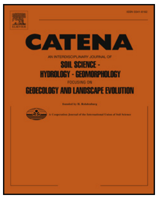
Catena 167 (2018) 385–398

Contents lists available at ScienceDirect

Catena

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



Interrill erodibility in relation to aggregate size class in a semi-arid soil under simulated rainfalls

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ARTICLE INFO

Keywords:
Aggregate stability
Interrill erosion
Rainfall intensity
Saturated hydraulic conductivity
Semi-arid region

ABSTRACT

Interrill erodibility can be affected by soil aggregates, especially by those aggregate size classes that are dominant in the soil. In the Water erosion Prediction Project (WEPP) model, interrill soil erodibility (K_i) is estimated using very fine sand content. Despite that some studies have indicated an effect of aggregate stability on the K_i, information on the relationship between the aggregate size class and K_i and factors controlling it, particularly in semi-arid region is limited. This study was conducted to determine the variation of K_i for different aggregate size classes under various rainfall intensities and evaluation of the WEPP model in estimating the K_i for different aggregate fractions. Five aggregate size classes (0.25–2, 2–4.75, 4.75–5.6, 5.6–9.75 mm, and 9.75–12.7 mm) were separated from a sandy clay loam soil sampled in an agricultural land and put in laboratory flumes of 100 cm × 50 cm. The flumes were placed on a 9% slope and exposed to ten sequential rainfall simulations varying from 10 to 60 mm h^{-1} for 30 min. The K_i of each aggregate size classes was determined using the interrill sediment delivery rate and compared this with the values estimated using WEPP. All physico-chemical properties were also determined in the aggregate size classes. Organic matter content in the aggregate size classes was very low (0.65–0.73%) and didn't show strong relationships with the aggregate stability and hydraulic conductivity, whereas clay was major factor controlling determining these properties for the different aggregate fractions. Significant differences were found among the aggregate size classes in clay content ($P < 0.05$), aggregate stability measured using both wet-sieving method ($P < 0.05$) and water drop test method $P < 0.05$, saturated hydraulic conductivity (K_s), and measured K_i ($P < 0.05$). The measured K_i was about 34 and 90 times bigger than the estimated K_i for the fine aggregates and coarse aggregates, respectively. The fine aggregates showed higher susceptibility to interrill detachment with increasing rainfall intensity as compared with the coarse aggregates. Significant decrease was observed in the measured K_i with increasing the aggregate size which was associated with increases in clay content, aggregate stability and K_s. The stability of aggregates against raindrop impact (CND) was an important indicator describing the effect of aggregate size on the interrill erodibility in semi-arid soils. Therefore, this indicator can be taken into account as a soil structure measure to develop a proper equation for estimating interrill erodibility (K_i) for agricultural lands. The minimum use of tillage practices is essential to prevent aggregate breakdown and control interrill erosion in semi-arid regions.

1. Introduction

Soil erosion is a global environmental crisis in the world of today that threatens the natural environment and agriculture (Manyevere et al., 2016; Wang et al., 2016b). Soil erosion by water is the main factor of land degradation, particularly in semi-arid agricultural areas where soil productivity is usually low and reduced soil quality can severely decrease crops yields (Cantón et al., 2011; Ochoa et al., 2016; Vaezi and Bahrami, 2014). Moreover inappropriate agricultural practices cause soils to be more and more exposed to erosion processes (Cerdà et al., 2016; Keesstra et al., 2016; Vaezi et al., 2017b) such as soil detachability and transportability (Saygın et al., 2011). So, soil structure is often unstable and is easily destroyed by the force of raindrop impact resulting in small individual soil particles (Vaezi et al., 2017b). In this way, aggregates and their stability influence a wide range of soil properties, including soil porosity, water infiltration, aeration, compaction, soil sealing, water retention, hydraulic conductivity and the resistance to water erosion (Cheng et al., 2015; Dıaz-

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https://doi.org/10.1016/j.catena.2018.05.003
Received 29 April 2017; Received in revised form 18 March 2018; Accepted 5 May 2018

Zorita et al., 2002; Pulido Moncada et al., 2015) and soil productivity and agricultural sustainability (Bronick and Lal, 2005). It is important to understand the role of structure to soil's resistance in water erosion and its relationship to other important soil properties, such as organic matter storage, porosity, water retention and hydraulic conductivity.

Soil aggregates can be evaluated by determining the extent of aggregation, the stability of the aggregates, and the characteristics of the pore space. Generally, the size distribution and stability of soil aggregates positively correlates with the main cementing agents, such as organic matter, clay minerals, multi-valent cations and their complex within the soil aggregates. According to the hierarchical theory of aggregate formation, these materials may be distributed unevenly in different size fractions of soil aggregates, and they may have close relationships with the stability of soil aggregates (Tisdall and Oades, 1982). While in many studies, tillage has been found to cause higher susceptibility of disrupted soil structure (Du et al., 2013; Kumar et al., 2014; Wang et al., 2016b), important interrelationships have been found between structural characteristics and inherent soil properties, including particle size distribution (PSD), organic matter (OM), lime, and exchangeable sodium percentage (ESP) (Apesteguía et al., 2015; Vaezi, 2014).

The size and stability of aggregates determine the soil's susceptibility to water erosion processes (Barthes and Roose, 2002; Cerdà, 2001; Dıaz-Zorita et al., 2002). Soil aggregation has been recognized as a key element in the stabilization of soil organic matter (Chaplot and Cooper, 2015) as organic matter associated with macro-aggregates is better protected against mineralization and leaching than organic matter not associated with small aggregates (Urbanek and Horn, 2006). The soil's resistance to water erosion processes can be assessed by the soil erodibility index. The soil erodibility is conceived of as the ease with which the soil is detached by splash during rainfall and/or overland flow (Renard et al., 1997). It is strongly dependent on the physicochemical soil properties, including PSD (Rachman et al., 2003), structural characteristics (Bronick and Lal, 2005), infiltration rate (Zehetner and Miller, 2006), OM (Rodríguez et al., 2006), lime (Imeson and Verstraten, 2005), and ESP (Bonilla and Johnson, 2012). Among the many factors affecting soil susceptibility to erosion and runoff, soil structure and the stability of aggregates are of principal importance (Fristensky and Grismer, 2009). The importance of soil structure in the erodibility was previously emphasized in the Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978). Based on the USLE, the soil erodibility factor (K) is the soil susceptibility to erosion by sheet, interrill and rill erosion. Management of soil structure and aggregate properties is essential to optimizing porosity, infiltration rate, soil water retention, soil water characteristics, and plant-available-water (Jastrow and Miller, 1991).

Interrill erosion is one of dominant types of soil loss in agricultural lands (Koiter et al., 2017; Meyer and Harmon, 1984). In this erosion soil particle detachment occurs by water raindrop impact on the soil surface and soil particle transportation by overland broad sheet flow is enhanced by the flow turbulence (Foster et al., 1985; Romero et al., 2007). Interrill soil erodibility represents the soil susceptibility to detachment by raindrops and transport by overland flow. The Water Erosion Prediction Project (WEPP) is a physically based model that predicts soil loss and deposition using a spatially and temporally distributed approach (Flanagan and Nearing, 1995; Nearing et al., 1989). In the original WEPP proposal, interrill erosion was related with rainfall intensity, slope factor and interrill soil erodibility (Elliot et al., 1989). In this model it is assumed that the interrill erodibility factor is an intrinsic soil property and that soil loss from a slope with a length of < 0.5 m is caused by interrill erosion (Meyer and Harmon, 1984). Laboratory rainfall simulators experiments on disturbed soil samples are often used to study fundamental interrill erosion processes and relate soil physical and chemical properties with soil erodibility (e.g., Fu et al., 2011; Le Bissonnais and Singer, 1993; Mahmoodabadi and Cerdà, 2013; Mirzaee et al., 2017; Vaezi et al., 2016). In addition to cost and time savings when compared to field measurements advantages of the laboratory rainfall simulations include better control of the test environment to facilitate the study of individual erosion processes (Ben-Hur and Agassi, 1997).

Knowledge of soil erodibility is an essential requirement for understanding human impacts on soil properties (aggregate size etc.) and thus on soil and water losses from agricultural areas (Brevik et al., 2015; Cerdà and Doerr, 2007). In various studies, the dependency of interrill erodibility on different soil properties such as PSD (Merzouk and Blake, 1991; Romero et al., 2007), organic matter (Bajracharya et al., 1992), sodium cation (Mamedov et al., 2002), water retention, initial water content (Rienzi et al., 2013), rock fragments (Cerdà, 2001) and surface soil conditions like surface crusting (Darboux et al., 2008) has been well known. Tillage is also major factor influencing breakdown of soil aggregates, surface sealing, runoff production and interrill erosion in agricultural areas (Chaplot and Le Bissonnais, 2003). Soil structure plays an important role in the susceptibility of a soil to interrill erosion processes. This soil physical property is often measured by the stability of soil aggregates (Bronick and Lal, 2005; Six et al., 2002). In some studies, the role of aggregate stability in the interrill erodibility has been investigated (Darboux et al., 2008; Valmis et al., 2005). The large differences in aggregate stability imply large differences in soil interrill erodibility (Algayer et al., 2014). Various aggregate fractions can be found in the soil which appears to have a different stability against external factors such as water erosion. In some studies, it has been noted that the larger aggregates enhance pore size, infiltration and/or provide depressions for water and thus allow more time for infiltration and subsequent delay of runoff generation (Braunack and Dexter, 1989; Lipiec et al., 2007). The percentage of each aggregate fraction in agricultural land would be influenced by different factors such as tillage. The abundance of water-stable aggregates at the soil surface determines the potential for sheet erosion and crust formation (Shouse et al., 1990). With an increasing in crust formation at the soil surface, the potential of soil to runoff production and sheet erosion increases (Maïga-Yaleu et al., 2015) and influence directly on the loss of organic carbon and soil nutrients (Mutema et al., 2015; Müller-Nedebock et al., 2016).

Measurement of the susceptibility of soil's aggregate fractions to water erosion can provide benefit information on the soil erodibility against water erosion. So, with the determination of dominant aggregate fractions in the soil after agricultural practices, the soil's susceptibility to water erosion can be evaluated. In spite of the importance of soil aggregation and its relation to soil erodibility, there is no information on the effect of aggregate size class on the interrill soil erodibility, particularly in semi-arid areas. Approximately 40% of the world's land surface and about two-third of the land surface of Iran (approximately a million km^2) is classified as arid or semi-arid regions (Vaezi et al., 2017a). In these regions, soils are weakly aggregated, especially under intensive agricultural practices (Cantón et al., 2009; Ochoa et al., 2016), resulting in the formation of crust at the soil surface and increasing runoff and soil erosion rates. Soils are very susceptible to water erosion processes and water erosion rate is more than arid to humid regions (Mutema et al., 2015). Determination of relationship between interrill soil erodibility and aggregate size can shed light on the importance of agricultural practices on the deterioration of soil structure, as well as in increasing interrill soil erodibility in semi-arid regions. In these areas, agricultural soils are often calcareous and have low amount of organic matter with unstable aggregates (Vaezi et al., 2008). Agricultural practices such as tillage, irrigation and fertilization affect soil structure and other physical properties through their impact on destruction forces and aggregate forming processes (Vaezi et al., 2008). Many studies showed that conventional tillage disrupts macro-aggregates and formerly incorporated organic carbon is exposed to microbial decomposition (Tan et al., 2007; Zotarelli et al., 2007). In agreement with this, Jacobs et al. (2009) found for long-term agricultural field experiments a decrease of macro-aggregate contents