Catena 151 (2017) 98–106

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Fern cover and the importance of plant traits in reducing erosion on steep soil slopes

N.L. Chau, L.M. Chu *

School of Life Sciences, The Chinese University of Hong Kong, Shatin, NT, Hong Kong, SAR, China

ARTICLE INFO

Article history:
Received 28 June 2016
Received in revised form 30 November 2016
Accepted 16 December 2016
Available online 22 December 2016

Keywords:
Erosion control
Ferns
Soil slope
Plant traits
Plot rainfall simulation

ABSTRACT

Soil slopes constructed in southern China are susceptible to serious erosion due to substrate characteristics and high precipitation, which is commonly mitigated by revegetation. Ferns are potentially useful for erosion control due to their dense plant cover and adaptation to slopes. However, information regarding the effectiveness of ferns in erosion control is scarce. This study assessed the erosion-reducing potential of recently planted ferns on slopes. Five native fern species of southern China, namely, *Blechnum orientale*, *Cyclosorus parasiticus*, *Dicranopteris pedata*, *Nephrolepis auriculata* and *Pteris vittata*, were chosen for the assessment. Each fern species was grown to reach two levels of cover (40% and 80%) in 1.0 × 0.5 m^2 soil boxes tilted to 50°, and boxes with bare soil acted as the control. The erosion control performance was tested using a rainfall simulator, which provided a rainfall intensity of 100 mm h^{-1} to reflect a heavy rainstorm event. Various plant traits were examined to explore their roles in reducing erosion. The results demonstrated that both cover and plant traits have significant effects on the erosion-reducing potential of ferns. The high cover of ferns (80%) could reduce the runoff volume by 65.0% and sediment loss by 96.1% compared with the control. The leaf area index (LAI), root area ratio (RAR) and root density (RD) were highly correlated with erosion-reducing potential. Among species, *N. auriculata* outperformed the other species by having stronger performance of these plant traits. To confirm the results further, more field experimentation and comparisons of ferns and grasses in mitigating runoff and sediment loss on soil slopes are necessary to evaluate the effectiveness of ferns in erosion control under in situ conditions.

1. Introduction

In southern China, similar to many sloped regions worldwide, rapid urban expansion has resulted in the degradation of natural landscapes (Wang et al., 2012). A large number of engineered soil slopes have been established to facilitate infrastructure development. The substrates of these slopes are greatly disturbed, with a reduced water holding capacity and poor soil structure (Cerdá, 2007). Soil erosion within this degraded landscape is a serious concern, especially in areas where completely decomposed granite (CDG) is the main substrate (Kimoto et al., 2002). The situation is exacerbated by steep slopes and high rainfall (annual mean precipitation over 1500 mm), resulting in high runoff and sediment detachment (Smets et al., 2007; Wang et al., 2015). With the implementation of engineering techniques, the revegetation of urban landscapes is a feasible approach to ameliorate the problems. It offers a more eco-friendly and lower cost approach to control soil erosion on sloping land than other conventional slope stabilization measures (e.g., shotcrete) in subtropical regions or other areas (Cao et al., 2015b; Herbst et al., 2006). Plant growth and development on slopes under favourable environmental conditions can also provide long-term mitigation measures for soil protection (Cao et al., 2006). Plant establishment can provide protection to slopes in various ways: 1) dense vegetation cover intercepts rainfall (Bassette and Bussière, 2008; Liu et al., 2014; Park and Cameron, 2008); 2) roots improve the soil structure by modifying aggregate stability and enhancing soil cohesion (Fattet et al., 2011); and 3) plant cover also improves the soil environment and enhances the biodiversity of landscapes (Stokes et al., 2008; Zou et al., 2012).

Trees are widely used for erosion control in southern China, and their effectiveness is well proven (Cao et al., 2015a; Fattet et al., 2011; Rahardjo et al., 2014). However, they are not recommended for planting on steep slopes because of the risk of uprooting that can cause mass movement (Pawlik, 2013). Groundcovers such as grasses can minimize the risk and are usually applied on soil slopes by hydroseeding or other techniques (Cao et al., 2010; Chen et al., 2013; Faucette et al., 2006). Nevertheless, the prolonged growth of grasses is not guaranteed. Certain microclimates of soil slopes, including heat stress and shade, can inhibit the establishment of sustainable grass covers and subsequently impair their capabilities for erosion mitigation (Bunnell et al., 2005).

Ferns are an alternative groundcover capable of forming relatively long-lasting and dense evergreen cover on both gentle and steep slopes in tropical or subtropical climates (Royo and Carson, 2006; Shiels et al., 2008). Some cultivated fern species such as *Nephrolepis auriculata* are

* Corresponding author.
E-mail address: leemanchu@cuhk.edu.hk (L.M. Chu).

http://dx.doi.org/10.1016/j.catena.2016.12.016

planted on steep slopes in southern China (Qian et al., 2012). Moreover, a variety of fern species can be found naturally on soil slopes because they are pioneer plants that can colonize disturbed habitats through extensive rhizome growth (Buonopane et al., 2013; Hayasaka et al., 2012). Due to the strong adaptations of ferns to low contents of nutrients and moisture, they are especially valuable in this region where CDG is common and there are relatively poor conditions for plant growth (Lan et al., 2003). Certain fern species can also tolerate shaded environments, which always hinder the growth of many plant species selected for revegetation (Watkins et al., 2006). A considerable number of fern species are native to southern China, which can impose additional benefits to the native plant communities (Tinsley et al., 2006). Furthermore, fern cover can moderate the physical environment (e.g., temperature) of landscapes to facilitate invertebrate colonization (Negishi et al., 2006).

Despite the strong adaptations and ecological benefits of ferns, their uses for the control of erosion on slopes are not widely applied. Several studies have demonstrated their positive roles for soil protection in southern China and other regions with similar precipitation but were restricted to certain fern species (Kimoto et al., 2002). Other studies focused on the roles of fern thickets on natural terrain with highly erodible substrates, while those targeting on soil slopes is lacking (Walker, 1994). As a result, the effects of different fern species on runoff and sediment loss reductions in urban landscapes under heavy rainfall scenarios are worth investigating.

Grasses, which can reduce runoff and sediment concentrations by 65–70% and 80–95%, respectively, have already received a great deal of attention (Xiao et al., 2010; Zhou and Shangguan, 2007), with dense grass leaves efficiently intercepting rainfall (Liu et al., 2016). Their cover also consists of numerous grass stems that enhance the soil roughness to slow down surface flow and trap sediment (Cao et al., 2015b). Grasses are also capable of forming root mats in the soil that act as mechanical barriers to sediment loss (Gyssels and Poesen, 2003). Such plant traits have yet to be identified in ferns, which differ from grasses. Indeed, the leaves of ferns (fronds) are larger and are arranged in multiple layers. Fern roots (rhizoids) are generally shallower than grass roots, yet the special root architecture in ferns may contribute to the erosion-reducing potential. There is certainly a need to understand the underlying mechanisms governing the capabilities of ferns in erosion control.

This study simulated water erosion on artificial soil slopes to (1) determine the erosion-reducing potential of ferns on soil slopes, (2) assess the effects of cover and plant traits on their capabilities for erosion control, and (3) examine fern morphology to identify the plant traits associated with their performance in slope protection.

2. Materials and methods

2.1. Installation of rainfall simulator and fern transplantation

Rainfall simulation was carried out in the Physical Experimental Station at The Chinese University of Hong Kong, Hong Kong SAR, China. A computer-controlled pressurized rainfall simulator manufactured by the National Soil Erosion Research Laboratory, United States Department of Agriculture, was used for the experiment. The rainfall simulator consisted of a water tank, pump, line pipe, and two nozzles (Fig. 1). The two nozzles were oscillating Veejet 80100 nozzles 0.5 m apart and were installed at a raindrop fall height of 3 m. The water in the tank was pumped to the nozzles to simulate rainfall. We adjusted the working pressure to 41.4 kPa to produce a raindrop velocity of 8.8 m s^{-1} and the rainfall intensity to 100 mm h^{-1} to simulate the heavy rainstorm events of subtropical regions. We calibrated the simulator to identify the valid area with a uniformity > 85% for the simulation. We used stainless steel soil boxes of 1.0 m × 0.5 m × 0.2 m for planting. The dimensions were specifically designed to fit the plant size (especially for the depth of rhizoids) and the valid area for rainfall simulation. Perforations were made at the bottom of the boxes to allow water drainage. We

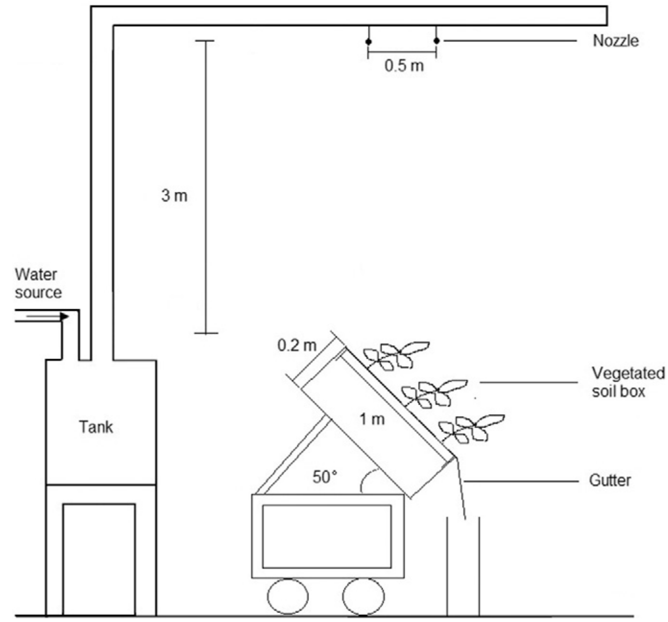

Fig. 1. Collection of runoff from a tilted soil box and rainfall simulator.

collected CDG from local excavations to fill the boxes. It was a sandy loam soil (82.7% sand, 8.32% silt and 8.98% clay) and had an initial water content of approximately 5%. After sieving the soil through a 2-cm wire mesh to remove gravels, we packed it into boxes in four layers of 5 cm to reach a bulk density of approximately 1.56 g cm^{-3} and porosity of 41.3%, to simulate the natural condition of soil slopes (Sun et al., 2016). All the filled soil came from the same source and was not reused between treatments.

We selected five fern species, *Blechnum orientale*, *Cyclosorus parasiticus*, *Dicranopteris pedata*, *Nephrolepis auriculata* and *Pteris vittata* for the study. They are widely distributed in Guangdong, Guangxi, Fujian and Zhejiang Provinces of southern China, as well as having genera common to other tropical and subtropical regions (Table 1). All of these species are commonly found on steep soil slopes, either through cultivation or natural growth, and are capable of forming dense cover (Walker et al., 2010). Their plant traits (e.g., leaf area, plant height and root structure) vary among species. We transplanted the ferns from a nursery to soil boxes (Fig. 1) to produce two levels of plant cover (40% and 80%) for each species, and we included bare soil (0%) as the control to evaluate the effects of ferns on erosion control. We measured the fern cover by taking high resolution digital photos and then estimating cover visually. Since the fern species were grown to different sizes, thereby influencing cover, the two target cover categories were achieved by adjusting the number of transplanted fern individuals of the same species in each box (Fig. 2). We used four to nine plant individuals to reach 40% and eight to eighteen plant individuals to reach 80% cover (Table 1). There were three replicates for both vegetated boxes and the control, and each replicate had the same number of fern individuals. We loaded the boxes into a metal frame tilted to 50° to simulate the steep slope

Table 1
Five fern species used in the rainfall simulation experiment.

Fern	Family	No. of fern individuals in each soil box	
		40% cover	80% cover
Blechnum orientale	Blechnaceae	6	10
Cyclosorus parasiticus	Thelypteridaceae	9	18
Dicranopteris pedata	Gleicheniaceae	9	18
Nephrolepis auriculata	Nephrolepidaceae	4	8
Pteris vittata	Pteridaceae	9	18