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Splash erosion potential under tree canopies in subtropical SE China

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ABSTRACT

Sand-filled splash cups were used to study the erosivity of rainfall and throughfall in the humid subtropics of southeast China. Our results showed that the splash cup measurements yielded precise and reproducible results both under open field conditions and under forest vegetation. The splash cups were exposed to forest stands of different age and to selected species (*Schima superba*, *Castanopsis eyrei*) in the Gutianshan National Nature Reserve (GNNR). The measurements in the open field revealed a close relationship between unit sand loss (g m^{-2}), rainfall amount (mm) ($R^2=0.94$) and maximum rainfall intensity (mm h^{-1}) ($R^2=0.90$). The highest correlation was obtained between unit sand loss (g m^{-2}) and the average of the five highest five minute interval rainfall intensities (mm h^{-1}) ($R^2=0.96$). This underlines the reliability of the splash cups used.

The best results on the relationship between variables related to precipitation and sand loss were obtained with the Vaisala sensor compared to a standard tipping-bucket rain gauge. This is mainly due to the fact that the drop impact-based Vaisala sensor (0.8–5.0 mm drops are recorded assuming their terminal velocity) does not measure drops with low kinetic energy, whereas drop size distribution plays no role for the measurements with the tipping-bucket rain gauge.

The results obtained under forest vegetation show that the erosive power of throughfall drops is 2.59 times higher compared to the open field, which accentuates the importance of shrub, herb and litter layers in forest ecosystems to protect the soil against erosion. Coalescing drops from leaves and branches (drips) are responsible for this enormous gain in erosive power. Moreover, the results show that the erosion potential under forest is related to the forest structure, especially height and canopy cover. The erosion potential of medium and old grown forests is 1.53 times higher than of young forests.

Further, differences in sand loss between *Schima superba* and *Castanopsis eyrei* indicate that the erosion potential and the spatial heterogeneity of throughfall is species-specific, highlighting the importance of selecting species for afforestation projects considering soil erosion potential.

1. Introduction

1.1. Forest vegetation controls on erosion

In soil erosion research it is widely accepted that vegetation is a key control for the type and intensity of erosion (e.g. Hudson, 1971; Wiersum, 1985; Thornes, 1990; Morgan, 2005). The controls of vegetation on erosion processes do not only tackle soil erosion on a single agricultural field but also link to landscape evolution and landforms on a regional scale (Kirkby, 1995; Bork and Lang, 2003). The current paradigm is that natural or quasi-natural vegetation protects the soil against erosion while agricultural land use generally enhances erosion. Most of the work during the past decades focused on the latter and less attention was paid to natural systems, which are difficult to study (Collins et al., 2004; Istanbulluoglu and Bras, 2005). Nevertheless, afforestation is widely used as a measure of soil protection against soil erosion.

Contrary to these findings, Zhou et al. (1999) and Cao (2008) could not confirm the positive effect of afforestation on erosion control. Runoff shows significant seasonal variations and tends to increase very fast if the canopy cover is thinning out due to leaf fall or low stand density. Recent findings from forest experiments in Japan underpin the latter. Forest stand density and management control soil loss largely, especially in forest plantations on slopes (Miura et al., 2002; Razafindrabe et al., 2010). Further, leaf exudates and low sunlight in dense forest plantation often result in bare ground and lack of a shrub or herb layer (Tsukamoto, 1991; Zhao, 2006; Nanko et al., 2008). In such places, the infiltration rate decreases and runoff occurs quite easily (Tsujimura et al., 2006).

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1.2. Splash erosion measurement techniques

In literature several methods for measuring splash erosion in the field are reported. Most of the methods are designed to measure the amount of soil splashed from the soil surface to a target. These include splash boards (Ellison, 1944), field splash cups (Morgan, 1978) and splash boxes (Van Dijk et al., 2003). The objective of these methods is to draw conclusions about the current soil loss under controlled conditions, which has been shown by several studies (e.g. Morgan, 1978; Salles and Poesen, 2000; Legout et al., 2005). However, these methods are not appropriate for estimating differences in kinetic energy of rainfall or throughfall as the results are confounded by the erodibility of the soil. This means that the soil properties at the soil surface would have to be controlled for, if using such a type of measurement for estimating kinetic energy of precipitation.

Other methods are designed to measure the erodibility of different soil material or standardized sediment by placing it into a unit cup and determine a difference in weight before and after a rainfall event. In most studies the sediment splashed out of a cup is measured. Splash cups were first introduced by Ellison (1947). Several researchers applied this method with few modifications of e.g. the diameter of the cup or of the material used (Poesen and Torri, 1988; Salles and Poesen, 2000; Cornelis et al., 2004; Erpul et al., 2005).

When using small sized cups the rim-effect (Bisal, 1950; Hudson, 1965) should be taken into account and bigger sized cups are supposed to better reflect the mean erosivity per unit area (Poesen and Torri, 1988; Van Dijk et al., 2003). The rim-effect is a result of a lowering of the sand surface in relation to the solid rim of the cup. The lower the sand surface inside the cup, the less sand will be detached from the cup. Moreover, Kinnell (1974) states that excess water on the sand surface could lead to an initial "wash-off" of sand out of the cup.

1.3. Drop formation by forest canopies and its measurement

Based on Chapman (1948), throughfall in forests shows higher erosivity compared to open field rainfall. Measurements were made in several regions of the world with different methods confirming Chapman's findings. For example Ovington (1954) in Great Britain, Tsukamoto (1966) in Japan, Mosley (1982) in New Zealand, Vis (1986) in Colombia, Brandt (1987, 1988) in Brazil, Hall and Calder (1993) in India, Brooks (1995) in Malaysia and more recently Nanko et al. (2004, 2008) in Japan. Key mechanisms of a forest vegetation cover in reducing or enhancing erosion are the modification of drop size distribution, retention of raindrop impact on the soil and changes in amount and spatial distribution of rainfall at the ground surface. Controlling determinants are rainfall intensity, drop size distribution, drop fall velocity, height and density of the canopy, crown and leaf traits, leaf area index and litter cover of the soil (Chapman, 1948; Mosley, 1982; Wiersum, 1985; Vis, 1986; Brandt, 1989; Hall and Calder, 1993; Park and Cameron, 2008). However, the mechanisms reducing or enhancing splash detachment under different types of vegetation, especially secondary shrub land and forest, are not well understood. Some studies indicate that raindrop impact is species specific (Calder, 2001; Nanko et al., 2006; Roldan and Fernandez, 2006) and some neglect the effects of species specific impacts (Brandt, 1989; Foot and Morgan, 2005). The methods applied for measuring erosive power of throughfall under vegetation were originally designed for studying properties of open field rainfall comprising the paper stain method (Wiesner, 1895), the flour pellet technique (Bentley, 1904) and laser disdrometers (Hall and Calder, 1993; Nanko et al., 2008). Except laser disdrometers these techniques were not able to determine species specific change in throughfall characteristics. They show a lack of temporal continuity as they only represent a very short time span of a rainfall event (Nanko et al., 2008). The advantage of disdrometers is to measure rainfall events without interrupts. However, the number of replications is limited because of high technical and financial demands. Taking into account these limitations, Mosley (1982) in New Zealand and Vis (1986) in Colombia used splash cups for estimating throughfall erosivity successfully. The major advantage of splash cups is their easy handling and the high number of replications that can be obtained at reasonable costs.

1.4. Objectives

This paper focuses on the application of sand-filled splash cups to study rainfall and throughfall erosivity in natural systems. In contrast to highly sophisticated and expensive techniques like laser disdrometers, splash cups allow a high number of replications and are easy to handle in mountainous and remote areas. The main objective of this study is to show that splash cups are an appropriate method for comparing erosivity of both rainfall and throughfall. Further objectives are:

(a) to show the performance of the splash cups by open field measurements
(b) to compare rainfall and throughfall erosivity in a natural forest ecosystem (regardless of the actual soil properties)
(c) to study the differences in throughfall erosivity between successional stages
(d) to test for a tree species specific effect on throughfall erosivity

2. Materials and methods

2.1. Study site

This study was conducted in the Gutianshan National Nature Reserve (GNNR), Zhejiang Province, PR China. The centre of the GNNR is located at N 29°14.657′ and E 118°06.805′ and covers an area of 81 km^2. The elevation ranges between 320 m and 910 m above sea level. The soils are predominantly Cambisols (cf. IUSS Working Group WRB, 2007) developed on granite or on saprolite. The climate at the GNNR is typical of subtropical monsoon regions with an annual average temperature of 15.1 °C and a mean annual rainfall of 1963.7 mm (Hu and Yu, 2008) (Fig. 1). The forest in the GNNR is extraordinary rich in species (Hu and Yu, 2008; Bruelheide et al.,

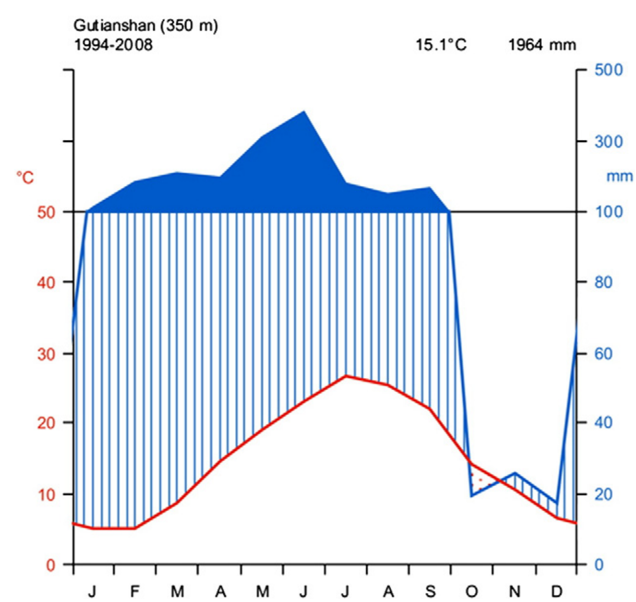

Fig. 1. Walter and Lieth climate diagram of monthly average temperature (red solid line) and precipitation (blue solid line) at Gutianshan National Nature Reserve (GNNR). Vertical area indicates moist season, dotted area indicates dry season.