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Research paper

Effects of concrete content on seed germination and seedling establishment in vegetation concrete matrix in slope restoration

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ABSTRACT

The Vegetation Concrete Base Spraying technique (VCBS) is an ecological slope restoration technique to strengthen slope stability and restore slope vegetation in the meantime. It restores vegetation on slopes by spreading a mix of concrete, greening additives, mulching materials and plant seeds on to slope surfaces. However, vegetation establishment on slopes is likely affected by concrete content in the vegetation concrete matrix. Here we conducted experiments with various concentrations of concrete content in vegetation concrete matrices to test the effect of concrete content on seed germination and seedling establishment for three pioneer species, *Festuca arundinacea*, *Magnolia multiflora* and *Medicago sativa*. We aimed to determine the appropriate concrete content to be used in the vegetation concrete matrix. Variations in seed germination, seedling survival and seedling growth were monitored. The results showed that the concrete content had significant effects on seed germination, seedling survival and growth of all three species. Seed germination of *F. arundinacea* and *M. sativa* decreased with increased concrete content. The germination of *M. multiflora* seeds peaked at 4% concrete content. The seedling survival of *F. arundinacea* and *M. sativa* increased, then decreased with increased concrete content, but the seedling survival of *M. multiflora* continually decreased. *F. arundinacea* and *M. multiflora* are more suitable than *M. sativa* for application in VCBS. Concrete content significantly influenced seedling growth of all three species. The leaf number, plant height, aboveground biomass, belowground biomass and root length, root crossing number of plants all increased with increased concrete content between the range of 0–8%, but decreased significantly when concrete content was over 8%. We concluded that 8% concrete content in the vegetation concrete matrix is appropriate in terms of seed germination and seedling establishment of the three studied species in the VCBS.

1. Introduction

Construction of hydropower engineering, highways, railways and urban development often produce a number of engineering slopes that pose numerous ecological and environmental problems, such as vegetation destruction, topographic and hydrological changes, soil erosion and slope slides (Zhou and Zhang, 2003; Xu et al., 2004). Traditionally, shotcrete face slope protection and con-retaining walls can effectively strengthen slope stability in a short time. However, such techniques create huge bald slope surfaces impacting ecological functions and landscape structure. Ecological restoration of concrete slope can not only strengthen slope stability, therefore minimizing the occurrence of landslides and debris flows (Huang et al., 2010; Xia et al., 2011a), but also improve microclimates, reduce soil erosion, and improve landscape function (Xia et al., 2012; Descheemaeker et al., 2006). However, it is hard for seeds to germinate and establish on slopes as many factors including direct factors (temperature, soil nutrients, humidity and light) and indirect factors (slope and orientation) influence seed germination and seedling establishment on slopes. Some may become limiting factors when seed germination and seedling establishment are affected by them. The Vegetation Concrete Base Spraying technique (VCBS) restores vegetation on slopes by spreading a mix of concrete, greening additives and plant seeds on slope surfaces. The mulching materials are covered on the restored slope after spreading to avoid rain crash (Li et al., 2006). The porous concrete used in slope ecological protection has characteristics of self-adaptation and self-supply as the special minerals in the greening additives can neutralize soil' pH, modifying the chemical properties, creating a friendlier environment for plants. The base body of vegetation restoration concrete is produced with many kinds of cementitious

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material and a complex of different aggregates (Fan et al., 2013). The key issues in VCBS include determining the composition of vegetation concrete matrices and selecting plant species suitable to the location, angle, rock properties and ecological function of the slopes (Xu et al., 2004; Wu et al., 2006). The concrete content in the vegetation concrete matrix is critical in the entire technique. It has to reach a certain content, usually ranging from 0 to 15% depending on slope, to strengthen slope stability while not impacting seed germination and stressing seedling establishment on slopes (Zhang and Sun, 2010; Xu and Chen, 2012a, 2012b). As a result, understanding the effects of different concrete contents on seed germination and seedling establishment of specific species is crucial to determine the appropriate concrete content range in the application of VCBS.

Pioneer plant species, such as *Festuca arundinacea*, *Magnolia multiflora* and *Medicago sativa*, have commonly been used in the ecological restoration of degraded ecosystems in Southwest China. *F. arundinacea* (Poaceae) and *M. sativa* (Fabaceae) are herbaceous perennials, and *M. multiflora* (Fabaceae) is a subshrub. These three species are fast growing with well-developed root systems; they are also drought-tolerant, and generally disease-resistant, with adaptations to poor soils, and therefore, particularly suitable for slope ecological protection with VCBS (Han et al., 2007; Li et al., 2004). However, it is not clear how these three species cope with concrete in the vegetation matrix in terms of seed germination and seedling establishment. In other words, the critical content of concrete in the matrix that is strong enough to strengthen the slope while not stress seed germination and seedling establishment remains to be determined. The hypothesis of this research was that seed germination and seedling establishment in VCBS were affected by concrete content in the matrix. The present study aims to answer two specific questions: (1) whether these species can be used in VCBS for slope ecological restoration from their adaptation of seed germination and seedling establishment to concrete content? and (2) What is the critical concrete content if they can be used in VCBS?

2. Methods

2.1. Experimental materials and experimental design

Mature seeds of *F. arundinacea*, *M. multiflora* and *M. sativa* were purchased from commercial seed suppliers. The effects of concrete content on seed germination, seedling survival and growth of each species were tested by a comparative experiment which included five concrete content treatments, and each with ten replicates. The experimental unit consisted 50 randomly distributed seeds in a plastic pot (25.5 cm in depth, 17.5 cm in diameter) filled with a mix of soil, concrete, organic matter (wood chips) and green additive. The five concrete content treatments were 0, 4%, 8%, 12% and 16%. Other environmental factors were controlled and kept the same except the concrete content. The experiments were conducted in green house. Seeds and seedlings were watered well through spray irrigation once every 2 days during the experiment to keep the experiment ongoing. The experimental treatment plots of each species were separated from each other to prevent the competitive effect. Within each treatment, pots were rotated randomly every 3 days to minimize positional effects.

2.2. Experimental observation

The trial began in April 2012. Germinated seeds were counted on a daily basis. The germination experiment was ended when no new emersion occurred, and then seed germination rate was calculated. The experiment continued for another 60 days to test the effects of concrete on seedling survival and seedling growth.

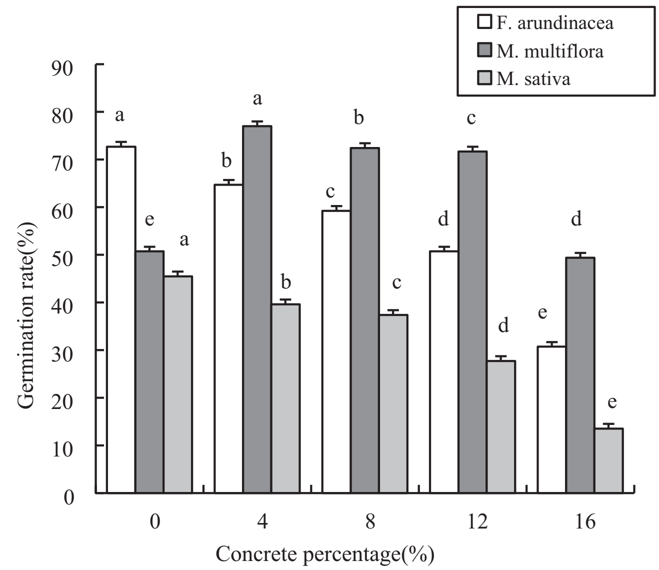

Fig. 1. Effect of concrete content on the seed germination of the three pioneer species (mean ± SE). The letter above the error bar indicates the level of difference among concrete content treatments at $p = 0.05$ within each species.

Seedling survival was counted for each pot. Ten seedlings were taken out randomly from each pot when the experiment was over. The leaf number, height and root system of each plant were measured. Plant material then was dried to a constant mass at 60 °C and was measured for aboveground and underground parts. The average values in each pot were used as the experimental value of each unit.

2.3. Data analysis

Pots were considered the unit of replication and measurements for individual plants were averaged within pots. Percentage of seed germination and seedling survival, biomass and biomass allocation, and seedling growth were calculated for tests. The effects of variables were analyzed using one-way analysis of variance (ANOVA) after Ln-transformation of data and means were compared with LSD test. All analyses were conducted using SPSS software (13.0).

3. Results

3.1. The effect of concrete content on seed germination

The ANOVA showed that concrete content significantly affected seed germination of all three species ($p < 0.01$) (Fig. 1). Seed germination of *F. arundinacea* and *M. sativa* decreased with increased concrete content. With 0% concrete, *F. arundinacea* achieved a germination rate of 72.2%, and 46.6% for *M. sativa*. At 16% concrete content, germination of *F. arundinacea* decreased to 27.4%, and to 41.3% for *M. sativa* (Fig. 1). Germination of *M. multiflora* seeds increased slightly when concrete content increased to 4%, and achieved the highest germination rate of 77.0% with 4% concrete content, while its germination rate decreased when concrete content increased from 4 to 16%. The average germination rate of *F. arundinacea*, *M. multiflora* and *M. sativa* was 55.6%, 64.2% and 22.7% in the matrix of VCBS respectively.

3.2. The effect of concrete content on seedling survival

Seedling survival of all three species was also significantly influenced by concrete content ($p < 0.01$) (Fig. 2). Seedling survival of