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Soil erosion and water retention varies with plantation type and age

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ABSTRACT

Soil erosion control and water retention is a major ecological function of plantations and may be affected by both plantation type and age. In this study, we investigated both surface runoff and sediment load under different plantations in southern China for six years (2008–2013) in order to illustrate the influence of plantation type and age on water retention and soil erosion. Our results showed that mature plantations functioned better than young plantations in terms of soil erosion control and runoff reduction, which reduced runoff and soil erosion by 64.5 ± 6.2% and 72.2 ± 7.9% more than young plantations, respectively. Our study indicated that plantations play a beneficial role in controlling soil erosion and reducing water loss, and this effect is more pronounced with plantation age. Both runoff coefficient and sediment load were least under *Eucalyptus* spp. either in young or mature plantations, suggesting that *Eucalyptus* spp. is better adapted for water retention and soil conservation compared to other plant species. Correlation analysis showed that herb species and herb Margalef index were the top two factors affecting the surface runoff and sediment load in young plantations but litter storage and tree Shannon index were the top two affecting factors in mature plantations. This shift was consistent with the decreasing trend of herbs and increasing trend of litter storage with the time of vegetation restoration.

1. Introduction

Soil erosion leads to soil degradation and productivity decline, which has become an increasingly serious ecological problem worldwide (Alexandridis et al., 2015). It is estimated that 1.2 billion ha of land is degraded in the world due to soil erosion (Lal, 2004). Previous studies have demonstrated that soil and water loss through runoff especially under storm rainfall can cause a serious decline in soil fertility (Pimentel et al., 1995; Kunimatsu et al., 2006; Atucha et al., 2013; Jarvie et al., 2013; Fortin et al., 2015). Many researchers have explored the possible effects of land use patterns and land use change on runoff yield and sediment load (Kosmas et al., 1997; Narain et al., 1998; Cammeraat and Imeson, 1999; Bellot et al., 2001; McDonald et al., 2002; Pardini et al., 2003). Afforestation or reforestation is an effective approach to control soil erosion and restore degraded land (Filoso et al., 2017; Li et al., 2017). However, the influence of forest type and age on runoff yield and soil erosion has been debated for decades. (Filoso et al., 2017). Observations from all over the world indicated the relationship between runoff yield and forests remains uncertain, and is likely dependent on including vegetation cover, forest litter cover, surface roughness and soil type (Zhou et al., 2015).

There are many factors affecting surface runoff and soil erosion (Hewlett and Hibbert, 2011). Among these factors, vegetation cover and forest litter cover have significant impacts on reducing the momentum of raindrops onto soil surface (Zumeta and Ellefson, 2000; Aguiar et al., 2010; Kateb et al., 2013). Different land use types can affect soil quality, resulting in differences in surface runoff and soil erosion (Fu et al., 2004; Alaoui et al., 2011). It was reported that annual runoff was reduced on average by 44% and 31% when grasslands and shrublands were converted into plantation forests, and runoff varied significantly with plantation age (Farley et al., 2005). However, herbs and shrubs were found to reduce soil erosion more effectively than trees in a study during the regrowth of different types and densities of vegetation following a severe wildfire in eastern Spain (Cerdà and Doerr, 2005). The researchers found herbs and shrubs reduced soil erosion and overland flow coefficients to negligible values 2 years after fire, whereas under trees and dwarf shrubs, appreciable overland flow and soil loss still occurred after 5 years. Forest litter cover could increase the roughness of the soil surface and may affect the route and flow rate of runoff, and the thickness of litter storage could affect the water holding

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capacity and change the pattern of surface runoff (Lowdermilk, 1930; Wang, 1993; Chen et al., 1996; Hart and Frasier, 2003). Long-term litter removal could increase soil bulk density, overland flow, soil erosion and temperature fluctuations and change the soil water balance, causing least soil water content during dry periods (Sayer, 2006).

There were 69 million ha plantations in China according to the report of the eighth national inventory of forest resources at year 2014, which was composed of more than 31,000 plant species including both native species and exotic species (SFA, 2014). These plantations have played important role in soil erosion control and water retention. However, it is unclear whether soil erosion and water retention vary with different plantations and what factors affect soil erosion and water retention. In our study site, there were nine plantations of different plant species and they were planted at two different times (either in 1986 or 2005), which provides us a natural experimental setup to look into these questions. In the present study, we investigated the surface runoff, sediment load, vegetation diversity, soil properties and litter storage under different plantations for the period 2008–2013. Our objectives are: (1) to illustrate how plantation type and age would affect soil erosion and water retention; and (2) to identify the factors affecting the surface runoff and sediment load.

2. Materials and methods

2.1. Site description

This study was conducted at the Heshan Hilly Land Interdisciplinary Experimental Station (22°68′N, 112°90′E), Chinese Academy of Sciences (CAS), Guangdong Province, China (Fig. 1). The climate is subtropical monsoon with obvious wet (from April to September) and dry season (from October to March). The mean annual temperature and precipitation are about 22.5 °C and 1668 mm, respectively. The soil is an acrisol.

The young plantations were planted in 2005 (Fig. 1), which are: (1) 10 species mixed forest (M1); (2) 30 species mixed forest (M2); (3) *Eucalyptus urophylla* monoculture plantation (EU1); (4) *Acacia crassicarpa* monoculture plantation (AC); (5) *Castanopsis hystrix* monoculture plantation (CH). A 300 m^2 catchment dimensioned 20 m × 15 m (projected area) was established for surface runoff and sediment load monitoring in each young plantation. The mature plantations were planted in 1986 (Fig. 1), which are: (1) A*cacia mangium* monoculture plantation (AM); (2) *Eucalyptus urophylla* monoculture plantation (EU); (3) *Schima superba* mixed plantation (SS); (4) *Pinus massoniana* monoculture plantation (PM). A 200 m^2 catchment dimensioned 20 m × 10 m (projected area) was established for surface runoff and sediment load monitoring in each mature plantation. More details of the site information such as site aspect, slope, altitude and plant species composition were listed in Table 1.

2.2. Sampling and measurements

2.2.1. Measurement of runoff and sediment load

Rainfall was measured using automatic weather station (VASALA MAWS301, made in Finland), the measurement accuracy was 0.1 mm. Data were automatically recorded continuously and downloaded monthly. Rainfall intensity was classified according to the standard issued by China Meteorological Administration (China Meteorological Administration, 2008; Zhu and Guo, 2017).

One surface runoff and sediment load monitoring catchment was established in each of the four mature plantations and five young plantations, respectively (Fig. 1). For each catchment, cement boards were inserted 20 cm deep into soil layer around the perimeter of the catchment, with another 10 cm above the ground. The surface runoff into the weir through the delta outflow is the only outlet of water, and the WGZ-1 automatic water level gauge was installed at the bottom of each catchment to record the water level for each measurable rain event. Sediment load was determined as suspended and bed load sediment. Suspended load samples were collected biweekly and obtained by multiplying the runoff volume and the percentage of soil in runoff. Bed load sediment samples were collected at the bottom of the catchment at the end of each year. Sediment sample including both suspended and bed load were dried to constant weight at 105 °C.

The triangle weir in the investigation is 20° (Fig. 2), the discharge equation is as follows: (Zhou, 1997).

$$Q_0 = 0.25H^{2.5} \tag{1}$$

$$Q = \sum_{i=1}^{n} 0.5 \times (Q_{0(1)} + Q_{0(2)})t_i \tag{2}$$

Q_0 is the water flow from a certain water level on the water level curve (m^3/s), H is the water level above the spillway (m). Q is the total runoff for a certain precipitation event. $Q_{0(1)}$ and $Q_{0(2)}$ are the flows (m^3/s) of the two-adjacent water levels (H_1 and H_2) on the rating curve of the weir. T is the time interval for times i − n. Finally, runoff is normalized by dividing by the area of the monitoring catchment and then converted to runoff depth (mm).

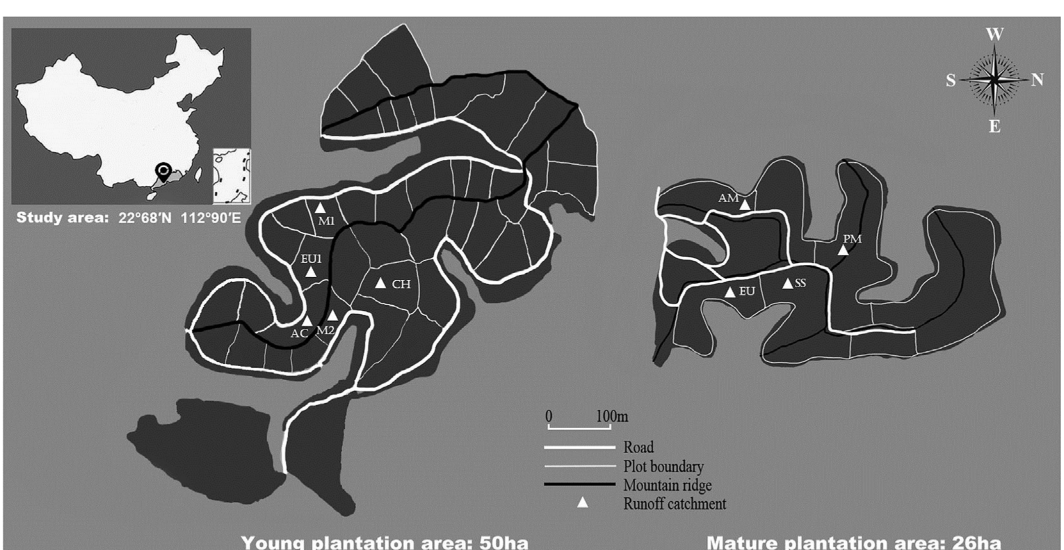

Fig. 1. Location map of the experimental area.