

Snow resisting capacity of *Caragana microphylla* and *Achnatherum splendens* in a typical steppe region of Inner Mongolia, China (Postprint)

Authors: YAN Min, ZUO Hejun, WANG Haibing, DONG Zhi, LI Gangtie, ZUO Hejun

Date: 2020-06-22T00:00:00+00:00

Abstract

Snow resisting capacity of vegetation is important for secondary distribution of water resources in seasonal snow areas of grassland because it affects the regeneration, growth and nutrient circulation of vegetation in grassland. This study investigated vegetation characteristics (canopy height, canopy length and crown width) of *Caragana microphylla* Lam. (shrub) and *Achnatherum splendens* (Trin.) Nevski. (herb), and snow morphologies (snow depth, snow width and snow braid length) in a typical steppe region of Inner Mongolia, China in 2017. And the influence of vegetation characteristic on snow resisting capacity (the indices of bottom area of snow and snow volume reflect snow resisting capacity) was analyzed. The results showed that snow morphology depends on vegetation characteristics of shrub and herb. The canopy height was found to have the greatest influence on snow depth and the crown width had the greatest influence on snow width. The canopy length was found to have little influence on morphological parameters of snow. When the windward areas of *C. microphylla* and *A. splendens* were within the ranges of 0.0–0.5 m² and 0.0–8.0 m², respectively, the variation of snow cover was large; however, beyond these areas, the variation of snow cover became gradually stable. The potential area of snow retardation for a single plant was 1.5–2.5 m² and the amount of snow resistance was 0.15–0.20 m³. The bottom area of snow and snow volume (i.e., snow resisting capacity) of clumped *C. microphylla* and *A. splendens* was found to be 4 and 25 times that of individual plant, respectively. The results could provide a theoretical basis both for the estimation of snow cover and the establishment of a plant-based technical system for the control of windblown snow in the typical steppe region of Inner Mongolia.

Full Text

Preamble

Snow Resisting Capacity of *Caragana microphylla* and *Achnatherum splendens* in a Typical Steppe Region of Inner Mongolia, China

YAN Min¹, ZUO Hejun^{1*}, WANG Haibing¹, DONG Zhi², LI Gangtie¹

¹Key Laboratory of Aeolian Physics and Desertification Control Engineering, Inner Mongolia Autonomous Region, College of Desert Control Science and Engineering, Inner Mongolia Agricultural University, Hohhot 010018, China

²Forestry College, Shandong Agricultural University, Tai'an 271018, China

Abstract: Snow resisting capacity of vegetation is crucial for the secondary distribution of water resources in seasonal snow-covered grasslands, as it affects vegetation regeneration, growth, and nutrient cycling. This study investigated vegetation characteristics (canopy height, canopy length, and crown width) of *Caragana microphylla* Lam. (shrub) and *Achnatherum splendens* (Trin.) Nevski. (herb), along with snow morphologies (snow depth, snow width, and snow braid length) in a typical steppe region of Inner Mongolia, China, in 2017. The influence of vegetation characteristics on snow resisting capacity—reflected by bottom area of snow and snow volume—was analyzed. Results showed that snow morphology depends on the vegetation characteristics of both shrubs and herbs. Canopy height exerted the greatest influence on snow depth, while crown width most strongly affected snow width. Canopy length had minimal influence on snow morphological parameters. When the windward areas of *C. microphylla* and *A. splendens* were within 0.0–0.5 m² and 0.0–8.0 m², respectively, snow cover variation was substantial; beyond these thresholds, variation gradually stabilized. The potential snow retention area for a single plant was 1.5–2.5 m², with a snow retention amount of 0.15–0.20 m³. For clumped vegetation, the bottom area of snow and snow volume of *C. microphylla* and *A. splendens* were 4 and 25 times greater than those of individual plants, respectively. These findings provide a theoretical basis for estimating snow cover and establishing plant-based technical systems for windblown snow control in typical steppe regions of Inner Mongolia.

Keywords: herb; shrub; snow cover; snow resisting capacity; field observation; steppe

Introduction

Seasonal snow cover represents a vital freshwater resource in grassland ecosystems [?, ?]. Vegetation effects on wind protection, snow blocking, and snow retention cause drifting snow to form secondary accumulations on the leeward side of shrubs and herbs, redistributing snow cover within a defined spatial range [?, ?]. Topography, wind force, snow source, and shrub-herb characteristics all influence the disturbance range, potential snow cover extent, and snow resisting capacity [?, ?, ?, ?]. Snow accumulation magnitude determines herb vegetation

revival timing, ground temperature, vegetation growth and development rates, and biomass in the following year [?, ?, ?]. Furthermore, snow formation in association with shrubs and herbs influences plant species composition, vegetation structure, soil carbon storage, surface water geochemistry, decomposition processes, invertebrate and vertebrate populations, and vegetation spectral reflectance [?, ?, ?, ?, ?].

The relationship between snow morphology and vegetation characteristics in steppe regions is complex [?, ?, ?]. Grassland hydrological processes (e.g., snow cover, distribution, and ablation) are considerably affected by vegetation characteristics [?, ?, ?]. Conversely, snow cover influences vegetation physiological and ecological processes in steppe regions; for instance, snow cover shows significant correlation with vegetation growth in the succeeding year [?, ?, ?, ?, ?, ?].

Based on field observation and numerical simulation, researchers have preliminarily established the status and function of vegetation-affected snow cover. For example, using the CLM4 (Community Land Model 4) and CAM4 (Community Atmosphere Model 4) models, [?, ?] found that a 20% increase in vegetation density could lead to a corresponding 40 cm increase in snow depth. Field observations indicate that snow accumulation is controlled by wind and blowing snow blocking. [?, ?] found that snow depth in tundra shrub areas is about 27% higher than in herbaceous areas, and that slight increases in shrub canopy height cause remarkable increases in snow depth. [?, ?] reported that snow depth in Arctic shrub areas was 4-5 times that in sparse vegetation areas. [?, ?] also found that vegetation height significantly affected snow depth, with greater snow depth in shrub areas than in non-vegetated areas. Individual shrub patches and edges of larger vegetation areas can serve as depositories for windblown snow by intercepting large amounts of snow blown from the tundra. The snow resisting capacity of vegetation is crucial for controlling snow-related damage in steppe regions during winter.

Current research on vegetation and snow cover in steppe regions primarily focuses on large-scale remote sensing monitoring, where snow cover and vegetation parameters can be extracted from AVHRR and MODIS data to establish relationships between snow cover and climate, vegetation, and topography. However, inversion accuracy is considerably affected by vegetation, particularly shrubs, which have been confirmed as the largest source of uncertainty in snow parameter extraction [?, ?, ?]. Moreover, the snow resisting capacity of shrubs and herbs has not been studied in depth.

In this study, we used bottom area of snow and snow volume to reflect the snow resisting capacity of shrubs and herbs. The temperate steppe region in Inner Mongolia represents an important component of the world's largest grassland biome in the Eurasian continent, covering a total area of 8.86×10^7 hm². *Caragana microphylla* Lam. and *Achnatherum splendens* (Trin.) Nevski. are typical shrubs and herbs in the steppe region due to their drought, cold, and saline resistance traits. We used these two representative vegetation types to study the influence of vegetation characteristics on snow formation, snow reten-

tion range and amount, and to analyze snow resisting capacity. The aim was to provide a theoretical basis for estimating snow cover and establishing plant-based technical systems for windblown snow control in typical steppe regions.

2.1 Study Area

Xilin Gol League (44°16'08"–44°25'25" N, 116°14'25"–116°29'09" E) is a typical steppe region located in central Inner Mongolia Autonomous Region, China. The area receives seasonal snow cover (in winter and spring) with long-term snow duration (100 days). Average annual precipitation is 286.4 mm, average annual snowfall is 23.2 mm, and average annual snow depth is 1–5 cm. The annual average temperature is 1.7°C and the frost-free period is 90–115 days. Annual average wind speed is 4.5 m/s, with 10–15 gale days per year and prevailing northwesterly winds. Xilin Gol League has experienced frequent natural disasters; over the past 50 years, the area has experienced 19 droughts and 22 snowstorms, including three major snowstorms in 1962, 1977, and 2000 [?, ?].

Figure 1 [Figure 1: see original paper] shows the distribution of shrubs and herbs in the typical steppe region of Xilin Gol League, Inner Mongolia, China. *A. splendens* is a typical herb species and *C. microphylla* is a widely distributed shrub species in the steppe. Snow morphology in the region is associated with these two vegetation types, which we selected as study materials. The study area terrain is reasonably flat, largely eliminating microtopographic influences on wind disturbance and snow morphology development around vegetation. Thus, the primary influences on snow morphology associated with shrubs and herbs in this study were the physical characteristics of the vegetation.

2.2.1 Field Survey

Snowfall is abundant in the study area during December–January due to frequent strong winds and extended low-temperature periods. January is the coldest month (Fig. 2 [Figure 2: see original paper]) and features the greatest snow accumulation. Therefore, field observations were conducted from 10–29 January 2017.

Overall, 60 specimens were selected: 30 *C. microphylla* and 30 *A. splendens* from five 5 m × 5 m plots. Additionally, three 10 m × 10 m plots were selected for each species to identify grouped vegetation types (Fig. 3 [Figure 3: see original paper]). *C. microphylla* is the dominant shrub species and *A. splendens* is the only associated species in the study area; thus, grouped vegetation types were defined by the distributional characteristics of *A. splendens*. Four grouped vegetation types were identified: Type A (two *A. splendens* plants side by side) (Fig. 3d), Type B (three *A. splendens* plants side by side) (Fig. 3g), Type C (one *A. splendens* in front and two at the back) (Fig. 3e), and Type D (crumbly and loose distribution of *A. splendens*) (Fig. 3h). The investigation included measurement of vegetation characteristics—shrub and herb height (H_p), crown width (W_p), and canopy length (P)—and snow morphologies—snow depth (H),

snow width (W), and snow braid length (L) (Fig. 3f). Measurement sets of L (x-axis), W (y-axis), and H (z-axis) were acquired at 10-cm intervals in both x and y directions using a steel rule. Statistical methods were then used for spatial interpolation of measured point coordinates (X, Y, and Z) to calculate bottom area of snow and snow volume using Surfer 11.0 software (Golden Software, USA).

2.2.2 Data Analysis

Correlation analyses were conducted between all morphological parameters (one-power factors) and parameter multiplications (quadratic and cubic factors) with bottom area of snow and snow volume to identify factors significantly affecting snow resisting capacity. Six factors were selected for bottom area of snow: H_p^2 , W_p^2 , P^2 , $H_p \times W_p$, $H_p \times P$, and $W_p \times P$. Ten factors were selected for snow volume: H_p^3 , W_p^3 , P^3 , $H_p \times W_p^2$, $H_p \times P^2$, $H_p^2 \times W_p$, $H_p^2 \times P$, $W_p \times P^2$, $W_p^2 \times P$, and $H_p \times W_p \times P$. Selected factors were used to establish relationships between bottom area of snow and snow volume, with significance tests used to determine snow resisting capacity across different snow morphologies.

3.1 Relationships Between Shrub and Herb Characteristics and Snow Morphologies

Figure 4 [Figure 4: see original paper] shows relationships between characteristics of *C. microphylla* and *A. splendens* and snow morphological parameters. Snow depth, snow width, and snow braid length were associated with canopy height, crown width, and canopy length of both species, with significant linear relationships ($R^2 > 0.50$). Among various parameters, *C. microphylla* height had the greatest influence on snow depth ($R^2 = 0.75$), while crown width ($R^2 = 0.91$) and canopy length ($R^2 = 0.76$) most significantly affected snow width. Canopy height, crown width, and canopy length of *A. splendens* all showed strong correlation with snow braid length, with R^2 values of 0.92, 0.85, and 0.69, respectively. Among all morphological parameters, the relationship between canopy height and snow depth was most significant for *A. splendens*, while for *C. microphylla*, the relationship between crown width and snow width was strongest. For shared characteristics of shrubs and herbs, canopy height and crown width (mean $R^2 = 0.75$) were the primary determinants of snow morphology, while canopy length had less influence (mean $R^2 = 0.63$).

3.2 Snow Characteristics of Individual and Grouped Herbs

Table 1 presents vegetation characteristics and snow morphologies of individual and grouped *A. splendens*. Snow morphologies differed significantly among grouped vegetation types. Bottom area of snow and snow volume of grouped *A. splendens* increased exponentially with vegetation height and crown width. For example, Type A showed bottom area of snow and snow volume approximately 2 and 4 times those of individual plants (mean of small, medium, and large

plants), respectively. In Type B, these values were 4 and 20 times greater; in Type C, 3 and 8 times; and in Type D, 4 and 25 times. The maximum bottom area of snow occurred in Type A, while maximum snow volume occurred in Type D.

3.3 Snow Resisting Capacity of Shrubs and Herbs

Variation in bottom area of snow affected by shrubs and herbs manifests snow resisting capacity. Figure 5 [Figure 5: see original paper] shows the relationship between bottom area of snow and windward area ($H_p \times W_p$) for *A. splendens* and *C. microphylla*. Bottom area of snow demonstrated significant relationships with windward areas of both species ($R^2=0.81$ and $R^2=0.75$), increasing as windward area increased. The increase was rapid for small windward areas (0.0–0.8 m^2 for *C. microphylla* and 0.0–0.5 m^2 for *A. splendens*) but became gradual and stabilized beyond these thresholds.

Figure 6 [Figure 6: see original paper] shows the relationship between vegetation volume ($H_p \times W_p \times P$) and snow volume for both species. Snow volume exhibited significant relationships with vegetation volumes of *C. microphylla* and *A. splendens* ($R^2=0.81$ and $R^2=0.82$), increasing with vegetation volume. Snow volume increased rapidly for smaller vegetation volumes (0.0–0.3 m^3 for *C. microphylla* and 0.0–0.6 m^3 for *A. splendens*) but tended to stabilize with further volume increases.

4 Discussion

Existing models of blowing snow and snow cover indicate that snow accumulation is highly sensitive to shrub canopy height and crown width, though shrub size remains an important factor in the accumulation process [?, ?, ?]. In alpine tundra areas, shrub height and canopy breadth significantly affect snow depth, with Arctic shrub areas showing snow depth 4–5 times greater than sparse vegetation areas [?, ?]. Similar results demonstrate that variations in shrub height and coverage can significantly alter snow morphological characteristics during accumulation in cold regions [?, ?]. This study found that crown width significantly influences snow morphology ($R^2>0.75$), while canopy length has minimal influence—a result that can guide selection of plant species with large crown width to improve snow damage resistance.

Field observations have shown that vegetation coverage determines regional snow cover amounts, with similar results obtained in grassland studies. Using monitored snow water equivalent in a penneplain stubble field as baseline, relative snow water equivalents were 0.60 for grazed grassland, 2.85 for ungrazed grassland, and 4.20 for shrubland [?, ?], implying that shrubs influence snow cover more than grasses. Observations have revealed significant correlations between shrub and herb vegetation parameters and snow depth, with greater snow amounts on shrubs than on grasses. This study showed significant correlations between vegetation parameters of both *C. microphylla* and *A. splendens* and

snow morphology. For *A. splendens*, crown width of 0.1–1.5 m resulted in snow braid length of 0.3–3.5 m, snow width of 0.1–2.0 m, and snow depth of 0.1–0.5 m. For *C. microphylla*, crown width of 0.5–4.0 m produced snow braid length of 1.5–7.0 m, snow width of 0.5–3.0 m, and snow depth of 0.1–0.4 m. The stagnant snow area for a single plant was 1.5–2.5 m², with snow volume of 0.15–0.20 m³.

Snow and sand accumulation associated with shrubs and herbs are products of snow drifting and windblown sand transport, both representing dual-phase gas-solid flows with similar migration trends. Snow grains are more viscous than sand grains, making snow accumulation easier on the leeward side of shrubs and herbs [?, ?, ?]. Studies of windblown sand prevention mechanisms by shrubs and herbs offer insights for understanding snow movement prevention. When windblown sand approaches an individual plant, a deceleration zone forms in front of the plant, depositing a portion of the sand, while acceleration zones form on either side and above the plant. On the leeward side, wind speed decreases rapidly due to eddy effects, forming a low-speed zone. Beyond a certain downwind distance, wind speed gradually recovers in a wake area, causing sand particle deposition [?, ?, ?, ?]. Vegetation morphology and wind field characteristics determined this study's observations and analytical results, verifying the similarity between sand and snow accumulation mechanisms associated with shrubs and herbs. Therefore, bottom area of snow partially and indirectly reflects shrub and herb snow resisting capacity, while snow volume directly reflects snow amount covered by vegetation, with both determining overall snow resisting capacity.

This study also confirms snow resisting capacity under different vegetation type combinations in the Inner Mongolia steppe region. When single plants align perpendicular to prevailing wind direction, wind blocking range increases and snowdrift deposits on the leeward side. However, when plants grow in the downwind direction, although plant coverage may increase, blocking range changes minimally, yielding minimal increase in wind and snow accumulation resistance. In contrast, clumped growth increases both plant coverage and density, significantly enhancing wind blocking range and snow accumulation capacity. Thus, clumped vegetation exhibits the greatest wind and sediment resistance capacity. Consistent with this study, we found that potential snow area and snow volume retarded in Type D were respectively 4 and 25 times those of a single plant, indicating that clumped vegetation distribution provides the greatest snow resistance capacity among the four vegetation types.

5 Conclusions

Canopy height most strongly influenced snow depth, crown width most strongly affected snow width and snow braid length, while canopy length had minimal effect on snow morphology. Snow resisting capacity was significantly altered by different clumped vegetation configurations. Shrubs and herbs with high coverage and canopy height, growing in the windward direction, demonstrated the greatest snow resistance in the Inner Mongolia steppe region.

Acknowledgements: This work was supported by the National Natural Science Foundation of China (41361012) and the Postgraduate Research and Innovation Funding Project of Inner Mongolia Autonomous Region (B2018111951).

References

- Ash J E, Wasson R J. 1983. Vegetation and sand mobility in the Australian desert dunefield. *Zeitschrift für Geomorphologie Supplementband*, 45: 7-25.
- Cacitua G, Bay C, Pedersen M R, et al. 2013. Quantifying snow and vegetation interactions in the High Arctic based on ground penetrating radar (GPR). *Arctic, Antarctic, and Alpine Research*, 45(2): 201-210.
- Conner L, Gill R, Harvey J. 2017. Earlier snowmelt accompanied by warmer soil temperatures in mid-latitude aspen forest and subalpine meadow: Implications for soil carbon. *Plant and Soil*, 417(1-2): 275-285.
- Cornelissen J H C, Makoto K. 2014. Winter climate change, plant traits and nutrient and carbon cycling in cold biomes. *Ecological Research*, 29(4): 517-527.
- Dolman A J, Hall A J, Kavvas M L, et al. 2001. *Soil-Vegetation-Atmosphere Transfer Schemes and Large-Scale Hydrological Models*. Wallingford: IAHS Press, 317-325.
- Essery R, Pomeroy J. 2004. Vegetation and topographic control of wind-blown snow distributions in distributed and aggregated simulations for an Arctic tundra basin. *Journal of Hydrometeorology*, 5(5): 735-744.
- Fan L L, Li Y, Tang L S, et al. 2013. Combined effects of snow depth and nitrogen addition on ephemeral growth at the southern edge of the Gurbantunggut Desert, China. *Journal of Arid Land*, 5(4): 500-510.
- Frank A, Kocurek K. 1996. Toward a model for airflow on the lee side of aeolian dunes. *Sedimentology*, 43(3): 451-458.
- Gavazov K, Ingrisich J, Hasibeder R, et al. 2017. Winter ecology of a subalpine grassland: Effects of snow removal on soil respiration, microbial structure and function. *Science of the Total Environment*, 590-591: 316-324.
- Gray D M. 1979. Snow accumulation and redistribution. In: Colbeck S C, Ray M. *Proceedings, Modeling of Snow Cover Runoff*. Hanover: US Army Cold Regions Research and Engineering Laboratory, 3-33.
- Hallinger M, Manthey M, Wilmking M. 2010. Establishing a missing link: Warm summers and winter snow cover promote shrub expansion into alpine tundra in Scandinavia. *New Phytologist*, 186(4): 890-899.
- Hao L, Gao J M, Yang C Y. 2006. Snow disaster system of grassland animal husbandry and control countermeasures. *Pratacultural Science*, 6: 48-54. (in Chinese)

- Johansson M, Callaghan T V, Bosio J, et al. 2013. Rapid responses of permafrost and vegetation to experimentally increased snow cover in sub-arctic Sweden. *Environmental Research Letters*, 8(3): 035025.
- Jones H G, Pomeroy J W, Walker D A, et al. 2001. *Snow Ecology: An Interdisciplinary Examination of Snow-covered Ecosystems*. Cambridge: Cambridge University Press, 34–48.
- Lawrence D M, Oleson K W, Flanner M G, et al. 2011. Parameterization improvements and functional and structural advances in version 4 of the community land model. *Journal of Advances in Modeling Earth Systems*, 3(1): 1–27.
- Leonard K C, Maksym T. 2011. The importance of wind-blown snow redistribution to snow accumulation on Bellingshausen Sea Ice. *Annals of Glaciology*, 52(57): 271–278.
- Liston G E, Hiemstra C A. 2011. Representing grass and shrub snow atmosphere interactions in climate system models. *Journal of Climate*, 24(8): 2061–2079.
- Marion G M, Henry G H R, Freckman D, et al. 1997. Open-top designs for manipulating field temperature in high-latitude ecosystems. *Global Change Biology*, 3(S1): 30–32.
- Marsh P, Bartlett P, MacKay M, et al. 2010. Snowmelt energetics at a shrub tundra site in the western Canadian Arctic. *Hydrological Processes*, 24(25): 3603–3620.
- Ménard C B, Essery R, Pomeroy J, et al. 2014. A shrub bending model to calculate the albedo of shrub-tundra. *Hydrological Processes*, 28(2): 341–351.
- Musick H B, Gillette D A. 1990. Field evaluation of relationships between a vegetation structural parameter and sheltering against wind erosion. *Land Degradation and Development*, 2(2): 87–94.
- Myers-Smith I H. 2011. *Shrub Encroachment in Arctic and Alpine Tundra: Mechanisms of Expansion and Ecosystem Impacts*. PhD Dissertation. Edmonton: University of Alberta, 7–19.
- Naito A T, Cairns D M. 2011. Patterns and processes of global shrub expansion. *Progress in Physical Geography*, 35(4): 423–442.
- Pomeroy J W, Marsh P, Gray D M. 1997. Application of a distributed blowing snow model to the Arctic. *Hydrological Processes*, 11(11): 1454–1464.
- Pomeroy J W, Bewley D S, Essery R, et al. 2006. Shrub tundra snowmelt. *Hydrological Processes*, 20(4): 923–941.
- Schmidt N M, Baittinger C, Kollmann J, et al. 2010. Consistent dendrochronological response of the dioecious *Salix arctica* to variation in local snow precipitation across gender and vegetation types. *Arctic, Antarctic, and Alpine Research*, 42(4): 471–475.

Sturm M, McFadden J P, Liston G E, et al. 2001. Snow-shrub interactions in Arctic tundra: A hypothesis with climatic implications. *Journal of Climate*, 14(3): 336-344.

Sturm M, Douglas T, Racine C, et al. 2005. Changing snow and shrub conditions affect albedo with global implications. *Journal of Geophysical Research: Biogeosciences*, 110(G1): 1-13.

Tinkham W T, Smith A, Marshall H P, et al. 2014. Quantifying spatial distribution of snow depth errors from LiDAR using random forest. *Remote Sensing of Environment*, 141: 105-115.

Tommaso C, Sprugnoli R, Manuela S, et al. 2014. Evaluation of events and temporal information at Evalita. In: *Proceedings of the First Italian Conference on Computational Linguistics CLiC-it 2014 & the Fourth International Workshop. Evalita*: Pisa University Press, 27-34.

Walker I J, Nickling W C. 2002. Dynamics of secondary airflow and sediment transport over and in the lee of transverse dunes. *Progress in Physical Geography*, 26(1): 47-75.

Walker K D, Ingersoll R C, Webber P J. 1995. Effects of interannual climate variation on phenology and growth of two alpine forbs. *Ecology*, 76(4): 1067-1083.

Wipf S, Rixen C. 2010. A review of snow manipulation experiments in Arctic and alpine tundra ecosystems. *Polar Research*, 29(1): 95-109.

Yan M, Zuo H J, Dong Z, et al. 2018. Capacity of Caragana microphylla shrub on counteracting snow movement and its influence on snow morphology in the Xilinhote Steppe, China. *Chinese Journal of Applied Ecology*, 29(2): 483-491. (in Chinese)

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv – Machine translation. Verify with original.