Measuring and Modeling Bare Topsoil Erosion by Wind from a Steppe Grassland of China

Zachary C. Landis[1], Nicholas M. Potter[1], Alston D. Chereskin[1], Devrick L. Johnson[1], Along Zhang[2], Ziyuan Qin[2], Dolan[3], Ruizhong Gao[2], Yanyun Luo[2], Ruihong Yu[3], Fengling Li[2], Linmin Duan[2], Tingxi Liu[2], **Xixi Wang**[1*]

[1] Department of Civil and Environmental Engineering, Old Dominion University (ODU), Norfolk, VA 23529, USA
[2] College of Water Conservancy and Civil Engineering, Inner Mongolia Agricultural University (IMAU), Hohhot, Inner Mongolia Automatic Region, China
[3] College of Environmental and Ecological Engineering, Inner Mongolia University (IMU), Hohhot, Inner Mongolia Autonomous Region, China

* Correspondence: Email: xxqqwang@gmail.com; Tel.: +1 (757) 683-4882

Background, Objectives, and Study Approach

- The Eurasian Steppe, the vast steppe ecoregion including the native grasslands in Inner Mongolia of China, stretches from Romania in west to Manchuria in east
- It is a global biome supply, provides multifaceted ecological services, and functions as carbon sink and source
- It is an important regulator of regional and global heat-water-carbon cycles and helps mitigate climate change and its impacts
- However, it has been degrading at an accelerating rate since 1980s due to overgrazing and climate change
- This has raised serious eco-environmental concerns , such as loss of productivity, desertification, and dust storm
- Such a concern is particularly true in winter and spring, when soil moisture and vegetation coverage are low while wind speed is high, increasing the vulnerability of topsoil to wind erosion
- The objectives of this study were to:
  - ☺ Devise and use a portable wind tunnel system to collect field data on bare topsoil erosion by wind
  - ☺ Use the data to parameterize the wind erosion module (Eq. 1) of the IAFP model developed by Wang *et al.* (2014)

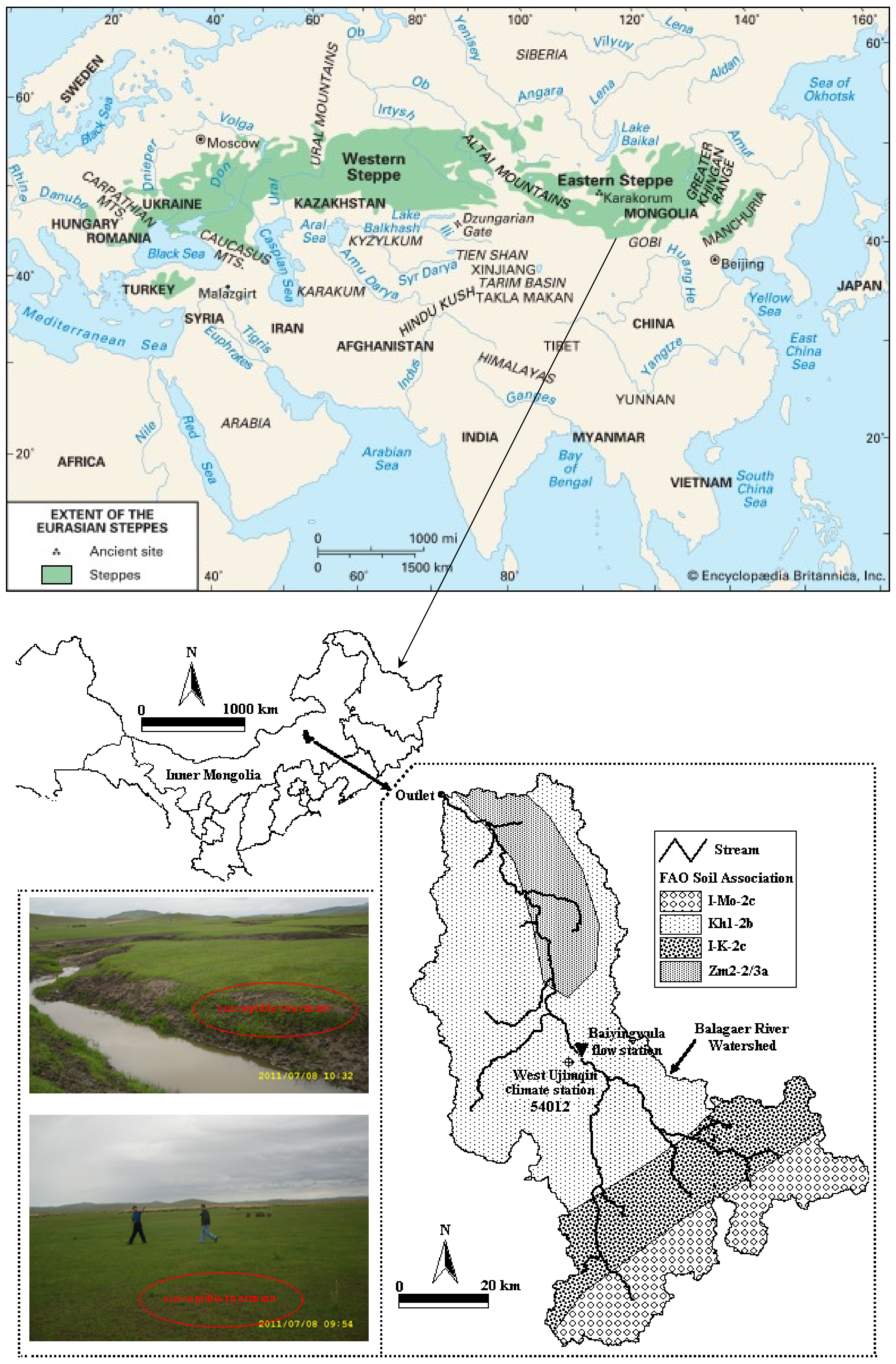

Figure 1. The study watershed.

- The 5350 km^2 Balagaer River watershed (44°00' to 44°15' N, 117°40' to 117°48' E), located in northeast Inner Mongolian Autonomous Region of China (Figure 1), was selected for this study
- Totally, 33 sites (e.g., Figure 2) of bare sandy soils were randomly selected for testing: the first three sites were tested for 6.33, 10, and 15 min, respectively, whereas each of the others had a testing duration of 20 min
- The soil moistures at the testing times ranged from 0.018 to 0.094, which are between the wilting point (θ_ψ = 0.012) and filed capacity (θ_{fc} = 0.095), and the wind speeds were controlled to vary from 3.63 to 6.23 m s^{-1}

wind shear stress (N m^{-2})

threshold soil shear strength (N m^{-2})

wind erosion modulus (g m^{-2} s^{-1})

$$q_a = C_a \cdot \left(\frac{\tau_* - \tau_{*c}}{\rho_{air}}\right)^{\frac{3}{2}} \quad \textbf{(Eq. 1)}$$

soil-specific coefficient of wind erosion when the surface soil is bare and dry (g m^{-5} s^2)

density of air (kg m^{-3})

Figure 2. Typical test site.

The Portable Wind Tunnel System

- The system consists of a 2-m-long 10-cm-wide 9-cm-high rectangular tunnel, a 30-cm-diameter system suction fan, a 2-cm-diameter sampler with a 1-cm-wide 8-cm-high cut slot, a steel collection container, a collection suction fan, and a 370-W 220-V motor with an air flow capacity of 2300 m^3 hr^{-1} (Figure 3)
- The valve installed through an open slot on the top of the control box can be adjusted to generate varying wind speeds by controlling its openings
- The wind speeds were measured using a hot-wire anemometer through three 1-cm-diameter holes on the top of the working section and at three vertical points, resulting in nine values of wind speed for each test
- The collection container is subdivided into two parts by a filer paper, allowing sediments to be left behind air flows and trapped in the container for collection
- For a given test, the total mass of eroded soils were determined as 11.25 times the mass of the collected sediments by assuming a uniform cross-sectional distribution
- The water contents were measured using an oven-drying method and converted into the responding soil moistures, which in turn were used to estimate the bulk densities

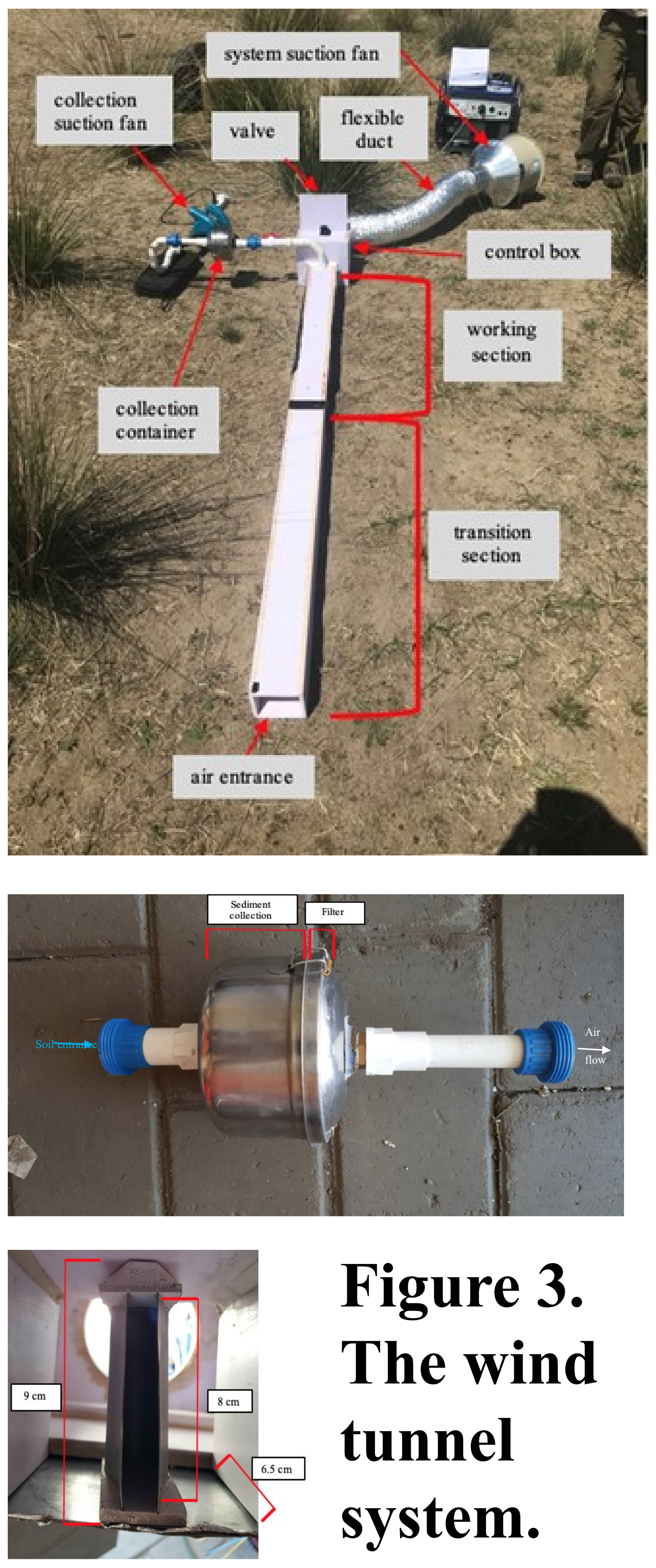

Figure 3. The wind tunnel system.

Results and Discussion

- The collected sediments tended to decrease with increase of soil moisture but to increase with wind speed
- Fitting Eq. (1) to the measured data resulted in $C_a = 2.37$ g m^{-5} s^2, which is comparable with Wang *et al.* (2014)
- With this C_a value, Eq. (1) well reproduced the measured wind erosion modulus ($R^2 = 0.96$ and slope of 0.98)
- At the watershed scale, the C_a value could be scaled up to 0.1×10^{-4} g m^{-5} s^{-1}
- For a wind speed of 6.0 m s^{-1} and a soil moisture of 0.02, which is common in winter and spring for the study watershed, the predicted $q_a = 2.592 \times 10^{-7}$ g m^{-2} s^{-1}, which is equivalent to 21,570 tonnes in these two seasons

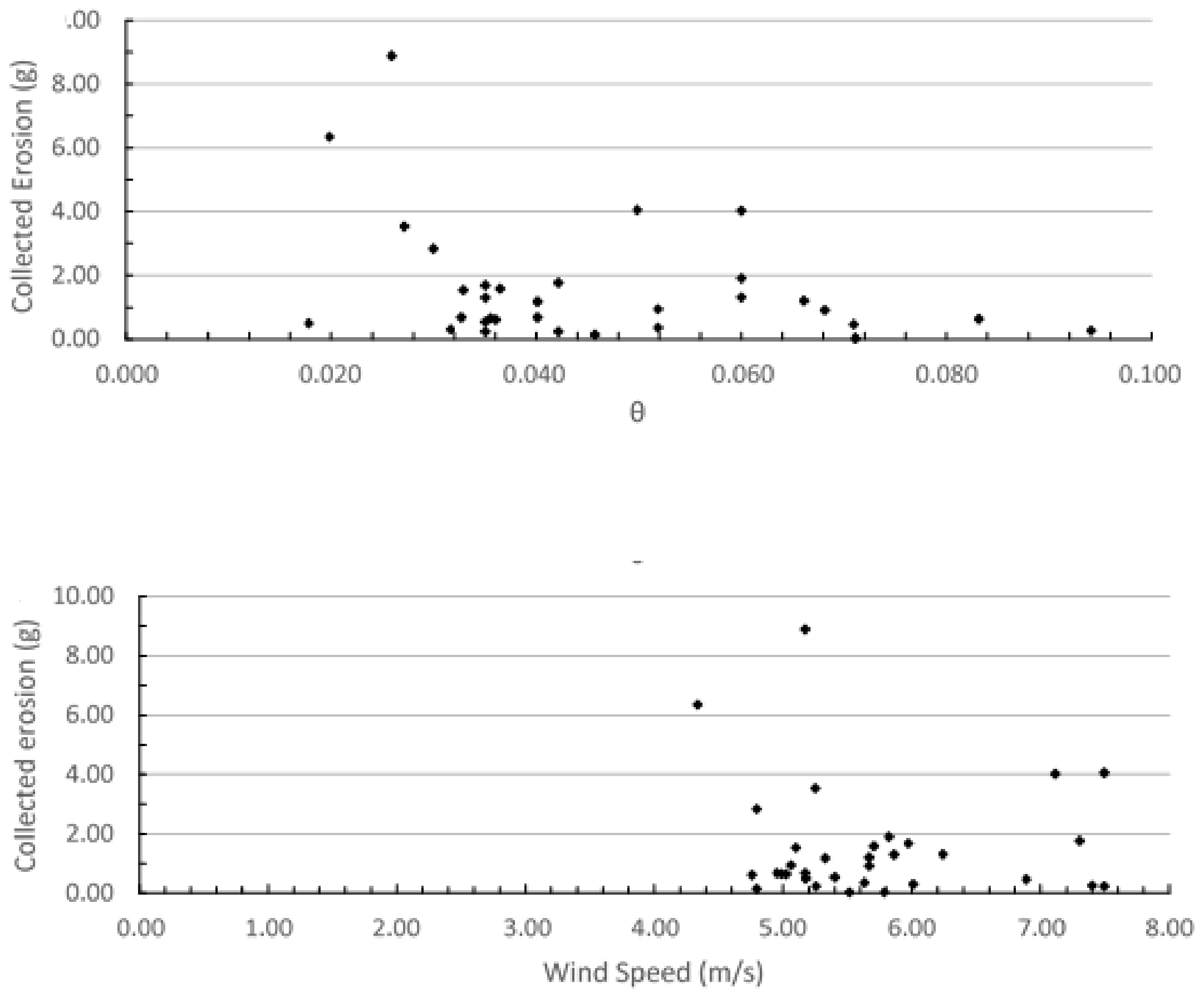

Figure 4. Collected sediment vs. soil moisture and wind speed.

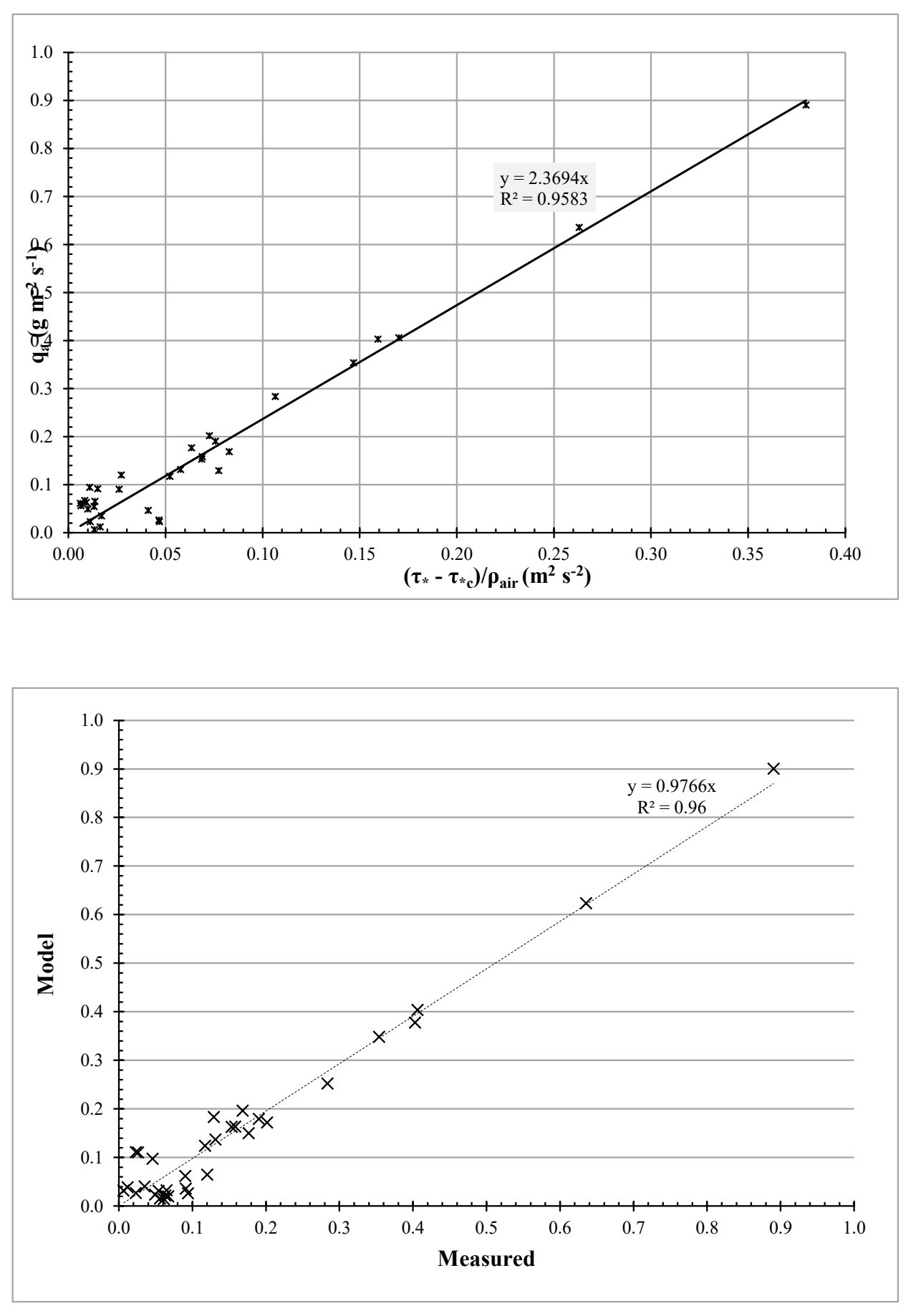

Figure 5. Goodness of fitting Eq. 1 to the measured data.

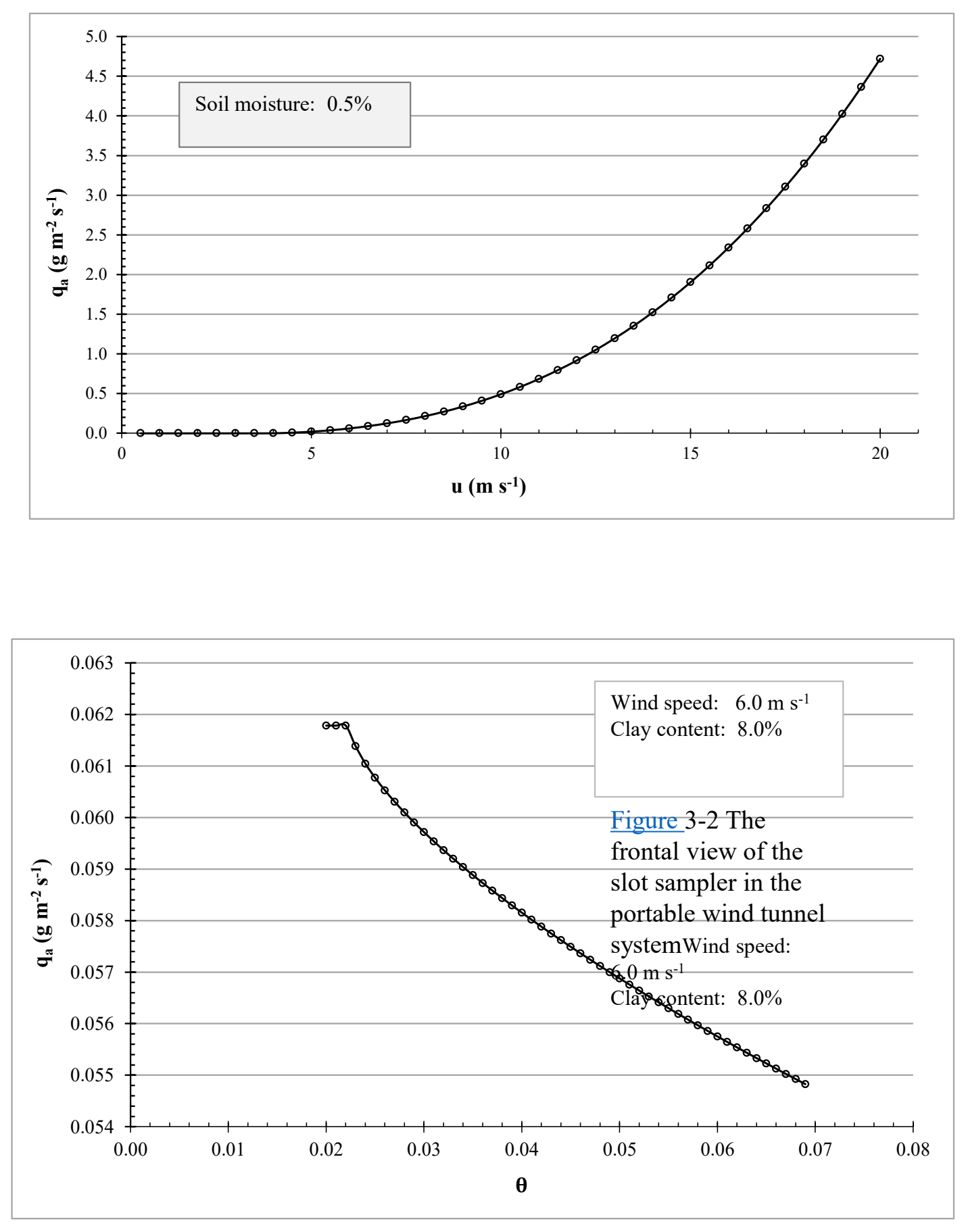

Figure 6.Predicted erosion changes with soil moisture and wind speed.

Conclusions

- The portable wind tunnel system proved to be a very helpful and handy tool for field testing of wind erosion
- The wind erosion module of the IAFP model is applicable for endangered areas , including the study watershed

Acknowledgements

This study is part of a ODU-IMAU-IMU collaborative project, funded by NSF-IRES (#1654957) and NSFC (#51469019)