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Developing an erodibility triangle for soil textures in semi-arid regions, NW Iran

Ali Reza Vaezi [a],*, Heidar Hasanzadeh [a], Artemi Cerdà [b]

[a] Department of Soil Science, Agriculture Faculty, University of Zanjan, 45371-38791, Zanjan, Iran
[b] Soil Erosion and Degradation Research Team, Departament de Geografia, Universitat de València, Blasco Ibàñez 28, 46690, Valencia, Spain

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ABSTRACT

There is a strong need to develop a simple method for rapid estimation of erodibility using readily available data. In this study, soil erodibility was measured using eleven soil textures at the plot scale (60 cm × 80 cm) on a slope of 9% in a semi-arid region. A total of 110 soil erosion experiments were conducted using ten simulated rainfalls ($50\ \mathrm{mm\ h^{-1}}$ for 30 min). A regression model was developed based on silt and clay content ($R^2 = 0.82$, $p < 0.001$) and was applied to estimate erodibility for 231 soils in the textural triangle. Kriging was used to spatial interpolate erodibility using these data to unknown soils on the textural triangle. A soil erodibility triangle was developed using kriging technique and its accuracy was evaluated using seven other soils. The technique showed a 5.4% error and allowed the prediction of soil erodibility in semi-arid areas by using the soil erodibility triangle.

1. Introduction

Soil erodibility expresses the soil's susceptibility to erosional processes and is conceived of as the ease with which soil is detached by splash during rainfall and/or surface flow (Renard et al., 1997). It is generally considered as an inherent soil property with a constant value which reflects the fact that different soils erode at different rates when the other factors that affect erosion are the same (Kirkby and Morgan, 1980; Brevik et al., 2015). This soil property is a result of the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport (Lal, 1994). It is an important factor in determining the rate of soil loss (Zhang et al., 2004), therefore it is widely adopted as an important factor in soil erosion prediction models such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and the Revised USLE (RUSLE) (Renard et al., 1997). Thus, knowledge of soil erodibility is an essential requirement for conservation planning and the assessment of sediment related environmental effects of watershed agricultural practices (Wang et al., 2013b). Soil erodibility is also a key factor in understanding pedon and slope erosional processes as well as landforms and landscape evolution (Bryan, 2000; Cammeraat, 2002; 2004). Soil erodibility research contributes to understanding human impacts on soil properties and thus on soil and water losses (Cammeraat and Imeson, 1998; Cerdà and Doerr, 2007; Brevik et al., 2015; Ochoa Cueva et al., 2015; Liu et al., 2015). The impact of the humankind by means of forest fires (Cerdà and Doerr, 2005), grazing (Palacio et al., 2015), ploughing (Zhao et al., 2015), and herbicides (Cerdà et al., 2009) affects soil erodibility. Moreover, research on soil erodibility can help to better understand soil formation and soil degradation processes (Cammeraat et al., 2002; Cammeraat and Risch, 2008; Cerdà and Doerr, 2010), the impact of water (Ziadat and Taimeh, 2013) and wind (Wang et al., 2013a; Borrelli et al., 2015; Colazo and Buschiazzo, 2015) on soil particle detachment, and also identify soil quality (Brevik, 2009; Zhao et al., 2015) and watershed erosion (Keesstra et al., 2014). The concept of erodibility and how to assess it are complicated since the susceptibility of the soil to erosion is influenced by a large number of properties such as physical, chemical, rheological, mineralogical and biological properties, not to mention soil profile characteristics such as the depth of the soil and its influence on vegetative growth (Morgan, 1995; Veihe, 2002). Several attempts have been made to devise a simple index of erodibility based on the properties of the soil determined either in the laboratory or field. For the first time, a nomograph was developed by Wischmeier et al. (1971) to estimate soil erodibility from measurable soil properties in the early 1970s from long-term soil erosion plots under natural rain and rainfall simulation experiments (Auerswald et al., 2014). In this method, soil erodibility was originally derived from five variables, namely the silt plus, the very fine sand content, clay content, organic matter content, an aggregation index, and a permeability index (Wischmeier et al., 1971). Later, a sixth variable, namely

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Abbreviations: Dg, geometric mean particle diameter; BD, bulk density; SP, saturated point; AD, mean weight diameter of soil aggregates; AS, mean weight diameter of water-stable aggregates; K_s, saturated hydraulic conductivity; ESP, exchangeable sodium percentage; OM, organic matter; CCE, $CaCO_{3,eqv}$; Gy, $CaSO_4$, $2H_2O$; SE, soil erodibility.

* Corresponding author.
E-mail addresses: vaezi.alireza@gmail.com, vaezi.alireza@znu.ac.ir (A.R. Vaezi).

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rock fragment cover, was added by Wischmeier and Smith (1978). Previously, Bryan (1968) found the mean-weight diameter of water-stable aggregates as one of the best indices of the soil susceptibility to erosion under simulated rainfalls. Le Bissonnais (1996) introduced aggregate stability against raindrop impact as a good indicator to assess soil crustability and erodibility. Rejman et al. (1998) found a close correlation between soil erodibility and soil moisture content. Barthès et al. (1999) and Barthès and Roose (2002) indicated that soil erodibility is related to topsoil properties such as aggregate stability. Misra and Teixeira (2001) showed that soils with well-aggregated structure have high strength against erosion and show little change in soil erodibility after wetting periods. Tejada and Gonzalez (2006) indicated that soil erodibility (K) can be affected by soil constituents such as type of organic matter and exchangeable cations, especially Na^+. Yu et al. (2006) obtained a quantitative relationship between the soil erodibility factor (*K*) and soil saturated permeability. Rhoton et al. (2007) proposed that aggregation index can be used to determine the erodibility over a range of soil and slope conditions at watershed scales. Vaezi et al. (2008) developed a model to predict the soil erodibility factor (K in the USLE) in calcareous soils using clay, permeability, and lime ($R^2 = 0.84$). Panagos et al. (2014) reported that since coarse fragments (>2 mm) act as protection against soil erosion, they should be taken into account for better estimation of soil erodibility (K). Soil erodibility can also be estimated by means of soil aggregate stability which indicates the strength of the clods and aggregates (Cerdà, 2000; Mataix-Solera et al., 2011; Gelaw et al., 2015) and is a definitive variable to understand soil erosion processes in agricultural and forest soils (García-Orenes et al., 2012; Haregeweyn et al., 2013; Lieskovský and Kenderessy, 2014; Nanko et al., 2015).

The literatures review shows that soil erodibility is a complex property that can be estimated by a wide range of interlinked soil properties. This soil property is not an essentially constant property for any soil type and can vary temporally due to changes in climatic conditions (Salvador Sanchis et al., 2008; Borselli et al., 2012) and changes in soil aggregates and soil water conditions (Bryan, 2000; Wang et al., 2001; Salvador Sanchis et al., 2008; Borselli et al., 2012). However, temporal variation of soil erodibility on an annual basis under fallow condition or in uncultivated soils would be mostly low when climate conditions are relatively constant. Under these conditions, percentage of soil primary particles or soil texture which is an easily-measurable soil property with the least temporal variability among soil properties, can have an important role in spatial variation of soil erodibility in an area. The importance of soil texture in hydrological behavior and the resistance to erosive factors is very evident, particularly in arid and semi-arid regions, where the soils are predominantly calcareous with low organic matter content and weakly-aggregated structures which are more susceptible to water erosion processes.

About 642,797 km^2 of land surface area in Iran (39% of the country) is located in a semi-arid climate, with an annual precipitation between 200 and 500 mm. Soil erosion by water is a major environmental concern in this region and can be observed as sheet, rill, gully and stream erosion (Vaezi et al., 2016). Average soil erosion varies from 10 to 20 Mg ha^{-1} yr^{-1}, while the soil formation rate is expected to be lower than 1 Mg ha^{-1} yr^{-1} (Vaezi and Abbasi, 2012). Determination of soil erodibility and the estimation of soil erosion are needed for planning and designing soil conservation measures in the area. The lack of information limits the implementation of many soil conservation programs in the area. The direct measurement of soil erosion with large plots under natural rainfall for a long-term period can help provide a more accurate estimate of soil erodibility. However, this method is time consuming and very expensive. As mentioned above, several indices were proposed for the estimation of soil erodibility using different soil physicochemical properties worldwide. These indices are often regional and typically require a relatively large number of measurements of specific physical and chemical soil properties that may not be widely available. Soil erodibility factor of the USLE is one of these indices which is currently used as a tool for quantifying the soil susceptibility to erosion worldwide. Attempts to simplify the K evaluation procedure have been carried out in the past and simplified relationships have been proposed for predicting K values of soils for which data are limited (Römkens et al., 1986; Römkens et al., 1997; Verstraeten et al., 2002; Bagarello et al., 2009). Early Borselli et al. (2012) attempted on alternative ways in order to infer the range of uncertainty of K-values associated to every combination of climate and of input soil properties. They developed a special software (KUERY: from "query" and K) to calculate the most probable soil erodibility for the given climate group using soil properties: Dg (geometric mean of the particle-size distribution), Sg (geometric standard deviation), organic matter and percentage rock fragments. The KUERY calculates the interpolated cumulative distribution curve of the K-value for any given Dg, Sg, organic matter and percentage rock fragments. However, reducing the number of input variables in the evaluation procedure of soil erodibility can be practically attractive for limiting laboratory analyses and resulting costs (Bagarello et al., 2011). Therefore, there is a strong need for developing a simple method to estimate soil erodibility based on readily-available soil properties in the semi-arid regions. This study was designed based on field measurements of soil loss in soils with different textures using simulated rainfall events in order to find soil textures susceptible to water erosion, determine soil properties influencing erodibility, and develop a simple technique for estimating soil erodibility in these areas.

2. Materials and methods

2.1. Study site

In order to quantify soil erodibility in semi-arid regions, soil sampling was carried out at different sites in Zanjan Province in early March 2012. This area is one of the semi-arid regions located in the north west of Iran with a mean annual precipitation of 298 mm and a mean annual temperature of 11 °C. Soils are often calcareous and are mostly classified as Typic Calcixerepts according to the Soil Taxonomy classification system (Soil Survey Staff, 2010). The soils usually have little vegetation cover especially during early springs when rainfalls are severe and frequent (Hasanzadeh et al., 2013). It is estimated that this area has the potential to produce15 Mg ha^{-1} of sediment per year, mostly around the Qezel Owzan river, the longest river in the Sefid Roud basin in NW Iran (Fig. 1). It seems soil erodibility is a critical erosion factor particularly in unprotected sloped lands (rainfed lands and rangelands) in the area.

2.2. Soil sampling

Soil samples were collected from 0 to 20 cm depth and were initially analyzed to determine particle size distribution in the lab. Finally, soils consisting of eleven soil textures according to the U.S. Department of

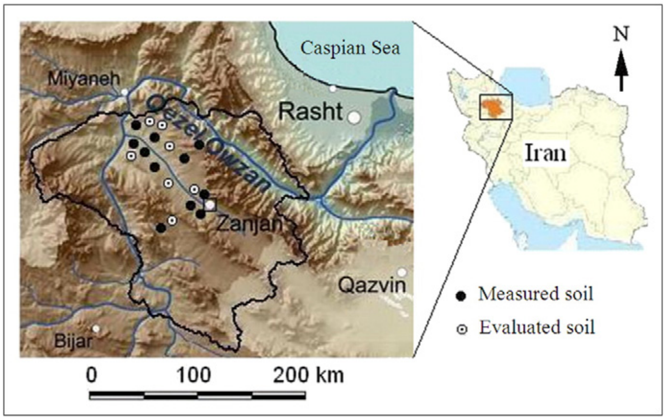

Fig. 1. Location of soil sampling points in Zanjan province, NW Iran.