Geoderma 284 (2016) 13–21

Contents lists available at ScienceDirect

Geoderma

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

Determination of soil erodibility using fluid energy method and measurement of the eroded mass

Derege Tsegaye Meshesha [a,*], Atsushi Tsunekawa [b], Nigussie Haregeweyn [b,c]

[a] Institute of Disaster Risk Management and Food Security Studies, Bahir dar University, Ethiopia
[b] Arid Land Research Centre, Tottori University, 1390 Hamasaka, Tottori 680-0001, Japan
[c] International Platform for Dryland Research and Education, Tottori University, 1390 Hamasaka, Tottori 680-0001, Japan

ARTICLE INFO

Article history:
Received 10 August 2015
Received in revised form 2 August 2016
Accepted 7 August 2016
Available online xxxx

Keywords:
Arid region
Erosivity
Soil treatment
Soil water content
Suspended sediment concentration

ABSTRACT

The resistance of soil to erosional processes, especially in hillslopes is generally well recognized and documented in many researches, however, the full implications of tillage (soil disturbance) and slope degree on erodibility of a soil are not considered and well investigated. Thus, in this paper we particularly examined the impact of tillage (soil disturbance) and surface slope on the erodibility of four types of soils (Masa, Oxisols, Andosols, Sand soil), and determined their thresholds of soil water content (SWC) and erosivity that initiate soil erosion. The soil samples were obtained in disturbed form, where the natural conditions of the soils such as structure, density and shear strength were changed. Hence, systematic compaction (soil pressing) treatment was carried out for a couple of months with the concept that the treated soil will be a surrogate of the soil at field condition (untilled-fallow soil) and the disturbed soil represents the soil in its tilled condition. We used dripper type of rainfall simulator to generate runoff and the suspended sediment concentration (SSC) in the runoff was measured using optical backscatter sensor, and the infiltration rate was measured with Mini disk portable tension infiltrometer. We used optical disdrometer under simulated rainfall to measure raindrop size, splash kinetic energy and erosivity of rain events; thereby, we applied fluid energy method to determine erodibility of different soils. The results revealed that both in disturbed and treated conditions, erodibility of Oxisols was the highest followed by Andosols, Masa and Sand soil. After the treatment, erodibility and threshold of SWC significantly decreased in most of the soils while their threshold of erosivity increased; and this implies that the treated soils had better resistance to erosion than disturbed soils. Slope had also notable impact on erodibility (t ha h/MJ mm ha) of all soils, where the measured soil erodibility varied from 0.08 to 0.21 in the gentlest slope (5.2°) and from 0.21 to 0.49 for the steepest slope (35.3°). Particularly, the erodibility of Oxisols and Andosols showed a remarkable increase in the steeper slope. Furthermore, the finding showed that erodibility, thresholds of SWC (%) and erosivity were different for different soils considered in the study. Masa soil had the lowest threshold of SWC and erosivity to initiate erosion followed by Sand soil, Oxisols and Andosols. In general, the treated soils had lower erodibility than the disturbed soil. The erodibility of all soils increased with slope, however, Oxisols and Andosols showed a significant increase towards higher slope degree. Thus, tilling steep slope areas of the latter two soils might cause significant erosion and soil loss due to their substantial increase in erodibility towards higher slope.

1. Introduction

Soil erosion is a two-phase process, which involves detachment of soil particles from the soil mass and their transport by erosive agents such as running water or runoff (Morgan, 2005). Originally, the terms erosivity and erodibility were associated with the R and K factors, respectively, in the Universal Soil Loss Equation (Wischmeier and Smith, 1958). Erodibility is an indicator of the resistance of the soil to both detachment and transport, while erosivity is the ability of rain to cause erosion (Renard et al., 1997). The soil's resistance to erosion is largely dependent on topography (LS factor) where the soil is located, amount of disturbance (tillage) and chemical and physical properties of the soil, such as soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content (Singh and Khera, 2009; David et al., 2003).

Many attempts have been made to develop a simple index of erodibility either based on the properties of the soil which is determined in the laboratory or in the field, or from the response of the soil to rainfall (Loch et al., 2001; Zhang et al., 2008). However, the most widely used methods are Wischmeier and Smith's K nomograph and related empirical equations. In some studies, soil color has been used to determine K-values but it is relatively less accurate as compared to other methods (Hellden, 1987; Hurni, 1985; Meshesha et al., 2012). The nomograph

* Corresponding author.
E-mail address: deremesh@yahoo.com (D.T. Meshesha).

http://dx.doi.org/10.1016/j.geoderma.2016.08.006
0016-7061/

based *K*-value, which represents the soil loss per unit of erosivity value (EI_{30}) as measured in the field plot of 22 m long and at 9% slope, can be empirically estimated if grain-size distribution, organic content, structure and permeability of the soil are known (Wischmeier et al., 1971). However, usually poor prediction of K-value is obtained when nomograph is applied to soils which have different characteristics with those soils in the USA. In such cases, the nomograph based K-value either overestimates or underestimates the actual erodibility value of the soil.

Theoretically, erodibility is the ratio of soil loss (t ha h) per unit of rainfall erosivity (MJ mm ha^{-1} h^{-1}). Thus, reasonable estimates of K-values (t ha h/MJ mm ha) can be computed from the total soil loss per total rainfall energy and intensity during the erosion phenomena (Wischmeier and Smith, 1978). Nevertheless, such approach of K-value measurement requires full understanding of rainfall characteristics such as, raindrop size distribution (mass), terminal velocity and maximum intensity of the rainfall in specific time interval. In line with this, the erosive power of a given rain, which can detach and transport soil particles, depends on rainfall characteristics (Grismer, 2011; Copeland and Foltz, 2009). Because the direct measurement of soil erodibility is costly and time consuming, more efforts have been made to empirically predict it from the soil physical and chemical properties. However, determining K-value without field measurement (e.g. using nomograph), does not enable to understand the relationship between several topographical (e.g. slope) and human factors (e.g. tillage) with soil erodibility.

Thus, even though the importance of soil erodibility or the resistance of soil to erosion processes is well studied by different researchers (e.g. Bagarello and Ferro (2010), Copeland and Foltz (2009), Grismer (2011), Sanguesa et al. (2010), Zhang et al. (2008), the acute influence of topographic factors (slope) and soil-tillage on erodibility, as well as, thresholds of erosivity (minimum rainfall energy/erosivity required to initiate erosion) and soil water content (minimum soil moisture required to initiate erosion) were not investigated and understood. Thereby, in most of previous researches (Zhang et al., 2008) it is assumed that erodibility is solely a function of soils' inherent (physical and chemical) properties, and thus, external entities such as slope and tillage were not considered as factors that affect erodibility of a given soil. Therefore, this study was conducted to assess the erodibility extent and thresholds of different soils using raindrop energy and measurement of eroded mass. The specific objectives were to: 1) evaluate the erodibility variation among soils of different properties; 2) examine the impact of disturbance (tillage) and slope on the erodibility of a given soil, and 3) determine thresholds of erosivity and SWC of different soils.

2. Materials and methods

2.1. Review of soil erodibility measurement techniques

There are several approaches to determine soil erodibility (K-value) in water erosion process, which can be summarized as use of field erosion plot, scouring experiment, empirical equations using physical and chemical properties of soil, and simulated rainstorm (Song et al., 2003).

Field erosion plots enable measurement of K under field conditions. It is carried out in the standard condition of bare soil using a plot of a certain length and slope, with continuous tillage in up and downslope and no conservation practice on it (Bagarello and Ferro, 2010). This approach is costly and time consuming so it deters researches from conducting such experiment.

In the scouring method, soil erodibility is directly measured from soil loss in scoured water. However, Gussak (1946) noted that this method doesn't show or explain the effect of topography and soil tillage on erosion.

Since the 1950s, *K* value has been predicted using experimental equations describing relationships between *K* and soil chemical and physical properties. The nomograph developed by Wischmeier and Smith (1978) calculates soil erodibility based on relationship between *K* and soil properties using the following equation.

$$100 K=2.1 x 104 x (2-OM) x m1.14+3.25 x (St-2)+2.5 x (Pt-3) \quad (1)$$

Where OM = Organic matter content (%), M = Silt plus fine sand content (%), St = Soil structure code (very fine granular = 1, fine granular = 2, coarse granular = 3, blocky, platy or massive = 4), Pt =

Fig. 1. Procedure of erodibility measurement using fluid energy method; setup of soil tank (soil exposure to rain) and runoff collector (a), SSC measurement using optical backscatter sensor (b), change soil sample (c) and runoff depth measurement (d).