Ecosystem Health and Sustainability
A SCIENCE PARTNER JOURNAL

RESEARCH ARTICLE

Wind Power Increases the Plant Diversity of Temperate Grasslands but Decreases the Dominance of Palatable Plants

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Citation: Ji G, Ganjurjav H, Hu G, Wan Z, Yu P, Li M, Gu R, Xiao C, Hashen Q, Gao Q. Wind Power Increases the Plant Diversity of Temperate Grasslands but Decreases the Dominance of Palatable Plants. *Ecosyst. Health Sustain.* 2023;9:Article 0014. https://doi.org/10.34133/ehs.0014

Submitted 2 September 2022
Accepted 3 January 2023
Published 15 February 2023

As an important clean energy source, the scale and quantity of wind power have steadily increased under the background of global change. The construction and operation of wind power facilities have massive impacts on grassland microclimates. However, the effect of wind power operation on the plant community composition is still unclear. To investigate this issue, we selected wind farms in 6 meadow grasslands and 6 typical steppes in the central region of Inner Mongolia, the province with the largest scale of grassland wind power operations in China. At these sites, we conducted field sample surveys to obtain species information, measure plant biomass, calculate plant diversity, and take soil samples to determine soil nutrients. The results showed that wind power operation significantly reduced the dominance of *Poaceae* and *Cyperaceae* plants in both types of grasslands and significantly increased the Shannon diversity of meadow grasslands. The inconsistent responses at each experimental site led to a nonsignificant overall effect of wind power operation on the plant beta diversity. In addition, wind power operation significantly increased plant biomass in meadow grasslands. Wind power operation did not change the soil total carbon, total nitrogen, ammonium nitrogen, or nitrate nitrogen. On the basis of the results, we suggest strengthening the long-term monitoring of temperate grassland plant community composition in wind farms, and replanting of community-building species could be done at appropriate times.

Introduction

Wind energy is developing rapidly worldwide; to date, it represents 5% of all electricity generated globally, and its share is expected to grow to 30% by 2050 [1]. China's wind energy generation will increase by nearly 1,500 MWh by 2030 [2] and will become the second largest renewable energy source after hydropower.

Wind energy is considered a clean energy source and can reduce carbon dioxide emissions [3]. However, Roy [4] and Keith et al. [5] first proposed the possibility that the operation of large-scale wind farms can affect the local and global climates. Remote sensing methods, large eddy simulation models, and mesoscale climate models have been widely used to investigate the impact of wind power operation on regional and global climates [6–8]. Most studies have shown that the operation of wind farms significantly affects local temperature or precipitation [8–10], while Li et al. [8] and Xu et al. [11] further proved that wind power could significantly improve plant growth and productivity due to temperature and precipitation increases.

Plant community properties such as plant composition and diversity are also important indicators for exploring the impact of wind farms on terrestrial ecosystems. Armstrong [12] proposed that wind power operation leads to changes in the microenvironment, such as temperature and radiation, which affects the carbon cycle and the composition and productivity of plants. Some studies further concluded that the reduction in soil moisture and nutrients was the main reason for the changes in plant diversity on wind farms [13,14]. Because of differences in the climatic environment, vegetation types, and other objective conditions in different study areas, some results have indicated that wind farm operation leads to lower plant diversity, e.g., in California and Inner Mongolia [15,16]; however, others have shown that wind farm operation can increase the cover of grassland vegetation [17] and beta diversity [18]. Obviously, the impact of wind farms on grassland communities is still a topic worth exploring. In addition, numerous studies have confirmed that changes in temperature or precipitation affect the species composition of grasslands [19]. However, studies related to wind farms are mostly at large scales and are dominated by remote sensing monitoring, and less research has been conducted on the effects of wind power on species composition. Therefore, whether there is a significant correlation between species and changes in community diversity, and biomass in wind farms also deserves further attention.

Temperate grasslands are the largest grassland ecosystem in the world, with important ecological value and livestock production value, as well as being one of the important land types for building land-based wind farms. Inner Mongolia, as the province with the largest scale of wind power development in China, possesses a cumulative grid-connected capacity of 30.33 million kW, and 80% of wind farms are located on temperate grasslands [20], mainly typical steppe and meadow grasslands. The temperate grasslands in Inner Mongolia are dominated by *Poaceae* and *Cyperaceae* plants, which are important for ecosystem stability and are palatable for livestock. Therefore, as a key option to achieve carbon emissions peak and carbon neutrality, the vigorous development of wind power generation should be accompanied by a focus on the synergistic development of animal husbandry and ecology. However, the current management of land-based wind farms focuses on the restoration of the surface and vegetation damaged by construction, lacking the monitoring and protection of vegetation composition. Moreover, the effects of wind farm operation on grassland plant composition are unclear. We hypothesized that wind farm operations would alter plant community structure and thus affect community diversity. To support the construction of eco-friendly wind farms and the sustainable utilization of plant resources, we investigated the vegetation inside and outside of 6 wind farms on typical grasslands and meadows in Inner Mongolia. We aimed to explore the effects of wind power operation on the grassland community composition of both types of grasslands and the relationship between changes in community composition and plant biomass or diversity.

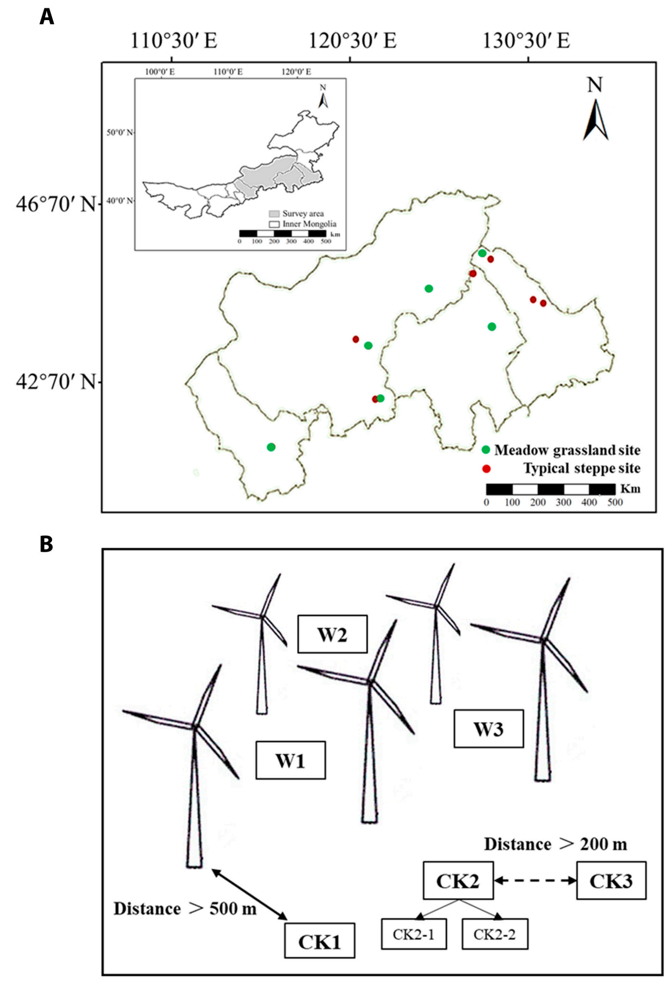

Fig. 1. Map of experimental site distribution (A) and quadrat setting (B). The test sample sites were set up in the central region of Inner Mongolia, and CK plots were set up in areas where the shortest distance to a wind turbine was more than 500 m. The distance between 2 adjacent plots was generally more than 200 m. Two quadrats were set up in each plot. CK, control plot; W, wind power plot.

Materials and Methods

Study site and experimental design

We selected 12 wind farms in Inner Mongolia (Fig. 1A), with 6 wind farms in meadow grassland (M) and 6 wind farms in temperate typical steppe (S). The details of the experimental sites are shown in Table 1. The row distance between the 2 turbines is approximately 500 m, the column distance is approximately 300 m, and the distance between turbines is almost the same in each observation sample site. The dominant species of the 2 grassland types are *Poaceae* or *Cyperaceae*. Additionally, the dominant species of the meadow grassland include *Leymus chinensis*, *Poa pratensis*, and *Stipa baicalensis*, and the dominant species of the typical steppe include *Leymus chinensis*, *Calamagrostis epigeios*, and *Carex duriuscula*. The study area has a monsoon climate, with an annual average temperature of approximately 0 to 7 °C and an annual precipitation of approximately 300 to 485 mm [21].

The experiment was carried out in late August 2021. We established 3 wind power plots (W) and 3 control plots (CK) in each experimental site, and each plot area was at least 10 m × 10 m. Shen et al. [22] found that the average area of grassland damaged by 1.5 MW of turbines was 2496 m^2, and a previous study showed that there was no difference between the grassland plant community in the wind power area and the grassland within 300 m of the wind turbines [23]. Therefore, in our experiment, the CK plot was established in an area more than 500 m from a wind turbine. The distance between 2 adjacent plots was far greater than the nearest distance between 2 turbines in the plot (generally more than 200 m). Two 1-m × 1-m quadrats were randomly set for each plot, and the distance between quadrats was 2 to 5 m. It should be emphasized that care was taken to avoid placing the quadrats in the wind power area in the ground-breaking area. The details for the plot and quadrat settings are shown in Fig. 1B.

Plant measurements and soil sampling

Before conducting the vegetation survey, GPS (Global Positioning System) and a Kestrel 5500 anemometer were used to record the latitude and longitude information of each plot and meteorological data such as wind speed and temperature. Then, the coverage and height of all plants in each quadrat were recorded, and the aboveground plants were mowed to measure the aboveground

Table 1. Sample site geographic information.

Site	Longitude	Latitude	Altitude	Turbine capacity	Grassland type	Buildup time
M1	118°00′18″	44°42′27″	1,125 m	1,500 kW	Meadow grassland	2010
M2	119°14′42″	45°04′30″	1,010 m	1,500 kW	Meadow grassland	2015
M3	119°42′16″	45°30′18″	919 m	1,500 kW	Meadow grassland	2008
M4	116°24′26″	42°16′11″	1,474 m	1,500 kW	Meadow grassland	2008
M5	116°03′13″	43°27′51″	1,352 m	1,500 kW	Meadow grassland	2009
M6	112°64′15″	41°11′25″	1,938 m	750 kW	Meadow grassland	2008
S1	119°55′59″	45°15′12″	798 m	1,500 kW	Typical steppe	2014
S2	121°28′7″	44°18′1″	162 m	1,500 kW	Typical steppe	2010
S3	121°42′6″	44°15′41″	137 m	1,500 kW	Typical steppe	2008
S4	120°03′24″	43°52′04″	589 m	1,500 kW	Typical steppe	2013
S5	116°20′7″	42°15′38″	1,435 m	1,500 kW	Typical steppe	2009
S6	115°39′15″	43°35′20″	1,167 m	1,500 kW	Typical steppe	2010

biomass. The mowed plant materials were dried in an oven at 105 °C for 15 min and then dried at 65 °C for 24 to 48 h to obtain the aboveground dry weight of the plants in each plot.

Soil samples were collected from 0 to 20 cm in each quadrat. Five soil cores (35-mm diameter) were randomly collected from each quadrat, and the soil samples were air-dried before the analysis of their chemical properties. The soil total carbon content was determined by dichromate digestion [24]. The soil total nitrogen concentration was measured using the Kjeldahl method [25]. The soil nitrate nitrogen (NO_3^-–N) and ammonium nitrogen (NH_4^+–N) contents were measured as described previously [26].

Data analysis

The importance values of each plant species [27] and the plant alpha diversity indexes, including the Shannon, richness, Simpson, and Pielou indexes, were calculated [28,29]. Specifically, the importance value was calculated as the average value of the sum of relative height, relative coverage, and relative biomass. Shannon diversity was calculated as $H' = -\sum P_i \ln P_i$, where P_i is the relative abundance of plant species i in one plot and defined as $P_i = n_i/N$, where n_i is the number of individuals of plant species i and N is the number of individuals of all plant species in one plot. The number of plant species in each plot was considered the species richness. The Simpson index was calculated as $D = 1 - \sum(n_i/N)^2$, and the Pielou index was calculated as $E_{H'} = H'/\ln S$, where S is the number of plant species in one plot. The beta diversity was calculated as the Jaccard dissimilarity of all pairs of plots [30].

All data are expressed as the mean ± standard error. All statistical analyses were performed in R 4.1.2. The Shannon, richness, Simpson, and Pielou indexes were calculated using the package "vegan", and the beta diversity was calculated using the "vegdist" function in the package "vegan". Two-way analysis of variance (ANOVA) was used to explore the separate and interactive effects of grassland type and wind farm operation on plant composition, plant diversity, plant biomass, and soil nutrients. A post hoc test was used to compare the differences between the CK and wind power plots. ANOVA was calculated by the aov function in R. A post hoc test was calculated by the TukeyHSD function in R. Pearson correlation analysis was used to show the relationships between biomass and diversity, the plant community characteristics, and the soil carbon and nitrogen content by the cor function in R.

Structural equation modeling was conducted using the package "lavaan". We hypothesized that wind power operation would influence plant species composition, plant diversity, soil carbon, and nitrogen content. Then plant biomass will be affected. On the basis of our hypothesis, we provided an a priori model (Fig. S1). Then, we selected the best model using the criteria of a nonsignificant chi-square test ($P > 0.05$), GFI (goodness-of-fit index) and CFI (comparative fit index) > 0.95, RMR (root mean square residual) < 0.05, and the lowest AIC (Akaike information criterion) value.

Results

Effects of wind power operation on plant biomass

Wind power operation increased plant biomass in meadow grasslands and typical steppes but to different degrees. As shown in Fig. 2, wind power significantly increased plant biomass in meadow grassland by nearly 54% compared to the CK plots. In contrast, the plant biomass of the typical steppe increased by 29.2% under the influence of wind power operation, but the increase was not significant. In addition, the results showed that there was no significant difference in plant biomass between the 2 types of grasslands.

Effects of wind power operation on plant composition

Wind power operation significantly reduced the sum of the dominance of *Poaceae* and *Cyperaceae* by 33.03% in the meadow grassland and by 33.8% in the typical steppe (Fig. 3D). Specifically, the dominance of *Poaceae* and *Cyperaceae* in the meadow grassland decreased by 24.3% and 24.2%, respectively, while the dominance of *Poaceae* and *Cyperaceae* in the typical steppe

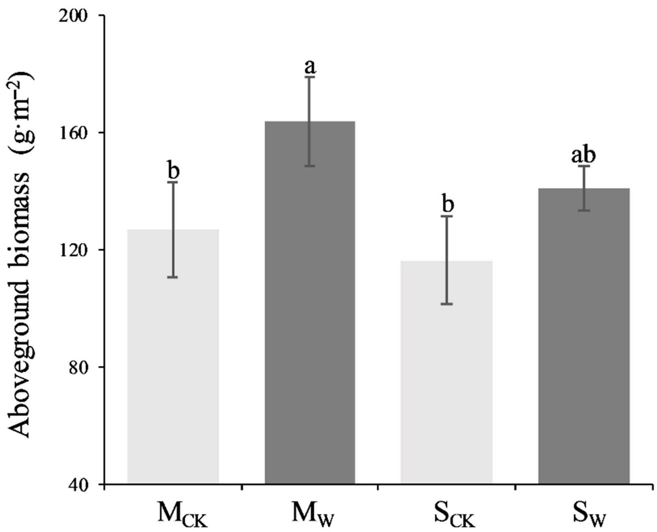

Fig. 2. Effects of wind power operation on the aboveground biomass of grassland plants. M, meadow grassland; S, typical steppe. Different lowercase letters indicate significant differences among treatments ($P < 0.05$).

decreased by 15.4% and 16.5%, respectively. Wind power operation did not significantly change the dominance of *Fabaceae*, *Compositae*, and forbs in the 2 types of grasslands. The results also showed that there was no significant difference in plant dominance between the 2 types of grasslands (Table 2).

Effects of wind power operation on plant diversity

The effect of wind power operation on alpha diversity in both types of grasslands showed consistent trends, with increases in the Shannon, richness, Simpson, and Pielou indexes compared to those in the CK area. However, only the meadow grassland showed a significant increase in the Shannon index, which increased by 12% compared to that of the CK plots (Fig. 4A). The research results showed that the change in the Shannon diversity of plants is jointly determined by wind power and grassland type (Table 2). Wind power operation had no overall effect on the beta diversity of these temperate grasslands. As a whole, the effect of wind power on the beta diversity of the 2 types of grasslands was not significant (Fig. 4E). Specific to each sample site, wind power significantly affected the beta diversity, but the trends were not consistent (Fig. S2). In the meadow grassland sites, the beta diversity of the M1, M2, and M3 sites decreased significantly by 21.1%, 24.7%, and 17.7%, respectively, due to wind power operation, while the beta diversity of the other 3 sites increased by 30.9%, 29.0%, and 9.9% (Fig. S2A). Similarly, the beta diversity of the typical steppe decreased significantly by 14.2%, 38.0%, and 19.5% in the M1, M2, and M5 sites and increased significantly by 20.1%, 18.7%, and 18.4% in the S3, S4, and S6 plots, respectively (Fig. S2B).

Effects of wind power operation on soil carbon and nitrogen content

The results showed that wind power operation did not significantly affect the 0- to 20-cm soil total carbon, total nitrogen, NH_4^+–N, and NO_3^-–N contents of either type of grassland

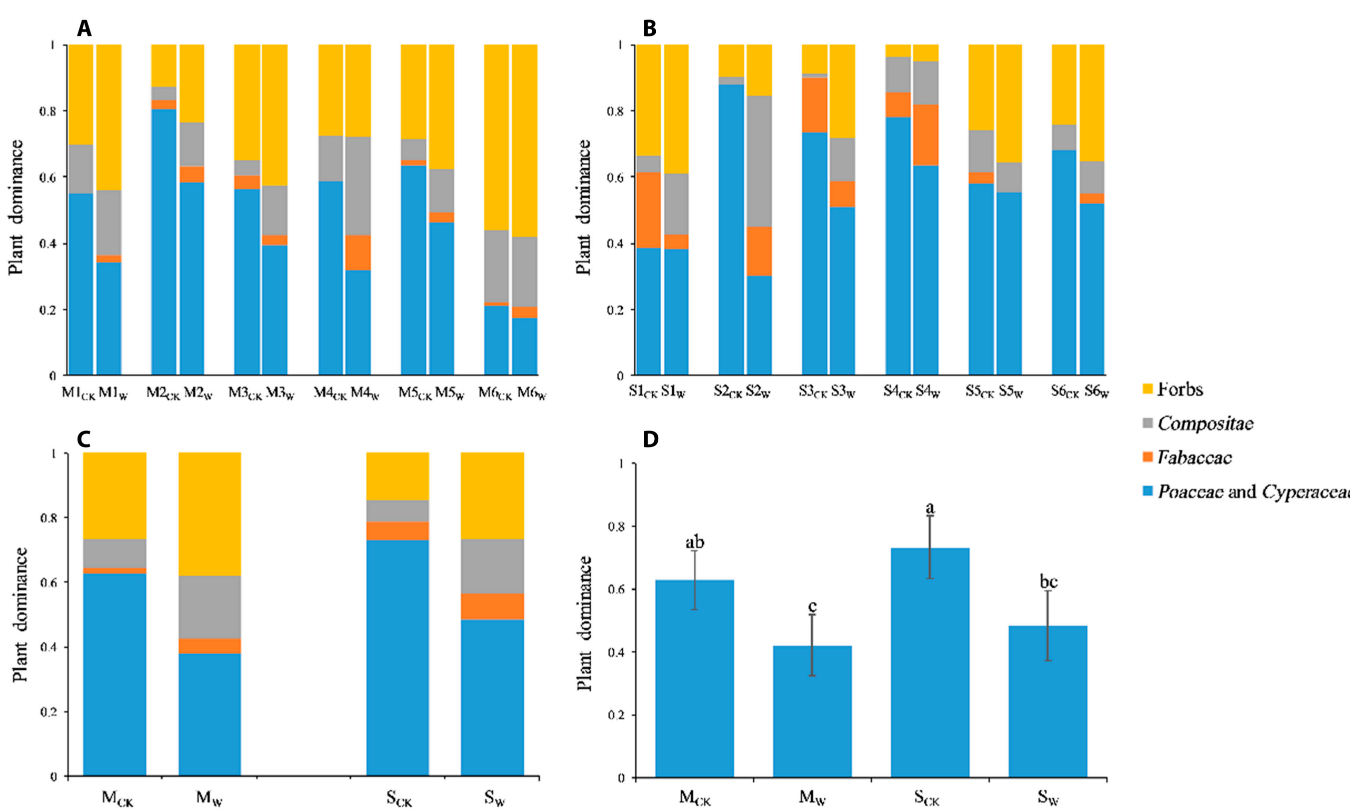

Fig. 3. Effects of wind power on the dominance of plant functional groups. (A) and (B) are based on the mean values of 6 quadrats from each sample plot of meadow grassland and typical steppe, respectively. (C) Based on the mean values of the 4 types of plant dominance in the 6 plots of meadow grassland and typical steppe. (D) Based on the mean values of the plant dominance of *Poaceae* and *Cyperaceae*. Different lowercase letters indicate significant differences among treatments ($P < 0.05$).

Table 2. Effects of grassland type and wind power operation on plant community characteristics and soil carbon and nitrogen content.

Indicator	Treatment	F	P
Importance value of *Poaceae* and *Cyperaceae*	Grassland type	2.169	0.159
	Wind	**21.712**	**0.002**
	Interaction	0.164	0.691
Aboveground plant biomass	Grassland type	1.088	0.319
	Wind	**18.958**	**0.001**
	Interaction	1.476	0.250
Shannon	Grassland type	**9.639**	**0.001**
	Wind	3.316	0.094
	Interaction	**8.984**	**0.011**
Richness	Grassland type	**16.842**	**0.000**
	Wind	0.496	0.489
	Interaction	0.284	0.600
Simpson	Grassland type	**5.983**	**0.0238**
	Wind	1.380	0.254
	Interaction	0.466	0.503
Pielou	Grassland type	2.145	0.159
	Wind	2.484	0.132
	Interaction	0.122	0.731
Soil total carbon	Grassland type	**23.098**	**0.000**
	Wind	1.803	0.186
	Interaction	0.599	0.443
Soil total nitrogen	Grassland type	82.571	0.000
	Wind	2.015	0.161
	Interaction	0.730	0.396
NH_4^+–N	Grassland type	0.256	0.618
	Wind	0.000	0.993
	Interaction	0.028	0.868
NO_3^-–N	Grassland type	6.289	0.023
	Wind	0.044	0.837
	Interaction	0.386	0.542

(Fig. 5). The results specific to each observation plot showed that wind power operation caused significant changes in the total carbon contents of some plots. The total carbon contents of the M1, M2, M3, and M4 sites decreased significantly by 53.6%, 43.6%, 12.74%, and 27.4%, respectively (Fig. S3A). Except for the S6 site, the total carbon contents of the other 5 sites increased significantly by 11.2%, 50.4%, 66.6%, 72.3%, and 29.6% (Fig. S3A). In addition, the total nitrogen contents of the M1, S3, S4, and S5 sites significantly changed by 26.2%, 108.2%, 32.2%, and 22.2%, respectively (Fig. S3B). Overall, there were significant differences in the soil carbon and nitrogen contents between the 2 types of grasslands ($P < 0.001$) and no significant interaction between grassland type and wind power operation (Table 2).

Correlation analysis of the plant community and soil carbon and nitrogen contents under wind power operation

The results of the correlation analysis showed that there was a significant negative correlation between plant biomass and total carbon content in the meadow grassland and typical steppe without wind power operation ($P < 0.01$), while wind power operation significantly weakened the relationship between them (Fig. 6). The biomass of the meadow grassland was not significantly correlated with the total carbon content (Fig. 6B), and the relationship between plant biomass and total carbon content in the typical steppe was significant, but the correlation coefficient decreased by 23.5%, and the P value was > 0.01 (Fig. 6C and D).

The correlations between the soil carbon and nitrogen contents and the plant biomass and diversity in both types of meadows were also significantly weakened by wind power operation. The results showed that there were only 4 pairs of significant correlations between plant biomass, plant diversity, and soil properties in the meadow grassland area with wind power operation, which was 55.6% less than that in the CK area. The number of significant relationships in typical grasslands was reduced by 81.8%.

However, wind power operation significantly strengthened the correlation between the plant dominance of *Poaceae* and *Cyperaceae* and the plant biomass and diversity. The results showed that wind power operation could enhance the positive correlation between plant dominance and biomass, while plant dominance had a significant negative relationship with plant diversity.

The structural equation model showed that the operation of wind power could reduce the dominance of *Poaceae* and *Cyperaceae* in grasslands, thereby significantly increasing the plant diversity and ultimately affecting the plant biomass. Meanwhile, the structural equation modeling results indicated that the presence of wind power significantly increased plant biomass. Overall, the entire structural equation model explained 47% of the plant biomass and 43% of the plant diversity (Fig. 7).

Discussion

Effects of wind power operation on plant composition

With the increasing scale of wind power, the impact of wind power on vegetation has received considerable attention from researchers. However, most studies have used remote sensing to explore the effects of wind farm operation on plant biomass and diversity, and few studies have focused on the changes in plant species composition on wind farms. Our ground survey results showed that wind power operation significantly reduced the dominance of *Poaceae* and *Cyperaceae* in the 2 studied grassland types, similar to the results of Liu et al. [13].

Changes in plant dominance may be related to changes in soil moisture [31]. Most studies have shown that wind power operation can alter the microclimate [32,33], leading to higher temperatures and CO_2 concentrations near wind farms [12,34] and accelerating soil moisture evaporation [35]. Changes in temperature and humidity can affect plant growth and even change plant growth strategies [36], as well as competition between plant groups [37]. Our study found that wind power operation significantly increased the dominance of taproots (Fig. S4B),

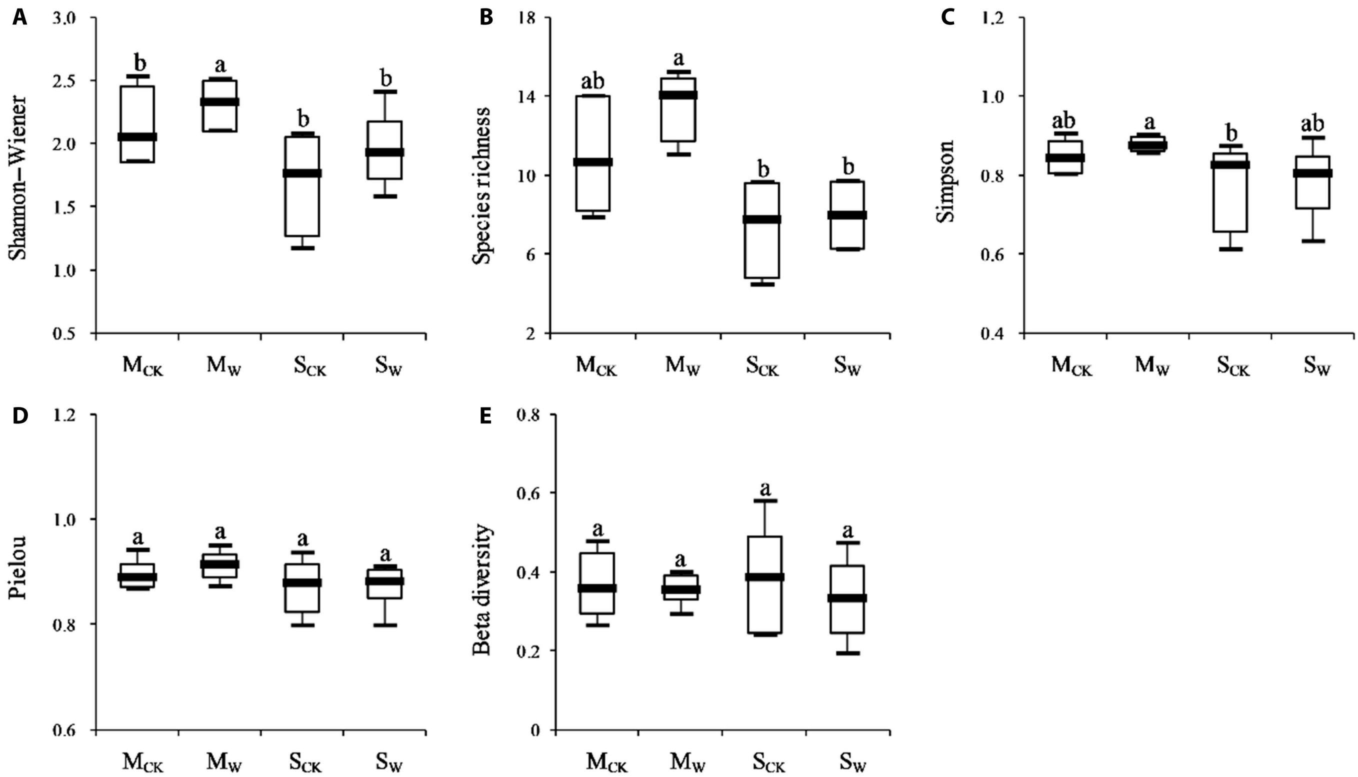

Fig. 4. Effects of wind power on the plant Shannon–Wiener index (A), species richness index (B), Simpson index (C), Pielou index (D), and beta diversity of meadow grassland and typical steppe (E). Different lowercase letters indicate significant differences among treatments ($P < 0.05$).

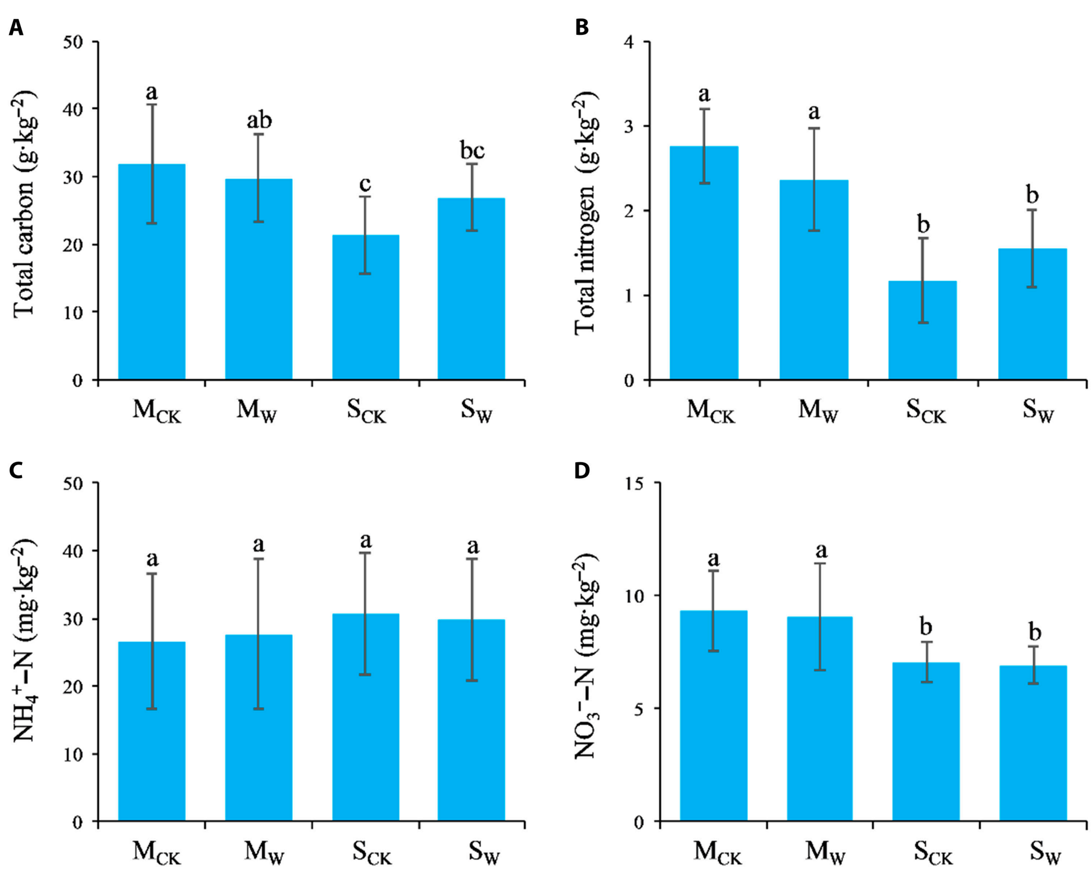

Fig. 5. Effects of wind power on the 0- to 20-cm soil total carbon (A), total nitrogen (B), NH_4^+–N (C), and NO_3^-–N (D) contents. Different lowercase letters indicate significant differences among treatments ($P < 0.05$).

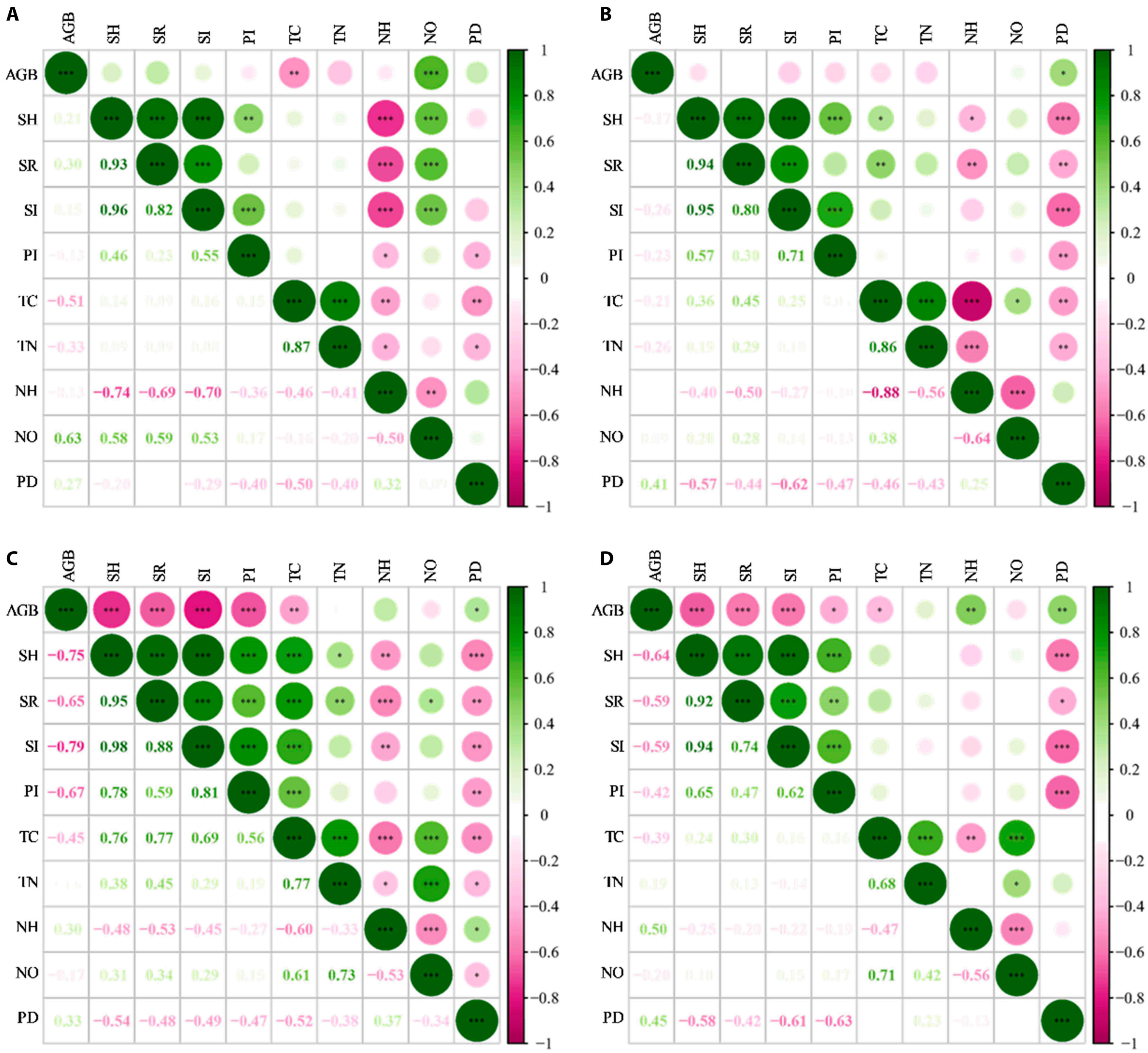

Fig. 6. Correlation analysis between plant and soil properties in meadow grassland (A and B) and typical steppe (C and D). (A) and (C) represent the CK results, and (B) and (D) represent the wind power results. AGB, aboveground plant biomass; SH, Shannon; SR, species richness; SI: Simpson; PI, Pielou; TC, soil total carbon; TN, soil total nitrogen; NH, NH_4^+–N; NO, NO_3^-–N; PD, plant dominance of *Poaceae* and *Cyperaceae*. The number in the heatmap represents the correlation coefficient of 2 indicators. *$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$.

which can utilize deeper soil moisture than fibrous rooted plants such as *Poaceae* and *Cyperaceae* [38]. Therefore, the dominance of plant populations with fibrous root system decreases after the start of wind power operation. In addition, Wang et al. [39] found that temperature increases could promote the decline of C3 plant dominance in plant communities, which is the same as the results of the typical steppe in our study (Fig. S4A). This may be one of the reasons for the decrease in *Gramineae* and *Cyperaceae* in our study. This may be related to the fact that C4 plants have higher water use efficiency and thus better environmental adaptability under the influence of wind power operation [40]. Moreover, the majority of the plants that increased in our study were annuals of *Artemisia* spp. in Asteraceae, which also likely reflects the greater adaptability of annuals to environmental changes [37].

Effects of wind power operation on biomass and diversity

Currently, most studies on the effects of wind power operation on plant biomass have been based on remote sensing monitoring. The results of Li et al. [16], Li et al. [8], and Tang et al. [35] showed that the plant biomass in wind farm areas was lower than that in the control area. The results of Liu et al. [13] indicated that the effect of wind power operation on plant productivity varied by grassland type. We found that wind

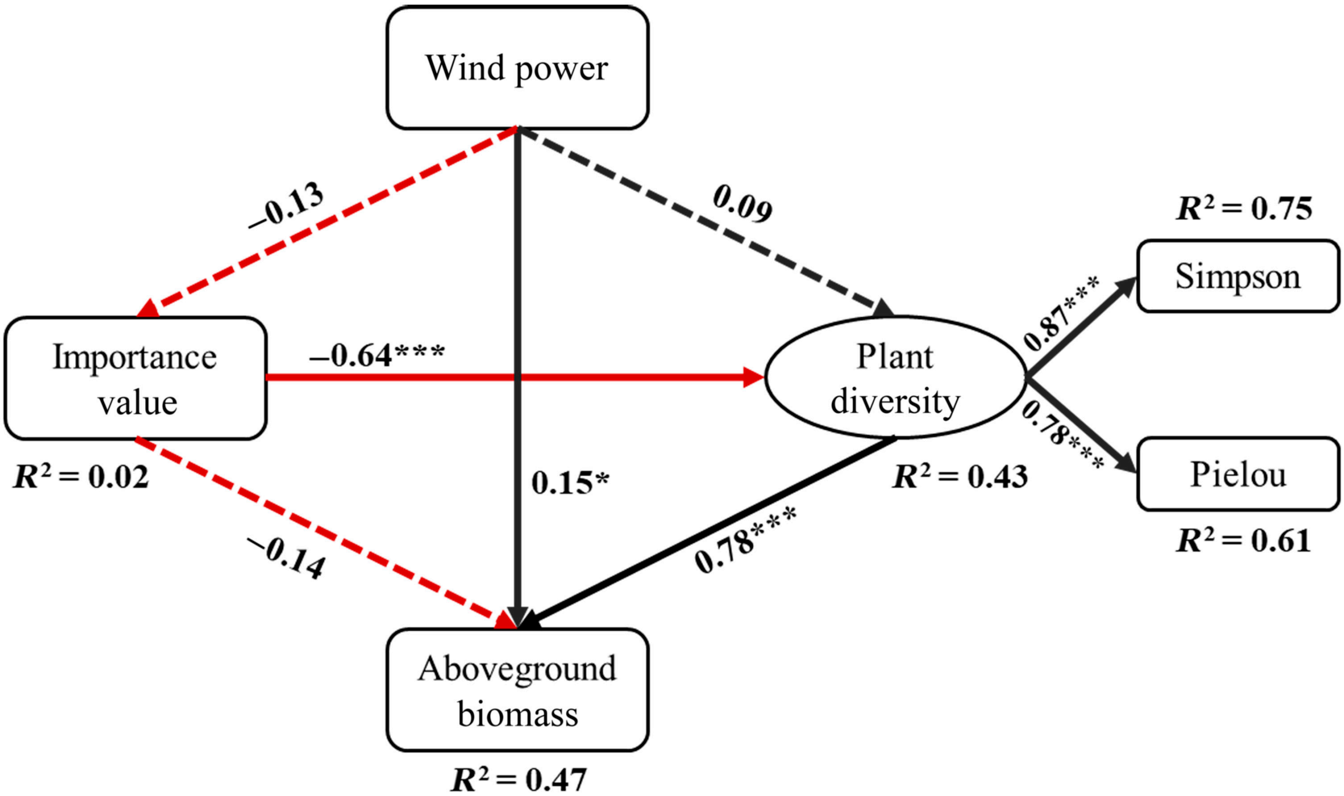

Fig. 7. Structural equation model of the effects of wind power generation on the plant community. Black and red arrows represent significant positive and negative pathways, respectively. The importance value represents the plant dominance of *Poaceae* and *Cyperaceae*. Dotted black and red arrows represent nonsignificant paths. Bold numbers indicate the standard path coefficients. R^2 represents the proportion of variance explained for each dependent variable in the model. *$P < 0.05$ and ***$P < 0.001$. Standard error of the mean fit index: $\chi^2 = 4.111$, df = 2, $P = 0.128$, GFI = 0.989, CFI = 0.990, and RMR = 0.020.

power operation could improve plant productivity in grasslands, which is consistent with the results of Li et al. [17] and Qiu et al. [41]. However, Liu et al. [13] found that wind power operation resulted in lower plant productivity in both meadow grasslands and typical steppes, and they concluded that wind farms not only increased water evaporation but also led to a decrease in soil available nutrients. However, our study did not find that wind power operation significantly reduced the soil nutrient content (Fig. 5), which may be the main reason for the different results between the 2 studies. We also found that wind power operation changed plant community composition, which, in turn, affected community diversity and ultimately increased plant biomass, although the final interpretation coefficient of this impact path was not very high (Fig. 7). The effects of the changes in microclimate on plant biomass should be further investigated in the future.

The impact of wind power operation on plant diversity is another issue worth exploring. Existing studies have mainly suggested that the plant diversity inside wind farms is lower than that outside wind farms because wind power operation can increase the temperature [42], evaporation, and soil nutrient loss [43,44]. Moreover, disturbances during wind power construction can directly reduce plant diversity [15]. However, our study indicated that wind power operation significantly increased the Shannon diversity index of the meadow grassland. The main reason is that wind power operation significantly reduced the dominance of *Poaceae* and *Cyperaceae*, while the dominance of *Compositae*, *Fabaceae*, and forbs increased to different degrees (Fig. 3C). However, the effects of wind power on both types of grasslands were not significant in terms of species composition (Fig. S5), suggesting that the effects of wind power on plant community diversity depend mainly on changes in species dominance. In addition, when setting quadrats, our study avoided the area where the soil and vegetation were directly damaged by wind power construction. Hence, the results of Keehn and Feldman [15] were not applicable to our study.

Implications and limitations

The time since the construction and the operation time of the wind farms selected in this study were not less than 6 years, and 75% of the plots had been established for 10 years or more (Table 1). Hence, our results are the phased results of the multiyear effect of wind farms on grassland plant communities. Compared with the CK area, wind power operation led to an increase in grassland plant productivity but a decrease in the dominance of *Poaceae* and *Cyperaceae*, which are the most favored forages for cattle and sheep [45]. Therefore, wind power operation may lead to a decline in grassland forage quality. Although wind power operation will increase the dominance of *Fabaceae*, which is also a source of high-quality forage [46], it cannot completely compensate for the reduction in *Poaceae* and *Cyperaceae*. Therefore, maintaining the stability of grassland community species composition should be a key concern in wind power development. However, ecological restoration is mainly focused on grassland soil and vegetation damaged by wind farm construction [47]. Therefore, we suggest that, in regions with a more developed livestock economy, it is necessary to conduct long-term monitoring of the plant community composition, soil nutrients, and climate. Moreover, management measures, such as replanting locally dominant forages, can be carried out on wind farms to simultaneously achieve the sustainable utilization of grassland plant resources and wind energy.

Although our research is based on the staged results of the multiyear impact of wind farms on grasslands, the results of only one survey cannot explain all wind farms' impacts on grassland vegetation. In the future, more regions should be included in long-term positioning research through ground investigation combined with climate models to explore how the change in the microclimate of wind farms affects the plant community composition.

Conclusions

Our study focused on the impact of wind power operation on the plant community composition, plant biomass, and plant diversity in meadow grassland and typical steppe sites. The results showed that wind power operation could significantly reduce the dominance of *Poaceae* and *Cyperaceae*, thereby increasing the plant biomass and alpha diversity of the plant communities. We provided evidence of plant community composition affecting plant biomass and diversity under wind power operation, which is difficult to conclude from remote sensing data. Furthermore, the results have important guiding significance for the management of grassland wind farms. We suggest strengthening the monitoring of plant community composition by focusing on plant biomass and diversity to realize the sustainable utilization of wind energy and plant resources.

Acknowledgments

Funding: This work was financially supported by Central Public-interest Scientific Institution Basal Research Fund (no. BSRF202210), Central Public-interest Scientific Institution Basal Research Fund (no. Y2022LM16), and the U.S./China Clean Energy Research Center for Water-Energy Technologies (CERC-WET) through the National Key Research and Development Program of China (grant no. 2018YFE0196000). **Competing interests:** The authors declare that they have no competing interests.

Data Availability

The data that support the findings of this study are available on request from the corresponding author, upon reasonable request.

Supplementary Materials

Fig. S1. Conceptual model for effects of wind power operations on grassland vegetation and soils.
Fig. S2. Effects of wind power on the plant beta diversity of meadow grassland (A) and typical steppe (B).
Fig. S3. Effects of wind power on the 0- to 20-cm soil total carbon (A), total nitrogen (B), NH_4^+–N (C), and NO_3^-–N (D) contents. M, meadow grassland; S, typical steppe; CK, control plot; W, wind power plot. *$P < 0.05$ and **$P < 0.01$.
Fig. S4. Effects of wind power on the dominance of C4 plants (A) and taproot plants (B).
Fig. S5. Nonmetric multidimensional scaling for species composition of 2 types of grassland.

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