AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-202212.00151

Postprint: Application of the WEPS Model in Tiger Nut (Cyperus esculentus) Cultivation Areas of the Ulan Buh Desert

Authors: Guiyun Liao, Wu Xiuqin, Tan Jin, Li Dan, Feng Mengxin, Wu Xiuqin

Date: 2022-12-20T00:00:00+00:00

Abstract

To investigate the wind erosion prediction performance of the WEPS model, wind erosion monitoring was conducted on surfaces under four different harvesting patterns in a Cyperus esculentus planting area of the Ulan Buh Desert in Inner Mongolia: complete harvest (CK), retain-4-harvest-6, retain-6-harvest-6 pure cropping of Cyperus esculentus, and Cyperus esculentus-Haloxylon ammodendron intercropping with stubble retention. The WEPS model' s wind erosion prediction results were validated using two measured wind erosion datasets from November 15, 2020, and December 26, 2020. The results showed that: (1) Compared with complete harvest, all three stubble retention patterns could effectively reduce wind erosion on the planting area surface, and the surface windbreak and sand fixation capacity increased with the number of retained stubble. (2) There were significant differences between the WEPS model' s predicted unit-width wind erosion amount and measured results; the maximum model value was 10.16 times the measured value, and the minimum was 0.58 times the measured value; the model prediction quality had uncertainty, and the prediction performance was poor on surfaces with higher vegetation coverage. (3) The model-predicted unit-width sediment transport rate increased as a power function with the increase of measured values, and could relatively accurately predict the variation trend of wind erosion amount under different surface characteristics; for quantitative wind erosion estimation, the WEPS model still needs to revise its formulas and parameters according to actual wind erosion environments.

Full Text

Arid Zone Research (ChinaXiv Partner Journal)
Vol. 39 No. 5 September 2022

Application of the WEPS Model in the Cyperus esculentus Planting Area of the Ulan Buh Desert

LIAO Guiyun, WU Xiuqin, TAN Jin, LI Dan, FENG Mengxin
School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China

Abstract

This study investigated the wind erosion prediction accuracy of the Wind Erosion Prediction System (WEPS) in the Cyperus esculentus planting area of the Ulan Buh Desert, Inner Mongolia. Wind erosion monitoring was conducted on surfaces under four different harvest modes: full harvest, retain-four-harvest-six, retain-six-harvest-six, and intercropped stubble (Cyperus esculentus with Haloxylon ammodendron). The WEPS model predictions were validated using measured wind erosion data from two wind erosion events. Results demonstrated that all three stubble retention modes effectively reduced wind erosion compared with full harvest. The intercropped stubble exhibited the strongest wind-proof and sand-fixing capacity, while retain-six-harvest-six showed the weakest performance. Surface protection capacity improved with increasing stubble retention quantity, and the wind-sand flow structure gradually transitioned from a tortuous pattern to a "1" shape configuration.

Sediment load in full harvest, retain-four-harvest-six, and retain-six-harvest-six plots decreased exponentially with height, whereas intercropped stubble showed a logarithmic decrease. The exponential fitting degree decreased progressively as stubble quantity increased, with the height distribution pattern evolving toward logarithmic functions. The WEPS predictions differed substantially from measured values, with maximum model estimates reaching 10.16 times observed values and minimum estimates at 0.58 times observed values. Model prediction quality exhibited uncertainty, particularly under high vegetation coverage. However, reasonable consistency existed as predicted unit-width sediment loads increased as a power function of measured values. The model effectively predicted wind erosion trends across different surface characteristics but demonstrated limited stability in quantitative predictions. Future research should strengthen multi-climate, multi-vegetation-type, and multi-temporal sequence investigations to establish comprehensive databases for parameter and formula calibration, thereby improving WEPS universality.

Keywords: Wind Erosion Prediction System; Cyperus esculentus; wind erosion; Ulan Buh Desert

1 Introduction

Wind erosion represents the detachment, transport, and redeposition of surface materials under airflow (wind force), constituting a primary cause of sandy desertification and a major environmental issue in arid, semi-arid, and partially semi-humid regions. Accurate wind erosion prediction is essential for soil conservation planning, guiding and evaluating control measures, mitigating air pollution, and maintaining sustainable land use. Current wind erosion estimation methods include field observation, wind tunnel simulation, factor analysis, particle size comparison, and model simulation. Wind erosion models are classified by scale: small-scale models (e.g., Wind Erosion Equation, WEQ; Revised Wind Erosion Equation, RWEQ; Wind Erosion Prediction System, WEPS) apply to areas <1000 m^2; medium-scale models (e.g., European Light Soil Wind Erosion Model, WEELS; Integrated Wind Erosion Model System, IWEMS) cover up to 10,000 km^2; and large-scale models (e.g., dust emission models) apply to >10,000 km^2 regions.

Developed by the USDA, WEPS represents the most comprehensive and advanced soil wind erosion prediction model, applicable to both cropland and grassland areas. However, WEPS version 1.5 lacks Chinese soil, crop, and management practice databases, preventing direct parameter selection for local simulations. Previous studies have applied WEPS to various regions: Chen et al. (2012) estimated soil wind erosion dust emission and migration in Tianjin suburbs; Wang et al. (2013) found close agreement between WEPS predictions and measured values in unvegetated Minqin desert areas; Liu et al. (2021) assessed potential wind erosion in northern China' s agro-pastoral ecotone with high accuracy. These studies demonstrate WEPS' s potential for small-scale wind erosion prediction in diverse environments.

Cyperus esculentus, native to African arid regions, possesses robust root systems, strong tillering capacity, and excellent stress tolerance, making it suitable for windbreak and sand fixation in northern China's sandy areas. Effective wind erosion estimation is prerequisite for developing scientific planting patterns. Traditional monitoring methods are labor-intensive, time-consuming, and limited in scope. Evaluating WEPS performance in Inner Mongolia' s Cyperus esculentus planting areas provides an efficient monitoring approach and theoretical foundation for small-scale wind erosion prediction in China.

2 Materials and Methods

2.1 Study Area Description

The study area is located in Dengkou County, Bayannur City, Inner Mongolia (106°9 -107°10 E, 40°9 -40°57 N), on the eastern edge of the Ulan Buh Desert, covering 2,847 km^2 with 2,843 km^2 of desert. Elevation ranges from 1,030 to 2,046 m, with terrain sloping southeast to northwest. The region features a temperate continental monsoon climate with mean annual temperature of 7.6 °C, annual precipitation of 142 mm, and annual evaporation of 2,398 mm. Soils are predominantly aeolian sandy soil, with lighter textures including irrigation silt, gray desert soil, meadow soil, and brown calcic soil. Sparse vegetation includes trees (Salix chaenomeloides, Populus euphratica, Ulmus pumila, Haloxylon ammodendron) and shrubs/herbs (Nitraria tangutorum, Astragalus adsurgens, Tamarix ramosissima, Caragana korshinskii, Corethrodendron scoparium, Hippophae rhamnoides).

2.2 Experimental Design

Within the Cyperus esculentus demonstration area, one pure Cyperus esculentus plot and three Cyperus esculentus-Haloxylon ammodendron intercropped plots were selected for wind erosion monitoring. Each 80 m × 140 m plot employed strip planting with 0.5 m row spacing. Pure plots oriented east-west; intercropped plots oriented north-south. One pure plot served as full harvest control (CK), while others contained experimental subplots with different harvest treatments: retain-four-harvest-six (34 m × 40 m), retain-six-harvest-six (39 m × 40 m), and intercropped stubble (40 m × 40 m). [Figure 2: see original paper] illustrates the layout.

Two wind erosion events were monitored across all treatments. Each subplot contained five sediment collectors (1 cm × 3 cm rectangular inlets at five heights) and three multi-profile anemometers (measuring wind speed at 0.5 m, 1.0 m, and 1.4 m). Vegetation parameters (height, leaf area index, band width, spacing, density) were measured in 1 m × 1 m quadrats. Soil bulk density and moisture content (0–15 cm) were determined using ring knife and oven-drying methods. Orthophotos were captured via UAV at 10 m altitude between 13:30–14:00 and processed using Agisoft PhotoScan. Vegetation coverage was extracted via color mixing analysis in ENVI5.3. Crust area ratio (non-erodible surface coverage) was calculated by classifying visible drip irrigation tape area using support vector machine classification.

2.3 WEPS Model Description

The Wind Erosion Prediction System (WEPS) is a modular, process-based daily time-step model comprising submodels, user interfaces, and databases. It simulates fundamental wind erosion processes and management effects on soil erodibility. WEPS version 1.5 lacks Chinese-specific databases, requiring direct parameter input for simulation. This study employed WEPS’ s wind erosion submodel to calculate daily erosion rates.

The unit-width sediment transport rate (Q_m) is calculated as:

$$Q_m = 0.4 \cdot \frac{\rho}{g} \cdot u_*^3 \cdot \left(1 - \frac{u_{*t}}{u_*}\right) \cdot \left(1 + \frac{u_{*t}}{u_*}\right)^2$$

where Q_m is unit-width sediment transport ($\mathrm{kg \cdot m^{-1} \cdot s^{-1}}$), u_* is friction velocity ($\mathrm{m \cdot s^{-1}}$), and u_{*t} is threshold friction velocity ($\mathrm{m \cdot s^{-1}}$).

Friction velocity calculations consider surface roughness and vegetation effects. For unobstructed surfaces:

$$u_* = \frac{k \cdot U_z}{\ln(z/z_0)}$$

where U_z is wind speed at height z, k is von Kármán' s constant (0.4), and z_0 is aerodynamic roughness length.

For vegetated surfaces, effective vegetation drag coefficient (c_d) is:

$$c_d = 0.2 - 0.15e^{-0.5 \cdot LAI}$$

where LAI is leaf area index. Canopy aerodynamic roughness (z_{0v}) is determined by:

$$z_{0v} = \begin{cases} 1.254 \cdot h_v \cdot e^{-3.714 \cdot c_d} & c_d > 0.1 \\ 0.001 & c_d \leq 0.001 \end{cases}$$

where h_v is vegetation height.

Threshold friction velocity incorporates surface crust, flat vegetation, and moisture effects:

$$u_{*t} = \max(u_{*ts}, u_{*tv}, u_{*tm}, 0.35)$$

where u_{*ts} accounts for soil crust/clods, u_{*tv} for flat vegetation, and u_{*tm} for moisture content.

3 Results

3.1 Sediment Transport Characteristics

3.1.1 Vertical Distribution Patterns Wind-sand flow structure evolved from tortuous to "1" shaped configurations as stubble retention increased. During both wind events, full harvest plots exhibited highest sediment loads at all heights within 0–0.21 m, while differences among treatments diminished above 0.21 m. Sediment load decreased with height following: full harvest > retain-four-harvest-six > retain-six-harvest-six > intercropped stubble, indicating superior sand fixation by intercropped stubble.

Vertical distribution followed exponential functions for full harvest, retain-four-harvest-six, and retain-six-harvest-six treatments, with highest R^2 values for full harvest. Intercropped stubble followed logarithmic relationships. As stubble quantity increased, exponential fitting degrees declined, shifting toward logarithmic functions. All stubble treatments significantly reduced sediment transport below 0.21 m compared with full harvest. [Figure 3: see original paper] and present detailed distribution patterns and fitting relationships.

3.1.2 Unit-Width Sediment Discharge Unit-width sediment discharge (Q_s), representing total sediment transport per unit width over time, characterizes wind erosion intensity. Calculated by integrating sediment flux across 0–0.39 m height:

$$Q_s = \sum_{m=1}^{5} Q_m$$

Significant differences existed among treatments ($P < 0.05$). During the first event, full harvest produced maximum Q_s ($10.06\ \mathrm{g \cdot cm^{-1} \cdot h^{-1}}$), while intercropped stubble yielded minimum values ($0.13\ \mathrm{g \cdot cm^{-1} \cdot h^{-1}}$). Retain-four-harvest-six and retain-six-harvest-six reduced Q_s by 74.61% and 84.50%, respectively. During the second event, full harvest Q_s was $10.43\ \mathrm{g \cdot cm^{-1} \cdot h^{-1}}$, with reductions of 69.64% (retain-four-harvest-six), 84.86% (retain-six-harvest-six), and 96.57% (intercropped stubble). summarizes these results.

3.2 WEPS Model Predictions

3.2.1 Input Parameters Model inputs included aerodynamic roughness, leaf area index, vegetation height, and surface coverage measured during wind events. Soil moisture effects were neglected as monitoring occurred during the withered period without irrigation. Wind speed gradients determined aerodynamic roughness via logarithmic profile fitting. presents input parameters for each treatment.

3.2.2 Model Output Parameters WEPS calculated friction velocity, effective vegetation drag coefficient, canopy roughness, and threshold friction velocity for each treatment. Friction velocity rankings (full harvest > retain-four-harvest-six > retain-six-harvest-six > intercropped stubble) indicated superior wind speed reduction by intercropped stubble. Intercropped stubble exhibited highest effective drag coefficient and canopy roughness values. Threshold friction velocities followed: intercropped stubble > retain-six-harvest-six > retain-four-harvest-six > full harvest, with minimum model value set at $0.35\ \mathrm{m \cdot s^{-1}}$. details these outputs.

3.3 Model Validation

Comparison of predicted versus measured unit-width sediment discharge revealed substantial discrepancies. Intercropped stubble showed largest differences, with predictions reaching 10.16 times measured values, while full harvest predictions were 0.58 times measured values. During the first event, WEPS performed best for full harvest; during the second event, retain-six-harvest-six predictions were optimal. However, the model consistently underestimated full harvest and overestimated vegetated treatments, particularly intercropped stubble.

Despite quantitative differences, predicted and measured values exhibited synchronous variation following: full harvest > retain-four-harvest-six > retain-six-harvest-six > intercropped stubble. Power function relationships between predicted and measured values yielded $R^2 > 0.85$ for both events, though root mean square error was higher for the second event. [Figure 4: see original paper] and [Figure 5: see original paper] illustrate these relationships, demonstrating that WEPS accurately predicted erosion trends but required calibration for quantitative accuracy, especially under high vegetation coverage.

4 Discussion

WEPS predictions showed reasonable consistency with measured values in terms of trend, aligning with German and American farmland studies. The model effectively simulated erosion mechanisms under varying vegetation cover and accurately reflected sand fixation capacity differences among harvest modes. However, prediction quality exhibited uncertainty, with maximum values 10.16 times measured and minimum values 0.58 times measured. Several factors contributed to these discrepancies: limited observation events and replications caused data instability; gust wind direction, speed, and frequency fluctuations created monitoring errors; WEPS's hourly time step neglected gust erosion effects, potentially causing underestimation. Additionally, the model assumes uniform vegetation structure, whereas the study area' s dense strip configuration prevented "venturi effects" that would increase flow velocity through canopy gaps, contributing to overestimation in vegetated treatments.

Overall, WEPS sensitivity to wind speed, surface, and vegetation characteristics makes it feasible for small-scale trend prediction and farmland management guidance. However, quantitative accuracy requires improvement. While increasing observation frequency, selecting sustained high-wind events, and reducing prediction time steps may enhance precision, these approaches remain limited by their focus on adapting field conditions to the model rather than improving model universality. Future work must strengthen multi-climate, multi-vegetation-type, and multi-temporal sequence research to develop comprehensive databases for parameter and formula calibration based on actual wind erosion environments.

5 Conclusions

1. All three stubble retention modes significantly reduced wind erosion compared with full harvest. Intercropped stubble exhibited strongest windproof and sand-fixing capacity, while retain-six-harvest-six was weakest. Protection capacity increased with stubble quantity.

2. Sediment load in full harvest, retain-four-harvest-six, and retain-six-harvest-six decreased exponentially with height, while intercropped stubble followed logarithmic decrease. Exponential fitting degrees declined as stubble quantity increased, with distribution patterns evolving

toward logarithmic functions.

3. WEPS predictions differed from measured values but showed reasonable consistency, with predicted unit-width sediment discharge increasing as a power function of measured values. The model accurately predicted erosion trends across surface types but exhibited uncertainty in quantitative estimation, particularly under high vegetation coverage. Establishing localized databases and calibrating formulas and parameters according to specific wind erosion environments are necessary to improve WEPS applicability.

References

[1] Dong Zhibao, Li Zhenshan, Yan Ping. An outline of the wind erosion research history in the world [J]. *Journal of Desert Research*, 1995, 15(1): 100-104.

[2] Yu Baole, Wu Wenjun, Zhao Xuejun, et al. Benefits of soil wind erosion control of the Beijing Tianjin sand source control project in Inner Mongolia[J]. *Arid Zone Research*, 2016, 33(6): 1278-1286.

[3] Liao Chaoying, Zheng Fenli, Liu Guobin, et al. A brief introduction to Wind Erosion Prediction System[J]. *Research of Soil and Water Conservation*, 2004, 11(4): 77-79.

[4] Xi Cheng, Zuo Hejun, Wang Haibing, et al. Wind proof and sand blocking characteristics of high vertical nylon mesh sand barrier and its rational allocation[J]. *Arid Zone Research*, 2021, 38(3): 882-891.

[5] Chen Li, Han Tingting, Li Tao, et al. Estimation of the effect derived from wind erosion of soil and dust emission in Tianjin suburbs on the central district based on WEPS model[J]. *Environmental Science*, 2012, 33(7): 2197-2203.

[6] Wang Yan, Wang Ping. Application of Wind Erosion Prediction System in Minqin desert area[J]. *Arid Land Geography*, 2013, 36(1): 109-117.

[7] Wang Rende, Zou Xueyong, Zhao Jingyan. Research on farmland soil wind erosion characteristics in semi humid region by wind tunnel simulation[J]. *Journal of Desert Research*, 2012, 32(3): 640-646.

[8] Liu Jun, Guo Zhongling, Chang Chunping, et al. Potential wind erosion simulation in the agro pastoral ecotone of northern China using RWEQ and WEPS models[J]. *Journal of Desert Research*, 2021, 41(2): 27-37.

[9] Zhang C, Zou X, Yang P, et al. Wind tunnel test and Cs tracing study on wind erosion of several soils in Tibet[J]. *Soil and Tillage Research*, 2007, 94(2): 269-282.

[10] Wang Rende, Chang Chunping, Peng Shuai, et al. Estimation on farmland wind erosion and dust emission amount in Bashang of Hebei Province by grain composition contrast[J]. *Transactions of the Chinese Society of Agricultural Engineering*, 2013, 29(21): 108-114.

[11] Böhner J, Schäfer W, Conrad O, et al. The WEELS model: Methods, results and limitations[J]. *Catena*, 2003, 52(3): 289-308.

[12] Maurer T, Herrmann L, Gaiser T, et al. A mobile wind tunnel for wind erosion field measurements[J]. *Journal of Arid Environments*, 2006, 66(2): 257-271.

[13] de Oro L A, Colazo J C, Buschiazzo D E. RWEQ wind erosion predictions for variable soil roughness conditions[J]. *Aeolian Research*, 2016, 20: 139-146.

[14] Wagner L E. A history of wind erosion prediction models in the United States department of agriculture: The Wind Erosion Prediction System (WEPS)[J]. *Aeolian Research*, 2013, 10: 9-24.

[15] Liu Y, Teng Y, Liang S, et al. Establishment of PM10 and PM2.5 emission inventories from wind erosion source and simulation of its environmental impact based on WEPS Models 3 in southern Xinjiang, China[J]. *Atmospheric Environment*, 2021, 248: 118222.

[16] 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.

[17] Qu Pingmei, Cheng Zhiying, Long Chunlin, et al. Comprehensive development of chufa (*Cyperus esculentus* sativus L. var.)[J]. *China Oils and Fats*, 2007, 32(9): 61-63.

[18] Wu Fangfang, Cao Yue e, Lu Gang, et al. Impact factors of soil wind erosion and estimation of soil loss in Zhundong, Xinjiang[J]. *Journal of Soil and Water Conservation*, 2016, 30(6): 56-60.

[19] Nan Ling, Du Lingtong, Wang Rui. Reviews on development of soil wind erosion models[J]. *World Sci Tech R & D*, 2013, 35(4): 505-509.

[20] Zou Xueyong, Zhang Chunlai, Cheng Hong, et al. Classification and representation of factors affecting soil wind erosion in a model[J]. *Advances in Earth Science*, 2014, 29(8): 875-889.

[21] Dong Zhibao, Gao Shangyu, Dong Guanrong. A review of wind erosion prediction research[J]. *Journal of Desert Research*, 1999, 19(4): 16-21.

[22] Yan G, Li L, Coy A, et al. Improving the estimation of fractional vegetation cover from UAV RGB imagery by colour unmixing[J]. *ISPRS Journal of Photogrammetry and Remote Sensing*, 2019, 158: 23-34.

[23] Hagen L J, Wagner L E, Skidmore E L. Analytical solutions and sensitivity analyses for sediment transport in WEPS[J]. *Journal of Electronic Packaging: Transactions of the ASME*, 1999, 42: 1715-1721.

[24] Funk R, Skidmore E L, Hagen L J. Comparison of wind erosion measurements in Germany with simulated soil losses by WEPS[J]. *Environmental Modelling & Software*, 2004, 19(2): 177-183.

[25] Hagen L J. Evaluation of the Wind Erosion Prediction System (WEPS) erosion submodel on cropland fields[J]. *Environmental Modelling & Software*, 2004, 19(2): 171-176.

[26] Tatarko J, van Donk S J, Ascough J C, et al. Application of the WEPS and SWEEP models to non-agricultural disturbed lands[J]. *Heliyon*, 2016, 2(12): e215.

[27] Liu L Y, Skidmore E, Hasi E, et al. Dune sand transport as influenced by wind directions, speed and frequencies in the Ordos Plateau, China[J]. *Geomorphology*, 2005, 67(3): 283-297.

[28] Maurer T, Gerke H. Modelling aeolian sediment transport during initial soil development on an artificial catchment using WEPS and aerial images[J]. *Soil and Tillage Research*, 2011, 117: 148-162.

[29] Zhang Yi, Xiao Huijie, Xin Zhiming, et al. Wind prevention and sand resistance of typical shrubs in Ulan Buh Desert[J]. *Science of Soil and Water Conservation*, 2021, 19(1): 87-96.

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

Source: ChinaXiv —Machine translation. Verify with original.