Soil erosion potential under forest vegetation in the humid subtropics of southeast China

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Abstract
Sand-filled splash cups were used to study the erosive power 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, Daphniphyllum oldhamii, Lithocarpus glaber)* in the Gutianshan National Nature Reserve (GNNR). The results obtained under forest vegetation show that the erosive power of throughfall drops is about 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. Further, differences in sand loss between the investigated tree species (deciduous, evergreen) showed that the erosion potential and the spatial heterogeneity of throughfall is species-specific, highlighting the importance of selecting specific species for afforestation projects considering soil erosion potential.

Key Words
BEF-China, biodiversity, soil erosion, soil erosion experiment, splash cups, throughfall erosivity.

Introduction
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; Thornes 1990; Morgan 2005). The current paradigm is that natural or quasi-natural vegetation protects the soil against erosion while agricultural land use generally enhances erosion. But even severe soil erosion may take place under forest vegetation with a well developed canopy but high amounts of bare ground due to lack of a shrub or herb layer (Zhao 2006; Nanko *et al.* 2008). Especially on steep slopes relocation of litter results in a patchy distribution of plant residues and litter. Thus parts of the forest floor remain uncovered and unprotected (Tsukamoto 1991). Moreover climate change induces a shift of the precipitation regime to exceptional intense rainfall events. Key mechanisms of a vegetation cover in reducing or enhancing erosion potential 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. This study focuses on the application of sand-filled splash cups to study rainfall and throughfall erosivity in natural systems. We will show the relationship of rainfall and vegetation characteristics to the sand loss measured by splash cups.

Materials and methods
This study was conducted in the Gutianshan National Nature Reserve (GNNR), Zhejiang Province, P.R. China. The GNNR is located at N 29°14.657´and E 118°06.805´ (center). 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 with a more or less thick saprolite cover. The climate at the GNNR is typical of subtropical monsoon regions with an annual average temperature of 15.3°C and a mean annual rainfall of 1963.7 mm (Hu and Yu 2008). Rainfall data was obtained from an automatic weather station in the centre of the GNNR.

Modified splash cups
The modified splash cups have a diameter of 4.6 cm and a surface of 16.619 cm^2. They were developed based on the archetype of Ellison (1947). We measure the unit sand remaining inside the cup after single natural rainfall events. By using unit sand with distinct properties (grain size: 125-200µm) it is possible to focus on other factors such as the differing characteristics of open rainfall and throughfall (Salles and Poesen 2000) or wind effects to rain (Cornelis *et al.* 2004). Sandloss as the target variable is calculated as the difference of initial weight and resulting weight. For a detailed description and calibration results of the splash cups, see Scholten *et al.* (submitted) and Geißler *et al.* (submitted).

Experimental design
The experimental design of the splash cup measurements under vegetation consists mainly of two parts: forest stand-based and species-based. The specific forest stands were selected along a biodiversity and succession gradient. To calibrate the method a set of five splash cups (surface = 83.095 cm^2) was positioned in a pentagon next to the climate station under open field conditions. To reveal effects of single tree species on the erosivity three sets of five splash cups at a time were positioned under the target trees. A target tree represents a typical individual of one of the selected species *(Schima superba, Castanopsis eyrei, Daphniphyllum oldhamii, Lithocarpus glaber)*. The splash cups were established 1 m above ground to avoid disturbance by animals, forest floor vegetation and differing inclination of slopes. One rainfall collector (collecting area = 13.396 cm^2) was positioned per splash cup. An outlier test was applied both to the rainfall data and the splash cup measurements with standard deviation * 2 + mean as a criterion for exclusion.

Results and discussion
Simultaneous measurements under open field conditions and in forest stands of the three successional stages showed a remarkable difference of sand loss (Figure 1). Throughfall in all varies between 57% and 70% of total precipitation. The average sand loss under vegetation (44.69 g/m^2) was about 2.59 times higher than under open field conditions (17.24 g/m^2). There was a non-linear increasing sand loss with increasing successional stage: the difference between the young successional stage and the intermediate successional stage (16.71 g/m^2, factor 1.51) is much higher than between the intermediate successional stage and the old successional stage (1.45 g/m^2, factor 1.03)(Figure 2).

Figure 1. Splash cup under open field conditions (a), under forest vegetation (b).

The resulting standard deviations between the measurement replicates can be considered in two ways: (i) For open field conditions the standard deviation is much lower than for all successional stages and (ii) the difference in standard deviation between the young successional stage (average 2.29) and the intermediate successional stage (average 3.61) was much higher than between the intermediate and the old successional stage (average 3.82). The standard deviation found under two common species (*Schima superba, Castanopsis eyrei*) was much higher (average 21.12 and 34.78 respectively) than under open field conditions (average 0.84). Nevertheless, there were significant differences in splash potential represented by sand loss between *Schima superba* (55.54 g/m^2) and *Castanopsis eyrei* (42.18 g/m^2), although the average amount of throughfall was quite similar (24.77 mm for *Schima superba* and 23.22 mm for *Castanopsis eyrei*).
The erosion potential of throughfall drops in forests was considerably higher (2.59 times) than under open field conditions and the spatial variability of the erosion potential was much more diverse in forests, caused by free throughfall and drip. By placing the splash cups under certain tree species it could be demonstrated that the erosivity of throughfall depended on the species and also on the successional stage of the forest stand.

Schima superba for example generated throughfall drops of higher erosivity than *Castanopsis eyrei.* We assume that this is an effect of the larger size of the leaves which generates larger throughfall drops, particularly drip. The erosion potential is also a function of stand height because throughfall drops are much more likely to reach terminal velocity under old grown forests. Therefore we conclude that the potential of throughfall to detach soil by splash is also related to the age of the specific forest stand: young forests have the lowest and old forests the highest erosion potential. This accentuates the importance of a shrub, herb and litter layer in forest ecosystems to protect the soil against erosion.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

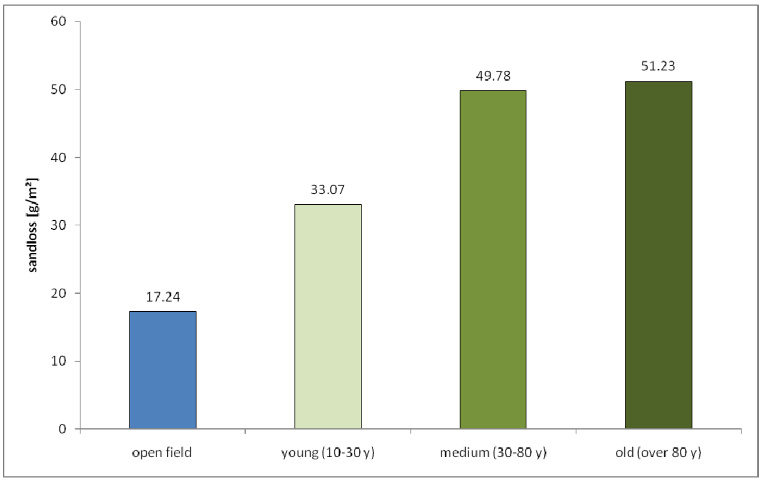

Figure 2. Throughfall erosivity as measured by splash cups under open field conditions and three successional stages.

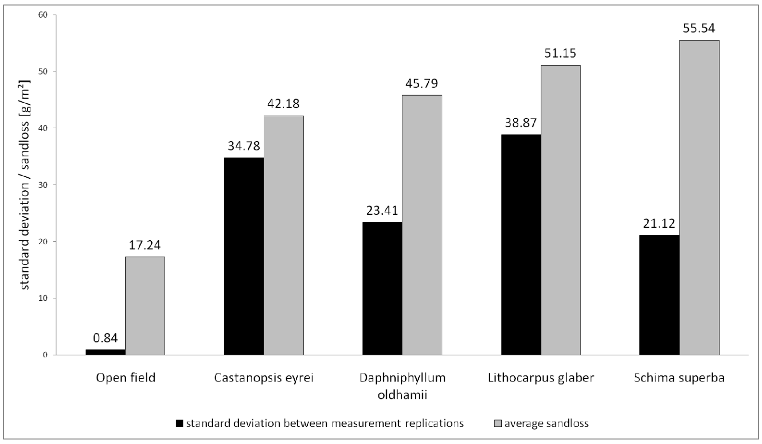

Figure 3. Erosive power of throughfall as measured by splash cups for four tree species.

Conclusion

We studied rainfall and throughfall erosivity in a subtropical forest ecosystem using sand-filled splash cups. Our results showed that the splash cup measurements yielded precise and reproducible results under both open field conditions and forest vegetation. The erosion potential of throughfall drops in forests was considerably higher (2.59 times) than under open field conditions and the spatial variability of the erosion potential was much more diverse in forests, caused by free throughfall and drip. By placing the splash cups under certain tree species and specific forest stands it could be demonstrated that the erosivity of throughfall depended on the species and also on the successional stage. *Schima superba* generated throughfall drops of higher erosivity than *Castanopsis eyrei.* We assume that this is an effect of the larger size of the leaves which generates larger throughfall drops, particularly drip. The erosion potential is also a function of stand height because throughfall drops are much more likely to reach terminal velocity under old grown forests. Therefore we conclude that the potential of throughfall to detach soil by splash is also related to the age of the specific forest stand: young forests have the lowest and old forests the highest erosion potential. This accentuates the importance of a shrub, herb and litter layer in forest ecosystems to protect the soil against erosion.

References

Cornelis WM, Oltenfreiter G, Gabriels D, Hartman R (2004) Splash-Saltation due to Wind-Driven Rain: Vertical Deposition Flux and Sediment Transport Rate. *Soil Science Society of America Journal* **68**, 32–40.

Ellison WD (1947) Soil Erosion Studies – Part II. *Agricultural Engineering* **28**,197–201.

Geißler C, Kühn P, Böhnke M, Bruelheide H, Shi X, Scholten T (2010) Measuring splash erosion potential under vegetation using sand-filled splash cups. *Catena* (submitted)

Hudson N (1971) 'Soil Conservation'. (Batsford: London).

Morgan RPC (2005) 'Soil erosion and conservation'. 3rd edition. (Blackwell: Malden, MA).

Nanko K, Mizugaki S, Onda Y (2008) Estimation of soil splash detachment rates on the forest floor of an unmanaged Japanese cypress plantation based on field measurements of throughfall drop sizes and velocities. *Catena* **72**, 348–361.

Salles C, Poesen J (2000) Rain properties controlling soil splash detachment. *Hydrological Processes* **14**, 271–282.

Scholten T, Geißler C, Wiegand C, Goc J, Kühn P (2010) A new splash cup to measure the erosion potential of rainfall under vegetation. (submitted)

Thornes JB (1990) 'Vegetation and erosion – processes and environments'. (Wiley: Chichester).

Tsukamoto J (1991) Downhill movement of litter and its implication for ecological studies in three types of forest in Japan. *Ecological Research* **9**, 333–345.

Zhao QG (2006) Some Considerations for Present Soil and Water Conservation and Ecology Security of South China. *Bulletin of Soil and Water Conservation* **26**, 1–8. (in Chinese)