Plant litter effects inversely on air and soil temperatures in *Leymus chinensis* grassland, Northeast China

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Abstract. Plant litter is an important component of grassland ecosystem, and has significantly reduced by human activities. These changes in natural systems cause variations in air and soil temperatures. This study described an experiment that different amounts of plant litter effect on air and soil temperatures in Songnen grassland, Northeast China. Plant litter reduction resulted in decreasing air temperature at 10 cm above surface and increasing soil temperature at 20 cm below soil surface in the growing season. The mean, maximum, and amplitude of air temperatures at 10 cm above soil surface of plots with plant litter were significantly higher than plots without litter. The mean, extreme, and amplitude of soil temperatures at 20 cm depth increased significantly as plant litter decreased in the growing season. Temperature differences between air and soil temperatures decreased significantly as plant litter decreased in the growing season. The results show that the soil and air temperatures respond differently to plant litter, and the changing temperature difference between air and soil temperatures has the potential to produce complex effects on grassland ecosystem.

1. Introduction

Grasslands are one of the most important constituents of the earth’s vegetation and they are characterized by diverse types with a very broad range of environmental conditions in all climate types [1-2]. Grasslands in China cover nearly 4 million km² (more than 40 %) of the total land area, and play an important role in livestock farming and environmental conservation [3]. However, grassland degradation is advancing over wide areas through human activities, such as overgrazing, excessive cutting and unregulated collection of fuel and medical plants [3]. One of the characteristics of grassland degradation is aboveground biomass decreasing which results in plant litter becoming less and less [4-5].

Plant litter is by the definition as “the dead plant material of small size laying loose on the ground” [4], which is an import component in grassland ecosystem. Besides significantly effecting on net primary production [5-6] and nutrient cycles [7], plant litter also modifies the local physical environment by providing cover, changing soil surface microclimate [5], especially soil temperature which is one of the most important factors for the grassland ecosystem.

Soil temperature has significant impacts on the rates of biochemical reactions and has a strong influence on the growth of plants and soil biota [8-11]. Extreme soil temperature also is particularly
important related to plant growth, for example, seed germination and early seedling growth are more highly correlated with daily maximum temperature of the soil than with air temperature [12]. The latest research showed that maximum and minimum warming asymmetrically effected on vegetation growth and carbon sequestration [13]. Therefore, a small changes of soil temperature would have great influence on ecosystems in all aspects [14].

Plant litter intercepts solar radiation and insulates the soil from air temperature, thus, modifies soil temperature. Many studies of the litter effecting on soil temperature focus on forest ecosystem [9-17] or tillage systems [18-20], only few studies show that litter removal increased the soil temperature in grassland by 5-8 °C at the beginning of the growing season [21-22]. Furthermore, there is general consensus that air temperature warming is asymmetric because of minimum temperature having increased at twice the rate of maximum temperatures [23-24]. However, it is unclear that how the maximum and minimum soil temperature changes by plant litter.

The objective of this study was to examine the influence of plant litter to soil temperatures of grassland in the growing season. First, we measured the daily average air temperature and soil temperatures of our study site to find the differences of them in the growing season, and second, we compared the maximum, minimum temperature and diurnal daily temperature range between different litter amounts.

2.Material and methods
2.1.Site description
The experiments were conducted at the Ecological Research Station for Grassland Farming (ERSGF) in Jilin Province, Northeast China (44°33’ N, 123°31’ E, elevation 145 m). The study area has a semi-arid, continental climate. Mean annual temperature is 4.9 °C. Annual precipitation is 300-500 mm [25]. The grassland was dominated by Leymus chinensis. The main soil type is meadow chernozem at the study site.

2.2.Experimental design
Experimental plots were set up following a randomized block design in 2007. Plant litter was simulated by adding hay on clipped grassland. The amounts were 0, 200, 600, 1000 g/m² with three replicates. Each plot was 1.5 m by 1.5 m, with 1 m intervals between plots.

In 2008, the temperatures at 10 cm above the soil surface and 20 cm soil depth were measured from 17th April to 29th August. EM50 sensor (Decagon, USA) was used to record temperatures automatically with 1 hour intervals.

2.3.Statistical analysis
The variations in daily mean (Mean), minimum (Min), maximum (Max), and amplitude (Max-Min) of air and soil temperatures during the experiment were evaluated in every fifteen days by repeated measure ANOVA with plant litter amount as the main between-subject factors and time as the within-subject factor. Univariate analysis in general linear model was used to detect the effect of the different amount litter treatment on averaged temperatures during the experiment, LSD was used to compare the multiple treatment mean values, all statistical analyses were carried out using SPSS 13.0 (SPSS Inc., Chicago, USA) at 0.05 level.

3.Results
3.1.Mean, extreme and amplitude of daily air and soil temperatures
Mean daily air and soil temperatures had a similar changing pattern from 17 April to 29 August. However, mean daily air temperatures were more fluctuating compared with soil temperatures, especially at the beginning of the measuring time (Figure 1a and 2a). Mean daily air temperatures were 2-5 °C higher than soil temperatures during the observation time. Temperature difference
between treatments decreased at the last 15 days for both mean daily air and soil temperatures (Figure 1a and 2a). There was no significant difference between the treatments of daily air temperatures at the beginning 30 days (Figure 1a). Mean daily soil temperatures were significantly different from 17 April to early August and decreased from 0 to 1000 g/m$^2$ (Figure 2a). Plant litter significantly affected on daily minimum, maximum and amplitude of air and soil temperatures (Figure 1 and 2).

![Figure 1. Changes in daily (a) Mean, (b) Min, (c) Max, and (d) Max-Min temperatures ($^\circ$C) from 17 April to 29 August 2008 at 10 cm above soil surface. ** $P < 0.01$, * $P < 0.05$, ns non-significant.](image)

3.2 Mean, extreme and amplitude of averaged daily air and soil temperatures

The averaged daily mean, maximum, and amplitude of air temperatures of the plots with plant litter were significantly higher than the plots without plant litter. However, there were no significant differences between treatments with 200, 600, and 1000 g/m$^2$ plant litter. The averaged daily mean air temperature of plots with plant litter was 0.5$^\circ$C higher than plots without plant litter (Figure 3a). However, the averaged daily minimum air temperature of plots with 1000 and 600 g/m$^2$ plant litter were significantly lower than the treatments with 200 and 0 g/m$^2$ plant litter (Figure 3a).

The averaged daily mean, minimum, maximum, and amplitude of soil temperatures at 20 cm depth increased significantly as plant litter decreased (Figure 3b). Both averaged daily mean and minimum soil temperatures were significant difference between the treatments. No significant differences were detected with regard to averaged daily maximum and amplitude of soil temperatures between the 1000 and 600 g/m$^2$ (Figure 3b).

The averaged daily mean, maximum and amplitude of air temperatures at 10 cm above soil surface were higher than that of soil temperatures at 20 cm depth (Figure 3c). Temperature difference between averaged daily air and soil temperatures decreased significantly as plant litter decreased except for the treatments with 1000 and 600 g/m$^2$ (Figure 3c). The temperature differences of averaged daily temperatures were 4.3, 4.0, 3.2, and 2.0 $^\circ$C for 1000, 600, 200 and 0 g/m$^2$ treatments, separately. The
averaged daily minimum air temperature was about 6.5 °C lower than that of soil temperature. However, there was no significant temperature difference between the treatments (Figure 3c). Temperature differences between the mean daily maximum air and soil temperatures with plant litter were significantly higher than plots without plant litter (Figure 3c), and there was also the same pattern of the temperature differences between averaged daily amplitude of air and soil temperatures between the treatments (Figure 3c).

![Figure 2](image-url)

**Figure 2.** Changes in daily (a) Mean, (b) Min, (c) Max, and (d) Max-Min temperatures (°C) from 17 April to 29 August 2008 at 20 cm below soil surface. **P < 0.01, *P < 0.05, ns non-significant.**

![Figure 3](image-url)

**Figure 3.** The average of daily Mean, Min, Max, and Max-Min temperatures (°C), from 17 April to 29 August 2008 in different treatments at (a) 10 cm above soil surface, (b) 20 cm below soil surface, (c) temperature difference between air and soil temperatures. Bars (mean ± SE) with different letters are significantly different (P < 0.05), “ns” non-significant (P > 0.05).
4. Discussion

Plant litter reduction by human activities has caused change in solar radiation energy fluxes between air and soil temperatures [4]. Our experiment showed that the plots with plant litter has significant higher air temperature and lower soil temperature than the plot without plant litter in the growing season (Figure 1a and 2a). It agreed with results of other studies involving soil temperature responding to grassland litter. Weaver and Rowland [21] found that soil temperature in a grassland with litter was 8 °C lower than that in a bare one. Hulbert [22] showed that both burning and litter removal by hand increased soil temperature in a grassland by 1-5 °C during the growing season. Our results found that plant litter removal increased the averaged daily mean, minimum, maximum, and amplitude of soil temperatures by 0.5-2 °C in the growing season (Figure 3).

It is well known that most researches are focused on comparing the soil temperatures between different vegetation types [9, 12] or just comparing covered plots with bare land [21-22]. However, within grasslands a degradation gradient may influence soil temperature significantly. Our results showed that different amounts of plant litter had significant impacts on soil temperature (Figure 3b). Linear regression of the histogram of averaged daily soil temperature showed that soil temperature increased 0.16 °C as plant litter decreased 100 g (P = 0.004, Figure 3b). Thus, litter reduction increased soil temperatures of grassland in the growing season.

Overgrazing and/or high production has degraded grasslands in spite of the suggestion of grassland studies that advised about necessity of their conservation [3]. In the past decades, e.g. Songnen grassland has experienced remarkable land use/cover changes as a result of human activities. The grassland had the most dramatic decrease from 1986 to 2000, when his area decreases in area of 6,127 km2. Nowadays, only 25.6% of the original area of 1986 remained [25]. The decrease in grassland cover caused by unreasonable development of stockbreeding has increased evaporation, soil temperature, and soil organic decomposition [26]. In this area, the dominant plant species of grasslands were wiped out, meanwhile the average vegetation coverage, height, density, and productivity decreased to a great extent [27]. The reduction of grassland contributes soil warming which could produce complex potential effects on grassland ecosystems.

The global climate has changed rapidly, the warming pattern shows that the minimum temperature increased two order of magnitude of the maximum temperature and the amplitude of temperature decreased, i.e. an asymmetric diurnal temperature increase [23-24]. However, plant litter reduction modified the air and soil temperatures near-surface in our study by altering the maximum temperature (Fig 3a, b). Interestingly, the amplitude of soil temperature became larger as plant litter decreased in the growing season (Figure 3c). Plant litter created a barrier to heat exchange between air and soil [4]. The amplitude of soil temperature increase was mainly due to the increase of the maximum soil temperature as plant litter reduction (Figure 3c). The changing pattern of soil temperature is likely to affect grassland ecosystem, such as seed germination especially in early growing season [4, 12].

Both air and soil temperatures are important abiotic factors of grassland ecosystem. Vegetation types also influence air temperature [12]. Air temperatures were significantly different between plots with and without plant litter, but there was no difference between treatments of 200, 600, 1000 g/m² plant litter (Figure 3a). This may be associated with the same vegetation type and similar community structure. Interestingly, temperature differences between air and soil temperatures were significantly different among the treatments except for the minimum temperature (Figure 3c). In other words, grassland degradation will decrease temperature difference between air and soil temperatures in growing season. The variation of temperature patterns may alter the microenvironment and affect the structure and dynamics of plant communities. For example, growth rates of shoots and roots of plants will change [12].

Grassland degradation leads to vegetation variations in height and density [28]. We simulated grassland degradation through decreasing the amount of plant litter on the plots. Unfortunately, our treatments may not reflect the gradient of grass height and density variations. We measured soil temperature of the unmoved grassland during the growing season from 17th April to 29th August 2008;
the mean soil temperature at 20 cm depth was 18.9 ± 0.18 °C which was between 200 and 600 g/m² treatment (Figure 3b). The standing biomass of the plant community was 196.5 g/m², and plant height was about 30 cm. Thus the height of the standing plant litter also influences mean soil temperatures [12].

5. Conclusions
Plant litter reduction resulted in decreasing mean, maximum, and amplitude of air temperature at 10 cm above surface and increasing mean, minimum, maximum, and amplitude of soil temperatures at 20 cm below soil surface in the growing season. The amplitude of air temperature decrease was due to the increasing rate of the maximum soil temperature higher than the minimum soil temperature as plant litter reduction. The temperature difference between air and soil temperature become less and less as plant litter reduction. The temperature increase due to the increasing rate of the maximum soil temperature as plant litter reduction. The temperature difference between air and soil temperature become less and less as plant litter reduction. Future work is needed to study the change of temperature patterns effect on grassland ecosystem.

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References
[1] Tuba Z, Kaligaric M 2008 Community Ecol. 9 3-12
[2] Luo C, Xu G, Chao Z, Wang S, Lin X, Hu Y, Zhang Z, Duan J, Chang X, Su A 2010 Glob. Change. Biol. 16 1606-1617
[3] Kang L, Han X G, Zhang Z B, Sun O J 2007 Phil. Trans. Roy. Soc. B-Biol. Sci. 362 997-1008
[4] Facelli J M, Pickett S T A 1991 Bot. Rev. 57 1-32
[5] Wang J, Zhao M, Willms W D, Han G, Wang Z, Bai Y 2011 J. Veg. Sci. 22 367-76
[6] Xiong S, Nilsson C 1999 J. Ecol. 87 984-94
[7] Liu P, Huang J, Sun O J, Han X 2010 Oecologia 162 771-80
[8] Jimenez C, Tejedor M, Rodriguez M 2007 Eur. J. Soil. Sci. 58 445-49
[9] Scull P 2007 Phys. Geogr. 28 360-73
[10] Knapp A K, Seastedt T R 1986 Bioscience 36 662-68
[11] Jacobs A F G, Heusinkveld B G, Holtslag A A M 2011 Agr. Forest. Meteorol. 151 774-80
[12] Green F H W, Harding R J, Oliver H R 1984 J. Climatol. 4 229-40
[13] Peng S, Piao S, Ciais P, Myneni R B, Chen A, Chevallier F, Dolman A J, Janssens I A, Penuelas J, Zhang G, Vicca S, Wan S, Wang S, Zeng H 2013 Nature 501 88-92
[14] Richter D 2007 Soil Sci. 172 957-67
[15] MacKinney A L 1929 Ecology 10 312-21
[16] Bonan G B 2001 J. Climatol. 14 2430-42
[17] Haskell D E, Flaspohler D J, Webster C R, Meyer M W 2012 Restor. Ecol. 20 113-21
[18] Gauer E, Shaykewich C, Stobbe E 1982 Can. J. Soil Sci. 62 311-25
[19] Grant R, Izaurralde R, Chanasyk D 1995 Agr. Forest Meteorol. 73 89-113
[20] Flachinger G, Sauer T, Aiken R 2003 Geoderma 116 217-33
[21] Weaver J, Rowland N 1952 Bot. Gaz. 114 1-19
[22] Hulbert L 1969 Ecology 50 874-77
[23] Easterling D R, Horton B, Jones P D, Peterson T C, Karl T R, Parker D E, Salinger M J, Razuvayev V, Plummer N, Jamason P, Folland C K 1997 Science 277 364-67
[24] Karl T R, Jones P D, Knight R W, Kukla G, Plummer N, Razuvayev V, Gallo K P, Lindsey J, Charlson R J, Peterson T C 1993 Bull. Amer. Meteorol. Soc. 74 1007-23
[25] 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 Chinese Geogr. Sci. 19 299-305
[26] Foley J A, DeFries R, Asner G P, Barford C, Bonan G, Carpenter S R, Chapin F S, Coe M T, Daily G C, Gibbs H K, Helkowski J H, Holloway T, Howard E A, Kucharik C J, Monfreda C, Patz J A, Prentice I C, Ramankutty N, Snyder P K 2005 Science 309 570-74
[27] Li X Y, Wang Z M, Song K S, Zhang B, Liu D W, Guo Z X 2007 Environ. Monit. Assess. 131 421-37
[28] Song Y T, Zhou D W, Zhang H X, Li G D, Jin Y H, Li Q 2013 Chinese .Sci. Bull. 58 907-12