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Research Paper

Measurement and prediction of soil erosion in dry field using portable wind erosion tunnel

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The purpose of this study was to develop a wind erosion prediction model by in situ measurement using portable wind erosion tunnel. The model has a modified form of the wind erosion equation (WEQ) to represent short-term wind erosion with fast and simple measurable factors. To collect the data under controlled wind conditions but on in situ soils, a portable wind erosion tunnel was designed and utilised during field experiments. Notwithstanding measurements might include any possible error, the multiple linear regression analysis of repetitive experimental data derived the wind erosion prediction model, which showed a good agreement with the measured data with $R^2 = 0.61$. The short-term wind erosion predicted by the model was made available to CFD simulation by coupling the erosion mechanism with sophisticated wind environment analysis over complex terrain. The land cover data was linked to the CFD simulation by mapping the virtual porosity and using user-defined functions. The CFD simulation coupled with the regression model produced useful results concerning spatial distributions of soil erodibility, erodible area and soil erosion over complex terrain showing good potential of coupling the experimental model with CFD simulation technique. It is also a promising method for evaluation of various wind erosion prevention measures as well as for effective planning and decision-making for wind erosion control.

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Nomenclature

C	Climatic factor of the Wind erosion equation (WEQ)
C_{ir}	Inertial resistance of the medium (m^{-1})
C_r	Chain roughness (%)
C_0	Correction factor
C_1, C_2, C_3, C_4	Exponents for a regression model
E	Soil erosion by wind (g m^{-2} min^{-1})
I	Soil erodibility factor of the WEQ (tonne ha^{-1} $year^{-1}$)
K	Soil roughness factor of the WEQ
K_r	Ridge roughness value
L	Unsheltered field width factor of the WEQ
$\overrightarrow{n}$	Normal unit vector of each cell in a terrain
P	Pressure (kg m^{-1} s^{-2})
R_c	Soil roughness with respect to ridge orientation
SR	Ratio of percentages of soil aggregates to soil particles
TWC	Topsoil water content (%)
u	Wind speed (m s^{-1})
$\overrightarrow{u_{hor}}$	Wind unit vector projected onto a horizontal plane
u_t	Threshold wind speed of wind erosion for dry soil particles (m s^{-1})
V	Vegetative cover factor of the WEQ
WD	Wind angle from the direction perpendicular to ridges (°)
w_f	Wind value (m^3 s^{-3})
α	Permeability of the medium (m^2)
θ	Ground slope (°)
ρ	Air density (kg m^{-3})
ℓ_1	Chain length (m)
ℓ_2	Horizontal distance between chain ends (m)
μ	Viscosity of air (kg m^{-1} s^{-1})

1. Introduction

Although global surface temperatures have warmed 0.74 °C over the past 100 years, as reported by the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), temperatures in Korea have increased by 1.7 °C. Wind erosion due to global warming leading to desertification was considered as an important issue in arid and semi-arid regions (Buschiazzo & Zobeck, 2008), but recent continuous abnormal warming has influenced Korea to prepare against possible wind erosion. Agricultural land in particular may result in a loss of crop production function by the removal of valuable loam as desertification accelerates the soil erosion process in dry fields. Although the most severe soil is caused by rainfall rather than wind, methods for supplementing and improving soil have become a burden to farmers. For example, the amount of soil supplement applied to fields reached 1770 t ha^{-1} every two to three years for dry fields in mountain region of Pyeongchang County where this study was conducted (Park, 2006). Eroded particles, nutrients and dust may also be scattered and dispersed to nearby habitation causing residents health problems or to farms causing the decline in crop and animal productions (Bitog et al., 2009).

The most well-known model to predict a soil erosion by wind is the WEQ (wind erosion equation) empirically developed in 1960s (Woodruff & Siddoway, 1965). Based on the WEQ, revised or new models, such as RWEQ (revised wind erosion equation, Fryrear, Saleh, & Bilbro, 1998) and WEPS (wind erosion prediction system, Hagen, 1991), have been suggested. The later models have supplemented various physical processes of soil erosion because the wind erosions predicted by models do not show significant level of agreement with measured in situ under certain situations due to varied, non-uniform and changing climate and soil conditions.

WEQ-based studies have been conducted through field measurement and numerical simulation targeting mostly large areas over long time frames using yearly or monthly units, and daily units in the particular case of the WEPS (Webb & McGowan, 2009). These long-term approaches give good predictions by reducing various factors that fluctuating from moment to moment, but this approach may decrease the accuracy and efficiency of predictions of temporal variation in soil erodibility caused by changes in wind conditions. For example, where wind breaks are installed to prevent wind erosion, the number, location, arrangement and direction of the breaks needs investigation at a suitable scale to develop methods that will efficiently prevent the soil erosion over the wider field.

Laboratory-based wind tunnels have been used to analyse the links between soil erodibility and various physical factors to derive a numerical relationship between them (Gillette, 1978; Hagen, 1999; Han et al., 2009; Liu et al., 2006). Wind tunnels provide a controlled environment protecting against variable field conditions in order to investigate the effects of several particular factors on soil erosion behaviour. Wind factors, such as vertical profiles of wind speed and turbulence quantities can be artificially controlled in the wind tunnel and soil factors including soil texture, grain size, water content, surface roughness, soil compactness, etc. can be manually adjusted to be similar to field conditions. However, while each of the soil properties can be independently varied it is possible to vary them beyond field conditions. If the properties of the soil samples used for testing are not realistic, the test results may produce errors and uncertainty despite the advantages of using a wind tunnel.

The use of a portable wind tunnel is an alternative method to overcome the uncertainty of using artificial soil samples. Portable wind tunnels have been used by installing them on the ground of test site thus removing the requirement for preparing soil samples to investigate soil erosion (Fister, Iserloh, Ries, & Schmidt, 2012; Fister & Ries, 2009; Gartmann, Fister, Schwanghart, & Muller, 2011; Leys & Raupach, 1991; Pietersma, Stetler, & Saxton, 1996). The strength of this approach is that erosion behaviour can be investigated on real soil whilst retaining the ability to control wind speed. Because the erosion area for testing is limited by the test area of the portable wind tunnel, which is typically a few square metres, very low soil losses through wind erosion, less than 1 g m^{-2} 10 min^{-1}, have been observed (Fister & Ries, 2009). Therefore minor errors or losses of tiny soil aggregates during the