Agriculture, Ecosystems and Environment 269 (2019) 148–155

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Adapting & testing use of USLE K factor for agricultural soils in China

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ARTICLE INFO

Keywords:
Soil erosion
K factor
USLE
Soil erodibility database
Soil erodibility map

ABSTRACT

Soil erosion has become a great challenge to agricultural development and food security at regional, national and global scales. China is an agriculture country with large amount of population and long farming history, and intensive cultivation activities result in accelerated erosion. To reduce soil erosion and conserve soil resources, soil erosion models have been widely developed and applied worldwide. Soil erodibility is a key factor in erosion prediction models, such as USLE (Universal Soil Loss Equation) and RUSLE (Revised Universal Soil Loss Equation). However, the three commonly used existing soil erodibility estimation methods (K_{nomo}, K_{epic}, K_{Dg}) would cause high biases for agricultural soils in China and the K_{nomo} method is not available in most regions of China. Therefore, this study proposed a linear combination of the revised K_{epic} and K_{Dg} methods for soil erodibility estimation based on data from the Second Nation Soil Survey. The new estimator performs well (R^2 = 0.590; RMSE = 0.0043). A soil erodibility map for China derived from this new method shows that soil erodibility decreases from the southeast to the northwest. The soil erodibility of China is bimodally distributed rather than following a Gaussian distribution, with modes of 0.012 and 0.023 $t{\cdot}h{\cdot}MJ^{-1}\,mm^{-1}$. Finally, a national database of K factors for agricultural soils was developed.

1. Introduction

Soil erosion is a worldwide land degradation process and a serious threat to the sustainability of agriculture. Approximately 10 million ha of cropland are lost worldwide per year due to soil erosion (Pimentel and Burgess, 2013). Soil erosion is also an urgent environment issue in China, near 5 billion tons of soil and 0.067 million ha of cropland are lost annually (MWR of PRC, 2002). Although soil erosion has been controlled remarkably since national 'Grain for Green Project' began, there are 129.32 million ha of land suffering from soil erosion (MWR of PRC, 2013). As the productive layer of topsoil is eroded due to the long-term intensive cultivation, crop yields and land values are reduced rapidly, soil erosion has become a serious challenge to local or national agricultural development and food security all over the world, especially in the developing countries such as China. Therefore, accurate estimation of soil loss, particularly at large scales, is imminently necessary to protect croplands and support food production (Pimentel et al., 1987; Labrière et al., 2015).

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) has been one of the most widely used soil erosion prediction tools in the past decades (Auerswald et al., 2014). In USLE model, the K factor is one of the primary factors, and defined as the rate of soil loss per rainfall erosion index (R) measured on a unit plot (Wischmeier and Mannering, 1969; Wischmeier and Smith, 1978). According to above definition, the K factor is determined by plot data.

In the early 1970s, a notable soil erodibility nomograph to determine the K factor from soil properties was published (Wischmeier et al., 1971) that relates K factor to five soil and soil profile properties. The nomograph has since been used as the basis for soil loss estimation using USLE/RUSLE in the United States, Australia, China and other countries (Wischmeier and Smith, 1978; Rosewell, 1992; Renard et al., 1997; Torri et al., 1997; Angima et al., 2003; Lu et al., 2004; Bonilla and Johnson, 2012; Chen and Zhou, 2013). Additionally, Young and Mutchler (1977); Römkens et al. (1977); Mulengera and Payton (1999); Vaezi and Sadeghi (2011) and Auerswald et al. (2014) proposed similar formulas for soil erodibility estimation under different conditions and depending on different databases. In addition to the nomograph approach, several other methods have been proposed to estimate the K factor using even fewer soil properties, such as Williams et al. (1984) EPIC model using soil particle size and organic matter and Shirazi and

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https://doi.org/10.1016/j.agee.2018.09.033
Received 1 June 2018; Received in revised form 26 September 2018; Accepted 27 September 2018
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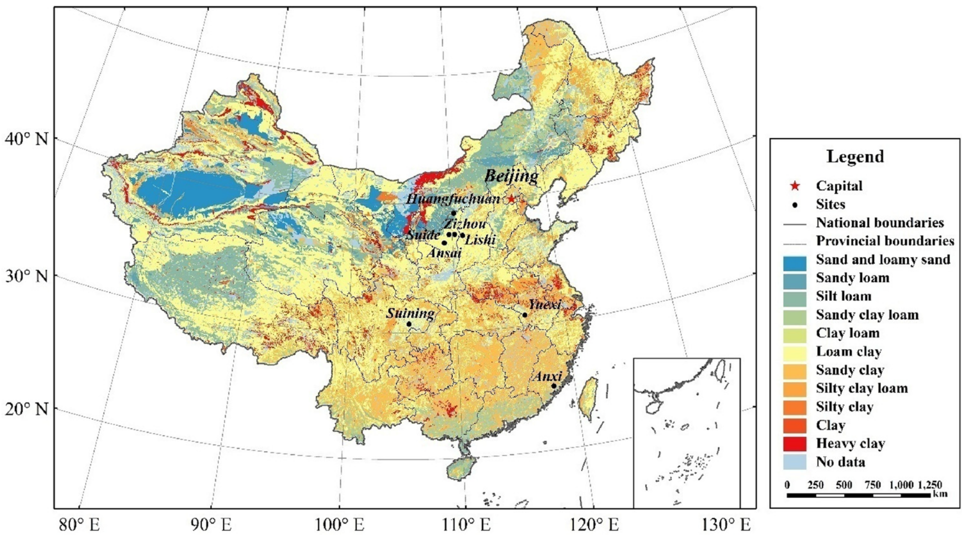

Fig. 1. Soil map of China using the International Soil Texture System (ISSS).

Boersma's (1984) formula using only the soil geometric mean diameter (K_{Dg}) to estimate the K factor. On the basis of these results, the K factor can generally be estimated using a nomograph supplemented with Williams's calculator and the Shirazi formula anywhere that a soil database is available. However, it is not sufficient to derive USLE/RUSLE to directly predict soil loss depending on the methods in many countries because the K factor is strongly conditioned on the climate and cropping system (Wang et al., 2001; Sanchis et al., 2010; Borselli et al., 2012; Kinnell, 2015). For these reasons, much effort is necessary to corroborate whether the estimated K factor from a nomograph, EPIC model or Shinrzi formula is applicable using local plot data before its use in a model to predict soil loss. For this purpose, Zhang et al. (2008, 2016) compared the values of K factors estimated using nomographs, the EPIC model and Shinazi's formula with that calculated using data from field plots in China. The results showed that direct application of the above-mentioned three K factor calculation methods in China will lead to overestimation (Zhang et al., 2008, 2016). Moreover, similar results have also been reported by many researchers in other countries and regions, such as Iran (Vaezi et al., 2008; Ayoubi et al., 2018), Ghana (Veihe, 2002), Algeria (Kamel et al., 2018), Iraq (Hussein et al., 2007), Central Europe (Auerswald et al., 2014), Southeast Poland (Rejman et al., 1998) and the United States (Wang et al., 2001). These findings imply that the methods and formulas for soil erodibility estimation based on the database of plots in the US might not be suitable for areas outside the US. It is essential to rectify and adjust the estimated K factor using nomographs or the EPIC model with local plot data before USLE/RUSLE is applied to predict soil loss; otherwise, large errors will result.

To derive USLE models in China, Zhang et al. (2008) conducted a series of investigations of K factor estimation. The findings showed that the K values from nomographs (K_{nomo}), the EPIC calculator (K_{epic}) and the Shirazi formula (K_{Dg}) all were biased but that it was feasible to use the estimated values to correct matching data from field plots using linear regressions, which means that although all the formulas mentioned above are not directly applicable in China, the estimated K factor can be used to predict soil loss in models after they are calibrated. In addition, it was also demonstrated that the calibrated K was the closest to the K value calculated from plot data when the average of the corrected K_{nomo}, K_{epic}, and K_{Dg} results was used to recalibrate K.

As required by the K_{nomo} method, soil permeability information is needed. Unfortunately, this information is usually unavailable in data-sparse regions of China. An alternative method proposed by Zhang et al. (2008) is to construct an estimator using only the K_{epic} and K_{Dg} results. This may allow the soil erodibility over China to be estimated based on the soil texture and organic matter information, which is required in the K_{epic} and the K_{Dg} calculations. Several successful researches had calculated soil erodibility based on survey datasets in national scale and region scale using GIS and RS (Panagos et al., 2014; Rammahi and Khassaf, 2018). Panagos et al. (2014) developed a soil erodibility map based on remote sense and LUCAS dataset in Europe. To map soil erosion risk in Lebanon, Kheir et al. (2006) defined erobility of soil and rock except urban land and divided it into three classes, then draw an erodibility map.

As a continuous study, we will investigate the feasibility of combining the K_{epic} and K_{Dg} methods to provide accurate estimation of K factors in China, construct a national database of K factors using our calculator based on the data from the Second National Soil Survey, and produce a national K factor map. The Chinese database and K factor maps suggested in the paper will not only support national soil loss surveys in China but also aid soil degradation evaluation worldwide.

2. Materials and methods

2.1. Soil erosion data and the measured K factor

The soil erosion or the soil loss data were collected from field runoff plots with 15° at 8 sites that represent the three main water erosion regions of China, Loess Plateau, Red soil Region and Purple Soil Region (Fig. 1 and Table 1). The plots are distributed across a wide range of climatic regions and soil types. The data from plots at 8 sites were used to verify the feasibility of K_{nomo}, K_{epic}, and K_{Dg} in China and to establish a calculator appropriate for agricultural soils in China. And then, the calculator was used to estimate the K factor for soils over the China based on soil property data from the Second National Soil Survey. In our previous studies, 13 sites in total were selected to determine K factor and verify the errors from model estimation. We found that the errors were very small when nomograph was used to estimate K factor in black soil region of northeast China. Hence, we suggested that K factor of soils in northeast region could be directly calculated via the formula in USLE. The data sites located in northeast region were not pooled to establish the calculator in this paper. The duration of the observations varies from 3 to 10 years. More detailed descriptions of the properties of these plots can be found in Zhang et al. (2008) and Table 1.

The K factor in the USLE is defined as:

$$K = \frac{A}{RLSCP} \tag{1}$$