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Are rubber-based agroforestry systems effective in controlling rain splash erosion?

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ABSTRACT

In order to evaluate the influence of different types of rubber-based agroforestry systems on soil erosion processes, rainfall and throughfall erosivity (splash erosion potential) were measured in an open field environment and under different vegetation types using sand-filled Tübingen splash cups. Our results indicate that the splash erosion potential under rubber monoculture was, on average, 3.12 times greater than those in the open environment. Splash erosion potential under agroforestry systems was higher than that of an open environment (ranging from 1.22 to 2.18 times greater), except for the rubber and tea system (0.87 times the open environment). However, in all but one system (the rubber and orange system), there was a significant reduction in splash erosion beneath multiple canopies compared to monoculture, especially for the rubber and tea system (0.27 times the monoculture) where it had high sub-canopy closure and low sub-canopy height. The erosion potential under the forest is closely related to the forest structure, especially height and canopy cover. These results indicate that low canopy height with high sub-canopy coverage is the major control on the amount of splash erosion, regardless of how the splash potential is increased by the canopy above. These results highlight the importance of selecting low near-surface intercrops for constructing rubber-based agroforestry systems. This also accentuates the importance of an intact litter layer in rubber plantations to protect the soil against splash erosion. Disturbance of these forests by latex tapping activities, herbicide application and removal of the litter layer during fertilization, for example, will also lead to higher actual splash erosion rates inside the forests in comparison with the open environment.

1. Introduction

Soil erosion is an important global issue which has ecological and financial implications (Sidle et al., 2006; Zhang, 2000; Zhou et al., 2010). Vegetation has been identified as an important key control on the type and intensity of soil erosion (Morgan, 2005; Su et al., 2010; Wei et al., 2005; Wiersum, 1985), and soil splash is the initial stage in the chain of processes that leads to soil loss and subsequent sediment transportation (Kinnell, 2005; Leguédois et al., 2005; Van Dijk et al., 2002).

In forested landscapes, vegetation canopy cover is one of the most important factors affecting soil splash erosion (Gyssels et al., 2005). Although it is generally accepted that throughfall beneath a forest canopy loses most of its splash erosion potential, the forest canopy does not necessarily protect surface soil from rain splash erosion (Calder, 2001). Although tree foliage can reduce the initial erosive power of rain, if water drops concentrate into larger drops, and if the fall height between the canopy and the soil is great enough, these falling drops can obtain a new erosive power that may exceed the initial erosive power of the original raindrop. For example, Mosley (1982), investigating soil erosion in a New Zealand beech forest, identified that soil splash was 3.1 times greater under the canopy than in the open environment. Brandt (1988) showed that, for a tropical rainforest, soil splash under multiple canopy layers was reduced to a minimum of 0.4 times splash compared to an open environment, but under a single canopy it increased to 6.65 times. Geißler et al. (2012a) showed that the rates of soil splash below the canopy of a subtropical forest were 2.59 times greater than those of open areas. The mechanisms involved in reducing or enhancing splash erosion under different types of vegetation cover, however, are still poorly understood (Nanko et al., 2008).

In areas containing natural forest, splash erosion does not typically occur as the understory vegetation and litterfall forms a protective layer over the soil surface (Wiersum, 1985). In some monoculture plantations, however, splash erosion has become a primary concern for soil conservation (Calder, 2001). Under a high, single forest canopy, the kinetic energy of water drops reaching the ground surface are significantly greater than those of natural rainfall (Mosley, 1982); under a low, single-layered vegetation cover, the kinetic energy of the water drops reaching the ground is believed to be lower (Vis, 1986; Wainwright et al., 1999). Relatively few studies, however, have investigated the throughfall erosivity, or splash erosion potential, under the canopy of

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tropical agroforestry systems (Bruijnzeel et al., 1998; Critchley and Bruijnzeel, 1996).

In Xishuangbanna, SW China, the most important driver of land-use/land-cover change over the past four decades has been the rapid increase in rubber monoculture plantations (*Hevea brasiliensis*). This change has been at the expense of primary and secondary tropical rainforest (Li et al., 2012). Due to economic demands, tropical rainforest in this region have been deforested and replaced with >400000 ha of rubber plantations; this being >20% of the total land area. It is commonly recognized, therefore, that the change in land-cover vegetation to rubber monoculture may result in excessive water loss and soil erosion (Xu et al., 2005b; Ziegler et al., 2009a); soil hardening and crusting (Liu et al., 2015); a loss of soil organic matter (Li et al., 2012); and rapid fluctuation of the microclimatic conditions (Feng, 2007). Some of these effects have already been noted in this region with noticeable, frequent dry season surface water shortages, an event which was rarely recorded prior to the change of vegetation (even during the driest year) (Qiu, 2009). To ensure the long-term sustainability of this plantation system, improving soil quality by developing sustainable land-use practices and reducing the rate of soil degradation is also very important.

Changes to the structure of a forest may arise through a number of different management practices. Changes in the use of forested land can result in changes in the sediment yield over short and long time periods (Brandt, 1988; Xu et al., 2005a; Young, 1990). It is also recognized that association of rubber trees with other cash tree crops can be an attractive practice to reduce competition for land, and at the same time diversifying farmers' income (Snoeck et al., 2013). In recent years, the Xishuangbanna local government has proposed building environmentally friendly rubber plantations (rubber-based agroforestry systems) which aim to reduce water and soil loss. Currently, Chinese scientists have developed a variety of rubber-based agroforestry systems to improve such degraded lands (Feng, 2007). In these agroforestry systems, rubber trees are commonly intercropped with economic plants like tea (*Camellia sinensis*), cacao (*Theobroma cacao*) and coffee (*Coffea arabica*); fruits such as pineapple (*Ananas comosus*), banana (*Musa saoientum*) and mandarin orange (*Citrus reticulata*); and traditional Chinese medicinal plants like *Flemingia macrophylla*, *Alpinia oxyphylla*, *Amomum longiligulare* and *Morinda officinalis*. Such crops, or combinations of crops, are grown under rubber trees to make use of available space at different heights to improve the effective use of the land resource. Currently, rubber and tea systems have replaced about 5% of the total area of rubber monoculture in this region. Other planting systems, such as rubber and coffee and rubber and cacao, have only been popularized by the local government in recent years. Although such systems can be highly effective in fixing carbon (Li et al., 2012), and are thought to be economically viable and ecologically sustainable in this region (Snoeck et al., 2013), little is known about their effects on controlling soil loss, especially on rain splash erosion (Liu et al., 2015).

In this study, we evaluated the influence of different types of rubber-based agroforestry systems and rubber monoculture on soil erosion processes. This study focused on changes in throughfall erosivity and plant characteristics which are related to their effects on splash erosion potential.

2. Materials and methods

2.1. Site description

The study site was located in the Xishuangbanna Tropical Botanical Garden (21°55′39″N, 101°15′55″E) in the Yunnan Province, SW China. Observations were conducted in a small catchment (19.3 ha) which consisted of rubber monoculture and different types of rubber-based agroforestry systems. The catchment spanned an altitudinal range of 560–680 m *a.s.l.* and had a slope of about 16° (Fig. 1). This region has a strongly seasonal climate with two main air masses alternating during the year. Climatologically, the Southwest Monsoon from the Indian Ocean delivers 80–90% of annual rainfall without influence from the Pacific typhoons during the rainy season (May to October), while the southern edges of the subtropical jet stream dominates the climate during the dry season (November to April). Climate records over the past 40 years show that the mean annual air temperature was 21.7 °C, with a maximum monthly temperature of 25.7 °C for the hottest month (June), and a monthly minimum of 15.9 °C for the coldest month (January). The mean annual rainfall was 1480 mm, of which most precipitation occurred between May and October, with very little precipitation between November and April (Liu et al., 2015).

The soil depth under the vegetation was about 2 m, and this soil was well drained with a clay loam texture (42% coarse sands, 34% silts, 24% clays). The soil is classified as a Ferralic Cambisol (IUSS Working Group WRB, 2015), developed from alluvial deposits derived from sandstone, with an ochric A horizon and a cambic B horizon with ferralic properties (Vogel et al., 1995). The parent material at a depth of 2 m consisted of a 30–40 cm thick layer of gravel deposited by the Luosuo River, a side branch of the Mekong River. Soil bulk density was 1.2 g cm^{-3} with an organic matter content of 25.9 g kg^{-1} (0–20 cm), and a pH of 5.4 (Li et al., 2012).

Rubber trees in this catchment were intercropped with five vegetation species commonly cultivated in this area: tea (*C. sinensis*), cacao (*T. cacao*), coffee (*C. arabica*), orange (*C. reticulata*) and *F. macrophylla*. For the rubber monoculture, rubber trees were planted in a traditional planting system with 2.1 m × 4.5 m spacing. For rubber-based intercropping systems, double rows of rubber trees were also planted with 2.1 m × 4.5 m spacing; the rows of rubber trees were then separated by 14 m wide inter-rows to allow intercropping. The associated crops were planted in the 14 m inter-rows in different arrangements to form five types of rubber-based agroforestry systems. These systems consisted of a rubber and tea system: six rows of tea planted in the middle of the inter-row at a density of 0.5 m × 2.0 m; rubber and cacao system: four rows of cacao planted with 3 m × 4 m spacing; rubber and coffee system: five rows of coffee planted with 2.5 m × 2.5 m spacing; rubber and orange system: four rows of orange planted with 1.5 m × 2.0 m spacing; and rubber and *Ficus macrophylla* system: eight rows of *F. macrophylla* planted with 0.5 m × 1.5 m spacing. In addition, a 1.5 m gap along each side of the rubber trees was kept for the convenience of tending, fertilizing and rubber latex tapping. All rubber trees were planted on the catchment slopes after deforestation of the native rainforest in 1989. The plantations subsequently received uniform agro management and were tapped for latex for 16 years. The crowns of the rubber trees were recorded to be between 11 and 18 m above the ground. The associated crops were planted in different years: tea and orange in 1997, and the others in 2005. In these forests, herbaceous plants were rarely present on the ground surface due to regular herbicide application. Comparison of the rubber trees in each of the treatments (monoculture *vs.* intercropping system) showed that there was no significant difference in their morphological characteristics (Table 1). More detailed information about the stands is provided by Liu et al. (2015).

Table 2 provides the morphological characteristics of the understory plant species in the different types of rubber-based agroforestry systems. The canopy closure rate and the crops' leaf area index (LAI) were determined by using a plant canopy analyzer (LAI-2200; Li-Cor Inc., USA). The canopy thickness and the height of the canopy center were visually estimated.

2.2. Rainfall, throughfall and splash erosion measurements

An open site and six throughfall observation sites (each 20 m × 20 m) were established in the different rubber plantations in the catchment. A tipping-bucket data-logging rain gauge (3554WD; Spectrum Technologies Inc., USA) with a 0.2 mm resolution was installed in the open. This rain gauge recorded rainfall volume and intensity, and the tip time was recorded at 10-min intervals. Three V-shaped