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# Relative contributions of wind and water erosion to total soil loss and its effect on soil properties in sloping croplands of the Chinese Loess Plateau

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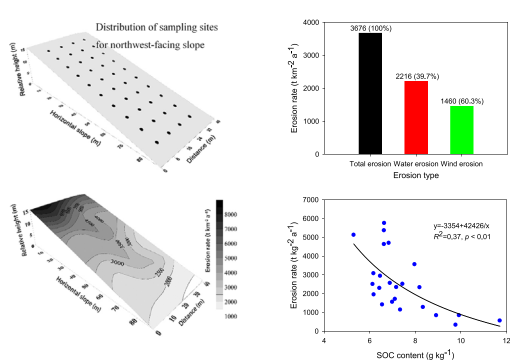
## HIGHLIGHTS

- This study quantified the contributions of wind and water erosion to total erosion.
- The sites with most serious erosion and nutrient loss located in the upper positions on northwest-facing slopes.
- Complex erosion by wind and water accelerated the degradation of the soil quality.
- Control water erosion could more effectively reduce soil loss compared to the control wind erosion.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Wind and water erosion are two dominant types of erosion that lead to soil and nutrient losses. Wind and water erosion may occur simultaneously to varying extents in semi-arid regions. The contributions of wind and water erosion to total erosion and their effects on soil quality, however, remains elusive. We used cesium-137 ($^{137}$Cs) inventories to estimate the total soil erosion and used the Revised Universal Soil Loss Equation (RUSLE) to quantify water erosion in sloping croplands. Wind erosion was estimated from the subtraction of the two. We also used $^{137}$Cs inventories to calculate total soil erosion and validate the relationships of the soil quality and erosion at different slope aspects and positions. The results showed that wind erosion (1460 t km$^{-2}$ a$^{-1}$) on northwest-facing slope was responsible for approximately 39.7% of the total soil loss, and water erosion (2216 t km$^{-2}$ a$^{-1}$) accounted for approximately 60.3%. The erosion rates were 58.8% higher on northwest- than on southeast-facing slopes. Northwest-facing slopes had lower soil organic carbon, total nitrogen, clay, and silt contents than southeast-facing slopes, and thus, the $^{137}$Cs inventories were lower, and the total soil erosions were higher on the northwest-facing slopes. The variations in soil physicochemical properties were related to total soil erosion. The lowest $^{137}$Cs inventories and nutrient contents were recorded at the upper positions on the northwest-facing slopes due to the successive occurrence of more severe wind and water erosion at the same site. The results indicated that wind and water could accelerate the spatial variability of erosion rate and soil properties and cause serious decreases in the nutrient contents in sloping fields. Our research could help researchers develop soil strategies to reduce soil erosion according to the dominant erosion type when it occurs in a hilly agricultural area.



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## 1. Introduction

Erosion by the forces of either wind or water is an important cause of soil degradation and reduction in plant productivity in agricultural areas (Galy et al., 2015; Du et al., 2017; Van Pelt et al., 2017). Although water and wind erosion are two common types of erosion and may occur in specific climatic zones: wind erosion in drier regions, and water erosion in wetter regions, erosion is complex in semi-arid environments, as combinations of wind and water erosion occurs on both temporal and spatial scales (Visser and Sterk, 2007; Tuo et al., 2016).

Many researchers have analyzed the importance of wind and water erosion processes (Song et al., 2005; Tuo et al., 2016; Wang et al., 2016). Wind-driven sediment can be deposited directly into channels, where it is stored until fluvial process to transport the sediment down the channel (Belnap et al., 2011). According to long-term monitoring in terraces, Van Pelt et al. (2017) showed that wind erosion is a larger component of net soil redistribution than water erosion. In an experiment that was first conducted with wind erosion and then with water erosion, Tuo et al. (2016) noted that wind erosion clearly has the capacity to intensify water erosion. In addition, some studies reported that the erosion change depended on natural factors and human factors (Du et al., 2017; Xue et al., 2017). Martínez-Graña et al. (2014, 2015) used a cartographic method to show a high risk of water erosion in areas with high slopes and elevations and little agricultural activity. The risk of wind erosion is higher in sectors with low vegetation cover and highly erodible textures. Although these studies could help soil conservation researchers develop strategies to reduce total soil loss, quantitative analysis of wind and water erosion is a complex task (Zhang et al., 2011; Wang et al., 2016), and few studies have been conducted to distinguish a single erosion from the total erosion and its relationship to soil quality (Breshears et al., 2003; Song et al., 2005; Zhang et al., 2018). These problems hinder the recognition of the consequences of erosion in regions where both types of erosion occur (Visser et al., 2004).

The greatest obstacle in partitioning wind and water erosion is the limitation of feasible methods and techniques to measure wind erosion compared to water erosion (Van Pelt et al., 2017). Previous studies for quantifying wind and water erosion by sampling and monitoring required many years and many points in a field (Zhang et al., 2011). Experiments that combined wind tunnels with simulated rainfall supported integrated research. Tuo et al. (2015, 2016) studied wind and water erosion to investigate the characteristics of runoff, sediment, and soil particles under a one-way wind erosion-rain erosion sequence. Breshears et al. (2003) compared the horizontal mass transport of wind- and water-driven materials in different semi-arid ecosystems. However, these techniques basically examined bare soil at horizontal wind velocity, the other conditions remain unknown. The measurements of sediment by wind and water are not necessarily indicative of relative soil erosion rates (Zhang et al., 2011). Recent studies suggested that model simulations for estimating soil redistribution across a landscape could produce a plausible result and provide a better understanding of wind and water erosion processes (Schmidt et al., 2017; Zhang et al., 2018).

Cesium-137 ($^{137}$Cs) has been widely applied as a surrogate to total soil erosion studies on almost every continent (Van Pelt et al., 2017) and has been used to determine the impacts of soil erosion on nutrient dynamics in a wide range of agricultural landscapes (Afshar et al., 2010; Nie et al., 2013). $^{137}$Cs is an artificial radionuclide (half-life of 30.17 years) that was released into the environment as a result of nuclear weapons tests primarily during the 1950s–1970s (Fang et al., 2012). The use of $^{137}$Cs to estimates of soil redistribution relies on four hypotheses (Parsons and Foster, 2011). First, $^{137}$Cs fallout is spatially and locally uniform. Second, the fallout is rapidly fixed onto soil particles. Third, the subsequent $^{137}$Cs redistribution is due to the movement of soil particles. Fourth, there is a reference site that should be undisturbed and representative of the entire study area. Finally, the estimates of soil erosion can be derived from measurements of $^{137}$Cs inventories.

The Revised Universal Soil Loss Equation (RUSLE) models soil loss to water erosion as a function of climate erosivity (the degree to which rainfall can result in erosion), topography, soil erodibility, and land management (Bowker et al., 2008). The RUSLE model is the most widely used empirical model to calculate water erosion at both basin and field scales resulting from sheet and rill erosion (Conforti et al., 2016; Conforti and Buttafuoco, 2017). Unlike process-based models such as WEPP and EUROSEM, the RUSLE model usually does not require extensive input data and calibration efforts (Tiwari et al., 2000; Khaleghpanah et al., 2016). The RUSLE model has its advantages over the process-based models, because it is accurate and easy to use in terms of parameterization (Gao et al., 2012). Li et al. (2017a) even noted that RUSLE models could produce sound predictions in the Chinese Loess Plateau.

This study selected typical sloped croplands with different aspects and positions on a field scale in the wind-water erosion crisscross region of the Chinese Loess Plateau. All sites were higher than the surrounding landforms and vegetation, and thus, soils at the surface were subject to erosion by water and wind. $^{137}$Cs was used to estimate the total soil erosion, and the RUSLE model was used to quantify water erosion. Wind erosion results from the subtraction of water erosion from total soil erosion. In addition, we used $^{137}$Cs to calculate the total soil erosion and soil physicochemical properties on slopes with different aspects and positions. The objectives of this study were to (1) quantify the contributions of wind and water erosion to total erosion in sloping croplands, and (2) investigate the relationships between total soil erosion and physicochemical properties for different slope conditions.

## 2. Materials and methods

### 2.1. Study area

The study area was located in the wind-water erosion crisscross region on the Chinese Loess Plateau (37°13′N, 107°56′E; Fig. 1). The average elevation of the area ranged from 1577 to 1705 m AMSL. The area is characterized by a semiarid climate, with a mean annual temperature of 7.9 °C and a mean annual precipitation of 361.9 mm. The rainfall was typically high-intensity and short duration rainstorms. The soils are classified as typical loessial soil, which originated from wind deposits and are characterized by the absence of bedding, a silty texture, looseness, and macroporosity, with an average thickness of 50–80 m on the Loess Plateau (Gao et al., 2017). Cropland is the main land use in the region because most of the native vegetation has been cleared due to the long history of crop production, resulting in severe soil erosion, land degradation and soil fertility loss (Jia et al., 2017). The crops in this area were mainly millet (*Setaria italica*), potato (*Solanum tuberosum*), and maize (*Zea mays* L.).

The soil in the study area is subjected to both wind and water erosion. Wind erosion is dominant during the winter and spring, and water erosion is dominant during rainy summers and the autumn. The main wind direction is from the northwest, followed by north and west. Wind rarely comes from the southeast. According to the China Meteorological Data Network, the annual northwest, north, and west winds in the study area (Dingbian County, China) accounted for 91.6, 4.8, and 3.6%, respectively, of the total wind in 2012–2014. The annual average wind speed is 3.2 m s$^{-1}$. The annual average days of wind speed >6 m s$^{-1}$ are 32, and these mainly occur in March, April, May, November, and December. By contrast, the monthly average precipitation is >60 mm in July, August, and September.

### 2.2. Selection of study sites and soil sampling

In the April of 2014, we selected land on northwest-facing slope (defined as S7, Table 1) with a long slope length (approximately 105 m) and a uniform slope gradient (approximately 10°) to investigate the