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Scientific Article
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Wind Erosion Resistance Effect of Conservation Tillage: The Case of Chestnut Soil in Mongolian Plateau[1]

Efeito da resistência à erosão eólica da lavoura de conservação: o caso do solo de castanheiro no planalto da Mongólia

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ABSTRACT - To quantitatively evaluate the effect of stubble height and mulching on soil resistance to wind erosion in protected cultivated chestnut soil farmland under different wind speed conditions, tests were carried out on conservation and conventional tillage in Mongolian Plateau, China, using a mobile wind erosion wind tunnel. Chestnut soils were a soil type in fragile semi-arid ecosystems that were susceptible to desertification following wind erosion and were found mainly in Central Asia and the North American continent. The results show that soil erosion on conservation tillage was lower than conventional tillage at different wind speeds. The resistance of conservation tillage to soil wind erosion increases with increasing stubble height and cover. At a stubble height of 300 mm and 50% cover, conservation tillage's average wind erosion resistance efficiency was 74.82%, effectively preventing wind erosion of agricultural soils.

Key Words: Conservation tillage. Soil wind erosion. Mobile wind tunnel. Wind erosion resistance efficiency. Chestnut soil.

Resumo - Para avaliar quantitativamente o efeito da altura do restolho e da cobertura morta na resistência do solo à erosão do vento em terras cultivadas protegidas de castanheiros sob diferentes condições de velocidade do vento, foram realizados testes de conservação e lavoura convencional no planalto da Mongólia, China, utilizando um túnel móvel de vento de erosão do vento. Os solos de castanha são um tipo de solo em ecossistemas semi-áridos frágeis que são suscetíveis à desertificação após a erosão pelo vento e são encontrados principalmente na Ásia Central e no continente norte-americano. Os resultados mostram que a erosão do solo na lavoura de conservação é menor do que a lavoura convencional em diferentes velocidades de vento. A resistência da lavoura de conservação à erosão do solo pelo vento aumenta com o aumento da altura do restolho e da cobertura. Com uma altura do restolho de 300 mm e uma cobertura de 50%, a eficiência média de resistência da lavoura de conservação à erosão pelo vento é de 74,82%, evitando efetivamente a erosão pelo vento dos solos agrícolas.

Palavras-chave: Lavoura de conservação. Erosão do vento no solo. Túnel de vento móvel. Eficiência na resistência à erosão do vento. Solo castanho.

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INTRODUCTION

Degradation is a significant problem for the world, and wind erosion is a significant threat to the productivity and sustainability of agricultural soils (DANIEL 2018; ZHEN, 2020). Soil wind erosion in agricultural fields and grasslands is more complex than deserts' general sand and wind movement (MENG, 2018). Wind erosion is a critical destabilizing factor in arid and semi-arid ecosystems, posing a major threat to the productivity and sustainability of agricultural soils, and is one of the main causes of farmland degradation in arid and semi-arid regions (QU, 2018). Wind erosion damages crops through abrasion, burial and dust deposition, indirectly reducing soil fertility and thus directly affecting crop yields (SANTRA, 2017). Due to long-term conventional farming methods, many agricultural soils are subject to moderate and strong wind erosion, the annual wind erosion of agricultural land is 1 to 3 mm, the loss of soil organic matter caused by soil wind erosion is greater than the amount absorbed by plants when the depth of wind erosion exceeds 1.5 mm (VIRTO, 2014).

The north side of the Yinshan Mountains is located in the middle of the agricultural-pastoral interlacing area in northern China. The main soil of the region is chestnut soil, which is the soil type more abundant in the arid and semi-arid regions of Asia, America and central Europe (BORRELLI, 2016; CHEN, 2016). For a long time, the tillage in this region has been fall plough by traditional farming methods. The tilled surface is exposed for more than six months, from November to the end of April of the following year. Combined with the arid climate and the high number of windy days, this has led to a pattern of soil degradation on agricultural land, mainly marked by wind erosion. The local climate is arid and windy, resulting in wind erosion degrading the agricultural soil (CHEN, 2010). The wind erosion of agricultural soils will become more serious if not take effective control measures.

Conservation tillage is an advanced agricultural farming technique that reduces wind and water erosion and improves soil fertility and drought resistance by applying no-till and reduced-tillage to farmland and covering the ground with crop stubble (RATTAN, 2018; JIA, 2019). Furthermore, some researchers have indicated that apoplastic vegetation is beneficial for the ecological recovery of semi-arid soil ecosystems (WU, 2021). However, different plant configuration barriers have different protective effects on different soils (WANG, 2020). Soil erosion processes are mainly controlled by natural and anthropogenic factors, such as soil texture, soil physicochemical composition, climatic conditions, topography, ground cover, especially plant cover, and seasonal influences on wind erosion (KOITER, 2017; WEI, 2017; CHAPPELL, 2018; ANDREAS, 2020). The main purpose of conservation tillage is to reduce wind erosion of agricultural soils by natural forces (TURNER, 2018). However, few studies have shown the relationship between plant cover and wind erosion in protected cropland in chestnut-calcic soil areas. This paper adopts the field wind tunnel in-situ test method to study the effects of stubble height and cover on the wind erosion resistance of chestnut soil in conservation tillage, and quantitatively evaluate the wind erosion resistance of conservation tillage farmland with wind erosion resistance efficiency as the evaluation index, to provide a scientific basis for adopting reasonable technical parameters of wind erosion resistance tillage.

MATERIAL AND METHODS

Study area

The trial site was selected in the demonstration area of the conservation tillage project in Wuchuan County, of Inner Mongolia, China (Figure 1), it is located in the south-central part of Mongolia Plateau, latitude 40°47'~41°23'N and longitude 110°31'~111°53'E. The region has a mid-temperate continental monsoon climate, with an average annual precipitation of about 354.1 mm and annual evaporation of 1,848.3 mm, which was five times the precipitation, so the winter and spring were windy-sandy (ZHAO, 2002). The experimental field includes conservation tillage farmland and conventional tillage farmland. The soil particle distribution, water content and organic matter content of the two surfaces were shown in table 1.

Test equipment

The main test equipment was the OFDY-1.2 mobile wind tunnel of Inner Mongolia Agricultural University (Figure 2) (ZHAO, 2007). The wind tunnel consists of a transition section, rectification section, contraction section and test section, of which the test section was 7.2 m, 1.0 m wide and 1.2 m high. The root mean square deviation of the airflow velocity at each point on each section of the wind tunnel from the average velocity of the section was less than 1%, the turbulence was less than 1.5%, and the axial static pressure gradient was less than 0.005 pa. The wind speed was steplessly adjustable from 0 to 20 $m \cdot s^{-1}$. The wind tunnel meets the requirements of similarity principles for testing soil wind erosion in dry farmland and grassland, as demonstrated by indoor simulations and in-situ surface aerodynamic similarity tests in the field, such as grassland and farmland. The wind speed profiler collects the wind speed data and was transmitted to the data acquisition software developed with LabVIEW through the data acquisition card and then displayed, recorded, and saved in the computer. Wind erosion sediments collected by a cyclone separating sand collector, which was 840 mm high, collect wind erosion at different heights in the vertical direction through 10 airflow tubes distributed along the height direction. The sand collector was placed at an axis 1200 mm from the exit of the wind tunnel axis, and the wind erosion sediments were weighed by an electronic balance with an accuracy of one thousandth. The instrumentation arrangement of the field wind tunnel test was shown in figure 3.

Figure 1 - The location of the experimental site in the Mongolian Plateau of China

The effect of different types of the field on soil wind erosion

The test was conducted in April when soil wind erosion was most severe. The measured land was conservation tillage farmland and traditional tillage farmland plowed with a spar plow after the autumn harvest. The conventional tillage farmland had no stubble cover and the conservation tillage farmland had oat stubble with 200 mm row spacing, 5 mm average plant diameter and 400 plants·m^{-2} average density. The wind tunnel was placed on the field of the traditional farmland and the corresponding conservation farmland to measure wind erosion, and the axis of the wind tunnels was perpendicular to the monopoly direction of the farmland. A total of 5 central wind speeds of 6, 9, 12, 15, and 18 m·s^{-1} were used for each surface for 10 min of continuous blowing in the wind tunnel to measure the wind erosion.

The MATLAB software was used to integrate the function of soil wind erosion collection as a function of height between 0 and 700 mm for different types of the field at different wind speeds to obtain the soil wind erosion in the vertical plane of 10 mm width and 0 to 700 mm height from the surface. Based on the wind tunnel test section (width of 1000 mm), the amount of soil wind erosion through the cross-sectional area of the wind tunnel airflow exit was obtained for 10 min of continuous blowing. The amount of soil wind erosion in 10 min through the cross-sectional area of the wind tunnel airflow outlet can be calculated. The equation is:

Table 1 - Soil particle distribution, humidity contents, and organic matter of two land surface

Surface type	Particle size/mm					Humidity content/%	Organic matter content/(g·kg^{-1})
	1~0.25	0.25~0.1	0.1~0.05	0.05~0.002	< 0.002		
	Particle distribution/%						
Conventional farming	26.43	12.43	18.32	11.77	1.78	5.39	2.414
Conservation tillage farmland	24.63	16.2	19.93	19.57	4.08	10.08	2.702

Figure 2 - Diagram of the OFDY-1.2 type push configured movable wind tunnel

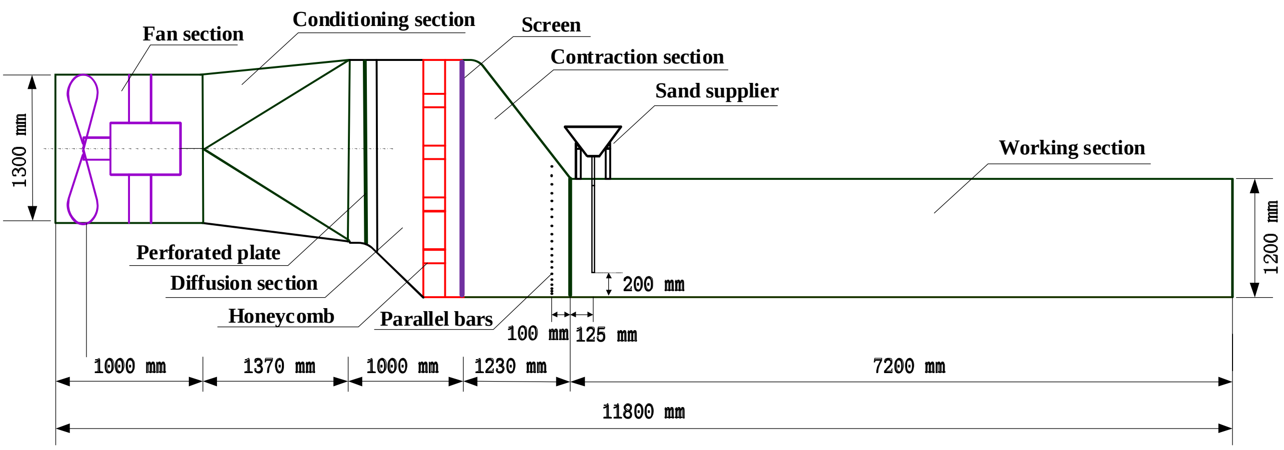
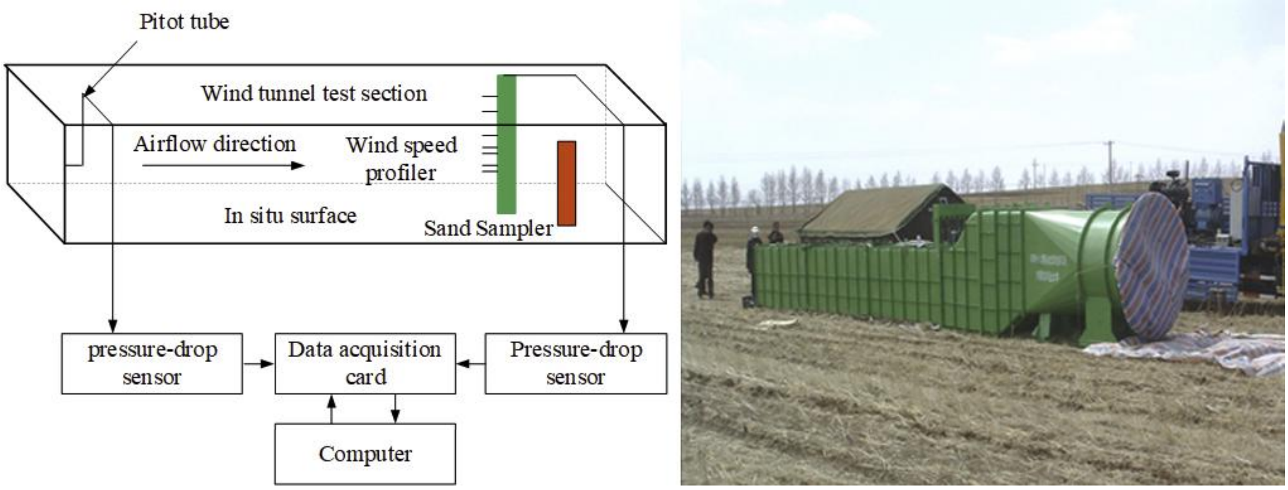


Figure 3 - Diagram of the test system in a movable wind tunnel test



$$Q = w \times \int_0^{70} q dz \quad (1)$$

where: Q, blowing 10 min through the wind tunnel hole cross-sectional area of the amount of wind erosion, g; w, the width of wind tunnel test section, mm; q, at each height of the soil wind erosion content, g/mm^2; z, height, mm.

Effect of stubble height and cover on wind erosion resistance efficiency

The increase in stubble height and coverage was beneficial in reducing soil moisture evaporation and erosion (CONG, 2016; TOURE, 2011). Sparse vegetation protects the ground, and crop stubble density affects the degree to which the soil surface was threatened by wind erosion (FUNK, 2015; JIANG, 2019; PI, 2020). However, studies have shown that for 10% cover, soil wind erosion was more severe than bare ground (FEIZI, 2019; RAKKAR, 2019). Therefore, it was interesting to study the height and cover of crop stubble on chestnut soils.

The presence of stubble increases the wind erosion resistance of conservation tillage farmland because the amount of soil wind erosion was lower than that of conventionally tilled farmland at all wind speeds after stubble retention. Using the wind erosion of conventional tillage farmland in the test as a benchmark, the ratio of the reduction in wind erosion of conservation tillage farmland with different stubble states relative to conventional tillage farmland to the benchmark wind erosion was called the wind erosion resistance efficiency of conservation tillage farmland. The equation is:

$$n = \frac{Q_1 - Q_2}{Q_1} \times 100\% \quad (2)$$

where: Q_1 is the wind erosion of traditional tillage farmland, g; Q_2 is the wind erosion of conservation tillage farmland, g; η is the wind erosion resistance efficiency of conservation tillage farmland, %.

RESULTS AND DISCUSSION

The amount of wind erosion is the solid flow of wind-sand flow, which is mainly influenced by wind power and subsurface. The relationship curves between different wind speeds and the amount of wind erosion of two agricultural fields were plotted according to the experimental results (Figure. 4).

Soil wind erosion in conservation tillage farmland was lower than conventional tillage farmland at all wind speeds, which shows in figure 4. Soil wind erosion increases sharply after wind speed reaches 12 m·s^{-1} in conventional farmland. The soil wind erosion in conservation tillage farmland also tends to grow with the increase of wind speed in general, but the increase was much smaller than that in conventional tillage farmland.

The wind erosion of the same surface at different wind speeds varies with height due to the movement of wind eroded soil particles in the airflow and the different particle sizes of soil particles. Figure 5 shows the distribution of soil wind erosion at different wind speeds over vertical heights for conventional tillage farmland and conservation tillage farmland collected using a wind tunnel sand collector. The wind erosion collected by the wind tunnel sand collector was smaller than that of the conventional tillage farmland under different wind speeds in the conservation tillage farmland. At low wind velocity (6 m·s^{-1}), the wind erosion was concentrated within a height of 0-200 mm from the surface, and the maximum collection was at the height of 60 mm from the surface. At high wind velocity (> 6 m·s^{-1}), soil wind erosion was mainly concentrated in the height range of 200-500 mm from the surface, and the maximum wind erosion collection occurred at the height of 400 mm from the surface when the wind speed reached the highest wind speed of the test. In contrast, a large amount of wind erosion in conventionally cultivated farmland was concentrated within a height of 0-250 mm from the surface, and the amount of wind erosion increases significantly with decreasing height.

Figure 4 - Variation curve of soil erosion of different field types

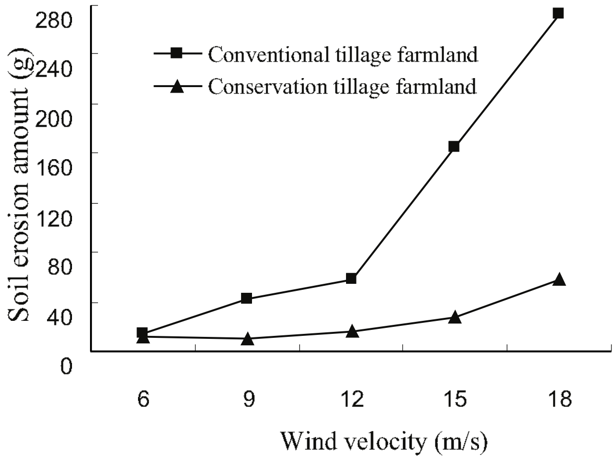
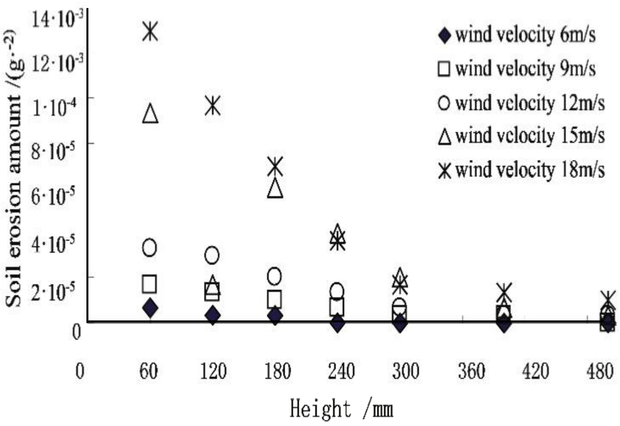
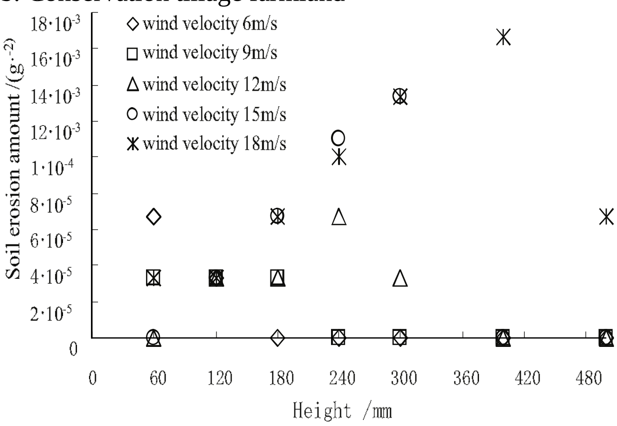


Figure 5 - Distribution of wind erosion amount with height over the different land surface

a. Conventional tillage farmland



b. Conservation tillage farmland



Studies on chestnut soils were consistent with previous findings that crop residues prevent or reduce wind erosion and farm dust (MIRI, 2019; SHARRATT, 2017; XIONG, 2018;). The main reason for the above results was that due to the large stubble cover on the surface of conservation tillage farmland, on the one hand, it reduces the wind velocity near the surface and reduces the wind shear stress on the ground; on the other hand, the surface was covered with stubble, which isolates the direct effect of wind and surface soil, and the amount of soil wind erosion was reduced accordingly. At the same time, the lifting effect of upright stubble on the airflow has changed the trajectory of wind erosion.

In order to quantify the effect of stubble cover on the wind erosion resistance of conservation tillage fields, the fields were designed to have 30%, 50%, and 70% cover at 300 mm stubble height and 100, 200, and 300 mm stubble height at 50% cover. The coverage was the percentage of the vertical projection of the stubble to the total surface area, and was obtained by the average of six measurements of the coverage by the pressure line method. The cover was the percentage of the vertical projection of the stubble to the total surface area and was obtained by taking the average of six cover measurements.

The wind erosion amounts of soil under conservation tillage at different wind speeds were shown in table 2 by using a mobile wind tunnel to test the surface at 300 mm stubble height corresponding to 30%, 50%, and 70% cover (Figure 6.) and at 50% cover corresponding to 100, 200, and 300 mm stubble height.

As shown in table 2, the wind erosion of conservation tillage farmland tends to decrease with the increase of stubble cover, and the decrease was relatively obvious. The wind erosion decreased by 40.41% when the coverage increased from 30% to 50%, and by 22.61% when the coverage increased from 50% to 70%. The average value of wind erosion resistance efficiency could reach 74.82% when the coverage degree was 50%, which achieved a better effect of wind erosion prevention.

The wind erosion resistance efficiency of conservation tillage farmland under different surface conditions was calculated from equation 2, as shown in figure 7.

Table 3 shows the amount of wind erosion versus wind velocity for different stubble height surfaces at 50% cover, which shows that the wind erosion on the surface of the three stubble heights decreased with the increase of stubble height, and the wind erosion decreased by 41.77% when the stubble height increased from 100 to 200 mm, and by 34.83% when the stubble height increased from 200 to 300 mm.

The wind erosion amounts were basically the same for 200 and 300 mm stubble heights at wind speeds less than 12 m·s^{-1}, indicating that the effect of both stubble heights on wind erosion amounts was not significant at low wind velocity. At the wind velocity of 18 m·s^{-1}, the wind erosion amount of 300 mm stubble height was the smallest, which has a better effect on wind erosion prevention.

Figure 6 - The testing surface with standing stubble (a. 30% coverage with a 300 mm stubble height; b. 50% coverage with a 300 mm stubble height; c. 70% coverage with a 300 mm stubble height; d. Testing in the wind tunnel.)

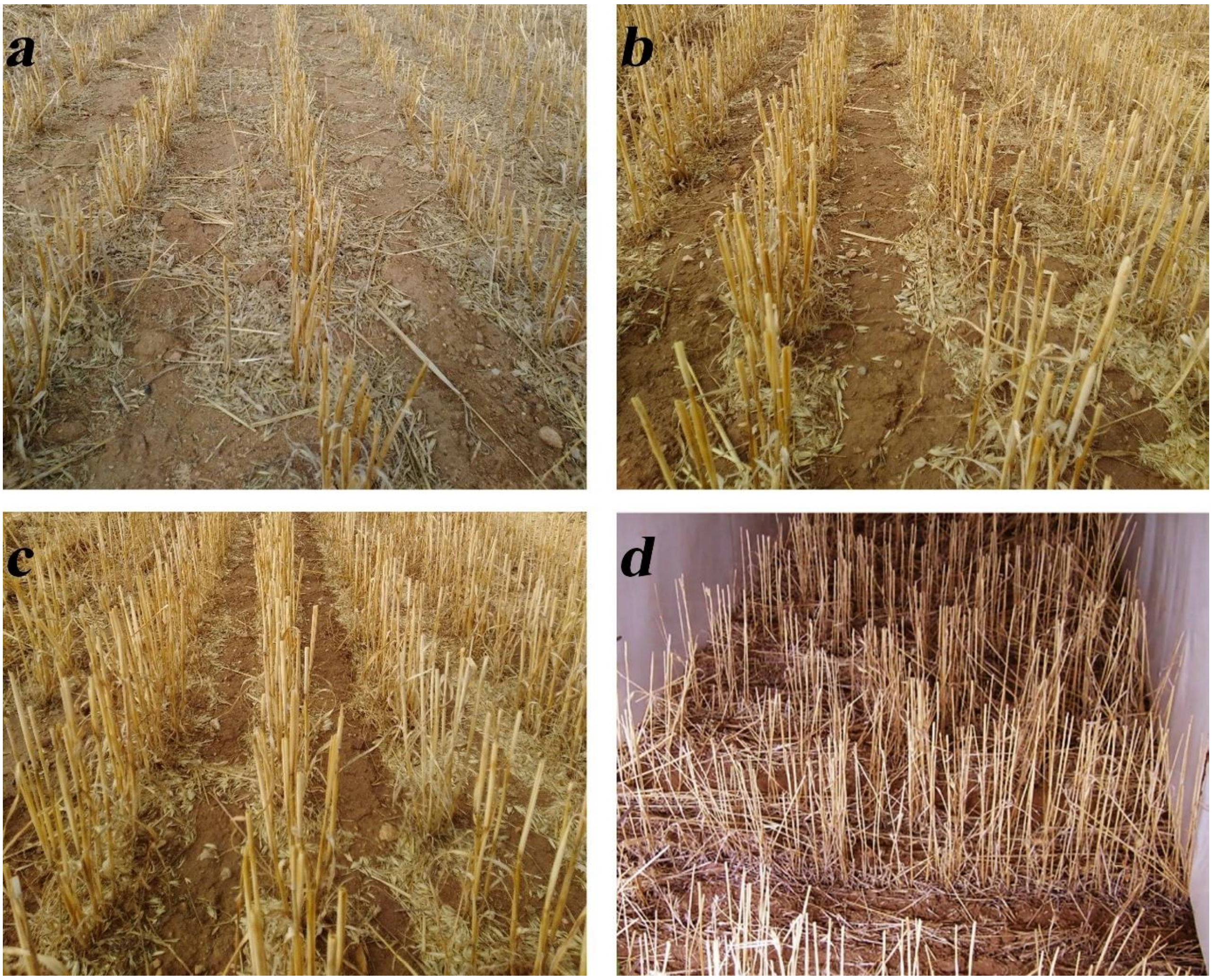


Table 2 - Wind erosion amount and resistance efficiencies of conservation tillage farmland with different stubble height and coverage

wind velocity/(m·s^{-1})	Stubble coverage/%			Stubble height/mm		
	30	50	70	100	200	300
6	23.93	11.15	6.13	26.96	11.46	11.15
9	36.34	10.48	5.32	36.93	16.74	10.48
12	41.60	15.39	11.28	43.62	19.41	15.39
15	43.30	27.93	26.39	60.21	42.14	27.93
18	61.85	58.44	46.35	157.43	99.58	58.44

Different stubble cover tests correspond to 300 mm stubble height; different stubble height tests correspond to 50% stubble cover

Figure 7 -. Anti-wind erosion efficiency of conservation tillage farmland with different stubble height and coverage

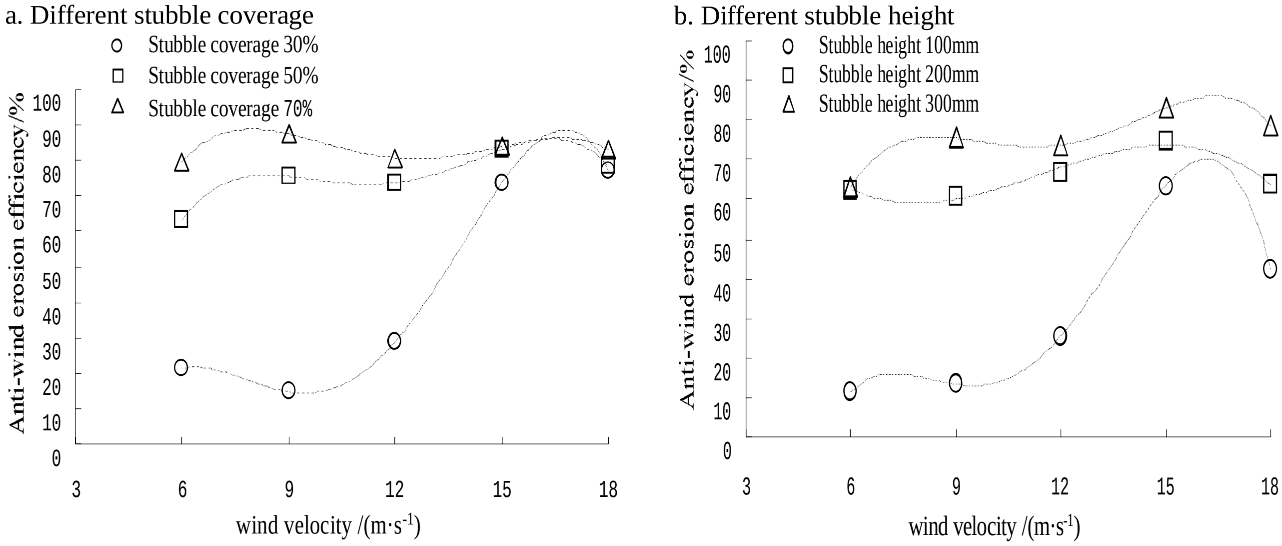


Table 3 - Wind erosion resistance efficiencies of conservation tillage farmland with different stubble height and coverage

wind velocity/($m·s^{-1}$)	Stubble coverage/%			Stubble height/mm		
	30	50	70	100	200	300
6	21.36	63.34	79.85	11.4	62.34	63.34
9	14.79	75.43	87.52	13.41	60.75	75.43
12	28.99	73.73	80.75	25.54	66.87	73.73
15	73.68	83.02	83.96	63.40	74.38	83.02
18	77.35	78.60	83.03	42.35	63.53	78.60

Different stubble cover tests correspond to 300 mm stubble height; different stubble height tests correspond to 50% stubble cover

CONCLUSIONS

The soil wind erosion of conservation tillage farmland was lower than that of conventional tillage farmland at different wind speeds, and its soil wind erosion decreases rapidly with the increase of stubble height and stubble cover. The average wind erosion resistance efficiency of the conservation tillage farmland with a stubble height of 300 mm and 50% cover was up to 74.82% at wind speeds of 6~18 $m·s^{-1}$, and it is wind erosion prevention effect was good. Therefore, from the perspective of controlling wind erosion of farmland soils, 300 mm stubble height and 50% cover can be regarded as the standard stubble height and cover for effective wind erosion suppression in conservation tillage farmland.

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