1 Evaluation of two empirical wind erosion models in arid and semi-arid regions
2 of China and the USA

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Abstract

Wind erosion models are important tools for assessing soil erodibility and identifying management practices to control erosion. The Agricultural Policy/Environmental eXtender (APEX) model and Revised Wind Erosion Equation (RWEQ) were tested using data collected from the Tarim Basin of China and Columbia Plateau of the United States of America. Adequate performance in simulating soil loss was achieved using the original APEX model and RWEQ in respectively a cotton field and desert-oasis ecotone in the Tarim Basin and winter wheat - summer fallow (WW-SF) field in the Columbia Plateau. We calibrated the APEX model and RWEQ to improve performance because both models have many empirical parameters. After calibration, both models adequately simulated soil loss from all land use types except the RWEQ from the red date orchard in the Tarim Basin. Inadequate performance of the calibrated RWEQ in the red date orchard was likely due to underestimating maximum mass transport.

Keywords: APEX; Columbia Plateau; RWEQ; Tarim Basin; wind erosion model

Introduction

The arid and semi-arid regions of the Tarim Basin in China and Columbia Plateau in the United States are influenced by continental air masses that produce little precipitation and/or topographic features that intercept atmospheric moisture (Mass, 2008; Petrov, 1976). The combined influence of low precipitation, low biomass production, dry soil, and high winds contribute to the occurrence of wind erosion and poor air quality in both regions (Shao and Wang, 2003; Sharratt and Feng, 2009). Sharratt et al. (2007), for example, reported wind erosion of cropland can increase the concentration of fine particulates in the atmosphere and result in exceedance on the National Ambient Air Quality Standard for PM₁₀ (particulate matter $\leq 10\mu\text{m}$ in aerodynamic diameter) in the Columbia Plateau.

Wind erosion involves the movement of particles across a landscape. Soil productivity is therefore influenced by wind erosion as a result of detaching and subsequently displacing or removing fertile topsoil from the land surface. Models that simulate the detachment, transport, or loss of soil by wind have undergone an evolution of development for many decades (Wagner, 2013). Indeed, models are useful tools for predicting soil transport and loss as well as aiding in the identification of land management practices that control or mitigate erosion. One wind erosion model, the APEX model, was developed by Texas A&M University as a tool to manage farm watersheds. The APEX model is an extension of the Environmental Policy Integrated Climate (EPIC) model, thus both models use the same wind erosion algorithm to simulate wind erosion (Wang et al., 2012). Nevertheless, the wind erosion algorithm in the APEX model has undergone limited testing. Potter et al. (1998) found the EPIC model adequately simulated erosion for six of seven high wind events that caused measurable erosion of a fallow agricultural field in Alberta. The model, however, simulated erosion on three days with no measurable erosion and lacked testing across multiple seasons and broad surface conditions. Van Pelt et al. (2004) found good performance of the EPIC model in simulating erosion

for eight high wind events that resulted in 0.2 to 1.0 kg m⁻² of soil loss from an agricultural field in Texas. The model, however, appeared to underestimate erosion during nine wind events with an observed erosion of >1.0 kg m⁻² and overestimated erosion during seven wind events with an observed erosion of <0.2 kg m⁻².

Another wind erosion model, the RWEQ, was developed by Fryrear et al. (1998) to improve the Wind Erosion Equation (WEQ) in simulating soil loss from agricultural fields. The WEQ was developed in the 1960's to assess annual soil loss based upon climate, soil, and vegetative cover (Woodruff and Siddoway, 1965). The RWEQ predicts short-term (daily) soil loss based upon wind, soil, and vegetative cover and orientation. Fryrear et al. (2001) noted that the RWEQ was the first wind erosion model to be tested outside the Great Plains of the United States and, while soil erodibility was key to predicting soil loss by the WEQ, wind was key to predicting soil loss by the RWEQ. Buschiazzo and Zobeck (2008) found that the RWEQ underestimated soil mass transport by 45% in a bare agriculture field and failed to predict erosion despite erosion occurring in fields subject to conventional and no tillage in Argentina. Similar underestimation of the RWEQ was found by Zobeck et al. (2001) and Van Pelt et al. (2004) at multiple sites in the United States. Youssef et al. (2012) found the RWEQ adequately predicted soil mass transport, but only after calibrating the model to local Syrian conditions. The RWEQ also poorly predicted mass transport in the Sahel (Visser et al., 2005).

Knowledge concerning the potential erodibility of soils will aid in developing management practices for the sustained use of lands in the Tarim Basin and Columbia Plateau. Pi et al. (2014a) used the Wind Erosion Prediction System (WEPS) erosion submodel to assess wind erosion in the Tarim Basin and found the submodel performed well in a desert-oasis ecotone but inadequately on agricultural land. Similar results were found by Feng and Sharratt (2009) in testing the erosion submodel on agricultural land in the Columbia Plateau. Despite these efforts to test the performance of WEPS

erosion submodel, there is a need for testing other models to assess the wind erosion risk across various land use types in the Tarim Basin and Columbia Plateau. The APEX model and the RWEQ are of interest in simulating wind erosion in these regions since the two models are regarded as important tools for assessing wind erosion of agricultural lands in the United States and other regions of the world (Fryrear et al., 1998; Liu et al., 2009). Few scientists, however, have tested these models under various land cover types in arid and semi-arid regions. Testing of models under varying climates, land use types, and soils will aid in using or further developing these models for assessing wind erosion potential and developing practices for the sustained use of agricultural and natural landscapes. We are not aware that the APEX model has been tested outside North America or on land use types other than agriculture. The objective of this study was therefore to test the APEX model and the RWEQ for contrasting surface conditions associated with agricultural and native ecosystems in the Tarim Basin and agricultural ecosystems in the Columbia Plateau.

2. Materials and Methods

This study was conducted in the Tarim Basin of northwestern China and in the Columbia Plateau of the Inland Pacific Northwest United States. The Tarim Basin encompasses an area of nearly 1 million km² and is an important agricultural region and a source of windblown dust that impacts air quality in Asia and North America (Haywood et al., 1999; Kurosaki and Mikami, 2005). Three contrasting land use types were examined in simulating wind erosion during the spring wind erosion season of 2012 and 2013. Land use types included a cotton field, red date orchard and desert-oasis ecotone and were located in Aksu County, Xinjiang Province (Fig. 1 and Table 1). The three land use types were located on soils classified as a sand with sand/silt/clay fractions being respectively 1.00/0.00/0.00 for the desert-oasis ecotone site, 0.89/0.11/0.00 for the cotton field, and 0.87/0.13/0.00 for the red date orchard.

Cotton and red dates are the most common agricultural crops grown in the region. Aksu County is characterized by an arid climate with mean annual precipitation of 53 mm and mean annual temperature of 11.3°C.

The Columbia Plateau is also an important agricultural region where direct suspension is the dominant wind erosion process that impairs air quality (Feng and Sharratt, 2007; Kjelgaard et al., 2004; Sharratt et al., 2007). The Columbia Plateau spans 75000 km² and receives from 150 to 600 mm of annual precipitation. Wind erosion was measured and simulated for a single land use type during 2003-2006 in east-central Washington (Fig. 1 and Table 1). The land use type consisted of WW-SF in which land is in wheat every other year and in fallow between crop years. This rotation is used on 1.5 million ha of the Columbia Plateau (Schillinger and Papendick, 2008). The WW-SF rotation was located on soil classified as silt loam with sand/silt/clay fractions being about 0.35/0.55/0.10. Wind erosion was measured and simulated only during the fallow phase of the rotation because tillage-based fallow creates bare, dry, and poorly aggregated soils that are very susceptible to wind erosion (Sharratt et al., 2007).

Fig. 1. Location of validation sites in the Tarim Basin, China and Columbia Plateau, USA. Shading is used to differential annual precipitation across Xinjiang Province in China and Washington state in the USA, with lighter shading denoting lower precipitation.

153 Table1. Location of validation experimental sites.

Experimental site	Year	Land Use	Latitude	Longitude
Tarim Basin, China	2012, 2013	Cotton	40°37'N	80°49'E
	2012, 2013	Red Dates	40°35'N	80°51'E
	2012, 2013	Desert-Oasis	40°28'N	80°20'E
Columbia Plateau, USA	2003	Winter Wheat	45°52'N	118°29'W
	2004	Winter Wheat	46°53'N	118°17'W
	2005	Winter Wheat	46°51'N	118°39'W
	2006	Winter Wheat	46°53'N	118°26'W

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2.1 Experimental sites

Non-erodible surfaces (consisting of canals, roads, tributaries or vegetative barriers) were maintained along the windward boundary to minimize sediment influx to experimental sites. Influx of sediment flux to the sites across all high wind events ranged from 0-0.1 kg m⁻¹ in the cotton field, red date orchard, and WW-SF field. Although sediment influx was not measured at the desert-oasis site, we did observe during a singular event (17-19Apr2013) no sediment being transported across the windward boundary even though sediment was being blown across the site. Sediment influx was accounted for in determining sediment discharge or loss from each site (see below).

The desert-oasis ecotone site in the Tarim Basin was characterized by expansive sand plains with sparse natural vegetation (<5% cover) comprised of salt bush (*Atriplex polycarpa* L.) and manaplant (*Alhagi sparsifolia* L.). The dimensions of the site were 400 m long and 100 m wide under prevailing NW winds (Fig. 2). To assess wind erosion when winds were not from the NW, the width of the site was expanded (up to 900 m) to maintain the presence of a non-erodible surface along the windward boundary. Location of instruments at the site provided a fetch of 100 to 877 m across all high wind events (Pi et al., 2016). A paved road (with >1 m of relief) and tributary, with intervening vegetation (≤2 m tall) providing 50% cover, abated the influx of sediment from the west. Two adjacent linear sand dunes, with intervening vegetation (≤2 m tall) providing 90% cover, abated the influx of sediment from the east (Fig. 2). The desert-oasis ecotone site remained undisturbed during our experiment.

Fig. 2. Location of instrumentation in the cotton field, red date orchard, and desert-oasis ecotone in the Tarim Basin.

The cotton (*Gossypium hirsutum* L.) and red date (*Zizyphus jujube* L.) experimental sites were located respectively at the Aksu Water Balance Experiment Station and 5 km from the Station. The dimensions of the experimental sites were both 100 by 100 m and location of instruments provided a fetch of 105 to 140 m within a 20-ha cotton field and 100 to 115 m within a 7-ha red date orchard across all high wind events. Cotton was grown in fields adjacent to our 20-ha cotton field and irrigation canals were located along the windward borders of the cotton field (Fig. 2). Cotton was mechanically sown in April and harvested in July. Prior to sowing cotton, the field was plowed in early spring to incorporate residue from the previous cotton crop. Cotton was sown in east-west rows using a one-pass operation which consisted of installing a drip irrigation system between every other set of paired seed rows (0.1 m spacing between paired rows and 0.65 m spacing between sets of paired rows), overlaying the drip system and seed rows with 1.25-m wide plastic film, securing the edges of the plastic film with soil, and sowing seed through the plastic film. The plastic film conserved soil moisture and effectively covered 40% of the field. The crop was drip irrigated weekly. The 7-ha red date orchard was established six years prior to this study. Red dates were grown on land adjacent to our orchard and a paved road and irrigation canal were located along the windward borders of the orchard (Fig. 2). The trees were pruned during winter to maintain a height of about 1 m. Weeds were controlled in red dates by tillage in spring and hand weeding during the growing season. The orchard was flood irrigated monthly to provide the water requirements during the growing season.

Multiple WW-SF field sites were monitored for wind erosion in the Columbia Plateau (Table 1) because wind erosion from a field site is only of concern every other year (during the fallow phase of the rotation). The sites had an annual precipitation of 220 to 300 mm and field dimensions varied from 200 m long by 100 m wide to 300 x 300 m. Location of instruments in the fields (Fig. 3) provided a fetch of 135 to 390 m across all high wind events. After

harvest of wheat in July, the sites were subject to conventional tillage or undercutter tillage practices during the fallow phase of the rotation. Conventional tillage practices were imposed at the sites during 2003 to 2006 while undercutter tillage practices were imposed on land adjacent to the conventional tillage sites in 2005 and 2006. Conventional tillage included disking wheat stubble in autumn and/or spring while undercutter tillage included undercutting with sweeps (0.8-m wide) in spring to retain the wheat stubble on the surface. The land was rodweeded two or three times between spring tillage and sowing of winter wheat to control weeds. Wheat was not sown in 2003 and was sown in NW-SE rows in August 2004 and E-W rows in August 2005 and 2006 using a deep furrow drill. Vegetation barriers were maintained along the windward borders of the fields; the barriers consisted of wheat, wheat stubble, or permanent grass to minimize the influx of sediment into the fields (Fig. 3).

2.2 Field measurements

Stem and leaf area indices were determined from stem diameter, length, and population and leaf width, length, and population within an area of 0.5, 1.0, or 40 m² at each experimental site. These indices were determined at three or four locations at each site. Oriented surface roughness associated with ridges or tillage tool marks was not present at the three sites in the Tarim Basin. In the Columbia Plateau, oriented roughness was present in the fallow fields after sowing wheat due to ridges created by the deep furrow drills. Ridge height (0.1 m) and spacing (0.45 m) were measured using a ruler.

Fig. 3. Location of instrumentation at field sites in the Columbia Plateau. The field sites were in the summer fallow phase of a WW-SF rotation and maintained using conventional and undercutter tillage practices.

Biomass characteristics were periodically (e.g. after high wind events) measured at each experimental site in the Tarim Basin (Pi et al. 2014a) and field site in the Columbia Plateau (Feng and Sharratt, 2007, 2009). Standing biomass, standing crop residue, and flat residue were assessed by collecting, drying, and weighing biomass taken within three 0.5, 1.0, or 40 m² areas. For the purpose of this study, standing biomass is living plant material that is anchored to and protrudes above the soil surface, standing crop residue is dead plant material that is anchored to and protrudes above the surface, and flat residue is dead plant material that is prostrate on the soil surface. Flat residue cover, soil crust cover, and surface random roughness were measured at three locations at each site using a pin-type profile meter. The meter consisted of a rigid, 1-m long frame and 40 equidistant pins that passed vertically through equidistant holes in the frame (Allmaras et al., 1966). Flat residue cover and soil crust cover were ascertained from the percentage of pins touching flat plant residue or soil crust. Random roughness, measured at three locations at each site, was computed as the standard deviation in pin elevation after correcting for the slope or change in elevation with distance over the length of the meter.

Soil characteristics were assessed at three locations at each experimental site in the Tarim Basin and Columbia Plateau. Soil water content, wilting point water content, and particle size distribution were assessed from samples taken from the upper 5 mm of the soil profile. Soil water content was determined before or after every high wind event by the reduction in weight of the samples after drying. Wilting point water content and particle size distribution were assumed not to vary with time at any given site, thus were assessed once after deploying all instrumentation each year. Wilting point water content was measured using an equitensiometer (Model 1500F1; Soilmoisture Equipment Corp., USA) and soil particle size distribution was determined on dispersed soil samples using a Mastersizer laser diffraction instrument (Malvern Instruments, Worcestershire, UK). Aggregate size distribution was assessed from soil

samples (1 kg) taken from the upper 30 mm of the profile before or after every high wind event. The samples were air dried and then separated by size using a horizontal sieve shaker for the desert-oasis site and a rotary sieve apparatus for all other sites.

Atmospheric temperature and relative humidity and wind speed and direction were measured at an automated weather station established at each experimental site. Temperature and wind speed sensors were placed at heights of 0.1 to 10 m. Sensors were monitored every 10 s and data recorded at least hourly. High wind events were defined by threshold wind velocities of $\geq 4 \text{ m s}^{-1}$ at a height of 1 m in the Tarim Basin and $\geq 6.4 \text{ m s}^{-1}$ at a height of 3 m in the Columbia Plateau.

Soil loss was assessed at all experimental sites using creep and Big Spring Number Eight (BSNE) collectors (Fryrear, 1986). Collectors were placed along the windward and leeward boundaries to monitor horizontal sediment flux at all sites except the desert-oasis site (Figs. 2 and 3). Creep collectors trapped sediment to a height of 0.025 m whereas BSNE airborne collectors were positioned 0.1, 0.2, 0.5, 1.0, 1.5, and 2.0 m above the soil surface. We deployed from two to six sets of collectors along the windward and leeward boundaries of the wheat fields, three sets of collectors along the windward and leeward boundaries of the cotton field and red date orchard, and three sets of collectors along the leeward boundary at the desert-oasis ecotone site. A more detailed description of the experimental design for assessing soil loss from the cotton and wheat field and red date orchard can be found in Pi et al. (2014a), Sharratt et al. (2007), and Sharratt and Feng (2009). Although no collectors were located along the windward boundary at the desert-oasis ecotone site, a tributary and paved road located along the NW boundary and two transverse linear dunes along the SE boundary provided non-erodible barriers to influx of sediment. Sediment in the collectors was retrieved from the sites after one high wind event or a series of high wind events having predominately unidirectional winds due to the remoteness of the

sites and infrequency of high winds sufficient to cause wind erosion. For wheat fields, sediment mass in each BSNE collector was corrected for the inefficiency of the collector in trapping fine particles emitted from loess in the Columbia Plateau (Sharratt et al., 2007; Sharratt and Feng, 2009). Sediment mass in each BSNE collector in the cotton field, red date orchard, and desert-oasis site was not corrected for inefficiencies associated with trapping particles emitted from sands in the Tarim Basin because the catch efficiency of the BSNE collector is >90% for sand (Fryrear, 1986).

Total horizontal sediment flux along the windward and leeward boundaries of the experimental sites was assessed from creep and BSNE sediment catch. Total horizontal sediment flux was determined as the sum of creep horizontal flux and BSNE horizontal flux. The equation of Zobeck and Fryrear (1986) was used to describe the vertical distribution of sediment captured by BSNE collectors according to:

$$q=\alpha z^{-\beta} \quad (1)$$

where q is sediment catch (kg m^{-2}), z is height (m) of the opening of the BSNE collector above the soil surface and α and β are fitted parameters. This equation provided a good fit to the measured data for all land use types in our study as R^2 ranged across high wind events from 0.90 to 0.99 for the desert-oasis ecotone, 0.82 to 0.99 for the cotton field, 0.86 to 0.99 for the red date orchard, and 0.90 to 0.99 for WW-SF fields. BSNE horizontal flux was determined by integrating Eqn. 1 from 0.025 to 2 m for the sandy soils in the Tarim Basin and from 0.025 to 5 or 7 m for the silt loam soils in the Columbia Plateau. The integrated flux for all high wind events approached a maximum value at a 2 m height in the Tarim Basin whereas dust plumes attained heights of 5 to 7 m during high wind events in the Columbia Plateau (Sharratt et al., 2007; Sharratt and Feng, 2009). Net soil loss from the agricultural sites was calculated as the difference between total horizontal sediment flux at the windward and leeward field positions divided by the distance between positions in the direction of the prevailing winds during the sampling period.

This method of assessing soil loss relies on measuring the influx of sediment at a point along the windward boundary in the direction of the prevailing wind and thus necessitated using data only for high wind events characterized by northwesterly or southeasterly winds at the desert-oasis site and northeasterly winds at the cotton field and red date orchard sites in the Tarim Basin and southwesterly winds in the Columbia Plateau.

2.3 APEX

The APEX model was {reprogrammed using Microsoft Excel based upon version 0806}. The reprogrammed model is available from the senior author and aided in calibrating the model. The performance of the reprogrammed APEX model was verified against the original model downloaded from Texas A&M (<http://epicapex.tamu.edu/apex>). The APEX model uses the following equations to simulate soil loss and discharge (Williams et al., 2012):

$$SL = SEF \times SRF \times VCF \times FLF \times \int_0^t \frac{ER}{WL} dt \quad (2)$$

and

$$SF = SEF \times SRF \times VCF \times FLF \times \int_0^t ER dt \quad (3)$$

where SL is simulated soil loss (kg m^{-2}), SF is simulated soil discharge (kg m^{-1}), SEF is soil erodibility factor, SRF is the surface roughness factor, VCF is the vegetative cover factor, FLF is the field length factor, ER is the potential erosion rate ($\text{kg m}^{-1} \text{s}^{-1}$), WL is the mean unsheltered travel distance of wind across a field (m), and t is the duration (s) when the friction velocity (u_*) exceeds the threshold friction velocity (u_{*t}) of the surface.

The ER term in Eqns. 2 and 3 is determined according to (Skidmore, 1986):

$$ER = c \left(\frac{\rho_a}{g} \right) \left[u_*^2 - u_{*t}^2 - 0.5 \left(\frac{sw}{wp} \right)^2 \right]^{1.5} \quad (4)$$

where c is a fitted parameter (value of 2.5), ρ_a is air density (kg m^{-3}), g is acceleration of gravity (9.8 m s^{-2}), u_* and u_{*t} are in m s^{-1} , and sw and wp are

respectively the soil water content and wilting point water content ($g\ g^{-1}$).

Friction velocity is estimated in the APEX model according to:

$$u_z = \left(\frac{u_*}{k}\right) \ln\left(\frac{z}{z_0}\right) \quad (5)$$

where u_z is wind speed ($m\ s^{-1}$) at height z (m), k is von Karman's constant (0.4), and z_0 is surface aerodynamic roughness (m). Since APEX uses a fixed value for z_0 , and recognizing that z_0 varies across space and time due to changes in surface roughness characteristics (e.g. standing biomass, ridge height and spacing, and random roughness) in our study, we used wind speed data to obtain u_* and z_0 from the respective slope and intercept of the $\ln(z)$ versus u_z relationship. Threshold friction velocity ($m\ s^{-1}$) is estimated in the APEX model according to:

$$u_{*t} = \alpha_{U_{*t}} \sqrt{\left[g \left(\frac{pd}{\rho_a}\right) pad\right]} \quad (6)$$

where pad is the particle diameter (m), pd is the particle density (assumed to be $2650\ kg\ m^{-3}$), and $\alpha_{U_{*t}}$ is an empirical coefficient assumed to have a value of 0.1 (Williams et al., 2012).

The SEF (dimensionless) in Eqns. 2 and 3 is defined as:

$$SEF = \frac{I}{695} + \alpha_{SEF} \quad (7)$$

where I is the soil erodibility factor ($t\ ha^{-1}$) from Woodruff and Siddoway (1965) which is dependent on the aggregate fraction $>0.84\ mm$ in diameter and α_{SEF} is an empirical coefficient assumed to have a value of 1.0 (Williams et al., 2012). The soil erodibility factor is influenced by soil properties other than aggregate size (e.g. aggregate density), thus α_{SEF} accounts for variations in erodibility associated with soil characteristics other than aggregate size.

The SRF (dimensionless) in Eqns. 2 and 3 accounts for both random (associated with surface clods) and oriented roughness (caused by an implement). The effect of oriented roughness varies with wind direction. The SRF is estimated by the function:

$$SRF = 1 - \exp\left[-\left(\frac{ad}{RFB}\right)^{RFC}\right] \quad (8)$$

where ad is the descent angle of saltating sand grains (15° from the horizontal). The coefficient RFC varies as a power function of ridge height (Potter and Zobeck 1990) while the coefficient RFB varies as a function of ridge height, wind direction, and random roughness according to:

$$RFB = \alpha_{SRF} \times [1 - \exp(-(\frac{RRU}{9.8})^{1.3})] + |\sin(wn2)| \times 1.27 \times RHT^{0.52} \quad (9)$$

where RRU is random roughness (mm), $wn2$ is the angle of the wind with respect to ridges, RHT is the ridge height (mm), and α_{SRF} is the empirical coefficient assumed to have a value of 11.9 (Williams et al., 2012).

The VCF in Eqns. 2 and 3 is dependent on standing biomass, standing crop residue and flat crop residue according to:

$$VCF = 1 - \frac{X1}{[X1 + \exp(-0.331 - \alpha_{VCF} \times X1)]} \quad (10)$$

where α_{VCF} is an empirical coefficient assumed to have a value of 1.055 (Williams et al., 2012). The coefficient $X1$ is determined by:

$$X1 = (\omega1SB + \omega2SR + \omega3RF) \quad (11)$$

where SB is standing live biomass ($t\ ha^{-1}$), SR is standing crop residue ($t\ ha^{-1}$), and RF is flat crop residue ($t\ ha^{-1}$). The $\omega1$, $\omega2$, and $\omega3$ are crop specific coefficients from the EPIC parameter (PARM) database that convert vegetative cover to a small grain standard or equivalent.

The FLF in Eqns. 2 and 3 is calculated based upon the field dimensions, orientation and wind direction (Cole et al., 1983) according to:

$$FLF = 1.0 - \exp[-(\frac{WL/1000}{\alpha_{FLF}})^2] \quad (12)$$

where WL is determined from wind direction and the length and width of the field (Stout, 1990) and α_{FLF} is an empirical coefficient with an assumed value of 0.07 (Williams et al., 2012).

2.4 RWEQ

The RWEQ used in this study was released in 1998 and was reprogrammed using Microsoft Excel based on the RWEQ technical bulletin (Fryrear et al., 1998) and is available from the senior author. The performance of the reprogrammed model was verified against the original model using data

reported by Fryrear et al. (1998) and Van Pelt et al. (2004). The RWEQ not only simulates average soil loss across a field, but also soil loss at specific points (*PSL*) along the length of an eroding field. The *PSL* (kg m^{-2}) is calculated according to:

$$PSL = \frac{2x}{S^2} Q_{\max} e^{-(x/s)^2} \quad (13)$$

where $Q_{\max}$ is maximum transport capacity (kg m^{-1}), S is critical field length (m), and x is the distance from the non-erodible border (m). The quantity of material being transported by wind will increase with an increase in field length and attain a maximum at distance S . Mass transport, however, is limited by field length and when field length is greater than S , mass transport begins to decline. This concept of mass transport capacity applies to erosion processes dominated by either saltation or suspension. Suspension, however, generally is not constrained by transport capacity (Hagen, 2004). As such, the RWEQ may have limited application in regions such as the Columbia Plateau where suspension can dominate the erosion process. The $Q_{\max}$ and S are estimated according to:

$$Q_{\max} = \beta_Q \times WF \times EF \times SCF \times Krr \times COG \quad (14)$$

and

$$S = \beta_{S1} \times (WF \times EF \times SCF \times Krr \times COG)^{-\beta_{S2}} \quad (15)$$

where WF is weather factor (kg m^{-1}), EF is soil erodible factor, SCF is soil crust factor, Krr is soil roughness factor, COG is crop factor and β_Q, β_{S1} , and β_{S2} are empirical coefficients having assumed values of respectively 109.8, 150.71, and 0.3711 (Fryrear et al., 1998).

In Eqns. 14 and 15, WF is determined as:

$$WF = \left(\frac{\rho_a}{g} \right) \cdot W_f \cdot S_w \cdot S_d \quad (16)$$

where W_f is the wind factor and dependent on wind speed, S_w is the soil wetness factor and dependent on precipitation and evapotranspiration, and S_d is the snow cover factor and dependent on snow cover ($S_d=1.0$ for this study).

The S_w is determined as:

$$S_w = \frac{ET_p - (R+I) \frac{R_d}{N_d}}{ET_p} \quad (17)$$

where ET_p is potential relative evapotranspiration (mm d^{-1}), R_d is number of rainfall/irrigation days, $R+I$ is rainfall plus irrigation (mm d^{-1}), and N_d is number of days (normally 15).

In Eqns. 14 and 15, the EF and SCF are determined as:

$$EF = \frac{\beta_{EF} + 0.31Sa + 0.17Si + \frac{0.33Sa}{Cl} - 2.59OM - 0.95CaCO_3}{100} \quad (18)$$

and

$$SCF = \frac{1}{1 + \beta_{SCF}(Cl)^2 + 0.021(OM)^2} \quad (19)$$

where Sa , Si , Cl , OM , and $CaCO_3$ are the percentage of sand, silt, clay, organic matter, and calcium carbonate. The coefficients β_{EF} and β_{SCF} are empirical with assumed values of respectively 29.09 and 0.0066 (Fryrear et al., 1998). The SCF equals 1.0 and is only determined by Eqn. 19 when cumulative precipitation since the last tillage operation is ≥ 12.5 mm. Similarly, the Krr and COG are determined as:

$$Krr = e^{(1.86RcKr - 2.41RcKr^{0.934} - \beta_K Crr)} \quad (20)$$

and

$$COG = e^{-0.0438(SC)} + e^{-0.0344(SA^{0.6413})} + e^{-\beta_{COG}(CC^{0.7366})} \quad (21)$$

where Rc is dependent on wind direction, Kr is dependent on ridge height and spacing, Crr is dependent on random roughness, SC is residue flat cover (%), SA is standing stem area index ($\text{m}^2 \text{m}^{-2}$), and CC is fraction canopy cover. Although fraction canopy cover was not measured in our study, we assumed canopy cover was equivalent to leaf area index ($\text{m}^2 \text{m}^{-2}$). This assumption appears valid for many crop species, particularly at low (< 0.4) leaf area index (Nielsen et al., 2012; Ramirez-Garcia et al., 2012). The coefficients β_K and β_{COG} are empirical with assumed values of respectively 0.124 and 5.614 (Fryrear et al., 1998).

The average soil loss (ASL in kg m^{-2}) from a field is defined as:

$$ASL = \frac{Q(x)}{x} \quad (22)$$

where

$$Q(x) = Q_{\max} \times (1 - e^{-(x/s)^2}) \quad (23)$$

and $Q(x)$ is mass transport or discharge (kg m^{-1}) at downwind distance x .

2.5 Model calibration

Models are often calibrated to overcome constraints associated with the spatial or temporal resolution of application (Donigian, 2002; Trombetta et al., 2016) and thereby improve performance (Absi and Mahadevan, 2016). For example, Youssef et al. (2012) tested the performance of the RWEQ on agricultural lands in Syria and found acceptable predictions of soil mass transport, but only after calibration of the RWEQ. In accordance with the approach taken by Youseff et al. (2012), we choose one or two parameters from each factor that governs wind erosion for calibrating the APEX model and RWEQ. Their brute force calibration technique required choosing parameter values at random within a specified range. Parameters chosen for calibration of the APEX model included $\alpha_{U_{*t}}$ for threshold friction velocity (Eqn. 6), α_{SEF} for soil erodibility (Eqn. 7), α_{SRF} for soil roughness (Eqn. 9), α_{VCF} for vegetation cover (Eqn. 10), and α_{FLF} for field length (Eqn. 12). Parameters chosen for calibration of the RWEQ included β_Q for $Q_{\max}$ (Eqn. 14), β_{S1} and β_{S2} for S (Eqn. 15), β_{EF} for soil erodibility (Eqn. 18), β_{SCF} for soil crust (Eqn. 19), β_K for surface roughness (Eqn. 20), and β_{COG} for vegetation (Eqn. 21). In addition, the RWEQ weather factor (Eqn. 16) is dependent on a wind factor described by:

$$W_t = \frac{\sum_{i=1}^{N_d} U_2 (U_2 - U_t)^2}{500} \times N_d \quad (24)$$

where U_2 is wind speed (m s^{-1}) at a height of 2 m, N_d is number of days in the period, and U_t is threshold wind speed. The U_t is empirically assumed to be 5 m s^{-1} , but U_t is affected by flat biomass cover, surface soil water content, and aggregate density (Pi et al., 2014b). A correction was applied to U_t as:

$$U_t = 5 + \beta_{wf} \quad (25)$$

where β_{wf} is a correction parameter. Therefore, we chose to also calibrate β_{wf} in determining the weather factor.

The aim of the calibration was to identify one set of parameter values that maximized the Willmott index of agreement (d) and coefficient of determination (R^2) in predicting soil loss (see section 2.6). For each parameter, we selected five different values within a specified range (see section 3.5). The calibration process was initiated using original parameter values specified in the APEX and RWEQ manuals or associated documentation. Calibration was done for all combinations of parameter value sets, resulting in approximately 3125 runs with the APEX model and 390625 runs with RWEQ. The d value was initially used to screen sets of parameter values. In the event that multiple sets of parameter values had the same d value, the set of parameter values used in the calibration models was based upon R^2 .

2.6 Statistical analysis

The uncertain turbulent motion at the soil surface and complex and broad landscapes susceptible to erosion presents a challenge in accurately simulating wind erosion (Shao, 2008). For this reason, standard statistical tests commonly used to assess model performance may have limited application in modeling wind erosion. Standard statistical tests employed in evaluating model performance include Nash Sutcliffe model efficiency (NSE), d, R^2 , and percentage bias (PBIAS). The NSE (Nash and Sutcliffe, 1970) and PBIAS (Ma et al., 2012) are described by:

$$\text{NSE} = 1.0 - \left[\frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (O_i - \bar{O})^2} \right] \quad (26)$$

and

$$\text{PBIAS} = \left[\frac{\sum_{i=1}^N (P_i - O_i)}{\sum_{i=1}^N (O_i)} \right] \times 100 \quad (27)$$

where P_i , O_i and $\bar{O}$ are respectively the predicted, measured, and average value and N is the number of comparisons. The d is determined according to:

$$d = 1.0 - \left[\frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \right] \quad (28)$$

with d ranging from 0 to 1.0 (Willmott, 1981). Higher values of d indicate better agreement between measured and simulated values.

Acceptable model performance has been characterized by $d > 0.7$, $\text{NSE} > 0.7$, $R^2 > 0.8$, and $|\text{PBIAS}| < 15\%$ (Ma et al., 2012). This set of performance criteria, however, depend on the spatial and temporal resolution of models. Moriasi et al. (2007), for example, found acceptable performance of water shed models using less stringent values for these statistical tests. As a result, we used meta-analysis (Hedges and Olkin, 1985) to identify an acceptable level of performance for wind erosion models based upon these statistical tests. Meta-analysis is a statistical analysis of the results obtained from multiple scientific investigations (Glass, 1976). Several data sources are available from previous research to evaluate model performance in simulating soil discharge or loss caused by wind erosion. Wind erosion models with acceptable performance were defined by the authors as “acceptable” or “encouraging” while inadequate performance was defined as “inadequate” or “not suitable”. Meta-data used to assess model performance are illustrated in Fig. 4. The d , NSE , PBIAS , and R^2 for the meta-data used to assess model performance are shown in Table 2. Although model performance was considered “acceptable” or “encouraging” for Buschiazzo and Zobeck (2008), Van Pelt et al. (2004), Youssef et al. (2012), and Zobeck et al. (2001), the NSE was ≤ 0.7 and/or $|\text{PBIAS}|$ was > 15 . Therefore, based upon these results, we did not use NSE and PBIAS to evaluate wind erosion model performance. We did, however, use d to evaluate model performance. According to Table 2, acceptable model performance was designated for all data sources having $d > 0.6$ and $R^2 > 0.35$.

Difference of mean and root mean square error (RMSE) are also widely used to evaluate models (Ma et al., 2012; Visser et al., 2005) and thus were used in our study. The difference of mean is the simulated minus measured value while the RMSE is described by:

$$RMSE = \sqrt{\frac{\sum_{i=0}^N (P_i - O_i)^2}{N}} \quad (29)$$

3. Results and Discussion

The performance of the original and calibrated APEX model and RWEQ was tested using data collected at each site during at least six high wind events over two years in the Tarim Basin and 12 wind events over four years in the Columbia Plateau (Table 3). The APEX model and RWEQ were validated by comparing measured and simulated sediment discharge and loss. Simulated soil discharge and loss from the cotton field during the 18-19May2012, 19-20Apr2013, and 11-12May2013 wind events assumed that 40% of the soil surface was not erodible due to the presence of the plastic film that was applied at the time of sowing (26 April 2012 and 18 April 2013). Since neither model provides a mechanism to account for non-eroding surfaces within the simulation domain, simulated soil discharge and loss from the cotton field during these three wind events was reduced by 40% to account for the non-eroding surface of the plastic film.

3.1 Measured soil loss and surface characteristics

The desert-oasis ecotone had greater soil loss compared to the agricultural sites, with loss ranging from 24 to 2271 g m⁻² (Table 3) during a sample period. The magnitude of measured soil discharge or loss, averaged across all erosion events, was similar for the agricultural land use types (Table 3). For example, soil discharge and loss averaged across all sample periods were respectively 10.3 kg m⁻¹ and 68.6 g m⁻² for the cotton field, 6.1 kg m⁻¹ and 40.7 g m⁻² for the red date orchard, and 10.6 kg m⁻¹ and 31.4 g m⁻² for the WW-SF rotation. Soil discharge and loss averaged across all sample periods for the desert-oasis

581 ecotone were an order of magnitude higher (72.2 kg m^{-1} and 471.1 g m^{-2} ,
582 respectively) than the agricultural land use types.

583

584 Table 2. Statistical comparisons of measured and simulated sediment flux and
585 loss using historical data sources.

Data sources	Location	Wind erosion model ¹	R ² (intercept≠0)	Index of agreement (d)	Nash Sutcliffe model efficiency (NSE)	Percent bias (PBIAS)
Funk et al. (2004)	Berlin, Germany	WEPS	0.93	0.98	0.92	-2.70
Feng and Sharratt (2007)	Washington, USA	WEPS	0.55	0.86	0.28	-6.10
Youssef et al. (2012)	Aleppo, Syria	RWEQ	0.57	0.83	0.41	-32.50
Van Pelt et al. (2004)	Texas, USA	RWEQ	0.50	0.74	0.43	-33.60
Zobeck et al. (2001)	Texas, USA	RWEQ	0.38	0.63	0.31	-35.70
Visser et al. (2005)	Kalahari, Burkina Faso	RWEQ	0.05	0.45	0.54	-54.00
Buschiazzo and Zobeck (2008)	La Pampa, Argentina	WEPS	0.89	0.90	0.70	-38.00
Buschiazzo and Zobeck (2008)	La Pampa, Argentina	RWEQ	0.90	0.86	0.60	-53.00
Fryrear et al. (2000)	Great Plains, USA	RWEQ	0.81	0.94	0.78	5.30
Fryrear et al. (2001)	Great Plains and Pacific Northwest, USA	WEQ	0.02	0.24	0.35	71.40
Fryrear et al. (2001)	Great Plains and Pacific Northwest, USA	RWEQ	0.93	0.98	0.92	4.90

586 ¹WEPS is Wind Erosion Prediction System; RWEQ is Revised Wind Erosion
587 Equation; WEQ is Wind Erosion Equation.

Fig. 4. Measured and simulated sediment flux and loss from historical data sources. Simulated sediment flux and loss was assessed using the Revised Wind Erosion Equation, Wind Erosion Equation, and Wind Erosion Prediction System.

The four land use types had different soil and biomass characteristics which can impact wind erosion in the Tarim Basin and Columbia Plateau. In the Tarim Basin, random roughness was greatest for the red date orchard (11.4 mm) and smallest for the desert-oasis ecotone (1.0 mm) (Table 4). Random roughness was greater for the red date orchard than the cotton field (5.6 mm) due in part to a smooth plastic mulch being applied over cotton rows. The small random roughness in the desert-oasis ecotone results from the single grain structure of the sand surface. The cotton field typically had the least amount of standing biomass (0 t ha^{-1}) of the three land use types during the early spring wind erosion season (April) in the Tarim Basin. The cotton field also had no standing biomass before or immediately after sowing which occurred on 26 April 2012 and 18 April 2013. Red dates were planted six years prior this study and standing biomass was 1.2 t ha^{-1} with an average canopy height of 1.1 m before the trees began to leaf in May. Cotton standing biomass increased from 0 to 0.4 t ha^{-1} during the seedling stage while standing crop residue was 2.43 t ha^{-1} prior to tillage in spring. The desert-oasis ecotone appeared to have the highest soil erodibility based on the smallest soil fraction $>0.84 \text{ mm}$ in diameter (highest *SEF* in Table 3). In the Columbia Plateau, random roughness averaged 10.3 mm across years (Table 4). Undercutter tillage resulted in greater retention of standing crop residue on the surface (0.205 t ha^{-1}) as compared with conventional tillage (0.062 t ha^{-1}). Soil erodibility for conventional and undercutter tillage appeared similar based upon nearly identical *SEF* (Table 3) and *EF* values (Table 5).

3.2 Performance of the original APEX model

The measured and original APEX simulated sediment discharge and loss for all erosion events observed in the Tarim Basin and Columbia Plateau are given in Table 3. There was acceptable agreement between the measured and simulated soil loss in the cotton field and in the desert-oasis ecotone. Model performance statistics included $d=0.81$ and $R^2=0.50$ for the cotton field and $d=0.81$ and $R^2=0.91$ for the desert-oasis ecotone (Fig. 5).

Wind speed and soil water content are the most sensitive parameters influencing the simulation of soil loss in the APEX model (Wang et al., 2006). Since we measured wind speed and soil water content, these parameters likely did not contribute to the inadequate simulation ($d < 0.6$) of soil discharge and loss from the red date orchard in the Tarim Basin and WW-SF field in the Columbia Plateau (Fig. 5). In comparing the model parameters used to simulate soil loss, we found the red date orchard had the smallest *SEF* and *VCF* of the three land use types in the Tarim Basin and WW-SF field in the Columbia Plateau (Table 3). Soil discharge and loss is directly proportional to *SEF* and *VCF*, thus the small *SEF* and *VCF* may be one reason for the APEX model underestimating soil discharge and loss in the red date orchard. The *SEF* appeared appropriate for the red date orchard based upon the aggregate size distribution, which was measured at each site. Therefore, we examined the impact of *VCF* on simulating soil loss. The *VCF* was set to a value of 1.0 to determine whether no vegetation would improve model performance in our study. Our results suggest that model performance improved when *VCF* was set to 1.0. This is evidenced by an increase in d for soil discharge and loss, but only for the red date orchard and desert-oasis ecotone in the Tarim Basin (Fig. 6). This finding indicates the sensitivity of biomass in simulating wind erosion, particularly in the red date orchard in the Tarim Basin.

644 Table 3: Original APEX model parameters and measured and simulated soil
645 discharge and loss during high wind events in the cotton field, red date orchard,
646 and desert-oasis ecotone in the Tarim Basin and winter wheat- summer fallow
647 field in the Columbia Plateau.

Land use	Year	Sampling Period	Model parameters						Total soil discharge (kg m ⁻¹)		Total soil loss (g m ⁻²)	
			<i>FLF</i>	<i>SEF</i>	<i>SRF</i>	<i>VCF</i>	<i>WL</i> (m)	Simulated <i>u_{st}</i> (m s ⁻¹)	Measured	Simulated	Measured	Simulated
Cotton Field	2012	10-11Apr	0.654	0.036	0.918	0.095	74.4	0.207	2.06	0.87	13.71	11.69
		22-24Apr	0.709	0.036	0.918	0.095	86.3	0.207	2.49	0.19	16.59	2.15
		18-19May	0.685	0.036	0.918	0.494	80.8	0.207	14.81	0.54	98.76	6.73
	2013	17-19Apr	0.659	0.036	0.918	1	75.2	0.207	21.34	12.75	142.25	169.37
		19-20Apr	0.650	0.036	0.918	1	73.6	0.207	13.50	1.77	90.00	24.09
		11-12May	0.639	0.036	0.918	0.494	71.2	0.207	7.50	3.95	50.00	55.15
Red Date Orchard	2012	10-11Apr	0.637	0.014	0.791	0.0004	70.9	0.165	3.75	0.0008	25.00	0.011
		22-24Apr	0.709	0.014	0.791	0.0004	86.3	0.165	3.91	0.0002	26.05	0.002
		18-19May	0.681	0.014	0.791	<0.0001	80.1	0.165	6.75	<0.0001	45.02	<0.001
	2013	17-19Apr	0.643	0.014	0.791	0.0004	72.0	0.165	9.49	0.0013	63.54	0.018
		19-20Apr	0.649	0.014	0.791	0.0004	73.2	0.165	10.68	0.0016	71.23	0.022
		11-12May	0.700	0.014	0.791	<0.0001	84.3	0.165	1.99	<0.0001	13.24	<0.001
Desert–Oasis Ecotone	2012	31Mar-11Apr	0.811	1.000	1.000	0.881	116.5	0.244	252.72	135.76	2271.43	1113.32
		20-24Apr	0.983	1.000	1.000	0.881	285.0	0.244	37.63	10.02	98.84	39.25
		16-18May	0.978	1.000	1.000	0.382	267.0	0.244	188.21	38.51	596.66	168.58
	2013	17-19Apr	0.991	1.000	1.000	0.881	333.5	0.244	15.55	22.82	25.92	69.07
		26-30Apr	0.781	1.000	1.000	0.881	106.4	0.244	17.17	4.39	161.35	38.46
		1-5May	0.987	1.000	1.000	0.876	301.8	0.244	69.60	64.04	215.08	199.33
		6-12May	0.781	1.000	1.000	0.672	106.4	0.244	45.70	42.01	448.60	370.25
		13-20May	0.995	1.000	1.000	0.454	366.4	0.244	20.57	34.83	23.45	90.97
		20-26May	0.754	1.000	1.000	0.303	98.2	0.244	38.83	17.09	386.82	157.24
		28May-2Jun	0.987	1.000	1.000	0.192	301.7	0.244	14.73	4.50	45.52	14.00
3-16Jun	0.780	1.000	1.000	0.137	106.1	0.244	94.02	30.37	908.16	267.76		
Winter Wheat-Summer Fallow	2003	12-22Sep-c ²	0.980	0.089	0.862	0.903	273.0	0.100	1.51	12.24	4.30	44.85
		3-15Oct-c	0.952	0.117	0.821	0.761	212.1	0.100	4.13	361.57	11.80	1704.49
		15-27Oct-c	0.953	0.167	0.805	0.804	214.2	0.100	1.54	201.33	4.40	939.83
		27-29Oct-c	0.957	0.160	0.800	0.826	219.6	0.100	81.10	394.31	231.70	1795.44
	2004	6-23Aug-c	0.983	0.007	0.796	0.060	283.9	0.107	5.52	0.28	13.80	0.98
		23Aug-9Sep-c	0.986	0.046	0.509	0.540	297.4	0.107	64.16	23.74	160.40	79.81
	2005	23Jun-8Jul-c	0.721	0.128	0.784	0.032	89.4	0.120	0.00	3.16	0	35.28
		23Jun-8Jul-u ³	0.721	0.096	0.755	<0.0001	89.4	0.120	0.00	0.01	0	0.10
		31Aug-14Sep-c	0.734	0.178	0.505	0.014	92.8	0.120	2.08	1.04	12.00	11.22

		31Aug-14Sep-u	0.734	0.313	0.520	0.006	92.8	0.120	1.47	0.01	8.50	0.09
	2006	14-19 Jul-c	0.871	0.096	0.835	0.361	143.2	0.103	0.81	11.32	2.90	79.06
		14-19 Jul-u	0.871	0.103	0.774	0.025	143.2	0.103	0.25	0.06	0.90	0.40
		19-25Jul-c	0.920	0.135	0.846	0.282	177.1	0.103	0.00	<0.001	0	<0.001
		19-25Jul-u	0.920	0.128	0.802	0.056	177.1	0.103	0.00	<0.001	0	<0.001
		29-30 Aug-c	0.870	0.153	0.501	0.392	142.8	0.103	11.50	14.36	40.10	100.55
		29-30 Aug-u	0.870	0.178	0.525	0.129	142.8	0.103	7.56	7.09	27.00	49.62
		30Aug-6Sep-c	0.869	0.153	0.501	0.390	142.2	0.103	7.22	16.15	25.80	113.59
		30Aug-6Sep-u	0.869	0.178	0.525	0.128	142.2	0.103	6.02	5.18	21.50	36.45

648 ¹ *FLF* is field length factor, *SEF* is soil erodibility factor, *SRF* is surface
649 roughness factor, *VCF* is vegetative cover factor, *WL* is field length factor,
650 and u_{*t} is threshold friction velocity.
651 ² *C* is conventional tillage.
652 ³ *U* is undercutter tillage.

653 Table 4. Input parameters required by the APEX model. Parameters were
654 measured at the time of high wind events in the cotton field, red date orchard,
655 and desert-oasis ecotone in the Tarim Basin and winter wheat- summer fallow
656 field in the Columbia Plateau.

Land use	Year	Sampling period ¹	standing biomass (t ha ⁻¹)	standing crop residue (t ha ⁻¹)	flat crop residue (t ha ⁻¹)	random roughness (mm)	Soil wilting point water content (g g ⁻¹)	water content (g g ⁻¹)	particle size diameter (mm)	Field length (km)	Field width (km)	Wind speed ² (m s ⁻¹)	
												Mean	Maxim -um
Cotton Field	2012	10-11Apr	0.000	2.430	0.000	5.6	0.157	0.020	0.166	0.10	0.10	5.68	6.41
		22-24Apr	0.000	2.430	0.000	5.6	0.157	0.020	0.166	0.10	0.10	5.17	5.64
		18-19May	0.400	0.000	0.000	5.6	0.157	0.020	0.166	0.10	0.10	7.01	7.74
	2013	17-19Apr	0.000	0.000	0.000	5.6	0.157	0.027	0.166	0.10	0.10	6.97	8.01
		19-20Apr	0.000	0.000	0.000	5.6	0.157	0.019	0.166	0.10	0.10	7.62	9.14
		11-12May	0.400	0.000	0.000	5.6	0.157	0.020	0.166	0.10	0.10	8.17	10.8
Red Date Orchard	2012	10-11Apr	1.211	0.000	0.000	11.4	0.167	0.030	0.105	0.10	0.10	6.25	7.07
		22-24Apr	1.211	0.000	0.000	11.4	0.167	0.030	0.105	0.10	0.10	6.02	6.8
		18-19May	2.200	0.000	0.000	11.4	0.167	0.030	0.105	0.10	0.10	5.01	5.68
	2013	17-19Apr	1.210	0.000	0.000	11.4	0.167	0.032	0.105	0.10	0.10	5.9	6.27
		19-20Apr	1.210	0.000	0.000	11.4	0.167	0.044	0.105	0.10	0.10	6.11	6.88
		11-12May	2.200	0.000	0.000	11.4	0.167	0.024	0.105	0.10	0.10	6.19	7.17
Desert-Oasis Ecotone	2012	31Mar-11Apr	0.026	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.12	5.3	8.3
		20-24Apr	0.026	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.40	4.9	5.7
		16-18May	0.180	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.32	4.8	6.6
	2013	17-19Apr	0.026	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.60	5.0	6.4
		26-30Apr	0.026	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.11	4.4	5.6
		5-11May	0.027	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.33	4.6	6.6
		6-12May	0.078	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.11	5.3	7.2
		13-20May	0.150	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.90	4.7	7.2
		20-26May	0.221	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.10	5.2	6.9
		28May-2Jun	0.303	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.33	4.6	5.7
		3-16Jun	0.364	0.000	0.000	1.0	0.157	0.000	0.230	0.40	0.11	5.5	8.3
Winter Wheat- Summer Fallow	2003	12-22Sep-c ³	0.000	0.000	0.044	7.7	0.074	0.041	0.039	0.3	0.3	6.7	12.5
		3-15Oct-c	0.000	0.000	0.115	9.6	0.074	0.019	0.039	0.3	0.3	7.6	14.4
		15-27Oct-c	0.000	0.000	0.093	10.5	0.074	0.015	0.039	0.3	0.3	7.2	11.9
		27-29Oct-c	0.000	0.000	0.082	10.8	0.074	0.019	0.039	0.3	0.3	10.3	17.6
	2004	6-23Aug-c	0.000	0.072	0.944	11.1	0.065	0.011	0.044	0.4	0.4	6.9	10.3
		23Aug-9Sep-c	0.000	0.048	0.148	10	0.065	0.014	0.044	0.4	0.4	7.1	10.7
	2005	23Jun-8Jul-	0.000	0.056	1.240	11.9	0.055	0.0084	0.056	0.2	0.1	6.9	13.0

		c											
		23Jun-8Jul- U ⁴	0.000	0.68	2.736	14.5	0.055	0.0066	0.056	0.2	0.1	6.9	11.9
		31Aug-14Se p-c	0.036	0.212	1.184	10.4	0.055	0.0042	0.056	0.2	0.1	5.7	9.7
		31Aug-14Se p-u	0.046	0.204	1.552	8.8	0.055	0.002	0.056	0.2	0.1	5.6	8.1
	2006	14-19 Jul-c	0.000	0.036	0.324	8.9	0.07	0.018	0.041	0.2	0.2	6.4	10.4
		14-19 Jul-u	0.000	0.128	1.188	12.7	0.07	0.022	0.041	0.2	0.2	6.3	8.7
		19-25Jul-c	0.000	0.036	0.416	8.4	0.07	0.022	0.041	0.2	0.2	5.6	9.3
		19-25Jul-u	0.000	0.128	0.848	10.7	0.07	0.018	0.041	0.2	0.2	5.6	8.5
		29-30 Aug-c	0.000	0.016	0.336	11	0.07	0.023	0.041	0.2	0.2	7.5	12.0
		29-30 Aug-u	0.000	0.044	0.696	8.3	0.07	0.017	0.041	0.2	0.2	7.4	11.5
		30Aug-6Sep -c	0.001	0.016	0.336	11	0.07	0.023	0.041	0.2	0.2	7.7	11.6
		30Aug-6Sep -u	0.001	0.044	0.696	8.3	0.07	0.017	0.041	0.2	0.2	7.7	10.8

657 ¹ Dates over which eroded sediment was collected at each site.

658 ² Mean and maximum wind speed during high wind events.

659 ³ C is conventional tillage.

660 ⁴ U is undercutter tillage.

661 Table 5: Original RWEQ parameters and simulated soil discharge and loss
662 during high wind events in the cotton field, red date orchard, and desert– oasis
663 ecotone in the Tarim Basin and winter wheat- summer fallow field in the
664 Columbia Plateau.

Land use	Year	Sampling Period	Model parameters ¹							Simulated erosion		
			WF	EF	SCF	Krr	COG	Q _{max} (kg m ⁻¹)	S (m)	Total soil discharge (kg m ⁻¹)	Total average soil loss (g m ⁻²)	Maximum point soil loss(g m ⁻²)
Cotton Field	2012	10-11Apr	0.020	0.585	1.000	0.932	0.984	1.19	808.4	0.04	0.25	1.26
		22-24Apr	0.022	0.585	1.000	0.932	0.984	1.28	785.4	0.04	0.29	1.40
		18-19May	0.090	0.585	1.000	0.932	0.925	4.97	475.3	0.25	1.78	5.38
	2013	17-19Apr	0.515	0.585	1.000	0.932	1.000	30.80	241.6	8.89	63.07	109.36
		19-20Apr	0.323	0.585	1.000	0.932	1.000	19.30	287.3	2.48	17.57	34.56
		11-12May	0.350	0.585	1.000	0.932	0.925	19.34	287.1	2.49	17.63	34.66
Red Date Orchard	2012	10-11Apr	0.028	0.753	1.000	0.887	0.999	2.03	662.8	0.09	0.64	2.63
		22-24Apr	0.054	0.753	1.000	0.887	0.999	3.99	515.8	0.29	2.04	6.63
		18-19May	0.001	0.753	1.000	0.887	0.152	0.01	5158.6	<0.001	<0.001	<0.001
	2013	17-19Apr	0.015	0.753	1.000	0.887	0.999	1.09	833.6	0.03	0.22	1.13
		19-20Apr	0.029	0.753	1.000	0.887	0.999	2.16	647.5	0.10	0.71	2.86
		11-12May	0.015	0.753	1.000	0.887	0.152	0.17	1675.0	<0.001	0.01	0.09
Desert–Oasis Ecotone	2012	31Mar-11Apr	0.442	0.600	1.000	0.980	0.998	28.44	248.8	5.16	46.33	98.05
		20-24Apr	0.053	0.600	1.000	0.980	0.998	3.42	546.2	1.31	3.45	5.37
		16-18May	0.049	0.600	1.000	0.980	0.243	3.08	567.4	0.08	0.26	0.70
	2013	17-19Apr	0.011	0.600	1.000	0.980	0.998	0.72	975.0	0.23	0.38	0.63
		26-30Apr	0.002	0.600	1.000	0.980	0.998	0.13	1832.6	0.0004	0.004	0.06
		1-5May	0.145	0.600	1.000	0.980	0.966	9.02	381.1	4.63	14.32	20.30
		6-12May	0.134	0.600	1.000	0.980	0.529	8.36	391.9	0.19	1.90	8.02
		13-20May	0.116	0.600	1.000	0.980	0.301	7.25	413.3	1.92	2.18	3.03
		20-26May	0.371	0.600	1.000	0.980	0.186	23.14	268.6	0.18	1.79	7.71
		28May-2Jun	0.016	0.600	1.000	0.980	0.113	1.02	855.1	0.00	0.01	0.05
		3-16Jun	1.192	0.600	1.000	0.980	0.080	74.31	174.2	0.33	3.23	12.07
Winter Wheat-Summer Fallow	2003	12-22Sep-c ²	0.122	0.445	1.000	0.914	0.999	5.45	459.2	2.40	6.87	10.19
		3-15Oct-c	1.938	0.445	1.000	0.900	0.999	85.03	165.7	84.05	240.15	440.18
		15-27Oct-c	0.717	0.445	1.000	0.893	0.999	31.24	240.3	27.50	78.56	111.52
		27-29Oct-c	2.516	0.445	1.000	0.891	0.999	109.39	150.9	108.88	311.09	621.70
	2004	6-23Aug-c	0.427	0.485	1.000	0.889	0.993	20.07	283.2	17.34	43.35	60.79
		23Aug-9Sep-c	2.780	0.485	1.000	0.332	0.538	26.42	255.7	24.14	60.34	88.64
	2005	23Jun-8Jul-c	0.010	0.485	0.606	0.884	0.986	0.29	1366.8	0.005	0.03	0.18
23Jun-8Jul-u ³		0.001	0.485	0.606	0.867	0.974	0.03	3382.7	<0.001	<0.001	0.01	

		31Aug-14Sep-c	0.034	0.485	1.000	0.224	0.555	0.22	1504.4	0.003	0.02	0.13
		31Aug-14Sep-u	0.010	0.485	1.000	0.227	0.494	0.06	2469.0	0.0003	0.002	0.02
	2006	14-19 Jul-c	0.129	0.456	1.000	0.905	0.991	5.78	449.4	1.86	6.64	11.03
		14-19 Jul-u	0.045	0.456	1.000	0.878	0.982	1.96	670.8	0.31	1.12	2.51
		19-25Jul-c	0.684	0.456	1.000	0.892	0.978	29.88	244.3	22.00	78.02	104.94
		19-25Jul-u	0.206	0.456	1.000	0.909	0.988	9.27	377.2	3.97	14.07	21.08
		29-30 Aug-c	0.347	0.456	1.000	0.283	0.994	4.89	478.3	1.42	5.06	8.76
		29-30 Aug-u	0.237	0.456	1.000	0.257	0.986	3.01	572.9	0.64	2.28	4.50
		30Aug-6Sep-c	0.257	0.456	1.000	0.248	0.953	3.04	570.6	0.65	2.32	4.57
		30Aug-6Sep-u	0.169	0.456	1.000	0.248	0.935	1.96	671.3	0.31	1.12	2.51

665 ¹ *WF* is Weather factor, *EF* is erodible fraction, *SCF* is soil crust factor, *Krr* is
666 roughness parameter, *COG* is crop factor, $Q_{\max}$ is maximum transport
667 capacity, and *S* is critical field length.

668 ² *C* is conventional tillage.

669 ³ *U* is undercutter tillage.

Fig. 5. Statistical comparisons of measured and simulated soil discharge and loss by the original APEX model and RWEQ in the cotton field, red date orchard, and desert– oasis ecotone within the Tarim Basin and winter wheat – summer fallow field in the Columbia Plateau. RMSE is root-mean-square-error, DOM is difference of mean, and d is index of agreement.

Fig. 6. Statistical comparisons of measured and simulated soil discharge and loss based upon original APEX simulations with no biomass in the cotton field, red date orchard, and desert- oasis ecotone in the Tarim Basin and winter wheat – summer fallow field in the Columbia Plateau. RMSE is root-mean-square-error, DOM is difference of mean, and d is index of agreement.

The above analysis suggested the APEX wind erosion model may overestimate the impact of vegetation in simulating soil discharge and loss. This overestimation may be due to the simplified vegetative cover factor that accounts for total biomass but not leaf area or stem area which affect wind shear at the surface. For example, the 10-11Apr2012 wind event in the cotton field and 18-19May2012 wind event in the red date orchard have similar total biomass (standing biomass plus standing crop residue) as indicated in Table 4. However, the leaf area index (LAI) and stem area index (SAI) were respectively $0.122 \text{ m}^2 \text{ m}^{-2}$ and $0.078 \text{ m}^2 \text{ m}^{-2}$ for the 10-11Apr2012 wind event and $0.227 \text{ m}^2 \text{ m}^{-2}$ and $0.031 \text{ m}^2 \text{ m}^{-2}$ for the 18-19May2012 wind event. Although cotton was not sown until 26 April 2012, leaf and stem area for 10-11Apr2012 event were assessed for crop residue that remained in the field after harvest. The relationship between soil loss ratio (SLR) and LAI and SAI can be described as (Armbrust and Bilbro, 1997):

$$SLR = \exp[-20.5 \times (SAI + LAI \times LAIFE)^{0.669}] \quad (30)$$

where SLR is the ratio of soil loss from a surface protected with vegetation to a surface devoid of vegetation and LAIFE is the fraction of LAI that aids in reducing soil loss. For this analysis, LAIFE was assumed to equal LAI. The SLR ranges from 0 for a non-eroding surface to 1.0 for a dry and loose surface devoid of vegetation. Based upon the above LAI and SAI, the SLR was 0.015 and 0.021 for respectively the 10-11Apr2012 wind event in the cotton field and 18-19May2012 wind event in the red date orchard. Thus, soil loss is similar for both events based upon vegetation characteristics. However, differences in the VCF between the cotton field (0.095) and red date orchard (<0.0001) suggests soil loss could be nearly 1000 times greater for the 10-11Apr2012 wind event in the cotton field than the 18-19May2012 wind event in the red date orchard.

The relationship between SLR and VCF was examined for the three sites in the Tarim Basin. Regression analysis between SLR and VCF for the cotton field ($Y=1.17X+0$, $R^2=0.73$) and desert-oasis ecotone ($Y=0.92X+0$, $R^2=1$) suggested nearly a 1:1 relationship between SLR and VCF at both sites.

However, regression analysis between *SLR* and *VCF* for the red date orchard ($Y=332.27X+0$, $R^2=0.98$) suggested a greater sensitivity or response in *SLR* to *VCF* than for the other two sites in the Tarim Basin. Since the APEX wind erosion model adequately simulated soil loss in the cotton field and desert-oasis ecotone site, the *VCF* parameter appeared to characterize soil loss for sites with low biomass ($<0.4 \text{ t ha}^{-1}$). For sites (e.g. red date orchard) with high biomass ($>1.2 \text{ t ha}^{-1}$), the *VCF* parameter failed to adequately characterize soil loss.

Regression analysis between simulated and measured soil loss ($Y=4.655X+131.17$, $R^2=0.25$) and positive difference of mean (245.87 g m^{-2}) suggested that the original APEX model overestimated fivefold the measured soil loss from the WW-SF field in the Columbia Plateau (Fig. 5). Overestimation of soil loss by the APEX model was not likely due to the impact of vegetation in simulating loss because WW-SF typically had low biomass ($<0.6 \text{ t ha}^{-1}$). Pi et al. (2014b, 2014c) compared the performance of wind erosion models, including the Lu and Shao model; Shao model; Texas Tech Erosion Analysis Model; and Wind Erosion on European Light Soils model, in simulating u_{*t} of soils managed in WW-SF in the Columbia Plateau. In comparing the measured u_{*t} with u_{*t} by the above wind erosion models and u_{*t} estimated by the APEX model (Eqn. 6), we found the APEX model simulated a much lower u_{*t} than those measured or simulated by the above models. A lower u_{*t} would lead to overestimation of soil loss. Thus, a possible reason for APEX overestimated soil loss in WW-SF is that the model simulated a low u_{*t} (Table 3).

3.2.1 APEX threshold friction velocity

The u_{*t} is a critical parameter that governs wind erosion and is influenced by soil crusting, water content, aggregate size, and texture (Sharratt and Vaddella, 2012, 2014; Sharratt et al., 2013). Eqn. 6 indicates that u_{*t} is estimated in the APEX model solely based upon particle density and diameter. Despite the simplistic method of estimating u_{*t} in the APEX model, this method of

estimating u_t did affect soil loss. For example, increasing u_t by 25% resulted in a 100 to 500% decrease in the simulated soil loss for all land use types. In contrast, Pi et al, (2014c) found that a 25% increase in the u_t in the WEPS model resulted in an 8000% decrease in simulated soil loss on the Columbia Plateau. The WEPS model, as a mechanistic model, appears to be more sensitive to changes in u_t when simulating soil loss as compared with the APEX model.

3.3 Performance of the original RWEQ

Soil discharge and loss as simulated by the original RWEQ model for land use types in the Columbia Plateau and Tarim Basin are documented in Table 5. In the Columbia Plateau, the RWEQ appeared to adequately simulate soil loss based upon $d > 0.6$ and $R^2 > 0.35$ (Fig. 5). The RWEQ adequately simulated the largest (measured soil loss was 231.7 g m^{-2}) and smallest (measured soil loss was 0 g m^{-2}) erosion events on respectively 27-29Oct2003 and 23Jun-8Jul2005. Nonetheless, the RWEQ inadequately simulated soil discharge and loss for the three land use types in the Tarim Basin as a result of $d < 0.6$ (Fig. 5). The negative difference of mean between simulated and measured soil discharge and loss indicated the model underestimated erosion. Buschiazzo and Zobeck (2008) found that RWEQ underestimated mass transport by 45% in a bare soil and the underestimation may have been caused by the high sensitivity to soil crusting (SCF). Similar results were found by Zobeck et al. (2001) and Van Pelt et al. (2004). Soil crusting was not observed during this study in the Tarim Basin, thus sensitivity to SCF was set to 1.0 and did not contribute to the inadequate simulation of RWEQ. Underestimation of soil discharge and loss by nearly two orders of magnitude in the red date orchard may have been due to incorrectly estimating $Q_{\max}$. The average $Q_{\max}$ in the red date orchard (1.58 kg m^{-1}) was a magnitude lower than in the cotton field (12.81 kg m^{-1}), desert-oasis ecotone (14.44 kg m^{-1}), and WW-SF rotation (18.78 kg m^{-1}). However, the magnitude of measured soil discharge or loss was similar for the agricultural land use types. This

suggested that RWEQ under-predicted maximum mass transport and thus soil discharge was underestimated in the red date orchard. Similar results were found by Visser et al. (2005) in the Sahel.

Wind speed, as a principle determinant of W_f , is key to predicting soil loss by the RWEQ. Based on the comparison between the measured soil loss and W_f , we found a reasonable relationship between the measured soil loss and W_f for the cotton and WW-SF field sites with an R^2 of respectively 0.56 and 0.67. In contrast, the relationship between the soil loss and W_f for the desert-oasis ecotone and red date orchard sites was poor with an R^2 of respectively 0.26 and 0.04. The poor association between soil loss and W_f may have contributed to inadequate simulation in the desert-oasis ecotone and red date orchard. Since u_t influences W_f and is specified as a constant in the RWEQ, incorrectly specifying u_t may lead to errors in estimating W_f and therefore WF in the desert-oasis ecotone and red date orchard. Underestimation of soil loss, as evidenced by a negative difference of mean, may imply the RWEQ underestimated WF (overestimated u_t) in the desert-oasis ecotone and red date orchard. Indeed, according to Table 5, WF was an order of magnitude lower in the red date orchard (0.02) as compared with all other land use types in the Tarim Basin (0.22 in the cotton field and 0.23 in the desert-oasis ecotone) and Columbia Plateau (0.59).

Maximum point soil loss in the RWEQ does not always occur at the downwind edge of the field, but occurs at a downwind distance of $S/\sqrt{2}$. This distance corresponds to the maximum transport capacity and is governed by wind direction (Fryrear et al., 1998). Table 5 shows the maximum point soil loss for all erosion events in the Columbia Plateau and Tarim Basin. In comparing the simulated maximum point soil loss to measured soil loss in the Tarim Basin, the performance of RWEQ improved (in contrast to comparing simulated and measured soil loss) based on an increase in d from 0.44 to 0.73 in the cotton field, 0.43 to 0.44 in the red date orchard, and 0.40 to 0.41 in the desert-oasis

ecotone. This result suggests that field length estimates are critical to the performance of RWEQ in the Tarim Basin.

3.4 Comparison of original APEX and RWEQ

The original APEX model adequately simulated erosion from the cotton field and desert-oasis ecotone in the Tarim Basin while the RWEQ adequately simulated erosion from the WW-SF field in the Columbia Plateau. Neither the original APEX model nor the RWEQ simulated erosion from the red date orchard in the Tarim Basin. The performance of both models were compared across multiple land use and soil types and time by consolidating the 41 erosion events observed in this study. Based upon the consolidation of erosion events, the original APEX model better simulated erosion. For example, model performance statistics for the original APEX model were $d=0.57$ and $R^2=0.13$ and for the original RWEQ were $d=0.27$ and $R^2=0.01$. Although no erosion was measured during four high wind events in the WW-SF field in the Columbia Plateau (Table 3), both the original APEX model and RWEQ simulated some erosion for these events. Thus, both models failed to simulate the nonoccurrence of erosion events.

3.5 Calibrated model performance

The APEX model and RWEQ were calibrated using data from three erosion events (two events in April 2012 and the 17-19April2013 event) for each of the three land use types in the Tarim Basin and six erosion events (all observed events in 2003 and 2005) in the Columbia Plateau. These events allowed calibration of the models for the range in soil loss measured across all events. In addition, calibration of the models was performed across years at each experimental site to minimize the influence of interannual site characteristics (e.g. weather) on wind erosion. Table 6 provides the range of parameter or factor values considered in the calibration process. Based upon the predicted and observed responses, each set of parameter values was evaluated based upon model performance statistics. From the predicted and observed soil loss during these events, one set of calibrated parameter values

were obtained to maximize d and R^2 . The results of the calibration process are shown in Table 7 and suggest good model performance was attained for these specific erosion events through parameter calibration, except for performance of the RWEQ in the red date orchard in the Tarim Basin. Calibration of the RWEQ in the red date orchard resulted in an $R^2 > 0.35$, but $d < 0.6$ (Table 7).

The parameter values obtained by the calibration process (Table 6) were used in the calibrated models to simulate the soil discharge and soil loss across all erosion events at each site. Model performance in simulating soil discharge and loss across all events improved as evidenced by an increase in d and R^2 when using the calibrated APEX model in the red date orchard and the calibrated RWEQ in the cotton field and desert-oasis ecotone (Fig. 5 and 7). Calibration of the APEX model did not influence model performance in the desert-oasis ecotone because parameter values in the APEX model remained unchanged by the calibration process in the desert-oasis ecotone (Table 6). The calibrated APEX model and RWEQ adequately simulated erosion from the cotton field and desert-oasis ecotone in the Tarim Basin and WW-SF in the Columbia Plateau. The calibrated APEX model also adequately simulated erosion from the red date orchard in the Tarim Basin. The improved simulation of the calibrated APEX model in the red date orchard is likely due to a twofold decrease in the α_{VCF} parameter (Table 6) resulting in at least a fourfold increase in VCF (Eqn. 10).

The performance of the RWEQ in simulating erosion in the red date orchard did not improve as a result of model calibration. This may be due to poor performance of the calibrated RWEQ in simulating erosion during major events (soil loss $> 40 \text{ g m}^{-2}$). For example, performance statistics of the calibrated RWEQ in simulating soil loss during major events were $d = 0.34$ and $R^2 = 0.92$ and minor events (soil loss $\leq 40 \text{ g m}^{-2}$) were $d = 0.63$ and $R^2 = 0.66$. For major erosion events, the difference of mean (-47.82 g m^{-2}) and regression analysis ($Y = 0.22X + 0$, $R^2 = 0.41$) suggested that the calibrated RWEQ underestimated soil loss by at least four times. The poor prediction of soil loss

905 by the calibrated RWEQ during major events may be due to underestimation of
906 *WF* because the average *WF* was 0.032 for minor erosion events and 0.015
907 for major erosion events.

908 Table 6. Original and calibrated parameter values for the APEX model and
 909 RWEQ. Calibrated parameter values were obtained from simulations of three
 910 erosion events for each land use type in the Tarim Basin and six erosion
 911 events in the Columbia Plateau.

Model	Factor	Parameter	Original value	Factor or parameter range ¹	Tarim Basin			Columbia Plateau
					Cotton field	Red date orchard	Desert - Oasis Ecotone	Winter Wheat - Summer Fallow
					Calibration results	Calibration results	Calibration results	Calibration results
APEX	Threshold friction velocity (u_t) ²	α_{U_t}	0.1	$0 \leq u_t \leq 3$	0.1	0.1	0.1	0.3
	Soil erodibility (SEF)	α_{SEF}	0.0	$0 \leq SEF \leq 1$	0.0	0.1	0.0	0.05
	Soil roughness (SRF)	α_{SRF}	11.9	$0 \leq SRF \leq 1$	11.9	11.9	11.9	221.8
	Vegetative cover (VCF)	α_{VCF}	1.055	$0 \leq VCF \leq 1$	1.55	0.01	1.055	-5.055
	Field length (FLF) ³	α_{FLF}	0.07	$0.05 \leq \alpha_{FLF} \leq 0.09$	0.09	0.07	0.07	0.09
RWEQ	Maximum transport (Q_{max}) ⁴	β_Q	109.8	$0 \leq Q_{max} \leq 1300$	115.16	316.54	1157.2	50.53
	Maximum distance (S) ⁴	β_{S1}	150.71	$0 \leq S \leq 150$	163.98	114.67	43.38	53.33
		β_{S2}	0.3711	$0 \leq S \leq 150$	-0.0645	0.099	0.417	0.073
	Wind factor (W_f) ⁵	β_{Wf}	0	$-5 \leq \beta_{WF} \leq 5$	0	0	-1.0	0
	Soil erodibility	β_{EF}	29.09	$0 \leq EF \leq 1$	34.09	29.09	29.09	29.09

	(EF)							
	Soil crust (SCF)	β_{SCF}	0.0066	$0 \leq SCF \leq 1$	0.066	0.066	0.066	0.0066
	Soil roughness (Krr)	β_K	0.124	$0 \leq Krr \leq 1$	0.024	0.024	2.124	0.124
	Crop (COG)	β_{COG}	5.614	$0 \leq COG \leq 1$	4.614	0.614	5.614	5.614

912 ¹ the range is for parameter or factors considered in the calibration.

913 ² range in values for u_{*t} from Shao (2008).

914 ³ range in values for α_{FLF} from Williams et al. (2012).

915 ⁴ range in values for Q_{max} and S from Fryrear and Saleh (1996).

916 ⁵ no information exists regarding the range in W_f . The range in β_{wf} increases
917 or decreases the threshold velocity by 100%.

Table 7. Statistical comparisons of measured and simulated soil loss by the calibrated APEX model and RWEQ. Comparisons are based on three erosion events (two events in April 2012 and the 17-19April2013 event) in the cotton field, red date orchard, and desert– oasis ecotone in the Tarim Basin and six events (all observed events in 2003 and 2005) in the winter wheat – summer fallow field in the Columbia Plateau.

Location		Tarim Basin			Columbia Plateau
Land use type		Cotton Field	Red Date Orchard	Desert–Oasis Ecotone	Winter wheat-summer fallow
Model	Statistic				
APEX	R ² (intercept≠0)	0.99	0.66	0.99	0.36
	R ² (intercept=0)	0.98	0.66	0.99	0.02
	RMSE ¹	7.41	12.92	349.89	160.33
	Difference of mean ²	-6.95	-2.46	-391.52	104.23
	Index of agreement	0.99	0.88	0.82	0.61
RWEQ	R2 (intercept≠0)	0.99	0.52	0.99	0.54
	R2 (intercept=0)	0.97	-1.43	0.99	0.36
	RMSE	8.12	40.44	22.24	68.48
	Difference of mean	-1.93	-10.27	-20.02	-4.97
	Index of agreement	0.99	0.20	0.99	0.83

Fig. 7. Statistical comparisons of measured and simulated soil discharge and loss by the calibrated APEX model and RWEQ. Comparisons are based on all erosion events in the cotton field, red date orchard, and desert– oasis ecotone within the Tarim Basin and winter wheat – summer fallow field in the Columbia Plateau. RMSE is root-mean-square-error, DOM is difference of mean, and d is index of agreement.

Conclusion

Wind erosion and soil and vegetation parameters were measured for various land use types in the Columba Plateau and Tarim Basin. These characteristics were used in testing the performance of the APEX model and RWEQ. The original APEX model showed acceptable agreement between measured and simulated soil losses in the cotton field and the desert-oasis ecotone in the Tarim Basin while the original RWEQ adequately simulate soil loss for WW-SF in the Columbia Plateau. The RWEQ appeared to underestimate erosion for the three land use types in the Tarim Basin, possibly due to under-predicting maximum mass transport. Calibration improved the performance of both models. For example, the calibrated APEX model adequately simulated soil loss for all land use types while the calibrated RWEQ adequately simulated soil loss for all land use types except the red date orchard in the Tarim Basin. The poor performance of the calibrated RWEQ in simulating soil loss from the red date orchard may be due to underestimating the weather factor (WF). Simulations by the calibrated APEX model and RWEQ were encouraging and represents significant progress for the application of wind erosion models in China and the USA. Indeed, the enhanced performance of the calibrated models provides confidence in using these models to simulate wind erosion in these regions.

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