15 and September 1. Belowground biomass was not affected by three factors on June 1 and September 1, but nitrogen addition distinctly improved belowground biomass on July 15 except WNP treatment.

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