Soil & Tillage Research 175 (2018) 62–70

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Tillage and haymaking practices speed up belowground net productivity restoration in the degraded Songnen grassland

Baba Diabate[a,b,1], Xinyu Wang[a,1], Yingzhi Gao[a,*], Pujia Yu[c], Zhengfang Wu[b], Daowei Zhou[c], Haijun Yang[a,b,c,*]

[a] Key Laboratory of Vegetation Ecology, Institute of Grassland Science, Northeast Normal University, Changchun 130024, Jilin Province, China
[b] Institute of Physical Geography, School of Geographical Sciences, Northeast Normal University, Changchun 130024, Jilin Province, China
[c] Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130012, Jilin Province, China

ARTICLE INFO

Keywords:
Belowground net primary productivity
Grassland restoration
Haymaking practice
Root fraction
Tillage practice

ABSTRACT

The improvement of productivity and soil organic matter is a central issue for the restoration of degraded land. Belowground net primary productivity (BNPP) is a major source of soil organic matter. Therefore, understanding BNPP dynamics is crucial to improving our knowledge of belowground C allocation and storage in grasslands. However, how tillage and haymaking practices affect BNPP and belowground C allocation remains poorly understood. To investigate effects of tillage and haymaking practices on BNPP and root fraction (f_{BNPP}), a field experiment set within three fenced areas, one each for maize cultivation, artificial grassland, and natural grassland, was carried out during 2012–2014. The treatments were: maize tillage; maize no-tillage, keeping residues; maize no-tillage, removing residues; artificial grassland, no haymaking; artificial grassland, haymaking; natural grassland, no haymaking; and natural grassland, haymaking. The ingrowth donuts method was used to determine BNPP. Across the years, BNPP varied from 220 to 1331 $g\,m^{-2}$. Tillage and haymaking practices significantly increased BNPP and f_{BNPP} in maize cultivation and grassland managements, respectively, suggesting that more C is allocated to soil with BNPP in those land-use practices. On average, f_{BNPP} ranged from 0.25 to 0.54 and was significantly higher in 2014 than in 2012 and 2013, irrespective of the practices, indicating that precipitation is the controlling factor for determining C allocation between belowground and aboveground. Our findings highlight that tillage and haymaking practices can enhance BNPP and belowground C allocation. Therefore, from the perspective of the whole plant, they should be considered as feasible management practices for restoration of degraded grassland.

1. Introduction

Net primary productivity (NPP) is composed of aboveground net primary productivity (ANPP) and belowground net primary productivity (BNPP). It is an important component of the global carbon budget and is used as an indicator of ecosystem function (Scurlock et al., 1999). In semi-arid grassland ecosystems, BNPP is greater than ANPP (Milchunas et al., 2005; Gao et al., 2008). Since approximately 60% of annual C originates from plants, BNPP constitutes a major source of organic matter in soil (Milchunas and Lauenroth, 2001; Chen et al., 2006; Li et al., 2011). Therefore, understanding BNPP dynamics is crucial to improving our knowledge of belowground C allocation and storage in grasslands.

There is a lack of information on the responses of BNPP and root fraction to different land-use practices due to methodology and difficulty of root research. Previous results from various studies across the world demonstrated that root biomass varied among grasslands. For example, in Central and Northern American grasslands, root biomass increased with increasing water input (Li et al., 2011; Fahnestock and Delting, 1999), whereas the results from an alpine meadow of India showed a decline of root biomass after a two-year application of N (Ram et al., 1991). In Inner Mongolian grasslands, clipping and removing aboveground biomass and leaves through grazing dramatically changed species composition and significantly decreased ANPP (Zhou et al., 2006) and BNPP (Gao et al., 2008) Unfortunately, knowledge of BNPP and root fraction is still quite limited compared to ANPP, despite the tremendous importance of belowground ecological processes (Milchunas and Lauenroth, 2001; Wu et al., 2011; Xu et al., 2012).

In China, grasslands occupy more than 400 million ha in comparison to 120 million ha of arable land, and they play an important role

* Corresponding authors at: Key Laboratory of Vegetation Ecology, Institute of Grassland Science, Northeast Normal University, Changchun 130024, Jilin Province, China
E-mail addresses: gaoyz108@nenu.edu.cn (Y. Gao), yang@nenu.edu.cn (H. Yang).
[1] Author Diabate B and Author Wang XY contributed equally to this work.

http://dx.doi.org/10.1016/j.still.2017.08.003
Received 27 March 2016; Received in revised form 7 July 2017; Accepted 10 August 2017
0167-1987/

for millions of people (Chen and Wang, 2000). The Songnen grassland, located in northeastern China, has been facing serious degradation due to anthropogenic activities and natural phenomena (Kang et al., 2007; Yi et al., 2012). Research has shown that over the past three decades, more than 30% of Songnen grassland has been changed into farmland, which may have consequences for ecosystem C processes and the cycle of nutrients (Liu et al., 2009; Yu et al., 2014; Diabate et al., 2015). Tillage and haymaking practices are important types of land-use management in grassland ecosystems. A suitable selection of tillage can improve the availability of water for yield performance by enhancing the storage capacity in soil water, reducing evaporation from the soil and allowing better development of root systems (Lampurlanés et al., 2001). Merrill et al. (1996) observed that spring wheat roots penetrate deeper into soil under no-tillage than under spring disking, with a higher density of root length due to cooler soil and higher water conservation in the near-surface area. Nevertheless, the practice of no-tillage can progressively increase mechanical resistance of the ground surface, limiting the distribution of roots within different soil profiles (Mosaddeghi et al., 2009). Roots are thinner and longer under tilled compared to no-tilled soil, and they are generally more profuse in tilled than in no-tilled soils at all depths (Karunatilake et al., 2000). The effects of haymaking on belowground productivity are different from tillage. Haymaking can accelerate the increase in carbon allocation to shoots, promote change in light regime and nutrient input, and create gaps and soil disturbance (Schaffers et al., 1998; Bakkar, 1989). As the constant supply of nutrients through atmospheric deposition can increase nutrient concentration, haymaking has become a significant tool in counteracting or reversing the changes in plant species decomposition of the vegetation (Schaffers et al., 1998).

To date, neither information about BNPP based on the ingrowth donut method nor information about effects of tillage and haymaking practices on BNPP and root fraction (f_{BNPP}) has been available for the Songnen grassland. Therefore, the present study was performed to investigate effects of tillage and haymaking practices on BNPP and root fraction (f_{BNPP}) at a site with three main management practices, i.e., cultivation, artificial grassland, and natural grassland. Specifically, two questions should be answered: (1) Can different management practices of tillage and haymaking speed up BNPP restoration, increase belowground C allocation, and further enhance soil organic matter? (2) Which land-use management is the best feasible approach for grassland restoration from the point of view of the whole plant? Understanding the effects of tillage and haymaking practices on BNPP and f_{BNPP} could improve our knowledge of the terrestrial C cycle, build a more complete theory framework, and provide suggestions for land-use practices and sustainable grassland ecosystems restoration.

2. Material and methods

2.1. Study site

2.1.1. Site description

This field experiment was carried out at Grassland Farming Research Station of Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences at the Songnen grassland, Changling County, Jilin Province, Northeast China. The Songnen grassland has an area of 300 ha and extends from 44° 34′ to 44° 38′ N and from 123° 30′ to 123° 35′ E. The study site is relatively flat, with an elevation about 145 m above sea level and characterized by a temperate, semi-arid continental monsoon climate. The climate is hot and wet in summer but very dry and cold in winter, with a mean temperature of 23 °C in July and −20 °C in January. The annual average air temperature is between 4.9 °C and 6.4 °C, and the frost-free period is about 140–160 days. The mean annual precipitation is around 450 mm, with 70% falling from June to September. The three experimental years were distinct in terms of precipitation (Supplemental Fig. S1). 2012 was a wet year with 481 mm of rainfall between June and September and an annual precipitation of 525 mm, while rainfall in 2013 was relatively low in terms of amount (355 mm) but with a clear seasonal distribution and most of the rain events occurring in July and August. The year 2014 had the driest season, with an annual precipitation of 248 mm. Mean annual temperature in 2012–2014 was between 5.15 °C and 6.96 °C (Supplemental Fig. S1). The soil type is meadow saline-alkali, with high basic salt content. The pH of the soil varied from 7.5 to 10. The dominant native species were *Leymus chinensis* (Trin.) Tzvel., *Chloris virgata* Sw., and *Puccinellia* spp (Yu et al., 2014). Community coverage was 60%-90%, with 100–200 g m^{-2} standing biomass.

2.1.2. Experimental design

The experiment includes three main types of management, i.e., maize cultivation; artificial grassland; and natural grassland. Maize cultivation management was divided into: maize tillage (MT); maize no-tillage, keeping residues (MNTKR); and maize no-tillage, removing residues (MNTMR). Artificial and natural grassland management was divided into no-haymaking (NHM) and haymaking (HM) treatments. Therefore, in each block (45 m in length, 11 m in width), there were seven treatments: MT; MNTKR; MNTMR; artificial grassland, no haymaking (AGNHM); artificial grassland, haymaking (AGHM); natural grassland, no haymaking (NGNHM); and natural grassland, haymaking (NGHM). A total of four blocks were established, with four replications for each treatment. Artificial grassland was composed totally (100%) of the perennial rhizome species *L. chinensis*, and the natural grassland was about 30% constituted of weeds species (*Carex duriuscula* and *Phragmites australis*) and about 40% of *C. virgata*. At the end of each growing season, all plants in maize cultivation management were harvested and cut down, with residues left until the early beginning of next growing season. During the same period, plants in haymaking plots of both artificial and natural grasslands were cut down to 5 cm height and taken away for hay, while in the no-haymaking plots, plants were kept intact throughout the entire study period. At the early beginning of following growing season, the first plot of maize cultivation management was completely tillage, while the second and third plots were not tillage. In the second plot, all maize and plant residues were kept, whereas in the third plot, residues were removed. In the haymaking plots, all plants residues were removed.

2.2. Plant samples collection and measurements

2.2.1. Aboveground net primary productivity (ANPP), belowground net primary productivity (BNPP), net primary productivity (NPP), and root fraction (f_{BNPP})

During the three years, plants were harvested when aboveground biomass attained its peak value between August and September. For each treatment, all the plants within an area of 1 m × 1 m with three replicates were collected by cutting at ground level and the aboveground biomass was considered approximately equal to the aboveground net primary productivity (ANPP). For maize cultivation management, only one replicate was considered. All samples were dried at 75 °C for 48 h.

The ingrowth donut method (Milchunas et al., 2005) was performed to determine BNPP (g m^{-2}). In autumn 2011, three PVC tubes were installed in every treatment for root collection throughout the entire experiment period. Roots were collected at the end of each growing season. Briefly, during root collection, PVC tubes were extracted from the holes. Soils and nylon mesh in the holes were collected, bagged, labeled, and taken to the laboratory for separation. All roots, residual impurities contained in soils, and nylon mesh were separated manually. Clean soil and nylon mesh were then returned to the original holes for the next sampling. Collected roots were handwashed and dried at 75° C for 48 h, and then weighed. BNPP was calculated as:

$$BNPP = \Delta x / \pi (R_1^2 - R_2^2)$$

Where, Δx: Total weight of root in the PVC column; π = 3.14; R_1: Radius of steel cylinder = 8.5 cm; R_2: Radius of PVC tube = 7.5 cm

Net primary productivity NPP (g m^{-2}) was determined by summing ANPP and BNPP:

$$NPP = ANPP + BNPP$$

The fraction of total NPP allocated to belowground (f_{BNPP}) (Hui and Jackson, 2006) was calculated as follows:

$$f_{BNPP} = BNPP/(ANPP + BNPP)$$

2.2.2. Soil moisture content and soil organic matter (SOM) measurement

Soil moisture content ($m^3\ m^{-3}$) was determined in the 0–10 cm soil layer using a portable "Campbell Scientific TDR 100 (Time Domain Reflectometry, Germany)" with a probe length of 7.5 cm. The measurement was taken at intervals of 15 days. Ten measurements were performed in each treatment in the vicinity of PVC tubes and the average value was used in analysis. For soil organic matter (SOM), soil samples were taken to a depth of 30 cm from five random locations within each treatment. The soil bulk density was similar for all treatments. Soil samples were put into plastic bags and stored in shade before being transported to the laboratory for measurement. All samples were air-dried, separated from the visible plant materials, and ground to pass first through a 2-mm sieve and then though a 0.49-mm sieve for SOM analysis. An amount of 0.5 g sieved soil was taken for analysis and a modified Mebius method was used to determine SOM.

2.3. Data analysis

Statistical analyses were performed using SPSS 17.0 (SPSS Inc, Chicago, IL, USA). Two-way analysis of variance (ANOVA) was used to analyze the effects of years, treatments, and their interaction on ANPP, BNPP, NPP, and f_{BNPP}. One-way ANOVA was performed to examine the effect of different treatments on soil moisture and soil organic matter. Correlation and regression analysis were conducted with SigmaPlot 10.0, while a post hoc least significant difference (LSD) test was used to compare the mean values within a patch. The significant difference level was at $P < 0.05$.

3. Results

3.1. Soil moisture content (SMC)

Soil moisture content (SMC) of all treatments had a similar seasonal dynamic and peaked at different levels across the three years of study (Fig. 1). In 2012, SMC peaked three times–in late June, mid-July, and mid-September (Fig. 1A). In 2013, SMC showed a similar pattern, with the peaks occurring in late May, mid-July, and mid-September (Fig. 1B). However, in 2014, SMC peaked twice, in late May and the middle of September (Fig. 1C). Overall, there was a trend showing that the highest mean SMC was obtained in MT and the lowest was found in AGHM treatments (Fig. 1A, B, C). Across the three growing seasons, 2012 showed the highest mean SMC ($m^3\ m^{-3}$) compared to those in 2013 and 2014 (2012: 31.57 ± 1.56; 2013: 19.58 ± 0.88; 2014: 15.85 ± 0.61).

3.2. Aboveground net primary productivity (ANPP) and net primary productivity (NPP)

There was a strong interaction between year and treatments affecting ANPP ($P < 0.001$, Table 1). During the three experimental years, ANPP ranged from 391 to 1822 g m^{-2}. There was a trend with MT leading to the highest ANPP value (1822 g m^{-2}), whereas the lowest value (391 g m^{-2}) was observed in the HGHM treatment (Fig. 2a). With respect to management individually and across the whole study period, ANPP decreased significantly ($P < 0.05$) from MT

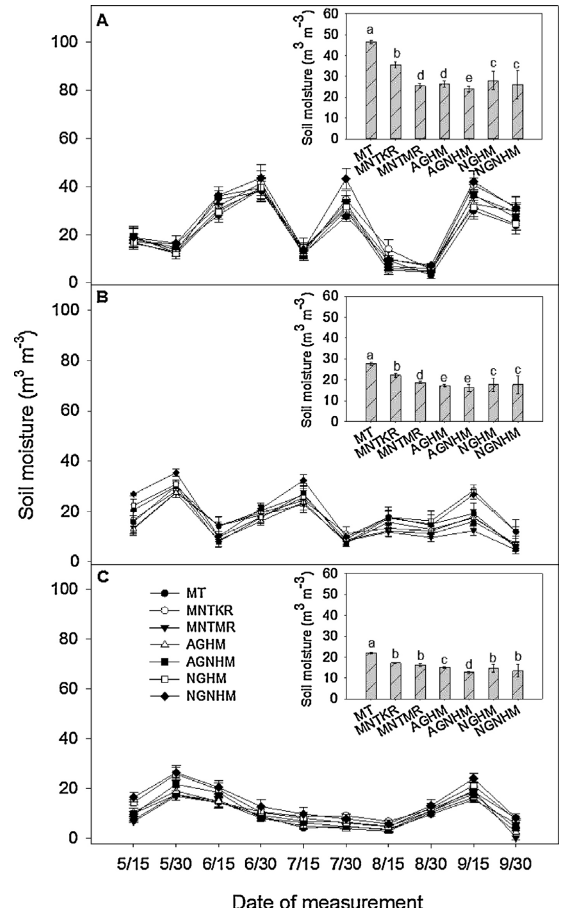

Fig. 1. Seasonal dynamics of soil moisture content (mean ± SE) at different treatment patterns in 2012 (A), 2013 (B), and 2014 (C). The insert figures show the average soil moisture content in different treatments during the growing seasons. The treatments include: MT (maize tillage), MNTKR (maize no-tillage, keeping residues), MNTMR (maize no-tillage, removing residues), AGNHM (artificial grassland no haymaking), AGHM (artificial grassland, haymaking), NGNHM (natural grassland, no haymaking), and NGHM (natural grassland, haymaking). Means with the same letter are not significantly different ($P > 0.05$).

to MNTMR in maize cultivation managements, while in both artificial and natural grassland management, ANPP decreased from HM to NHM treatments. In general, ANPP decreased from 2012 to 2014 (2012: 880.48 g m^{-2}, 2013: 828.80 g m^{-2}, and 2014: 652.95 g m^{-2}) (Fig. 2a).

Like ANPP, NPP was significantly affected ($P < 0.05$) by treatments over the three years (Table 1). NPP decreased significantly ($P < 0.05$) from MT to MNTMR in maize cultivation management and also decreased from AGNHM to AGHM in artificial grassland management over the three experimental years (Fig. 2b). However, as to the natural grassland management, haymaking significantly decreased NPP in 2012 and 2014, while it significantly increased NPP in 2013 ($P < 0.05$) (Fig. 2b).

3.3. Belowground net primary productivity (BNPP) and root fraction (f_{BNPP})

There was no significant interactive effect between year and treatment on BNPP ($P = 0.710$, Table 1). On average, BNPP varied from 254 to 1331 g m^{-2}. Overall, MT (1331 g m^{-2}) tended to have the highest BNPP value, while the lowest was found in AGNHM (220 g m^{-2}). Across the different treatments, BNPP decreased significantly ($P < 0.05$) from MT to MNTMR in maize cultivation management, whereas BNPP was higher in the haymaking treatment than the no-haymaking treatment in both artificial and natural grassland

Table 1
Results of two-way ANOVA analysis for effects of Year (Y), Treatment (T) and their interaction (Y x T)on aboveground net primary productivity (ANPP), belowground net primary productivity (BNPP), net primary productivity (NPP) and root fraction (f_{BNPP}).

Factors	ANPP			BNPP		NPP		f_{BNPP}	
	df	F	Sig.	F	Sig.	F	Sig.	F	Sig.
Y	2	52.910	< 0.001	30.114	< 0.001	16.949	< 0.001	2.292	0.109
T	6	183.368	< 0.001	536.670	< 0.001	103.845	< 0.001	25.076	< 0.001
Y x T	12	8.604	< 0.001	0.737	0.710	2.057	0.033	1.519	0.141

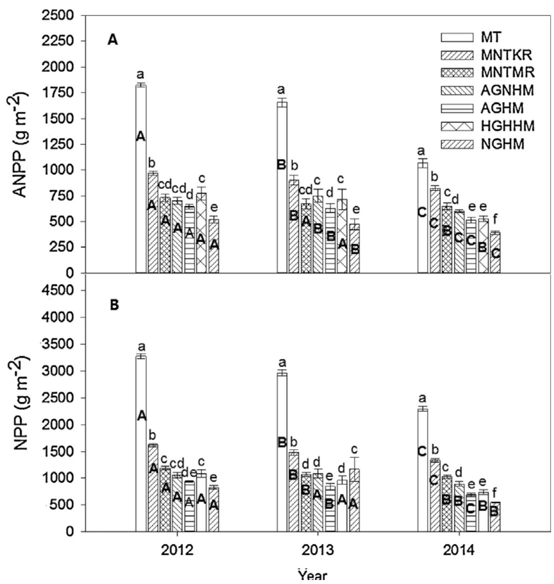

Fig. 2. Aboveground net primary productivity (A) (ANPP, g m^{-2}) and net primary productivity (B) (NPP, g m^{-2}) (mean ± SE), of different treatments across the experimental years. The treatments are as indicated in Fig. 1. The different lowercase letters represent significant different (P < 0.05) between treatments in the same year. The different capital letters represent significant different (P < 0.05) between years within the same treatment.

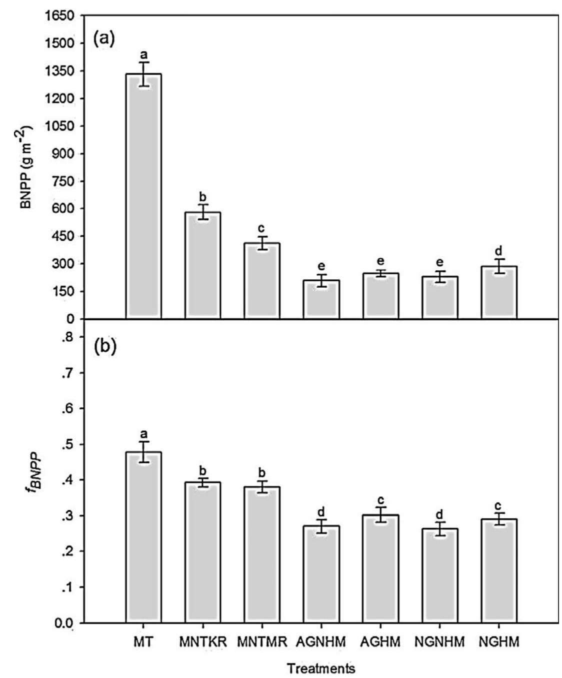

Fig. 3. Belowground net primary productivity (a) (BNPP) and root fraction (f_{BNPP}) (b) (mean ± SE) of different treatments during study periods. The different treatments are as indicated in Fig. 1. Means with the same letter are not significantly different (P > 0.05).

managements (Fig. 3a). Natural grassland (323 g m^{-2}) had more BNPP than artificial grassland (280 g m^{-2}). In terms of years, BNPP was higher in 2012 than in 2013 and 2014.

As with BNPP, there was no significant interactive effect between year and treatments on f_{BNPP} (P = 0.141, Table 1). Root fraction (f_{BNPP}) ranged from 0.25 to 0.54 during the whole experimental period. Overall, f_{BNPP} in MT (0.48) was the highest, while the lowest value was found in AGNHM (0.28). f_{BNPP} was greater in 2014 than in 2013 and 2012, respectively.

3.4. Soil organic matter (SOM)

Soil organic matter (SOM, g kg^{-1}) in both 0–10 cm and 10–20 cm soil profiles varied across treatments (Fig. 4). In general, the highest concentration (8.7 g kg^{-1}) was observed in MT in 10–20 cm soil profile, whereas the lowest concentration (4.3 g kg^{-1}) was found in AGHM in 0–10 cm soil profile. SOM decreased significantly (P < 0.05) from MT to MNTMR, AGNHM to AGHM, and NGNHM to NGHM, respectively (Fig. 4). For artificial grassland management, there was no significant effect of the haymaking practice on SOM.

3.5. Correlation comparisons

There was a significant positive relationship between SMC and ANPP ($r^2 = 0.333$, $P < 0.0001$), BNPP ($r^2 = 0.222$, $P < 0.0001$), whereas no significant correlation was found between SMC and f_{BNPP}

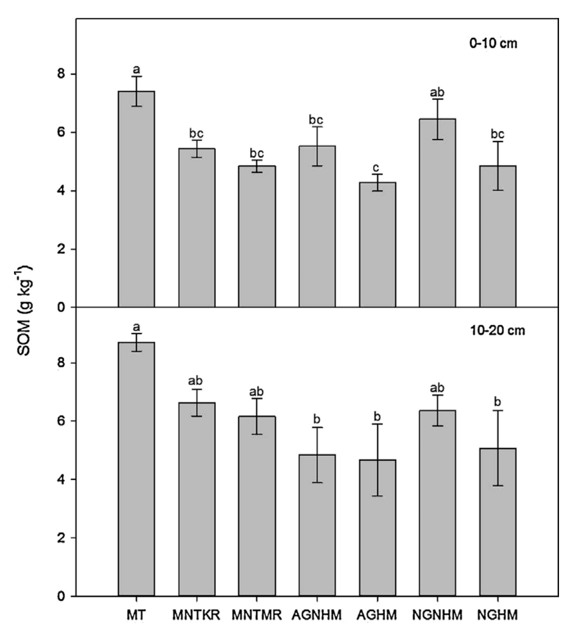

Fig. 4. Soil organic matter (SOM) of different treatments at 0–10 cm and 10–20 cm soil depths. Means with the same letter are not significantly different (P > 0.05).

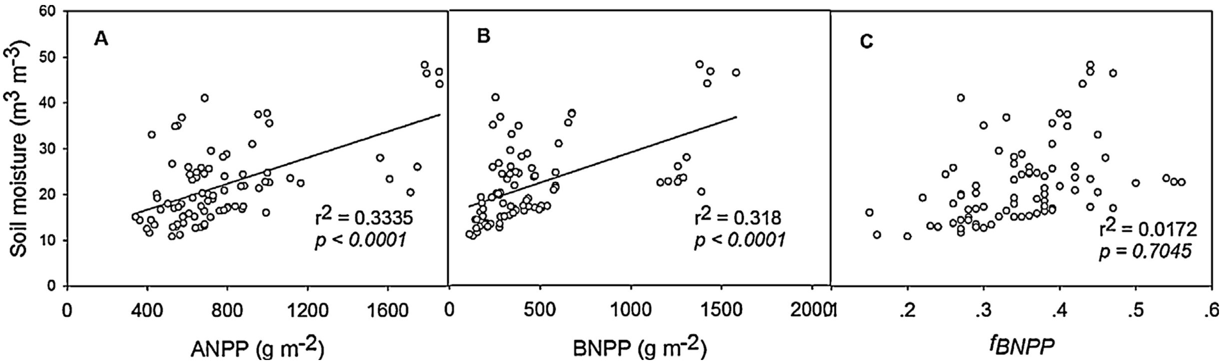

Fig. 5. Correlation between soil moisture content and ANPP (A), BNPP (B), f_{BNPP} (C) over the three experimental years. For A: $y = 11.0374 + 0.0142\,x$, $r^2 = 0.335$, $p < 0.0001$; B: $y = -15.872 + 0.013\,x$, $r^2 = 0.318$, $p < 0.0001$.

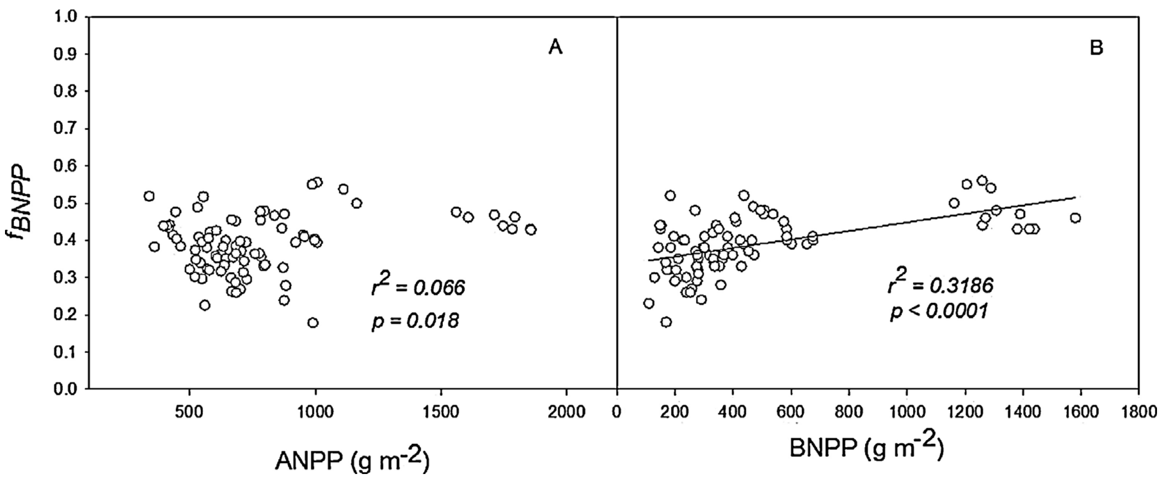

Fig. 6. Relationship between root fraction (f_{BNPP}) and ANPP (A) and BNPP (B). For B: $y = 0.5645 + 0.0001x$, $r^2 = 0.3186$, $p < 0.0001$.

($r^2 = 0.017$, $P = 0.71$) (Fig. 5). f_{BNPP} and *BNPP* were significantly positively correlated (Fig. 6) ($r^2 = 0.318$, $P < 0.0001$), but there was no significant relationship between f_{BNPP} and *ANPP* (ANPP: $r^2 = 0.066$, $P = 0.018$) (Fig. 6). The correlation between SOM and ANPP, BNPP, NPP in both 0–10 cm and 10–20 cm soil profiles was analyzed by regression analysis (Fig. 7). As for ANPP, there was significant positively correlated with SOM in both profiles (0–10 cm, $r^2 = 0.376$, $p = 0.0001$; 10–20 cm, $r^2 = 0.234$, $p = 0.009$). BNPP was significantly positively correlated with SOM in both profiles (0–10 cm, $r^2 = 0.403$, $p < 0.0001$; 10–20 cm, $r^2 = 0.435$, $p < 0.0001$). NPP was also significantly positively related to SOM in both 0–10 cm soil profiles ($r^2 = 0.414$, $p < 0.0001$) and 10–20 cm soil profiles ($r^2 = 0.353$, $p = 0.001$).

4. Discussion

4.1. Effects of tillage and haymaking practices on soil moisture

Water availability, whether precipitation or soil moisture content (SMC), has been widely used as the key controlling factor for grassland productivity (Niu et al., 2008; Liu et al., 2009; Han et al., 2011). In this study, the positive correlation between SMC and ANPP, and also between SMC and BNPP throughout multifactor linear regression analyses (Fig. 5), confirmed that water is the dominant factor controlling grassland productivity. This result is also in agreement with previous studies showing that grassland productivity is dependent on SMC (Knapp and Smith, 2001; Weng and Luo, 2008). In addition, our results showed that SMC decreased from MT to MNTMR, through MNTKR in maize cultivation management and from no-haymaking to haymaking treatments in both artificial and natural grassland managements (Fig. 1, insert A, B, C). Previous studies reported that tillage had a significant effect on SMC by affecting the amount of infiltrating precipitation water into soil and evaporative water losses (Gao et al., 1999; Tremberth et al., 2003; IPCC, 2007; Xu et al., 2013). In tillage treatments, soil was well structured, less compacted, and therefore prepared to retain the precipitation efficiently, leading to an increase in water storage. Evaporation from the soil is an important component of evapotranspiration and can be regulated by management of the surface, such as through tillage, maize residue envelopment, and mulching, which can change soil water content (Wang et al., 2007; Guan et al., 2015). In the present study, our results revealed that in no-tillage treatments, SMC was greater in MNTKR than in MNTMR treatment (Fig. 1 insert). Monneveux et al. (2006) reported that keeping maize residues on the ground improved the capacity of soil to intercept rainfall, reduced soil temperature, and therefore increased SMC, as observed in the present study. Furthermore, the increase of SMC in no-haymaking treatments consistently matched previous studies, likely due to the availability of water and nutrients, as reported in the studies by Sherry et al. (2008) and Xu et al. (2012) that haymaking by removing aboveground biomass reduced soil moisture content due to exposing the grassland to light, radiation, and evaporation.

4.2. Effects of tillage and haymaking practices on ANPP and NPP

Our results indicated that tillage and haymaking practices directly affected grassland aboveground net primary productivity (ANPP). ANPP and NPP decreased markedly from MT to MNTMR in the maize cultivation management (Fig. 2). Previous studies concluded that tillage, by breaking soil compaction, promoted soil water infiltration capacity, root growth, and penetration, and finally enhanced ANPP and

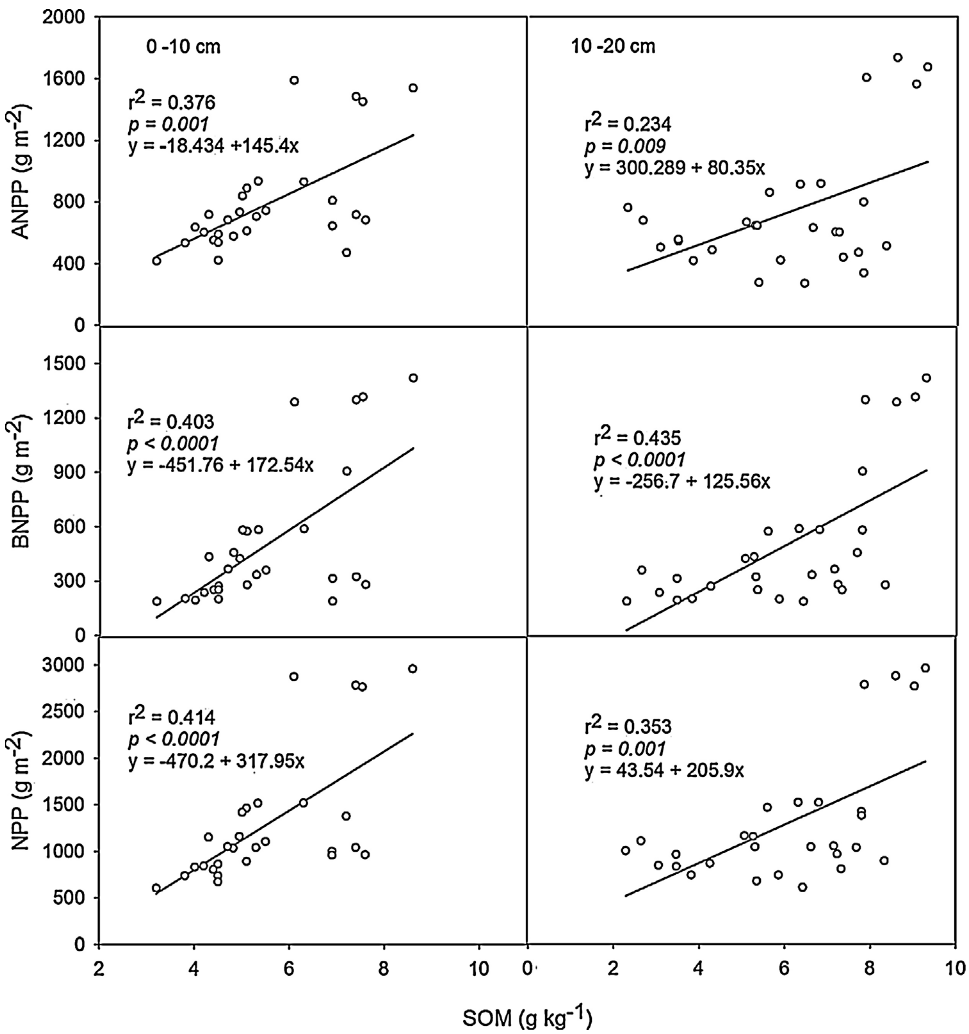

Fig. 7. Relationship between SOM and ANPP, BNPP, NPP at 0–10 cm and 10–20 cm soil depths. For ANPP: *((0–10 cm); y = -18.434+ 145.4x, r^2 = 0.376, p = 0.0001, (10–20 cm) y = 300.289 + 80.35x, r^2 = 0.234, p = 0.009)*, for BNPP: *((0–10 cm); y = -451.76 + 172.54x, r^2 = 0.403, p < 0.0001, (10–20 cm); y = -256.7 + 125.56x, r^2 = 0.435, p < 0.0001)*; for NPP: *((0–10 cm); y = -470.2 + 317.95x, r^2 = 0.414, p < 0.0001, (10–20 cm); y = 43.57 + 205.9x, r^2 = 0.353, p = 0.001).*

NPP (Pikul and Aase, 1999; Pikul and Aase 2003; Guan et al., 2015). Our results are in agreement with those studies. Moreover, maize residues on the soil surface protect the soil from evaporation and erosion, and provide substrates for soil microorganisms, which accounts for higher yield (Dong et al., 2009). For artificial and natural grasslands, the results showed that ANPP varied from 462 to 684 g m^{-2} and reached 640 g m^{-2} and 567 g m^{-2} in the artificial and natural grassland managements, respectively. Previous studies have shown that ANPP varied from 50 to 250 g m^{-2} with an average of 150 g m^{-2} in natural conditions (Bai et al., 2004); however, ANPP ranged from 568 g m^{-2} to 1028 g m^{-2} at moderately and heavily grazed sites, under condition of sufficient water and nitrogen addition, respectively, in the Inner Mongolian semi-arid steppe (Li et al., 2011). According to Li et al. (2014) and Diabate et al. (2015), ANPP ranged from 100 to 730 g m^{-2} in a patchy natural Songnen grassland, and our data fall in that range. Our results revealed that haymaking increased ANPP due most likely to the increase in carbon allocation to leaf, nutrient input, and/or change in life regime (Han et al., 2011). ANPP was higher in the artificial grassland than in the natural grassland, likely due primarily to species composition. Artificial grassland was 100% composed of the native perennial rhizomatous species *L. chinensis,* which is the dominant species in the Songnen grassland (Zhou et al., 2006). The high increase of ANPP in artificial grassland is mainly due to the capacity of *L. chinensis* to tolerate harsh conditions, the small seed size, which contributes to the promotion of more seeds, the rapid maturity of seed, and early fall (Donath and Eckstein, 2012; Miglécz et al., 2013; Li et al., 2014). It is widely known that species with larger seeds mature and fall later, which reduces their possibility to reach soil, and they therefore have less opportunity to germinate and grow (Li et al., 2014). Furthermore, *L. chinensis* is a typical clonal grass with great economic value and high resistance to various stresses. It has been reported that this species generally tolerates the damage of defoliation with its ability for compensatory or over-compensatory growth (Zhao et al., 2008). The higher ANPP in NHM compared to HM treatments may be attributable mainly to the presence of optimal conditions for germination and growth. Litter can provide optimal conditions for the soil in no-haymaking treatment by maintaining water availability and by decreasing evaporation, which in turn increases productivity. It has been widely reported that a reasonable amount of litter facilitates germination and vegetation growth by providing optimal conditions during extreme environmental conditions (Brooker et al., 2008; Eckstein et al., 2012; Javier et al., 2012; Li et al., 2014).

4.3. *Effects of tillage and haymaking on BNPP*

Belowground net primary productivity (BNPP) is expected to play a large role in the availability of resources compared to ANPP (Li et al., 2011). In the present study, BNPP varied with different managements and decreased significantly from MT to MNTMR in maize cultivation management, whereas it increased markedly from no-haymaking (NHM) to haymaking (HM) treatments in both artificial and natural grassland managements (Fig. 3a). Furthermore, BNPP was higher in 2012 than in 2013 and 2014, probably due to the high precipitation amount that was 1.47 and 2.11 times greater in 2012 than in 2013 and

2014, respectively (Supplementary Fig. S1). Previous studies reported that precipitation promoted plant growth in relatively dry conditions (Sala et al., 1988; Huxman et al., 2004; Xu et al., 2013). Our results showed positive effects of tillage on plant root growth and BNPP, and this finding is consistent with the previous studies. Guan et al. (2015) found that plow tillage improved the spatial and temporal patterns of root system distribution, and that root length density was positively correlated with grain yield. Similarly, Pikul and Aase, (1999) and Pikul and Aase (2003) reported that sub-soiling reduced soil compaction and enhanced root growth, yield, and water use efficiency (Bennie and Botha, 1986). In addition, Guan et al. (2015) reported that no-tillage practice can delay plant growth and maturity, as was typically observed in this study. Furthermore, BNPP in natural grassland was greater than in artificial grassland, probably due to their species composition. Natural grassland was composed of annual and biannual species such as *Salsola collina* Pall, *Chenopodium glaucum* L., *Artemisia annua* L., *Sonchus arvensis* L., *Setaria viridis* (L.) Scop. Considered opportunistic species, they have the ability to rapidly occupy space by displaying strong ramets when resources are available (Gao et al., 2011; Diabate et al., 2015). However, in both artificial and natural grasslands, haymaking practice significantly increased BNPP (Fig. 3a), and this is probably due to the compensatory growth mechanism effects. Previous studies reported that after cutting or clipping of aboveground biomass, plants may adjust their growth through compensatory growth that can stimulate belowground biomass production due to increased sink strength (McNaughton et al., 1998; Xu et al., 2012). Moreover, haymaking can change plant physiological processes and allocation patterns, leading to the increase of BNPP, as previously reported by Xu et al. (2012) and confirmed in this study.

4.4. Effects of tillage and haymaking on root fraction (f_{BNPP})

Root fraction (f_{BNPP}) is a vital parameter in plant ecology and evolution as well as in C cycling models (Enquist and Niklas, 2002; Ågren and Franklin, 2003; Hui and Jackson, 2006). In the present study, f_{BNPP} was higher in 2014 than in 2012 and 2013, due mainly to lower precipitation and higher temperatures occurring in that period. Previous studies reported positive effects of warming on f_{BNPP} in grassland ecosystems. For example, Xu et al. (2012) reported that warming remarkably increased f_{BNPP}, indicating that plants were adjusting their allocation patterns to maximize their relative growth rate. Warming induced dry conditions increasing f_{BNPP} when plants allocated proportionally more biomass to roots in response to low moisture conditions, based on the optimal partitioning theory (Bloom et al., 1985; Chapin et al., 1987), which is supported by several studies (Hui and Jackson, 2006; McCarthy and Enquist, 2007). The estimates of f_{BNPP} in this study varied from 0.25 to 0.54 with a mean of 0.38. The values were smaller compared to the estimates of data compiled across the world's grasslands, which range from 0.40-0.86 with a mean of 0.71 (Hui and Jackson, 2006). This is probably attributable to sampling and calculation methods: our estimation was based on ingrowth donut methods for root collection, while the previous studies either used soil auger methods to get total belowground biomass, then estimate or calculate BNPP (Hui and Jackson, 2006; Gao et al., 2008), or else used ^{14}C dilution methods for BNPP (Milchunas and Lauenroth, 1992). The estimated f_{BNPP} in this study may be underestimated due to biases of method performed. The shallow depth of donuts (30 cm) may be one of the main reasons for the f_{BNPP} underestimation, even though it has been stated that 85% of roots are concentrates in 0–20 cm soil depth in grassland ecosystems (Jackson et al., 1996). However, we found that there are parts of roots in deep soil layers, especially in maize cultivation management, that will not be covered by this method, thus leading to the underestimation f_{BNPP}. As with all methods for collecting root samples, the ingrowth donuts method also has some inherent disadvantages that may underestimate BNPP (Milchunas et al., 2005). For example, plants with a principal vertical spatial orientation of roots tend to grow vertically to the ingrowth walls, resulting in an underestimation of root production when the plants are horizontally established to the ingrowth structure. Also, the diameter of the ingrowth donut in a link to potentially full available area may constitute a factor influencing estimate of root production. Previous studies reported that the diameter of an ingrowth donut greater than the horizontal root spread of a species would have some area without any root biomass, yet that area would still be included in the calculation, resulting in underestimation of production in root occupied area (Milchunas et al., 2005; Milchunas, 2009). Here, we need to mention that this is the only feasible method of direct measuring BNPP in this salt alkali soil, although ingrowth donuts can induce some bias. Our results also showed that f_{BNPP} decreased from MT to MNTMR in maize cultivation management probably due to the optimal conditions caused by tillage (see BNPP discussion). In both artificial and natural grassland, haymaking led to the highest f_{BNPP} value (Fig. 3b). Similar studies have reported positive effects of cutting aboveground biomass on root fraction by disturbing the balance between ANPP and BNPP (Gao et al., 2008; Xu et al., 2012), leading to the increase of f_{BNPP}. After haymaking, soils are more exposed to evaporation, leading to water loss, which can stimulate root growth by capturing more water in deeper soil, as supported by previous studies that reported plants growing at low water availability exhibiting stronger growth in BNPP compared to those under favorable water conditions (Hui and Jackson, 2006; Gao et al., 2011; Xu et al., 2012). Plants may have adjusted physiological processes because the aboveground biomass demand of water and nutrients decreased dramatically after haymaking, leading to reallocation of more resources to roots (Oesterheld and McNaughton, 1988).

4.5. Effects of tillage and haymaking on soil organic matter (SOM)

Considered the main source of SOM in grassland ecosystem, productivity, including ANPP and BNPP analysis, is a significant component of the terrestrial carbon cycle, especially carbon sequestration (Devagiri et al., 2013). This concept was corroborated by a strong relationship between SOM and ANPP and BNPP and NPP (Fig. 7). Usually, the reclamation of native grassland to agricultural land can dramatically reduce SOM absorption and storage due to soil heterotrophic activity and microbial decomposition of SOM (Wang et al., 2009; Syswerda et al., 2011; Yu et al., 2014). However, the grassland we studied is heavily degraded and had been cultivated for a long time before being abandoned. As shown in our results, SOM content was less than 10 g kg^{-1}, while SOM of intact native grassland is around 30–40 g kg^{-1} (Song et al., 2009; Wang, 2009). In the present study, we sought to learn which managements can enhance both ANPP and BNPP, as well as NPP and SOM. SOM in the maize cultivation management was higher compared to those in artificial and natural grasslands at both soil profiles (Fig. 4), possibly due to the height of the maize community. Chave et al. (2005) reported that average height of community is a good predictor of net primary productivity (NPP) for plants, which directly influences the amount of carbon contained in vegetation and incorporated into the soil as litter (Lavorel and Grigulis, 2012; Devagiri et al., 2013; Diabate et al., 2015). We also found that SOM was higher in the natural grassland than in the artificial grassland (Fig. 4), mainly because of the differing abilities of the plant species to capture, store, and release carbon. The artificial grassland was 100% composed of the perennial species *L. chinensis*, whereas the natural grassland was about 30% composed of weed species (*C. duriuscula* and *P. australis*) and about 40% of windwill grass (*C. virgata*), and the combined functional characteristics of plant communities under a given regional climatic management are a key driver of carbon sequestration in terrestrial ecosystems (Duiker and Lal, 1999; Thompson et al., 2009). For both artificial and natural grassland management, SOM remarkably increased in the no-clipping treatment compared to the clipping treatment, probably due to the removal of litter in the clipping treatment. The positive correlation between SOM and BNPP confirms that more C is allocated to soil and therefore may increase global C sequestration.

5. Conclusion

Grassland degradation through excessive reclamation has become a serious social, environmental, and ecological problem in China, and its restoration is a pressing matter. To solve this problem, it is necessary to include belowground parts of the plants for successful and sustainable management and restoration of degraded grassland from the whole plant perspective. Our findings indicate that land-use practices had significant effects on BNPP and f_{BNPP}. Practices such as tillage and haymaking enhanced BNPP, belowground C allocation, and also SOM in maize tillage practice. Therefore, these practices should be given great consideration in grassland management.

Acknowledgments

The authors acknowledge support from National Key Basic Research Program of China (2016YFC0500703), the National Natural Science Foundation of China (31670446, 31270444), the program for New Century Excellent Talents in University (NCET-13-0717), and China Scholarship Council for Baba Diabaté.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.still.2017.08.003.

References

Ågren, G.I., Franklin, O., 2003. Root: shoot ratios, optimization and nitrogen productivity. Ann. Bot. 92, 795–800.
Bai, Y.F., Han, X.G., Wu, J.G., Chen, Z.Z., Li, L.H., 2004. Ecosystem stability and compensatory effects in the Inner Mongolia grassland. Nature 431, 181–184.
Bakkar, J.P., 1989. Nature Management by Grazing and Cutting. Junk, Dordrecht.
Bennie, A.T.P., Botha, F.J.P., 1986. Effect of deep tillage and controlled traffic on root growth: water-use efficiency and yield of irrigated maize and wheat. Soil Till. Res. 7, 85–95.
Bloom, A.J., Chapin, F.S., Mooney, H.A., 1985. Resource limitation in plants-an economic analogy. Annu. Rev. Ecol. Syst. 16, 363–392.
Brooker, R.W., Maestre, F.T., Callaway, R.M., Lortie, C.L., Cavieres, L.A., Kunstler, G., Liancourt, P., Tielbörger, K., Travis, J.M.J., Anthelme, F., Armas, C., Coll, L., Corcket, E., Delzon, S., Forey, E., Kikvidze, Z., Olofsson, J., Pugnaire, F., Quiroz, C.L., Saccone, P., Schiffers, K., Seifan, M., Touzard, B., Michalet, R., 2008. Facilitation in plant communities: the past, the present, and the future. J. Ecol. 96, 18–34.
Chapin, F.S., Bloom, A.J., Field, C.B., Waring, R.H., 1987. Plant responses to multiples environmental factors. Bioscience 37, 49–57.
Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B., Yamakura, T., 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145, 87–99.
Chen, Z.Z., Wang, S.P., 2000. Typical Steppe Ecosystems of China. Science Press, Beijing.
Chen, Y.X., Lee, P., Lee, G., Mariko, S., Oikawa, T., 2006. Simulating root responses to grazing of a Mongolian grassland ecosystem. Plant Ecol. 183, 265–275.
Devagiri, G.M., Money, S., Sarnanm, S., Dadhwal, V.K., Patil, P., Khaple, A., Hubballi, S., 2013. Assessment of above ground biomass and carbon pool in different vegetation types of south western part of Karnataka, India using spectral modeling. J. Trop. Ecol. 54, 149–165.
Diabate, B., Gao, Y.Z., Li, Y.H., Wang, C., Sun, B.R., Asch, F., Zhou, D.W., 2015. Associations between species distribution patterns and soil salinity in the Songnen grassland. Arid Land Res. Manag. 29, 199–209.
Donath, T.W., Eckstein, R.L., 2012. Litter effects on seedling establishment interact with seed position and earthworm activity. Plant Biol. 14 (1), 163–170.
Dong, W.X., Hu, C.S., Chen, S.Y., Zhang, Y.M., 2009. Tillage and residues management effects on soil carbon and CO2 emission in a wheat-corn double-cropping system. Nutr. Cycl. Agroecosyst. 83, 27–37.
Duiker, S.W., Lal, R., 1999. Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. Soil Till. Res. 52, 73–81.
Eckstein, R.L., Ruch, D., Otte, A., Donath, T.W., 2012. Invasibility of a nutrient-poor pasture through resident and non-resident herbs is controlled by litter, gap size and propagule pressure. PLoS One 7, e41887.
Enquist, B.J., Niklas, K.J., 2002. Global allocation rules for patterns of biomass partitioning in seed plants. Science 295, 1517–1520.
Fahnestock, J.T., Delting, J.K., 1999. Plant responses to defoliation and resource supplementation in the Pryor Mountain. J. Rang. Manag. 52, 263–270.
Gao, Z.Q., Jun, Y., Miao, G.Y., Gao, F.W., 1999. Effects of tillage and mulch methods on soil moisture in wheat fields of loess plateau, China. Pedosphere 9, 161–168.
Gao, Y.Z., Giese, M., Lin, S., Sattelmacher, B., Zhao, Y., Brueck, H., 2008. Belowground net primary productivity and biomass allocation of grassland in Inner Mongolia as affected by grazing intensity. Plant Soil 307, 4–50.
Gao, Y.Z., Wang, Y.H., Yang, F., Li, Z.J., Giese, M., Zhang, J., Yang, Y.N., 2011. Small amount of salt stimulates regrowth of *Leymus chinensis* and *Stipa baicalensis* IX Internat. Rang. Congress 79.
Guan, D., Zhang, Y.S., Al-Kaisi, M.M., Wang, Q.Y., Zhang, M.C., 2015. Tillage practices effect on root distribution and water use efficiency of winter wheat under rain-fed condition in the North China Plain. Soil Till. Res. 146, 286–295.
Han, Y., Zhang, Z., Wang, C.H., Jiang, F.H., Xia, J.Y., 2011. Effects of mowing and nitrogen on soil respiration in three patches in old-field grassland in Inner Mongolia. Plant Ecol. 5, 219–228.
Hui, D.F., Jackson, R.B., 2006. Geographic and interannual variability in biomass partitioning in grassland ecosystems: a synthesis of field data. New Phytol. 169, 85–93.
Huxman, T.E., Smith, M.D., Fay, P.A., Knapp, A.K., Shaw, M.R., Loik, M.E., Smith, S.D., Tissue, D.T., Zak, J.C., Weltzin, J.F., Pockman, W.T., Sala, O.E., Haddad, B.M., Harte, J., Koch, G.W., Schwinning, S., Small, E.E., Williams, D.G., 2004. Convergence across biomes to common rain-use efficiency. Nature 429, 651–654.
IPCC, 2007. Summary for policymakers. Climate Change 2007: The Physical Science Basis.
Jackson, R.K., Canadell, J., Ehleringer, J.R., Mooney, H.A., Sala, O.E., Schulze, E.D., 1996. A global analysis of root distributions for terrestrial biomes. Oecologia 108 (3), 389–411.
Javier, V.B., Marie, C.D.B., Maria, Z., 2012. Effects of *Pinus pinea* litter on seed germination and seedling performance of three Mediterranean shrub species. Plant Growth Regul. 66, 285–292.
Kang, L., Han, X.G., Zhang, Z.B., Sun, O.J.X., 2007. Grassland ecosystems in China: review of current knowledge and research advancement. Philos. Trans. Roy. Soc. (B) 362, 997–1008.
Karunatilake, U., van Es, H.M., Schindelbeck, R.R., 2000. Soil and wheat response to plow tillage and no-tillage after alfalfa-to-wheat conversion on a clay loam soil in New York. Soil Till. Res. 55, 31–42.
Knapp, A.K., Smith, M.D., 2001. Variation among biomes in temporal dynamics of aboveground primary productivity. Science 291, 481–484.
Lampurlanés, J., Angés, P., Cantero-Martinez, C., 2001. Root growth: soil water content and yield in barley under different tillage systems on two soils in semiarid conditions. Field Crop Res. 69, 27–40.
Lavorel, S., Grigulis, K., 2012. How fundamental plant functional trait relationships scale-up to trade-offs and synergies in ecosystem services. J. Ecol. 100, 128–140.
Li, J.Z., Lin, S., Taube, F., Pan, Q.M., Dittert, K., 2011. Above and belowground net primary productivity of grassland influenced by supplemental water and nitrogen in Inner Mongolia. Plant Soil 340, 253–264.
Li, Q., Yu, P.J., Chen, X.Y., Li, G.D., Zhou, D.W., Zheng, W., 2014. Facilitative and inhibitory effect of litter on seedling emergence and early growth of six herbaceous species in an early successional old field ecosystem. Sci. World J. 1–11 Article.
Liu, D.W., Wang, Z.M., Song, K.S., Zhang, B., Hu, L.J., Huang, N., Zhang, S.M., Luo, L., Zhang, C.H., Jiang, G.J., 2009. Land use/cover changes and environmental consequences in Songnen Plain. Northeast China. Chinese Geogr. Sci. 19, 299–305.
McCarthy, M.C., Enquist, B.J., 2007. Consistency between an allometric approach and optimal partitioning theory in global patterns of plant biomass allocation. Funct. Ecol. 21, 713–720.
McNaughton, S.J., Banyikwa, F.F., McNaughton, M.M., 1998. Root biomass and productivity in a grazing ecosystem: the Serengeti. Ecology 79, 587–592.
Merrill, S.D., Black, A.L., Bauer, A., 1996. Conservation tillage affects root growth of dryland spring wheat under drought. Soil Sci. Soc. Am. J. 60, 575–583.
Miglécz, T., Tóthmérész, B., Valkó, O., Kelemen, A., Török, P., 2013. Effects of litter on seedling establishment: an indoor experiment with short-lived *Brassicaceae* species. Plant Ecol. 214 (2), 189–193.
Milchunas, D.G., Lauenroth, W.K., 1992. Carbon dynamics and estimates of primary production by harvest, ^{14}C dilution and ^{14}C turnover. Ecology 73, 593–607.
Milchunas, D.G., Lauenroth, W.K., 2001. Belowground primary productivity by carbon isotope decay and long-term root biomass dynamics. Ecosystems 4, 139–150.
Milchunas, D.G., Mosier, A.R., Morgan, J.A., LeCain, D.R., King, J.Y., Nelson, J.A., 2005. Root productivity and tissue quality in a shortgrass steppe exposed to elevated CO_2: Using a new ingrowth method. Plant Soil 268, 111–122.
Milchunas, D.G., 2009. Estimating root production: comparison of 11 methods in shortgrass steppe and review of biases. Ecosystems 12, 1381–1402.
Monneveux, P., Quillero, E., Sanchez, C., Lopez-Cesati, J., 2006. Effect of zero tillage and residues conservation on continuous maize cropping in a subtropical environment (Mexico). Plant Soil 279, 95–105.
Mosaddeghi, M.R., Mahboubi, A.A., Safadoust, A., 2009. Short-term effects of tillage and manure on some soil physical properties and wheat root growth in a sandy loam soil in western Iran. Soil Till. Res. 104, 173–179.
Niu, S.L., Wu, M.Y., Han, Y., Xia, J.Y., Li, L.H., Wan, S.Q., 2008. Water-mediated responses of ecosystem carbon fluxes to climate change in a temperate steppe. New Phytol. 177, 207–217.
Oesterheld, M., McNaughton, S.J., 1988. Intraspecific variation in the response of *Themeda trianda* to defoliation: the effect of time of recovery and growth rates on compensatory growth. Oecologia 77, 181–186.
Pikul, J.L., Aase, J.K., 1999. Wheat response and residual soil properties following subsoiling of a sandy loam in estern Montana. Soil Till. Res. 51, 61–70.
Pikul, J.L., Aase, J.K., 2003. Water infiltration and storage affected by subsoiling and subsequent tillage. Soil Sci. Soc. Am. J. 3, 859–866.
Ram, J., Singh, S.P., Singh, J.S., 1991. Effect of fertilizer on plant biomass distribution and net accumulation rate in alpine meadow in central Himalaya. Indian J. Rang. Manag. 44, 140–143.
Sala, O.E., Parton, W.J., Joyce, L.A., Lauenroth, W.K., 1988. Primary productivition of the central grassland region of the United States. Ecology 69, 40–45.

Schaffers, A.P., Vesseur, M.C., Sykora, K.V., 1998. Effects of delayed hay removal on the nutrient balance of roadside plant communities. J. Appl. Ecol. 35, 349–364.
Scurlock, J.M.O., Cramer, W., Olson, R.J., Parton, W.J., Prince, S.D., 1999. Terrestrial NPP: towards a consistent data set for global model evaluation. Ecol. Appl. 9, 913–919.
Sherry, R.A., Weng, E.S., Arnone III, J.A., John, A., Johnson, D.W., Schimel, D.S., Verburg, P.S., Wallace, L.L., Luo, Y.Q., 2008. Lagged effects of experimental warming and doubled precipitation on annual and seasonal aboveground biomass productivity in a tallgrass prairie. Glob. Chang. Biol. 14, 2923–2936.
Song, R., Liu, L., Wu, C.S., Guo, J.X., 2009. Reclamation on organic matter content and structural properties in steppe soil of Northeast Songnen Plain. Grassl. China 31, 91–95.
Syswerda, S.P., Corbin, A.T., Mokma, D.L., Kravchenko, A.N., Robertson, G.P., 2011. Agriculture management and soil carbon storage in surface vs deep layer. Am. J. Soil Sci. Soc. 75, 92–101.
Thompson, I., Mackey, B., McNulty, S., Mosseler, A., 2009. Forest Resilience, Biodiversity, and Climate Change: A Synthesis of the Biodiversity/Resilience/Stability Relationship in Forest Ecosystems. Secretariat of the Convention on Biological Diversity, Montreal, QC, Canada.
Tremberth, K.L., Dai, A.G., Rasmussen, R.M., Parsons, D.B., 2003. The changing character of precipitation. Bull. Am. Meteorol. Soc. 84, 1205.
Wang, C., Wei, L., Wang, H.Z., Wang, J.Z., 2007. Influence of bed-planting and strew winter wheat in North China Plain. Acta Agric. Boreali-Sin. 22, 115–120.
Wang, Q., Zhang, L., Li, L., Bai, Y., Cao, J., Han, X., 2009. Changes in carbon and nitrogen of Chernozem soil along a cultivation chronosequence in a semi arid grassland. Eur. J. Soil Sci. 60, 916–923.
Wang, Y., 2009. Response of Indicator Species (*Iris lacteal* Pall. Var. *Chinensis* Koidz) of Grassland Degradation in Songnen Plain to Saline-alkali Environment. Phd Thesis. Northeast Normal University, China.
Weng, E., Luo, Y., 2008. Soil hydrological properties regulate grassland ecosystem responses to multifactor change: a modeling analysis. J. Geogr. Res. 113, G03003. http://dx.doi.org/10.1029/20078JG000539.
Wu, Z., Dijkstra, P., Koch, G.W., Peñuels, J., Hungate, B.A., 2011. Responses of terrestrial ecosystems to temperature and precipitation change: a meta-analysis of experimental manipulation. Glob. Chang. Biol. 17, 927–942.
Xu, X., Sherry, R.A., Niu, S.L., Li, D.J., Luo, Y.Q., 2012. Net primary productivity and rain-use efficiency as affected by warming altered precipitation, and clipping in a mixed-grass prairie. Glob. Chang. Biol. 19, 2753–2764.
Xu, X., Sherry, A.R., Niu, S.L., Li, D.J., Luo, Y.Q., 2013. Net primary productivity and rain-use efficiency as affected by warming altered precipitation, and clipping in a mixed-grass prairie. Glob. Chang. Biol. 19, 2753–2764.
Yi, H., Zhang, Z., Wang, C.H., Jiang, F.H., Xia, J.Y., 2012. Effects of mowing and nitrogen addition on soil respiration in three patches in old-field grassland in Inner Mongolia. J. Plant Ecol. 5, 219–228.
Yu, P.J., Li, Q., Jia, H.T., Li, G., Zheng, W., Shen, X.J., Diabate, B., Zhou, D.W., 2014. Effect of cultivation on dynamics of organic and inorganic carbon stocks in songnen plain. Agron. J. 106, 1574–1582.
Zhao, W., Chen, S.P., Lin, G.H., 2008. Compensatory growth responses to clipping defoliation in *Leymus chinensis (Poaceae)* under nutrient addition and water deficiency conditions. Plant Ecol. 196, 85–99.
Zhou, Z., Sun, O.J., Huang, J., Gao, Y., Han, X., 2006. Land use affects the relationship between species diversity and productivity at the local scale in a semi-arid steppe ecosystem. Funct. Ecol. 20, 753–762.