Effects of Crop Residue on Wind Erosion in Tiger Nut (Cyperus esculentus) Cropland (Postprint)

Authors: Tan Jin

Date: 2022-04-16T00:34:44+00:00

Abstract

Tiger nut (Cyperus esculentus) is an oil crop with low soil nutrient requirements, making it suitable for promotion and cultivation in the sandy areas of northern China to adjust agricultural planting structures. However, soil disturbance during the harvesting process can potentially increase the risk of wind erosion in farmland, necessitating investigation and evaluation of the ecological benefits of tiger nut residues. Based on field sand collection experiments and wind speed profile measurement experiments, a systematic study was conducted on the windbreak and sand fixation capacities of three residue types: intercropped tiger nut and Haloxylon (not harvested), pure tiger nut with 4 rows left and 6 rows harvested, and pure tiger nut with 6 rows left and 6 rows harvested. The results showed that the intercropped tiger nut and Haloxylon residue type exhibited the lowest sand transport flux, with total sand transport flux significantly smaller than the other two patterns ($P<0.05$), and also the highest aerodynamic roughness (0.553 cm and 1.156 cm) and friction velocity (0.304 and 0.332). The 4-rows-left/6-rows-harvested pattern showed increasing sand transport flux over time, even exceeding that of the fully harvested pattern, with aerodynamic roughness approaching zero and the lowest friction velocity. The sand transport flux of the 6-rows-left/6-rows-harvested pattern fell between the former two, with aerodynamic roughness of 0.100 cm and 0.137 cm, and friction velocity of 0.240 and 0.272. Overall, the wind speed reduction effect of single wide-strip tiger nut residues was inferior to that of crop residues with interspersed high-low configurations. Tiger nut cultivation could consider selecting appropriate harvesting spacing and intercropping with suitable erect plants to retain residues during the long fallow period after tiger nut harvest, thereby mitigating wind erosion and protecting farmland. Rational crop residue retention during the fallow period is one of the key measures for mitigating soil wind erosion, which holds important ecological value for the sustainable development of farmland in arid regions.

Full Text

Effects of Crop Residues on Farmland Wind Erosion in Cyperus esculentus Planting Areas

TAN Jin[1,2], WU Xiuqin[1,2], RUAN Yongjian[1,2], ZHANG Huan[1,2], FENG Mengxin[1,2], SHA Rina[1,2]

[1]School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China
[2]Yanchi Ecology Research Station of the Mu Us Desert, Yanchi 751500, Ningxia, China

---

Abstract

Cyperus esculentus is an oil crop with low soil nutrient requirements, making it suitable for promotion in wind-sand regions of northern China to adjust agricultural planting structures. However, land disturbance during harvest potentially increases the risk of farmland wind erosion, necessitating investigation and evaluation of the ecological benefits of C. esculentus residues. Based on field sand collection experiments and wind speed profile measurements, we systematically studied the wind prevention and sand fixation capabilities of three residue retention patterns: (1) intercropping of C. esculentus with Haloxylon ammodendron (unharvested), (2) pure C. esculentus planting with 4 ridges retained, and (3) pure C. esculentus planting with 6 ridges retained. Results showed that the intercropped unharvested residue type exhibited the lowest sand transport flux among all patterns, with total sand flux significantly smaller than other types ($P < 0.05$). This pattern also demonstrated the highest aerodynamic roughness (0.553 cm and 1.156 cm) and friction velocity, indicating superior wind speed reduction. The 4-ridge retention pattern showed increasing sand flux over time, eventually exceeding that of the complete harvest control, with aerodynamic roughness approaching 0 cm and the lowest friction velocity. The 6-ridge retention pattern produced intermediate results. Overall, single wide-strip C. esculentus residues were less effective at reducing wind speed than high-low interspersed crop residues. We recommend that C. esculentus cultivation adopt appropriate harvest spacing and intercropping with suitable upright plants to retain residues during the long post-harvest fallow period, thereby mitigating wind erosion and protecting farmland. Rational crop stubble retention during fallow periods is a key measure for reducing soil wind erosion and holds important ecological value for sustainable farmland development in arid regions.

Keywords: Cyperus esculentus; crop residues; sand flux; wind-sand flow; aerodynamic roughness; friction velocity

---

1. Introduction

Soil wind erosion is a primary factor causing productivity decline in agricultural regions of China's arid and semi-arid wind-sand zones, with up to 9.1×10^{6} hm^2 of farmland abandoned annually due to wind erosion. Wind erosion not only destroys soil structure and coarsens soil texture but also leads to reduced soil fertility and decreased sustainable productivity. Consequently, numerous scholars have conducted in-depth research on suppressing farmland wind erosion to protect agricultural productivity. These studies demonstrate that conservation tillage measures such as residue cover, stubble retention, and no-tillage can effectively reduce wind speed, intercept sand particles, dissipate wind energy, enhance soil erosion resistance, and protect farmland soil.

Inner Mongolia spans China' s arid and semi-arid regions, encompassing four of the eight major deserts and all sandy lands. The harsh environment characterized by dryness, low rainfall, and intense wind-sand activity severely impacts agricultural production and development. During inspections in Inner Mongolia, President Xi Jinping emphasized the need to explore a new high-quality development path that aligns with strategic positioning, reflects Inner Mongolian characteristics, and prioritizes ecology and green development. Under global climate change and rapid economic development, agricultural planting structures urgently require new approaches to adapt to complex and variable climates. Traditional crops in Inner Mongolia—including wheat (*Triticum sativum*), corn (*Zea mays*), potato (*Solanum tuberosum*), soybean (*Glycine max*), and sunflower (*Helianthus annuus*)—can no longer meet the demands of scientific and ecological planting structures.

Cyperus esculentus, designated by the Ministry of Agriculture as a pollution-free organic agricultural product (Announcement No. 86), exhibits drought resistance, barren tolerance, saline-alkali tolerance, and contains high-quality vegetable oil. These characteristics make it suitable for cultivation in sandy regions, where it can alleviate land pressure and improve the environment, demonstrating enormous development potential. Consequently, it has been incorporated into the *National Planting Structure Adjustment Plan (2016-2020)* by the Ministry of Agriculture and Rural Affairs and the Ministry of Science and Technology. In 2020, Inner Mongolia and the Ministry of Science and Technology launched the "Revitalizing Inner Mongolia through Science and Technology" initiative, with modern agriculture and ecological environment construction as crucial components. Research on the promotion, economic value, and ecological value of C. esculentus represents an important measure for achieving ecological industrialization and industrial ecologicalization.

The primary economic product of C. esculentus is its underground tubers. Harvesting for economic benefit inevitably disturbs farmland, leaving soil exposed and substantially increasing wind erosion hazards. Conversely, excessive residue retention for wind erosion prevention wastes C. esculentus' s abundant oil resources. Some scholars have proposed various planting and harvesting methods to enhance wind prevention and sand fixation benefits, including strip-interval stubble retention, rotation intercropping, and three-dimensional planting. However, the wind prevention and sand fixation effectiveness of these models remains unclear. This study, conducted in the C. esculentus planting demonstration area of Ulan Buh Farm in Dengkou County, Inner Mongolia, aims to clarify the effects of different C. esculentus residue retention patterns on farmland wind erosion and provide a scientific basis for soil wind erosion prevention in C. esculentus planting areas.

---

2. Materials and Methods

2.1 Study Area Description The study area is located in the C. esculentus planting demonstration area of Ulan Buh Farm, Dengkou County, Bayannur City, Inner Mongolia, with geographical coordinates of 106°33 28 –106°34 19 E, 40°27 32 –40°27 44 N. The region has a temperate continental climate with scarce rainfall, large diurnal temperature variations, but abundant light and heat resources and a long frost-free period. Annual average precipitation is 139.2 mm, concentrated in July–September. Annual average temperature is 7.5°C, with maximum temperatures reaching 35.5°C and minimum temperatures dropping to -23.7°C. Annual sunshine hours total 3263 h, and the frost-free period extends to 130 days. Natural vegetation consists primarily of shrubs including *Nitraria tangutorum*, *Zygophyllum xanthoxylon*, *Haloxylon ammodendron*, and *Calligonum mongolicum*, along with herbs such as *Agriophyllum squarrosum*, *Phragmites australis*, and *Glycyrrhiza uralensis*. Soils are predominantly aeolian sandy soils, with localized distribution of grey desert soil and irrigated silt soil.

2.2 Residue Type Classification The demonstration area primarily uses ridge drilling, with 6 rows of C. esculentus per ridge and an average ridge width of approximately 0.7 m. Harvesting employs a self-propelled C. esculentus harvester (Patent No.: CN201811584002.4) that harvests in ridge units. Based on actual conditions in the demonstration area, crop residue types are classified into three patterns (Fig. 2):

1. **Intercropping unharvested**: 1 ridge of C. esculentus intercropped with 1 row of *Haloxylon ammodendron*, with neither species harvested. During investigation, the *Haloxylon* had withered and the surrounding area was covered with natural vegetation dominated by *Agriophyllum squarrosum*.
2. **Pure planting–retain 4 ridges**: Retain 4 ridges and harvest 6 ridges.
3. **Pure planting–retain 6 ridges**: Retain 6 ridges and harvest 6 ridges.

The first two residue types of C. esculentus are oriented east–west, while the intercropped unharvested C. esculentus is oriented north–south. Simultaneously, wind erosion monitoring was conducted on completely harvested bare farmland as a control (Fig. 2). Surface characteristic parameters for different residue types are presented in Table 1, and basic soil physical and chemical properties are shown in Table 2.

Table 1 Characteristic parameters of different residue types

Residue type	Ridge height (cm)	Ridge width (cm)	Coverage (%)	Belt spacing (m)
Intercropping unharvested	45.6±5.2	70.0±5.0	35.0±5.0	0.7±0.1
Retain4ridges	15.3±2.1	70.0±5.0	25.0±3.0	1.5±0.2
Reta…				
All harvest	0	0	0	0

Table 2 Soil basic physical and chemical properties

Residue type	Bulk density (g · cm^{-3})	Organic matter (g · kg^{-1})	Clay content (<50 m, %)
Intercropping unharvested	1.49±0.02	25.65±0.67	3.46±0.29
Retain4ridges	1.59±0.01	16.09±0.38	4.35±0.43
Retain6ridge…			

Note: Values are mean ± standard deviation.

2.3 Sand Transport Flux and Wind-Sand Flow Structure Sand transport flux was measured using combined multi-channel sand collectors deployed in completely harvested plots and plots with different residue types. The sand collectors had 16 channels at heights of 0–3, 3–6, 6–9, 9–12, 12–15, 15–18, 18–21, 21–24, 24–27, 27–30, 30–33, 33–36, 36–39, 39–42, 42–45, and 45–48 cm, with a channel length of 1.5 cm and width of 3.0 cm.

To enable simultaneous sand collection within approximately the same distance (referenced to the shortest windward distance in intercropping), 2 sand collectors were installed in the completely harvested plot as a reference. For each of the three different residue types, 2 sand collectors were deployed: one 1.5 m behind the first belt and the seventh belt in the intercropping pattern, and 4.5 m behind the first and second belts in the retain 4 ridges and retain 6 ridges patterns (Fig. 2). Due to varying wind erosion prevention capabilities of different surface characteristics and the need to collect sufficient sand for weighing, collection duration was determined based on wind strength, wind direction stability, and surface dust emission intensity. Monitoring dates, prevailing wind directions, and average wind speeds are presented in Table 3.

Table 3 Average wind speed and direction in different monitoring periods

Monitoring date	Prevailing wind direction	Average wind speed at 200 cm ($m \cdot s^{-1}$)
2020-11-05	NW	6.8
2020-11-20	NW	7.2
2021-03-04	NW	8.5

Collected samples were weighed using a 0.0001 g precision electronic balance. Sand transport flux at different heights and total sand flux were calculated using the following formulas:

$$Q_k = \frac{W}{S \cdot T}$$

$$Q_{\text{total}} = \sum_{k=1}^{16} Q_k$$

where Q_k is the sand transport flux of the kth gradient ($g \cdot cm^{-2} \cdot min^{-1}$), Q_{total} is the total sand flux ($g \cdot cm^{-2} \cdot min^{-1}$), W is the collected sand weight (g), S is the channel inlet cross-sectional area (cm^2), and T is the collection time (min).

2.4 Near-Surface Wind Field Characteristics To better understand the influence of different surfaces on wind-sand activity, wind speed profiles were measured using a handheld anemometer (Smart AS8336) at heights of 5, 25, 50, 100, 150, and 200 cm. The measurement frequency was 1/60 Hz, with 5-minute averaging intervals. Wind speed profiles were plotted when the average wind speed at 200 cm reached 5 $m \cdot s^{-1}$. In the completely harvested plot, a 20 m fetch without crops was maintained to ensure adequate boundary layer development.

Wind measurement positions were 2 m from the sand collectors, with the line connecting sand collectors and wind measurement points parallel to the C. esculentus planting direction. Position labels corresponded to sand collector identifiers (Fig. 2). To assess wind speed reduction capacity after prolonged wind erosion and deposition processes, wind speeds at different heights were measured on March 4, 2021.

Aerodynamic roughness (z_0) and friction velocity (u_*) were calculated from wind speed profiles to characterize surface effects on wind-sand activity. Larger roughness and friction velocity indicate stronger wind speed reduction. The calculation formulas are:

$$u_z = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right)$$

or equivalently:

$$\ln(z) = a + b \cdot u_z$$

$$z_0 = e^{-a/b}$$

$$u_* = b \cdot k$$

where u_z is wind speed at height z ($\mathrm{m \cdot s^{-1}}$), k is the von Kármán constant (0.4), a and b are regression coefficients, z_0 is aerodynamic roughness (cm), and u_* is friction velocity ($\mathrm{m \cdot s^{-1}}$).

---

3. Results

3.1 Differences in Total Sand Transport Flux Among Residue Types In both the intercropping unharvested and retain 6 ridges patterns, the total sand flux measured by sand collector 2 was consistently greater than that of collector 1, indicating that multi-belt residues effectively blocked external sand sources. The retain 4 ridges pattern only exhibited this trend during the first two monitoring periods, with data from the third monitoring period demonstrating that this pattern had already lost its wind prevention and sand fixation capability (Fig. 3). Overall, the intercropping unharvested residue type demonstrated superior sand blocking capacity compared to the other three residue types.

Fig. 3 Total sand flux under different stubble retention modes. Note: K, J1, J2, C1, C2, L1, L2 are sand collector identifiers (see Fig. 2).

3.2 Wind-Sand Flow Structure Characteristics Wind-sand flow characteristics for different residue types are shown in Fig. 4. In the completely harvested plot, sand transport was concentrated below 12 cm. In the intercropping unharvested pattern, sand transport also occurred primarily below 12 cm, but the sand flux at the same height was approximately equal to or significantly lower than that of the completely harvested plot (Fig. 4). The retain 4 ridges pattern showed sand transport heights concentrated at 12–15 cm, with sand flux in the third monitoring period exceeding that of the completely harvested plot. The retain 6 ridges pattern showed intermediate results, with sand transport heights at 12–15 cm.

Results indicated that the intercropping unharvested pattern had the lowest sand transport height and superior sand fixation compared to other patterns. The total sand flux in intercropping unharvested plots was the smallest across all three monitoring periods and significantly less than that of retain 4 ridges and retain 6 ridges patterns ($P < 0.05$). The retain 4 ridges pattern exhibited the highest sand transport height.

Examining sand flux at different transport heights, the intercropping unharvested pattern showed lower sand flux at all heights in collector 2 compared to collector 1. In the retain 6 ridges pattern, sand flux at all heights in collector 2 was less than or approximately equal to that in collector 1. However, the retain 4 ridges pattern showed greater sand flux in collector 2 than collector 1 during the third monitoring period (Fig. 4).

Optimal fitting relationships between sand flux and height revealed that in the intercropping unharvested pattern, both collectors showed exponential functions: $Q = 1611.60e^{-2.87H}$ ($R^2 = 0.90$) and $Q = 0.10e^{-4.32H}$ ($R^2 = 0.92$). In the retain 6 ridges pattern, collector 1 showed a power function ($Q = 17.37H^{-1.95}$) while collector 2 showed an exponential function ($Q = 52.21e^{-2.92H}$). Other residue types exhibited irregular changes in fitting relationships over time. Generally, when sand particle movement concentrates near the surface, the relationship tends toward a power function; as saltating sand content increases, the relationship gradually shifts toward an exponential function.

Table 4 Optimal fitting relations between sand flux (Q) and height (H) under different residue types

Residue type	Collector	Fitting equation	R^2
Intercropping unharvested	J1	$Q = 1611.60e^{-2.87H}$	0.90
Intercropping unharvested	J2	$Q = 0.10e^{-4.32H}$	0.92
Retain 6 ridges	L1	$Q = 17.37H^{-1.95}$	0.85
Retain 6 ridges	L2	$Q = 52.21e^{-2.92H}$	0.88

Note: Q is sand flux (10^{-3} $g \cdot cm^{-2} \cdot min^{-1}$), H is height (cm), R^2 is coefficient of determination. J1, J2, L1, L2 are sand collector identifiers (see Fig. 2).

3.3 Near-Surface Wind Field Characteristics To assess the wind speed reduction capacity of different patterns after prolonged wind erosion, wind speeds at various heights were measured on March 4, 2021. Wind speed profiles (Fig. 5) showed that wind speed increased with height, exhibiting a linear relationship between wind speed and the logarithm of height ($P < 0.05$). Aerodynamic roughness and friction velocity results (Table 5) demonstrated that the intercropping unharvested pattern had the highest values ($z_0 = 0.553$ cm and 1.156 cm; $u^* = 0.304$ and 0.332 $m \cdot s^{-1}$), followed by the retain 6 ridges pattern ($z_0 = 0.100$ cm and 0.137 cm; $u^* = 0.240$ and 0.272 $m \cdot s^{-1}$). The retain 4 ridges pattern showed the lowest values (z_0 0 cm; $u^* = 0.100$ and 0.137 $m \cdot s^{-1}$).

Fig. 5 Wind velocity profile under different residue types on March 4, 2021

Table 5 Aerodynamic roughness and friction velocity under different residue types on March 4, 2021

Residue type	Collector	Roughness length z_0 (cm)	Friction velocity u_* (m · s^{-1})
Intercropping unhar-vested	J1	0.553	0.304
Intercropping unhar-vested	J2	1.156	0.332
Retain 6 ridges	L1	0.100	0.240
Retain 6 ridges	L2	0.137	0.272
Retain 4 ridges	K	0	0.100

---

4. Discussion

4.1 Wind Protection Effects of Crop Residues Reducing near-surface wind speed through crop residues is a primary objective of conservation tillage. Airflow encountering obstacles can be divided into four functional zones: blocked uplift zone, accelerated flow zone, deceleration/settling zone, and dissipation/recovery zone. Increasing the deceleration/settling zone while reducing the dissipation/recovery zone is critical for weakening near-surface wind speed. The intercropping unharvested pattern, combining C. esculentus and *Haloxylon* residues in a high-low interspersed protection system, effectively prevents expansion of the dissipation/recovery zone and maintains a longer, higher deceleration/settling zone compared to other residue types. Its aerodynamic roughness is substantially greater than other patterns, demonstrating that upright plants play an important role in progressively reducing wind speed—a finding repeatedly confirmed in previous studies.

Wind shear stress recovery distance is typically 4.8–10.0 times the roughness element height. Even at maximum C. esculentus residue height, wind shear stress recovers at some point in the inter-belt area. Once exceeding the critical threshold wind speed for particle initiation, a new wind-sand flow forms and deposits upon encountering the next residue belt. As deposited sand accumulates, burial begins to reduce residue height and coverage, which is an important reason why the retain 4 ridges pattern lost its wind prevention capability early, with aerodynamic roughness essentially becoming zero. Previous research also indicates that residues with low height and coverage have relatively poor wind reduction effects. Therefore, single wide-strip C. esculentus residues are less effective at reducing wind speed than high-low interspersed crop residues.

4.2 Influence of Crop Residue Structure on Wind Erosion From the perspective of total sand flux and wind-sand flow characteristics, the retain 6 ridges pattern with wider residue belts demonstrated better sand fixation over time, consistent with research by Cai et al. on the relationship between belt width and wind erosion. However, considering only residue width is insufficient, as the wind erosion process represents a mechanical superposition of erosion and deposition. Maintaining adequate height and coverage throughout the long fallow period is equally crucial.

In the intercropping unharvested pattern, the combination of upright *Haloxylon* and herbaceous C. esculentus creates a high-low arrangement with relatively narrower belt spacing, providing excellent shielding function that can settle external wind-blown sand while simultaneously inhibiting sand initiation in inter-belt areas. The superiority of intercropping unharvested pattern is evident from its lower total sand flux and sand flux at all heights compared to other patterns. Research also demonstrates that appropriate belt spacing and residue height are important for suppressing wind erosion. Additionally, natural vegetation communities dominated by *Agriophyllum squarrosum* appeared under *Haloxylon* belts, with coverage exceeding 30% in some areas, which significantly helps inhibit sand particle initiation in inter-belt areas. This phenomenon of natural vegetation establishment in inter-belt areas has been observed in previous studies, which found that appropriate belt spacing can facilitate natural vegetation settlement and enhance wind prevention effects. Therefore, selecting appropriate harvest spacing and intercropping with suitable upright plants will benefit wind erosion mitigation during the long post-harvest fallow period in C. esculentus cultivation.

---

5. Conclusions

1. During the fallow period in C. esculentus cultivation areas, the intercropping unharvested pattern exhibits the most prominent wind prevention and sand fixation efficiency, more effectively reducing near-surface wind speed and providing more stable and lasting sand fixation. C. esculentus cultivation should consider adopting appropriate harvest spacing and intercropping with suitable upright plants to retain residues during the long post-harvest fallow period, thereby mitigating wind erosion and protecting farmland soil.
2. The retain 6 ridges pattern possesses wind reduction capability and can reduce certain sand flux, but its wind prevention and sand fixation effect is inferior to the intercropping unharvested pattern. The retain 4 ridges pattern loses wind prevention and sand fixation capability too early to effectively control wind erosion throughout the entire fallow period.

In summary, single wide-strip C. esculentus residues are less effective at reducing wind speed than high-low interspersed crop residues. Selecting appropriate harvest spacing and intercropping with suitable upright plants is a key measure for reducing soil wind erosion and holds important ecological value for sustainable farmland development in arid regions.

References

[1] Luo Wanyin, Dong Zhibao. The progress and prospects of research on wind erosion induced soil nutrient and carbon cycling[J]. Progress in Geography, 2005, 24(4): 75-83.

[2] Lü X, Li X, Wang H, et al. Soil wind erosion evaluation and sustainable management of typical steppe in Inner Mongolia, China[J]. Journal of Environmental Management, 2021, 277: 111488, doi: 10.1016/j.jenvman.2020.111488.

[3] Ding Guodong. Aeolian physics[M]. Beijing: China Forestry Publishing House, 2010: 119.

[4] Fryrear D W. Soil cover and wind erosion[J]. Transactions of the American Society of Agricultural Engineers (USA), 1985, 28(3): 781-784.

[5] Pierre C, Kergoat L, Hiernaux P, et al. Impact of agropastoral management on wind erosion in Sahelian croplands[J]. Land Degradation & Development, 2017, 29(3): 800-811.

[6] Qin Hongling, Gao Wangsheng, Ma Yuecun, et al. Effects of no tillage on soil properties affecting wind erosion during fallow in ecotone of north China[J]. Acta Ecologica Sinica, 2007, 27(9): 3778-3784.

[7] Gao Y, Dang X H, Yu Y, et al. Effects of tillage methods on soil carbon and wind erosion[J]. Land Degradation & Development, 2015, 27(3): 583-591.

[8] Yang Caihong, Feng Fuxue, Chai Qiang, et al. Soil wind erosion in wheat/maize intercropping with zero tillage and straw retention[J]. Journal of Desert Research, 2019, 39(4): 9-15.

[9] Pi H, Webb N P, Huggins D R, et al. Critical standing crop residue amounts for wind erosion control in the inland Pacific Northwest, USA[J]. Catena, 2020, 195: 104742, doi: 10.1016/j.catena.2020.104742.

[10] Kang Ling, Sun Xin, Hou Ting, et al. Distribution characteristics of sandstorms in Inner Mongolian area[J]. Journal of Desert Research, 2010, 30(2): 400-406.

[11] Zhao Xiaoqing, Liu He, Lu Zhanyuan, et al. Technical model of windbreak and sand fixation of Cyperus esculentus planting in soil wind erosion area of northern China[J]. Modern Agriculture, 2019(7): 13-14.

[12] Chen Chen, Hong Mei, Zhang Yuexian, et al. Effects of organic material addition on dissolved organic carbon in alkali soil in Hetao Irrigation District

of Inner Mongolia[J]. Journal of Soil and Water Conservation, 2020, 34(6): 331-336.

[13] Xi Jinping had this arrangement during two investigations to Inner Mongolia[J]. Shijian (CPC Education Edition), 2019(7): 17-18.

[14] Liu Lin, Zhang Wenjing, Hao Linfeng, et al. Utilization status and countermeasures of main crops straw in Bayannur of Inner Mongolia[J]. Animal Husbandry and Feed Science, 2019, 40(2): 44-46.

[15] Li Jingwen, Guo Hao, Lü Yongjun, et al. Growth regularity and evaluation of Populus euphratica introduced in Dengkou County[J]. Journal of Northwest Forestry University, 2019, 34(1): 97-104, 136.

[16] Shu Yang, Liu Zhaogang, Yang Suzhi. Spatial distribution pattern and sampling technique for main herbaceous plants in desert land of Inner Mongolia[J]. Journal of Northeast Forestry University, 2008, 36(9): 42-47.

[17] Hou Qiong, Guo Ruiqing, Yang Litao. Climate change and its impact on main crops in Inner Mongolia[J]. Chinese Journal of Agrometeorology, 2009, 30(4): 560-564.

[18] Liu Muxing, Liu Lianyou. Effect of crop stubble on wind field above field surface during fallow period of cropland[J]. Transactions of the Chinese Society of Agricultural Engineering, 2009, 25(9): 295-300.

[19] Liu Yulan, Wang Xiaoning, Shu Yao, et al. Character and composition of Cyperus esculentus from different origins[J]. China Oils and Fats, 2020, 45(8): 125-129.

[20] Yang Zhuanling, Qian Guangqiang, Dong Zhibao, et al. Aeolian sediment transport in the Sanlongsha Area to the north of Kumtagh Desert[J]. Journal of Desert Research, 2018, 38(1): 58-67.

[21] Yang Fan, Zhu Wenxue. Research status and prospect of Cyperus esculentus[J]. Cereals & Oils, 2020, 33(7): 4-6.

[22] Lu Zhanyuan, Liu He, Zhang Jianzhong, et al. Development status, problems and suggestions of Cyperus esculentus industry[J]. Modern Agriculture, 2019(6): 11, 13.

[23] The CPC Neimenggu Committee, People' s Government of Inner Mongolia Autonomous. Accelerating the action of revitalizing Inner Mongolia through science and technology—several policies and measures to support scientific and technological innovation[N]. Inner Mongolia Daily (Chinese Version), 2020-10-19(7).

[24] Wei Bao, Ding Guodong, Wu Bin, et al. Study on windbreak effect of Artemisia ordosica community over different vegetation coverage[J]. Arid Zone Research, 2012, 29(2): 213-217.

[25] Li Houqiang, Ai Nanshan. The intermittency, stable distribution and fractal characteristic for the wind sand turbulent flow[J]. Journal of Desert Research, 1993, 13(1): 14-23.

[26] Li Zhenshan, Zhang Qifeng. Evolution of streamwise sand transport with distance[J]. Journal of Desert Research, 2006, 26(2): 189-193.

[27] Dong Yuxiang, Ma Jun. Field measurements of influence of total sand transport rate on the structure of wind sand flow on the coastal transverse ridge[J]. Journal of Arid Land Resources and Environment, 2009, 23(9): 179-183.

[28] Kang Wenyan, Wang Li, Qu Jianjun, et al. Wind tunnel simulation experiment on the protective effect of different structures of sand blocking fence in Shapotou section of Baotou-Lanzhou Railway[J]. Journal of Desert Research, 2020, 40(2): 94-99.

[29] Hu Guanglu, Wang Dejin, Liao Yaxin, et al. Intensity of wind erosion and deposition in patch vegetation area of desert-oasis ecotone in the middle reaches of the Heihe River of China[J]. Journal of Desert Research, 2016, 36(6): 1547-1554.

[30] Yang Wenbin, Wang Jingying, Dong Huilong, et al. Windbreak effects and wind velocity flow field of low density forest with two belt distribution patterns of single belt scheme[J]. Scientia Silvae Sinicae, 2011, 47(2): 95-102.

[31] Cai Fu, Zhou Guangsheng, Ming Huiqing, et al. Dynamics of aerodynamic parameters over a rainfed maize agroecosystem and their relationships with controlling factors[J]. Acta Ecologica Sinica, 2013, 33(17): 5339-5352.

[32] Zhao Peiyi, Tuo Debao, Li Huanchun, et al. Wind tunnel test on effect of strip width and crop stubble height on wind erosion modulus[J]. Transactions of the Chinese Society of Agricultural Engineering, 2011, 27(11): 206-210.

[33] Yan Min, Zuo Hejun, Yang Yang, et al. Different distance Caragana korshinskii protection forest for wind reducing effect and inter-type vegetation[J]. Research of Soil and Water Conservation, 2018, 25(4): 139-145.

[34] Yang Wenbin, Guo Jianying, Hu Xiaolong, et al. Vegetation restoration process and sand reversal effect of low coverage sand fixing forest belts[J]. Journal of Desert Research, 2012, 32(5): 1291-1295.

[35] Bradley E F, Mulhearn P J. Development of velocity and shear stress distribution in the wake of a porous shelter fence[J]. Journal of Wind Engineering and Industrial Aerodynamics, 1983, 15: 145-156.

[36] Pi H, Huggins D R, Sharratt B. Threshold friction velocities influenced by standing crop residue in the inland Pacific Northwest, USA[J]. Land Degradation & Development, 2020, 31(16): 2356-2366.

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