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Throughfall kinetic energy in young subtropical forests: Investigation on tree species richness effects and spatial variability

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ABSTRACT

Soil erosion threatens ecosystem functioning by reducing soil organic carbon stocks or relocating nutrients. A common measure to protect soil against erosion is afforestation. There is growing evidence that mixed-species forest stands have beneficial effects on ecosystem functions (growth rates, nutrient cycling). In addition, species-rich forests tend to have higher and denser crown cover and thus might affect soil erosion. This study investigated the role of tree species richness on throughfall kinetic energy (TKE) as an important part of the soil erosion process and examined the spatial variability of TKE in mixed-species forest stands.

The research was conducted within BEF-China, a large-scale forest biodiversity experiment in subtropical China. In summer 2013, 1800 TKE measurements were carried out during five rainfall events. TKE was measured using splash cups and related to tree height, crown base height, number of branches, leaf area index, stem ground diameter and crown area.

Our experiment showed that TKE was not influenced by tree species richness at the plot level. This is likely due to the young age of the experimental forest where a dense and high tree canopy has not yet been developed. However, TKE was influenced by neighborhood tree species richness indicating that tree species richness only affected TKE on a small spatial scale within the direct neighborhood in young forests.

TKE showed distinct spatial variability. Directly below the first branch of the tree individuals TKE was lowest (430 J/m^2) while it was highest in the middle of four tree individuals (556 J/m^2). Mean freefall kinetic energy (FKE) was 480 J/m^2. Lower TKE below the first branch than FKE can be attributed to low rain drop velocities due to short falling heights. Higher TKE in the middle of four tree individuals than FKE can be ascribed to a larger crown area on which drops can confluence resulting in an increase of drop mass. Furthermore, TKE was positively affected by the number of influencing tree individuals with a 13% increase of TKE from one to four influencing tree individuals. However, further investigation on TKE below mature trees and dense canopies is needed to confirm our findings for later successional stages.

1. Introduction

Soil erosion threatens ecosystem functioning by reducing soil organic carbon stocks, relocating nutrients and reducing the species diversity of plants, animals and microbes (Pimentel, 2006; Pimentel and Kounang, 1998). A common measure to overcome severe soil loss is afforestation, which increases ground cover and stabilizes soil aggregates by roots. In particular, rainfall erosivity is influenced by forest canopies and crown architecture. However, little research has been conducted on this part of the soil erosion process (Geißler et al., 2013). Rainfall erosivity is the product of kinetic energy and rainfall intensity (Renard and Freimund, 1994). In forests, throughfall kinetic energy (TKE) is a widely used measure to describe the power of raindrops to erode soil. Main determinants controlling

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TKE in forests are abiotic factors, such as rainfall amount, drop size distribution and drop fall velocity as well as biotic factors, such as tree height and density of the canopy, crown cover, leaf traits, leaf area index and branch architecture (Cao et al., 2008; Geißler et al., 2012b; Gómez et al., 2001; Hall and Calder, 1993; Herwitz, 1987; Nanko et al., 2008; Staelens et al., 2008; Tsukamoto, 1966). For instance, higher crown cover and density can alter TKE by creating slower, but larger rain drops and additionally change throughfall amount. These transformation processes can lead to higher TKE in forests than in open field (Geißler et al., 2012a; Nanko et al., 2004), yet this might be detected only in advanced succession (Geißler et al., 2010). A higher TKE than freefall kinetic energy (FKE) can be attributed to a drop size increase by confluence of drops on leafs and branches with different drop growth mechanisms under varying vegetation types (Nanko et al., 2013). However, the influence of drop velocity on an increasing TKE varies. While small drops can reach their terminal velocity at heights of only 0.3 m, large drops (>3 mm) need a detachment height of more than 13 m (de Moraes Frasson and Krajewski, 2011). This effect on drop velocity means young forests (<13 mm) can alternatively have lower TKE than FKE due to slower large drops.

Most often, afforestation takes place by the establishment of easily manageable monocultures. Besides the increase of timber, fuel and pulp wood production, the reduction of atmospheric CO_2 by carbon sequestration in forest soils, or the stabilization of regional climate conditions (Dixon and Wisniewski, 1995; Houghton et al., 2012), erosion control is also a driving factor. However, TKE as main driver of the erosion process is highly species-specific. For instance, TKE below *Castanea henryi* and *Quercus serrata* was higher than that of *Schima superba*, *Elaeocarpus decipiens* and their mixture (Geißler et al., 2012b). These distinctions can be attributed to species-specific differences regarding the number of branches and the angle of the first branch. Branches transfer throughfall water laterally and release it as indirect throughfall (André et al., 2011). In addition, even within a monoculture below a single tree, TKE is spatially variable (Clements, 1971; Staelens et al., 2008; Stout and McMahon, 1961). Nanko et al. (2011) showed a distance to stem effect, where TKE increased below a single Japanese cypress *Chamaecyparis obtusa* with increasing distance to the stem. In addition, TKE under this tree species was negatively affected by canopy thickness (Nanko et al., 2008).

In recent years, monocultures have increasingly come under criticism due to their greater susceptibility to adverse environmental conditions, pathogens (Hantsch et al., 2013) or herbivores (Jactel and Brockerhoff, 2007), and their negative long-term impacts on soil fertility (Puettmann et al., 2008). There is growing evidence that mixed-species forest stands have beneficial effects on ecosystem functions and services (like growth rates, biomass production, nutrient cycling, light harvesting, plant nutrition, crown cover; Forrester et al., 2006; Forrester, 2014; Gamfeldt et al., 2013; Kelty et al., 1992; Loreau et al., 2001; Richards et al., 2010). Species-specific differences in growth and biomass allocation patterns as well as plant architecture are due to niche separation. As a result, stratified canopies with a high degree of crown overlap and, thus an increased mean vegetation cover and greater biomass density can be found in mixtures compared to monocultures (Lang et al., 2010, 2012; Menalled et al., 1998; Pretzsch, 2014). Concerning soil erosion, TKE in particular reacts strongly to these tree characteristics (Geißler et al., 2013; Nanko et al., 2006, 2008). As a consequence, tree species richness might affect soil erosion processes. However, very few studies have reported tree species richness effects on TKE. In tropical conditions, a negative correlation between plant diversity and soil erosion was found (Shrestha et al., 2010). In contrast, a positive tree diversity effect on TKE was observed in a subtropical secondary forest along a range of successional stages (Geißler et al., 2013). This effect was attributed to an increase of tree species richness and canopy height with increasing stand age. Throughfall drops are more likely to be re-intercepted by a thicker vegetation layer of different heights resulting in decreasing TKE (Geißler et al., 2013). However, TKE might be unaffected if structural biodiversity effects are leveled out by an increase of TKE with increasing stand height (Brandt, 1988; Wiersum, 1985).

Such biodiversity effects on rainfall erosivity were mostly assessed by using a plot-level approach (Geißler et al., 2013). However, in mixed-species stands it has been shown that local neighborhood interactions strongly influence individual-tree growth and architecture (Biging and Dobbertin, 1992; Getzin et al., 2008) and, hence, might affect TKE. As a consequence, spatially explicit approaches are needed to analyze the effect of biodiversity on TKE in structurally complex forest stands with a heterogeneous mixture of species at the subplot-level. As biodiversity effects become more pronounced with time (Jonsson, 2006; Marquard et al., 2009; Reich et al., 2012), most studies analyzed the relationship between biodiversity and ecosystem functions in late succession stands (Geißler et al., 2013). Hence, research on possible biodiversity effects on ecosystem functions in early succession stands is limited and it is not clear at which time those effects set in.

In this study, we present a new approach for assessing TKE in subtropical forests at an early successional stage. We investigated the influence of tree species richness as a proxy for biodiversity on TKE by making use of a high number of replicates at the plot-level. Local neighborhood tree species richness was examined at the subplot-level. Furthermore, investigations of several spatially-specific effects on TKE were combined to analyze these effects among a wide range of species. We developed a sampling design that can assess the influence of tree characteristics on TKE, for instance the distance to stem effect and the first branch effect. We analyzed how the spatial distribution of TKE is affected by different numbers of tree individuals. As TKE is higher than FKE in mature forests (Geißler et al., 2012a), we additionally compared TKE to FKE in a young forest. Our experiment includes a large species richness gradient from 1 to 24 species and thus provides more general, non-species-specific results.

With this approach, we tested three hypotheses:

(1) TKE increases with increasing tree species richness at plot and local neighborhood scale.
(2) TKE is spatially variable due to differences in tree characteristics.
(3) TKE is higher than FKE.

2. Materials and methods

2.1. Study site

The study site is located at Xingangshan, Jiangxi Province, PR China (29°08–011, E117°90–93) and is part of the “Biodiversity and Ecosystem Functioning (BEF-) China” project (Bruelheide et al., 2014) with a total size of 26.7 ha (Yang et al., 2013). Elevation of the study site ranges from 108 m to 250 m with a mean of 190 m a.s.l. Slopes range from 0 to 45°. The climate in Xingangshan is typical of subtropical summer monsoon regions with an average annual temperature of 17.4 °C and a mean annual rainfall of 1635 mm (own measurements of three years, Fig. A.1). The wet season lasts from April to August whereas winters are relatively dry.

The experimental area holds 261 plots with seven richness levels of 0–2, 4, 8, 16 and 24 tree species. Trees were planted after harvest of the previous stand in 2008. The plot size is 25.8 m × 25.8 m and 400 tree individuals were planted with a horizontal distance of 1.29 m. Species were randomly assigned to individual planting