

Vegetation patches increase wind-blown litter accumulation in a semi-arid steppe of northern China

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Vegetation patches increase wind-blown litter accumulation in a semi-arid steppe of northern China

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Yuchun Yan^{1,4}, Xiaoping Xin^{1,4}, Xingliang Xu², Xu Wang¹, Ruirui Yan¹ and Philip J Murray³¹ Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, People's Republic of China² Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy Sciences, 11A, Datun Road, Chaoyang District, Beijing 100101, People's Republic of China³ Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK⁴ Authors to whom any correspondence should be addressed.E-mail: yanyuchun@caas.cn and xinxp@sina.com**Keywords:** litter accumulation, nutrient redistribution, vegetation coverSupplementary material for this article is available [online](#)**Abstract**

Litter decomposition is an important source of soil organic matter and nutrients; however, few studies have explored how vegetation patches affect wind-driven litter mobility and accumulation. In this study, we aimed to test the following hypotheses: (1) vegetation patches can reduce litter removal and facilitate litter accumulation, (2) litter mobility results in the heterogeneous redistribution of carbon and nutrients over the land surface, and (3) litter removal rates differ among different litter types (e.g., leaf and stem). Four vegetation patch types and six litter types were used to investigate the impacts of vegetation patches on litter mobility and accumulation. The results show that compared with almost bare ground patches, patches with vegetation cover had significantly higher litter accumulation, with the shrub patch type having the highest accumulation amount. The rate of litter removal due to wind was highest for the almost bare surface type (P4) and lowest for the shrub patch (P1) and *Stipa grandis* community (P2) types. There were significant differences in the removal rate among the different litter types. These findings indicate that wind-based litter redistribution among bare, *S. grandis*-dominated, and shrub-dominated patches is at least partially responsible for increasing the spatial heterogeneity of resources on a landscape scale.

1. Introduction

Litter decomposition is an important pathway that contributes organic matter and nutrients to the soil; thus, litter plays a significant role in ecosystem nutrient cycling. Litter manipulation experiments have indicated that litter removal alters the soil physical and chemical characteristics (e.g., texture, temperature, moisture content and pH), carbon cycling (e.g., decomposition and microbial respiration), and nutrient cycling (e.g., mineralization), thus directly and indirectly affecting plant growth rates (Sayer 2006, Kumada *et al* 2009). In addition, litter cover can form a protective layer over the soil, thereby reducing soil water evaporation, improving soil infiltration to increase soil moisture, and performing

drought resistance functions. Importantly, litter can effectively prevent soil erosion. In arid and semi-arid steppe, litter loss directly leads to soil exposure, increasing the risk of wind-based soil erosion and subsequent grassland degradation and desertification. Thus, litter presence and abundance have become the most important indicators in steppe ecosystem health evaluation (Wang 2011).

Typically, the amount of litter in an ecosystem is primarily determined by the balance between litterfall and decomposition (Day 1979, Kumada *et al* 2009) assuming no deposition of litter from external sources and no wind- or water-driven removal. However, wind has been widely recognized as an important driver of the transportation of materials across landscape components. Most previous studies have focused on

wind-eroded dust or soil particles and the positive and negative environmental impacts of wind erosion (Breshers *et al* 2003, Li *et al* 2008, 2009, Belnap *et al* 2009, Yan *et al* 2011). For example, an estimated 2000 Mt of dust is emitted globally into the atmosphere each year, 75% of which is deposited onto the land and 25% into the ocean (Shao *et al* 2011). This dust influences the soil carbon and nutrient balance from local to global scales depending on transport distance (Okin *et al* 2004, Poortinga *et al* 2011, Prospero *et al* 2012). Compared with wind-blown nutrient movements associated with different soil particle types, nutrient transfer by wind-blown litter and its ecological significance have been less studied (Shen *et al* 2011), despite the fact that litter plays a key role in ecosystem nutrient cycling (Hättenschwiler *et al* 2005).

A few studies have shown that wind can play an important role in litterfall and litter transfer processes. For example, Kumada *et al* (2009) showed that the main cause of litter removal in a forest was wind and not flooding. They found that in *Acacia aneura* forests, the annual physical removal of litter reached 70%–82% of the annual litterfall, and approximately 40%–60% of the existing litter was removed annually from all sites (Kumada *et al* 2009). In Arctic landscapes, wind often redistributes litter and snow from hill and ridge tops to leeward locations during the winter, subsequently forming patches of litter accrual after the snow melts in the spring (Fahnestock *et al* 2000). This can further reduce photosynthetically active radiation and soil temperature, increase C and N accumulation, and stimulate soil CO₂ efflux at litter deposition sites throughout the growing season (Fahnestock *et al* 2000). In arid and semi-arid landscapes, wind-blown fine soil particles and plant detritus from inter-shrub spaces contribute to the formation of fertility islands after deposition in shrub-occupied patches, thereby altering the spatial distribution patterns of soil properties and contributing to desertification (Schlesinger *et al* 1996). Shen *et al* (2011) measured the litter nutrient transfer from an *Acacia mangium* plantation to a *Dimocarpus longan* orchard in an agroforestry landscape and showed that approximately 11% of the total litterfall of the *Acacia* plantation was transported to the *D. longan* orchard annually by wind, accounting for ca. 9%–59% of the total litter nutrient input to the orchard. The results of these studies indicate that wind-blown litter transfer is a common phenomenon with important ecological impacts in various landscape types, and it deserves more study.

In the process of redistributing materials across the land surface, the condition of the vegetation cover is an important factor in protecting materials against wind-blown transfer. Most previous studies have focused on the effects of vegetation cover on wind erosion and dust accumulation, primarily because increasing vegetation cover can effectively protect surface soil and reduce wind velocity, thus preventing dust entrainment and transport. For example, Dong

et al (1996) showed that the rate of wind erosion increased exponentially with decreasing vegetation cover, and Yan *et al* (2011, 2013) showed that increasing vegetation cover can both decrease wind erosion and increase sediment capture. Recently, Field *et al* (2012) confirmed that the sediments captured by a vegetation patch directly increase resource redistribution. The capture of wind-blown litters by the shrub canopy is an even more important process than sediment deposition in increasing carbon and nutrient accumulation under the shrub canopy (Schlesinger *et al* 1996, Field *et al* 2012). However, the underlying assumption that a vegetation patch will increase litter accumulation and successively influence the redistribution of carbon and nutrients has not been explicitly tested in the field.

There is nearly four hundred million hectares of grassland in China, which accounts for approximately 40% of the total land area and represents the largest terrestrial ecosystem in China. The Inner Mongolia temperate grassland, located in Eurasia, is the main body of northern China grassland and plays important roles in the ecological environment and in regional socio-economic development (Piao *et al* 2004). However, because of increased human activities, such as overgrazing, cultivation, and subsequent severe soil erosion by winds, grassland degradation has become the main problem affecting local governments and herdsman in Inner Mongolia grassland (Yan *et al* 2013). Currently, the heterogeneous land surface is the most common landscape type in the semi-arid steppe of northern China, which is due to the presence of residual community patches such as those caused by selective intake by livestock or shrub encroachment related to increasing disturbance and climate change (Li *et al* 2013). Studies show that more than 5.1×10^6 ha of Inner Mongolian grassland has been encroached upon by *Caragana microphylla* Lam (Li *et al* 2013), occupying more than 35% of sandy grassland area. The wind-driven movement and redistribution of litter is a common phenomenon in this area, leading to the wind-blown accumulation of litter in traps, shrub patches and fenced regions (figure 1). However, few studies have investigated how wind alters litter accumulation, mobility and redistribution in this region. We aimed to examine the following hypotheses: (1) vegetation patches can reduce litter removal and facilitate litter accumulation, (2) litter mobility results in the heterogeneous redistribution of carbon and nutrients over the land surface, and (3) litter removal rates differ among the different litter types (e.g., leaf and stem).

2. Methods

2.1. Site description

This study was conducted in the Baiyinxile pasture located in the Xilinge grasslands in Inner Mongolia,

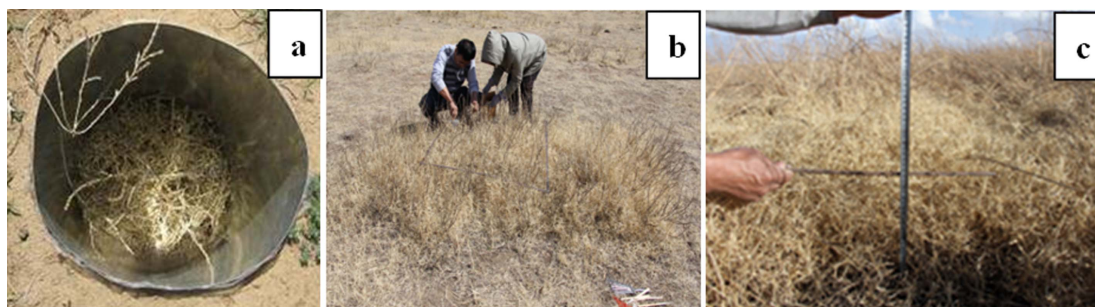


Figure 1. The accumulation of wind-blown litter in a trap (a), a shrub (b), and in fenced grassland (c).

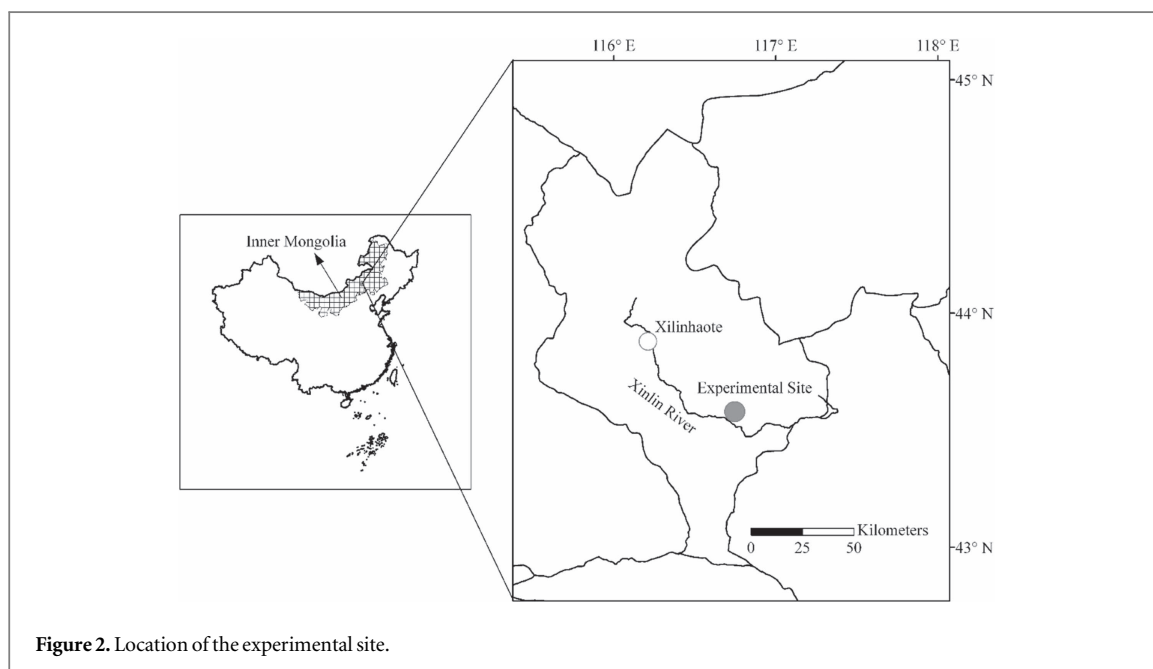


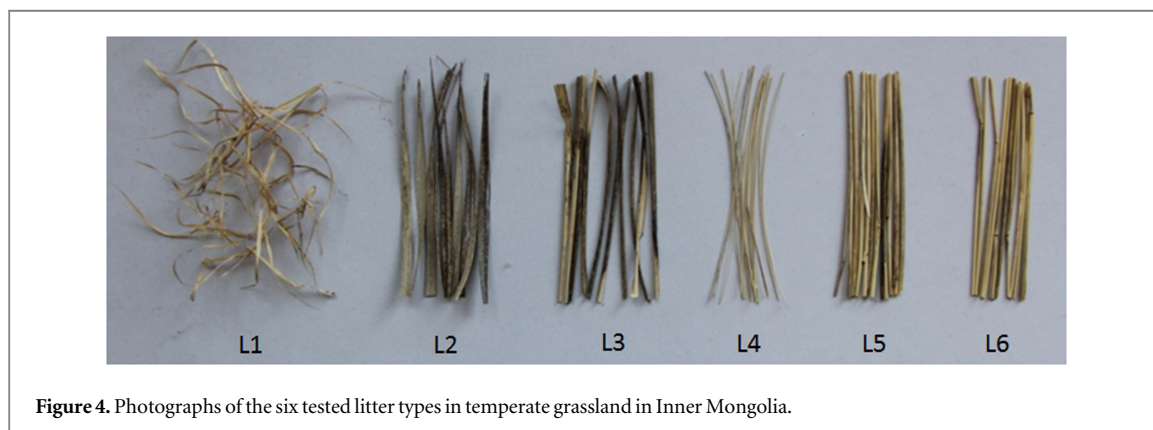
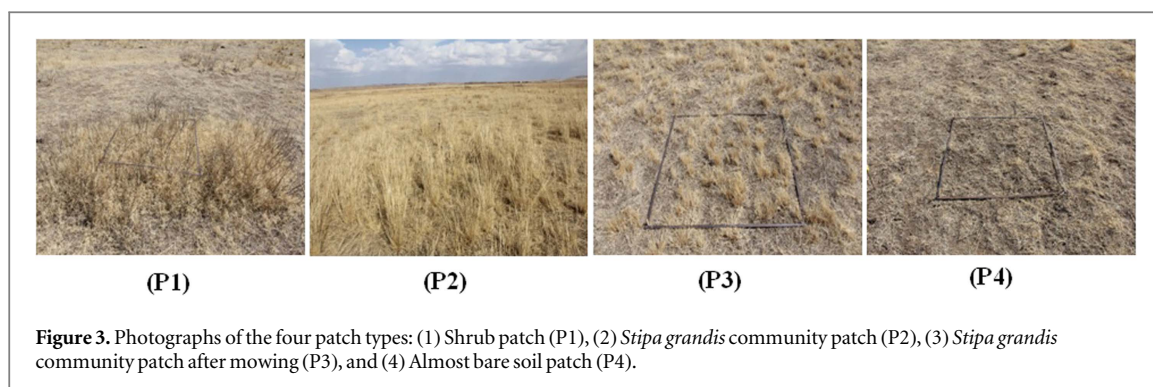
Figure 2. Location of the experimental site.

China (43°26'N, 116°04'E) (figure 2). A fixed sand belt 10-km wide lies to the north of the study site. This semi-arid region was formed on basalt plateaus and is mainly covered with fine-sand loess with typical chestnut and calcic chernozem soil types (Yan *et al* 2011). The area is characterized by a semi-arid steppe climate: cold and dry in the winter but mild and humid in the summer, with an annual average rainfall of 270 mm (1981–2014). Precipitation is highly variable, with 75% of the annual total occurring between June and September, and the average daily temperature is -22.3°C in the coldest month (January) and 18.8°C in the hottest month (July). Strong winds associated with dust and litter transport occur from March to May, with an average monthly speed of up to 4.9 m s^{-1} . The dominant plant species found in the natural steppe are *Stipa grandis*, *Cleistogenes squarrosa*, *Artemisia frigida*, and *Leymus chinensis* (Yan and Tang 2008). The main land use in the study area is grazing, and there is a small amount of farming. The grassland in this area suffers from severe degradation due to continuous overgrazing (>2.5 sheep per hectare) and increased anthropogenic disturbances

over the past three decades. As a result, *Caragana microphylla* expansion occurs in many places (Li *et al* 2013), and a mosaic pattern of shrub and grass patches is common.

2.2. Observation of community patch properties

The study was initiated in April 2014. We established three $80 \times 150\text{ m}$ plots as replicates within a 5 ha area; in each plot, four representative vegetation patch types were selected: (1) *Caragana microphylla* shrub (P1); (2) *Stipa grandis* community (P2); (3) *Stipa grandis* community after mowing (P3), which was similar to P2 but was cut to a residual height of approximately 8 cm; and (4) Almost bare, which largely lacked vegetation (P4) (figure 3). For each patch type, three $1 \times 1\text{ m}$ patches were selected as observation patches in each plot. Before litter manipulation, the patch size was measured, and a $1 \times 1\text{ m}$ quadrat was established in the patch center. Within the quadrat, the fractional vegetation cover, the average height of each species (from 1 cm above the soil surface), and the number of each dominant species were recorded. Then, litter was collected from the different community patches in the



plots and weighed to the nearest 0.01 g with an electrical balance. Because the newly accumulated litter was almost entirely composed of *Cleistogenes squarrosa* in the shrub patch type, with the upper layer of new litter drawn in from the outside on top of the existing litter, new litter and old litter could be clearly distinguished. Therefore, we measured the new litter (*C. squarrosa*) and the old litter from the shrub patches separately.

2.3. Observation of litter removal rates in different plant community patches

Six types of litter from three plant species were selected for the litter removal experiment. (1) *Cleistogenes squarrosa* (L1) is a small, densely clumping, xeric perennial grass. According to the field observations, it is one of the most easily wind-blown litter types. After drying, its litter often forms a circular shape that is easily caught on fences or shrubs (Wang *et al* 2002). The other litter types consisted of (2) the upper end of leaves of *Leymus chinensis* (L2), (3) the end of leaves of *Leymus chinensis* (L3), (4) the leaves of *Stipa grandis* (L4), (5) the stems of *Leymus chinensis* (L5), and (6) the stems of *Stipa grandis* (L6). L1 was collected from the grassland enclosures, where large amounts of *Cleistogenes squarrosa* litter had accumulated. *Leymus chinensis* and *Stipa grandis* are two dominant species of the grasslands in Inner Mongolia, and their litter was collected from standing dead grasses in a grassland enclosure. L1 consisted of intact above-ground parts, and the other five litter types comprising different

parts of their respective plants were cut into pieces 10 cm in length with scissors (figure 4). The true density of each litter sample was measured by an automatic true density analyzer (3H-2000TD1, China), and the weight of each litter sample was determined by an electrical balance to 0.001 g. The detailed properties of the six litter types are presented in table 1.

Twelve 1×1 m quadrats (3 replicates \times 4 patch types) were established in each plot, and the original accumulated litters were removed by iron rake. Then, 20 samples of each litter type (totaling 120 samples over all six litter types) used for the experiment were marked with different colors of paint and randomly placed in each quadrat. For the patch types with vegetation coverage, the tested litter fragments were placed under the canopy. Litter removal was monitored as the numerical losses of litter in each quadrat. The number of remaining litter samples was counted eleven times between April 14, 2014 and May 14, 2014. The meteorological data, including wind speed and precipitation, during the litter removal experimental period were obtained from the Inner Mongolia Grassland Ecosystem Research Station, Chinese Academy of Sciences, which is approximately 1 km from the experiment site.

2.4. Determination of the threshold wind speed for litter transport

The tested litter was placed on the bare soil surface 0.1 m above the ground surface with the broad surface

Table 1. Description of the properties of the tested litter types. Values shown are means (standard errors) ($n = 10$).

Litter type	Shape	Length (cm)/diameter (mm)	Individual weight(g)	Density (g cm^{-3})
<i>Cleistogenes squarrosa</i> (L1)	Irregular shape	8–10/–	0.018 (0.002)	1.070 (0.012)
The upper end of leaves of <i>Leymus chinensis</i> (L2)	Flat or involute	10/–	0.022 (0.001)	1.422 (0.010)
The end of leaves of <i>Leymus chinensis</i> (L3)	Flat or involute	10/–	0.043 (0.002)	1.138 (0.054)
The leaves of <i>Stipa grandis</i> (L4)	Elongated cylindrical	10/0.2	0.010 (0.001)	1.256 (0.011)
The stem of <i>Leymus chinensis</i> (L5)	Elongated cylindrical	10/1.5	0.102 (0.007)	0.919 (0.012)
The stem of <i>Stipa grandis</i> (L6)	Elongated cylindrical	10/1.5	0.089 (0.008)	0.866 (0.011)

of each litter sample facing the wind direction. The wind speed at 0.1 m above the ground was measured using a wind measurement instrument that consisted of a data logger (FC-2, China), a three-cup anemometer and a wind vane. Observations were initiated during weak or no wind; upon litter movement, we recorded the corresponding wind speed as the value of wind speed for transport. Each litter type was observed fifteen times to determine the threshold wind speed for transport.

2.5. Data analysis

Statistical analysis was performed using the SPSS 10.0 software package. Statistical significance was considered at the $p < 0.05$ level. One-way analysis of variance (ANOVA) was used to test the effects of vegetation patch type on litter accumulation and removal rate, and multiple comparisons were performed with Tukey's honestly significant difference (HSD) tests. Similar analyses were used to evaluate differences in threshold wind speed for transport among litter types. The homogeneity of variance was tested before performing the ANOVA tests.

3. Results

3.1. Community properties of different vegetation patches

The properties of the vegetation patch types are shown in table 2. The vegetation cover of the shrub (P1) and the *S. grandis* (P2) patch types are 30% and 35%, respectively, with no significant difference ($p > 0.05$). The coverages of P1 and P2 are higher than those of P3 and P4 ($p < 0.05$). The cover and height of the almost bare patch type (P4) are the lowest among the four patch types ($p < 0.05$); the cover is below 3%, and the height is below 1 cm due to the removal of vegetation by grazing.

3.2. Litter accumulation in different vegetation patches

Different vegetation patch types had significantly different litter accumulation amounts (table 2). Litter accumulation reached 387 g m^{-2} in the shrub patch type (P1), representing the highest amount among the four vegetation patch types, followed by the *S. grandis* patch type (P2), the *S. grandis* community after mowing type (P3) and the almost bare land type (P4) ($p < 0.05$). The new litter that originated from outside of the shrub patches was almost entirely composed of *C. squarrosa* (L1), with a mass of 139.4 g m^{-2} .

3.3. Litter removal rates in different vegetation patches

The precipitation and wind speed conditions of the study site during the litter removal experimental period are shown in figure 5. The average wind speed during the experimental period is 5.82 m s^{-1} , and the

total precipitation during the experimental period is 40.2 mm.

The rate of litter removal differed among the vegetation patch types and the litter types (figure 6). The most rapid loss occurred on the almost bare soil (P4), and the litter removal rates in the shrub patch type (P1) and the *S. grandis* patch type (P2) are similar and the lowest among the four vegetation patches. All of the *C. squarrosa* litter (L1) and the upper end of leaves of *L. chinensis* litter (L2) placed in the almost bare soil quadrats were removed after 5 and 20 days, respectively. On the almost bare soil, even stem litter fragments were rapidly removed from the quadrats (more than 35% of the stem litter was lost after 30 days). In contrast, more than 20% of the *C. squarrosa* litter (L1) and more than 80% of the other five litters remained in the shrub (P1) and the *S. grandis* (P2) quadrats after 30 days (figure 7).

The rate of decrease was highest for the *C. squarrosa* litter (L1), followed by the upper end of leaves of *L. chinensis* litter (L2) and the end of leaves of *L. chinensis* litter (L3). The rates of decrease of these three litter types were higher than those of the other three litter types (figure 7).

The threshold wind velocity for transportation of the six litter types are shown in figure 8. The threshold wind velocity for transportation of all of the tested litter types is below 2 m s^{-1} , with significant differences among litter types. The stems of *L. chinensis* (L5) and *C. squarrosa* (L1) have the highest (2 m s^{-1}) and the lowest (0.7 m s^{-1}) threshold wind velocity for transportation among the six litter types, respectively.

4. Discussion

4.1. Wind-driven litter redistribution with respect to vegetation patch pattern and the development of heterogeneous landscapes

Our investigation provided the first field-based estimates of litter accumulation and removal rates at the vegetation-patch scale of bare patches and *S. grandis*- and shrub-dominated patches. These patch types are the basic fundamental components of semi-arid grassland that has been encroached upon by shrub (Zhou 1990, Zhang *et al* 2006), and they are important in influencing the patterns of wind-driven litter mobility and accumulation across the landscape (Schlesinger *et al* 1996). Although our results are based on measurements from only one site, the fundamental patch types that were evaluated in this study are pervasive in semi-arid grassland and may therefore provide relevant information on the overall importance of these patch types with respect to their ability to influence wind-blown litter mobility and redistribution processes at the vegetation-patch scale. Our results, although limited and site specific, clearly show that the type of vegetation patch had a significant influence on both litter mobility and litter

Table 2. Description of the properties of the different patch types. The new litter that originated from outside of the shrub patches (P1) was almost entirely composed of *C. squarrosa*, with a mass of 139.4 g m^{-2} . Values shown are means (standard errors). Different letters in a column indicate significant differences between patches at the 5% level (Tukey's test).

Patch type	Dominant species	Patch size (m^2)	Number of dominant species (species m^{-2})	Height of dominant species (cm)	Community cover (%)	Litter accumulation (g m^{-2})
Shrub patch (P1)	<i>Caragana sinica</i>	4.89 (0.87)	27 (5.03)	53 (10.14)a	30 (2.87)a	387.11(89.42)a
<i>Stipa grandis</i> community (P2)	<i>Stipa grandis</i>	9.56 (1.31)	13 (1.15)	64 (1.86)a	35 (1.67)a	138.72(4.48)b
<i>Stipa grandis</i> community after mowing (P3)	<i>Stipa grandis</i>	>10	31 (0.67)	8 (0)b	25 (3.33)b	95.04(8.55)c
Almost bare patch (P4)	<i>Stipa grandis</i>	>10	/	<1c	<3%c	39.53(2.06)d

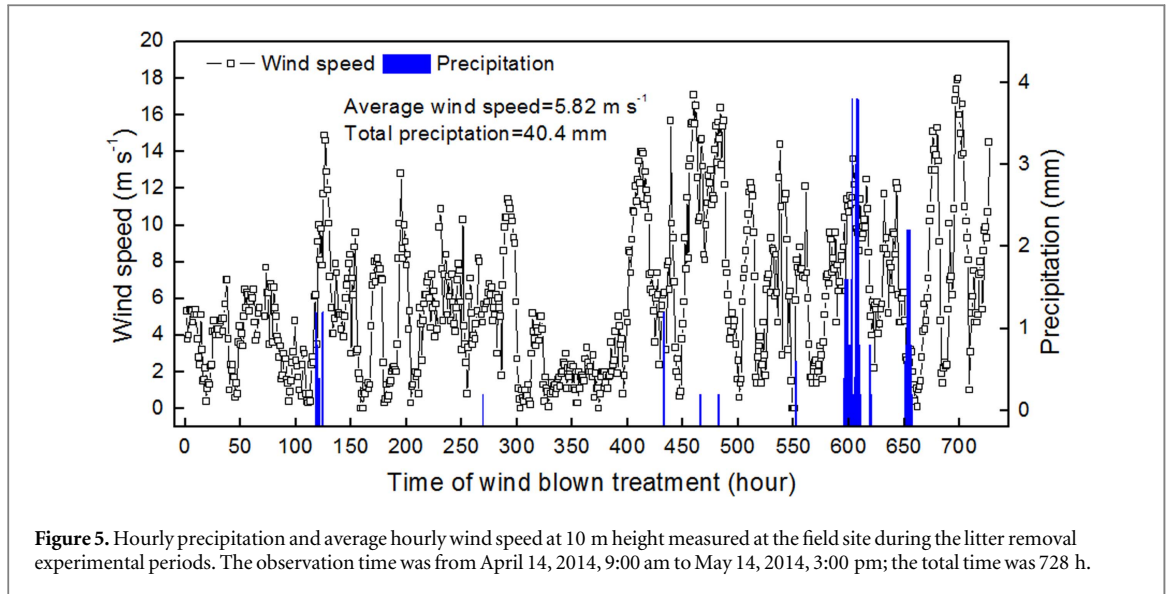


Figure 5. Hourly precipitation and average hourly wind speed at 10 m height measured at the field site during the litter removal experimental periods. The observation time was from April 14, 2014, 9:00 am to May 14, 2014, 3:00 pm; the total time was 728 h.

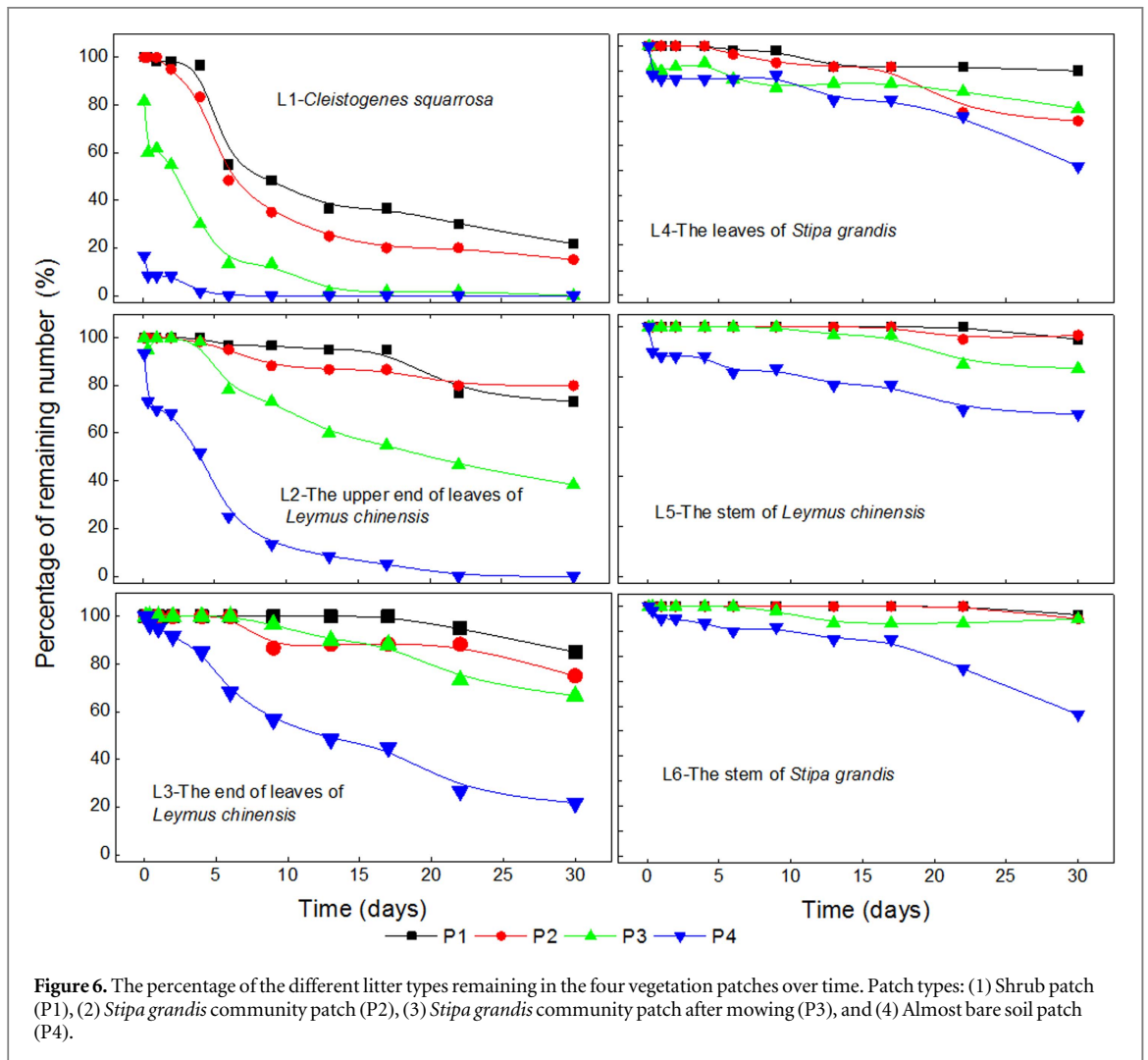
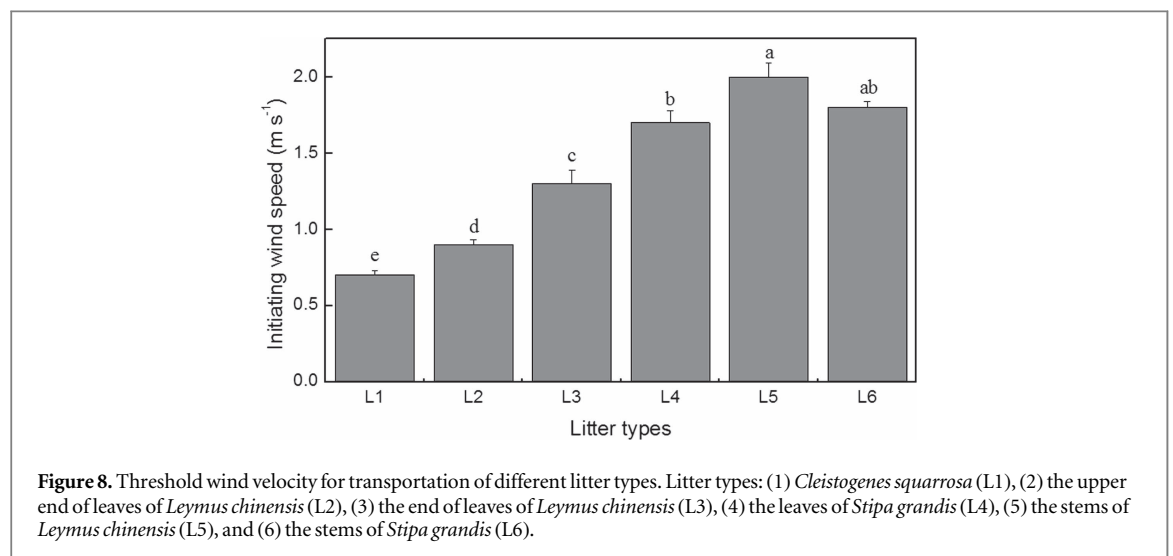
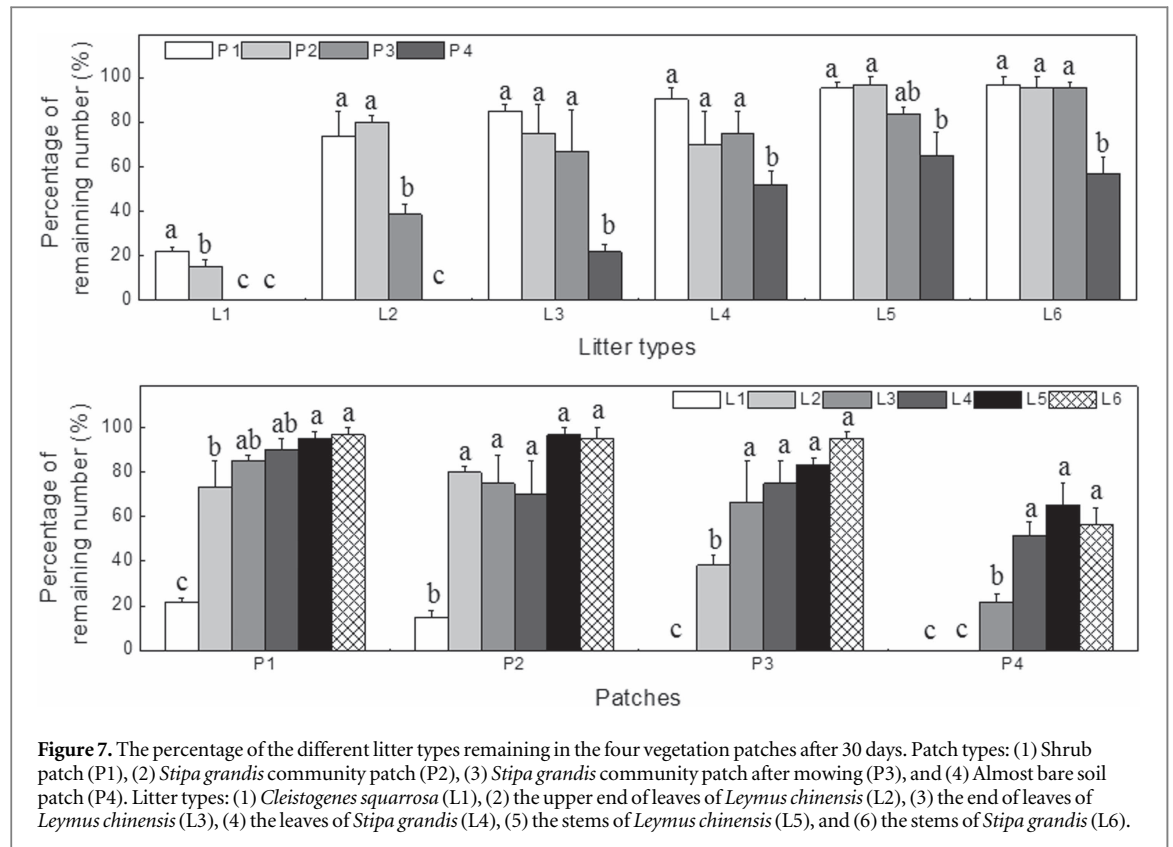


Figure 6. The percentage of the different litter types remaining in the four vegetation patches over time. Patch types: (1) Shrub patch (P1), (2) *Stipa grandis* community patch (P2), (3) *Stipa grandis* community patch after mowing (P3), and (4) Almost bare soil patch (P4).

accumulation at a small spatial scale. Specifically, the shrub patch type (P1) had the highest litter accumulation amount (387 g m^{-2}), which is 3.1 times greater than the above-ground biomass measured at the study area and 9.8 times greater than the litter accumulation

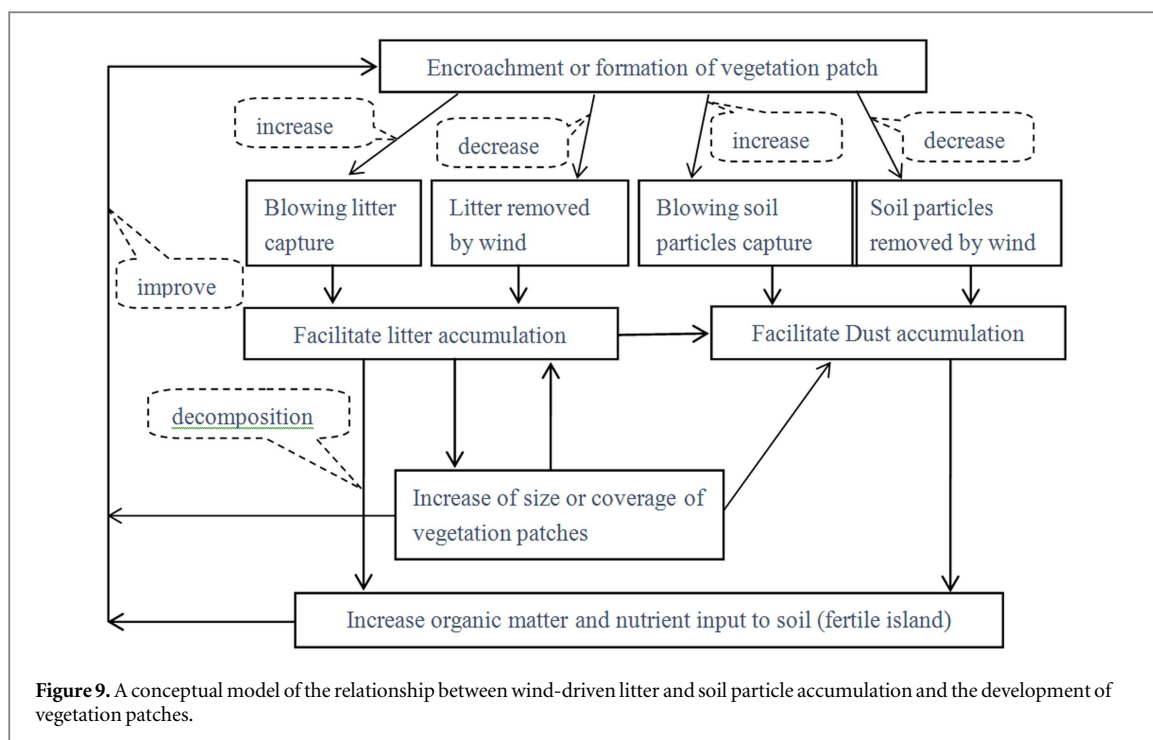
amount of the almost bare patch type (P4). The litter removal experiment showed that the almost bare patch (P4) had the fastest litter removal rate among the four patch types (figure 6). Therefore, although the lack of litter accumulation in the almost bare patch



(P4) could be partly due to the lack of litter sources under the overgrazing condition, the low trapping ability (the high removal rate by wind) is the decisive reason for the low litter accumulation in the almost bare patch.

There has been no quantitative description of vegetation patch patterns increasing wind-driven litter accumulation and decreasing litter removal in the past. Previous studies demonstrated that increasing vegetation cover or patches can decrease wind erosion and increase the capture of sediments (Field *et al* 2012, Li *et al* 2007, 2009, Yan *et al* 2011, 2013). Therefore, we can conclude that dust and litter redistribution in heterogeneous landscape systems of arid or semi-arid

areas likely share similar characteristics because both are driven by wind. These findings also provide direct evidence of the greater ability of shrub-dominated patches to capture wind-blown litter and dust relative to bare and herbaceous patches. In addition, these findings also showed that both wind-driven litter and dust redistribution are influenced by vegetation patch patterns and contribute to the spatial patterns of soil nutrients in semi-arid grassland (Schlesinger *et al* 1996). This relationship is a key assumption of many earlier and more recent conceptual models of desertification that has remained largely unsupported by field measurements (Schlesinger *et al* 1996, D'Odorico *et al* 2013).



The most well-known cases of vegetation patches increasing nutrient redistribution are the shrub ‘fertilizer islands’ of arid deserts or grasslands (Zhai *et al* 2015). Previous studies have concluded that (1) the shrub formation mechanism can decrease wind speed, prevent wind erosion, and increase sediment capture; (2) the shrub canopy can provide a habitat for birds or mammals, and animal excrement can increase soil nutrients; and (3) the stem flow and through flow from rainfall can promote the development of ‘fertile islands’. Our results provide additional explicit support for the untested assumption that wind-blown litter will be redistributed and remain in patches with high vegetation cover.

In addition, plant litter generally contains more carbon and nutrients than dust; for example, the carbon, total nitrogen, and total phosphorous contents of plants have been reported as 42.0%–46.6%, 1.7%–2.6%, and 0.1%–0.3%, respectively (Huang *et al* 1996, Yan and Tang 2008), whereas the corresponding contents of local dust have been reported as 0.5%–2.1%, 0.1%–0.2% and 0.02%–0.1% (Yan *et al* 2011). These results indicate that the carbon and nutrient contents of 1 g of litter are equivalent to those in 10–90 g of dust. Although the litter requires a decomposition process for transformation into bioavailable soil nutrients, this does not influence the deduction that wind-blown litter is another potentially important factor, in addition to airborne dust, in the redistribution of organic carbon and nutrients in arid and semi-arid regions where shrub encroachment and heterogeneous landscapes are common. Accordingly, we present a conceptual model of the development of vegetation patches by wind-driven dust and litter redistribution in figure 9. This study also highlights

the fact that the loss of grasses or shrub cover is a compounding problem that not only increases litter and dust removal rates but also reduces dust and litter capture. Such a loss may have regional and global relevance to the development of heterogeneous landscape systems.

4.2. Responses of different litter types to wind

The new litter originating from outside of the shrub patches is almost entirely composed of *C. squarrosa* (L1). The mass of this litter reached 139.4 g m^{-2} , which is a very high amount equivalent to or slightly higher than the peak biomass of local grassland. These results are not surprising because *C. squarrosa* (L1) is a small, dense clump xeric perennial grass that can be easily picked up by wind. In addition, the litter of *C. squarrosa* typically curves into a spherical shape when it dries, making it a readily wind-blown shape that easily catches on fences or shrubs and accumulates (Wang *et al* 2002). Because *C. squarrosa* (L1) is one of the main components of the typical steppe community, its biomass can reach $7.6\text{--}20.1 \text{ g m}^{-2}$, which accounts for 3.5%–11.2% of the total community biomass (Yan 2008). These findings indicate that the large amount of *C. squarrosa* litter in shrub patches that is redistributed by winds will improve shrub development in the long term through organic carbon and nutrient inputs. Therefore, the wind-driven relationship between *C. squarrosa* and *C. sinica* shrub deserves further investigation.

Our findings provided first field observations of the responses of six litter types to wind. The results showed that the properties of the litter directly influenced the threshold wind velocity for transportation and the disappearance rates of litter. We found that the

individual weight of a given litter fragment was a dominant factor affecting the threshold wind velocity for transportation. This threshold increases with increasing litter weight, except for the leaves of *S. grandis* (L4), which are very fine, with a smooth surface and very low center of gravity. These characteristics cause L4 to have a higher threshold wind velocity for transportation than that of L1 and L2 despite a lower weight. We hypothesized that litter with greater threshold wind velocities for transportation would have lower disappearance rates, and our observations showed that the stems of *L. chinensis* (L5) and the stems of *S. grandis* (L6) have the highest threshold wind velocities for transportation among the six litters, followed successively by L4, L3, L2, and L1 ($p < 0.05$). These results lead to the prediction that the disappearance rates should follow the reverse order. Indeed, *C. squarrosa* (L1) has the highest removal rate, followed successively by L2, L3, L4, L5, and L6. The results suggest that different litter types have different responses to wind. Differences among litter types in the response to wind have also been reported in a study of litter mobility in several natural forests in an arid region of Western Australia. In that study, the mobility of woody litter was estimated to be approximately 20% that of leaf litter, suggesting that climatic factors move leaves more easily than twigs (Kumada *et al* 2009). Overall, the findings of our study indicate that litter with high susceptibility to wind, such as *C. squarrosa* or the leaves of plants, will have a greater contribution in the wind-driven redistribution of resources driven than will litter with low susceptibility to wind, such as the stems of plants.

Because our study mainly focused on the effect of different vegetation patch patterns on litter accumulation and removal rates, in the study, the tested litters we selected have relatively uniform size (with a relatively large size of approximately 10 cm length) for comparability among different plant species or organism parts. In addition, the relatively large size facilitates observation of the loss rate through accurate counts of the fragments. Nevertheless, we speculate that litter size is also an important factor influencing the response of litter to wind; therefore, further studies are recommended to consider the redistribution characteristics of litter fragments of different sizes in different vegetation patch patterns.

5. Conclusions

In conclusion, we found that (1) there are large differences among vegetation patch types in the ability to capture wind-blown litter, (2) vegetation patches increase litter accumulation and decrease litter removal rates compared with bare land, and (3) shrub patches exhibit the largest litter accumulation amount and the lowest litter removal rate among the four patch types. These findings indicate that wind-driven litter

redistribution among bare, *S. grandis*-dominated, and shrub-dominated patches is at least partially responsible for increasing the spatial heterogeneity of resources on a landscape scale. Our findings can help inform the effective management of litter resources and the control of litter loss at the vegetation-patch scale. Moreover, our findings indicate that different litter types have different susceptibilities to wind; *C. squarrosa* litter has the lowest threshold wind velocity for transportation among the tested six litter types, and their leaves were more easily moved than were their stems. These findings indicate that wind-driven litter mobility should be addressed to understand the dynamics and heterogeneity of soil organic carbon in temperate grasslands where winds prevail.

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