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Development and soil reinforcement characteristics of five native species planted as cuttings in local area of Beijing

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ABSTRACT

It is important to select the appropriate plants for soil bioengineering by taking their development and the root anchorage into consideration. The aims of the study were to evaluate the survival rate and anchorage capability of five species planted as cuttings and to further investigate the interrelationship of pull out force and plant morphology.

Above 90% of *Salix matsudana cv. Umbraculifera*, *Populus canadensis Moench*, *Salix alba var.Tristis* and *Salix purpurea* cuttings survived. Less than 30% of *Amorpha fruticosa L.* survived. The highest number of roots had developed in the 30–40 cm stem section in the deepest layer of soil.

A total of 77 cuttings were vertically pulled out and the morphological characteristics of their root structure were measured. Cuttings of *S. matsudana cv. Umbraculifera* showed the greatest uprooting resistance (1214.8 N), followed by *A. fruticosa* L. (1043.9 N), *P. canadensis Moench* (879.7 N), *S. purpurea* (802.9 N) and *S. alba var. Tristis* (765.2 N). Uprooting resistance was effected mostly by the roots than by the shoot profiles. The pull out resistance force (F_{max}) has shown the best relationships with multiple morphological parameters as total number of roots combined with root dry mass ($P < 0.0001$).

The species with the highest capability suitable for purposes of soil bioengineering should be *S. matsudana cv. Umbraculifera*, *P. canadensis Moench*, *S. purpurea* and *S. alba var. Tristis*. *A. fruticosa* L. is not suitable for being used in soil bioengineering techniques due to its low level of survival rate.

1. Introduction

Vegetation-based soil bioengineering is accepted widely as the effective, affordable and environment friendly technique to prevent soil erosion and to rehabilitate streambanks (Barrett et al., 2006; Gray and Sotir, 1996; Li and Eddleman, 2002; Li et al., 2006; Simon and Steinemann, 2000). On one hand vegetation helps to enhance the aesthetic value of slopes and to restore the ecosystem (Gray and Sotir, 1996; Petrone and Preti, 2010). On the other hand, roots and stems of vegetation provide the major structural and mechanical elements by acting as a slope protection system (Docker and Hubble, 2008; Wu et al., 1979).

The selection of appropriate plant species is most relevant for a local application of this resource-saving and environment friendly techniques. Some techniques of soil bioengineering such as cuttings, live fascines and brush mattress, in combination with such techniques as vegetated geo-grids and geo-gabions have been mostly employed in the river bank construction. Cutting method was the simplest form of soil bioengineering, which simply involved the insertion and tamping of live, vegetative cuttings into the ground (Schiechtl, 1980; Gray and Leiser, 1982; Schlüter, 1971). Except for their self-reproducing capability of plants, the survival rate of cuttings could be affected by soil moisture and sediment texture (Pezeshki et al., 2007). According to Schlüter (1971), only the plants that have the survival rates of 70% and higher should be considered for being used in soil bioengineering practice. Successful soil bioengineering using cuttings is dependent on a well-developed root system to resist flooding which is typically important in the early planting stage. Root anchorage is critical

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to survival of cuttings in active floodplains. Correlations between flooding tolerance and uprooting resistance of willow and cottonwood species were verified (Karrenberg et al., 2003).

Plant anchorage depends on a combination of the types and the morphologies of root systems (Crook and Ennos, 1996; Dupuy et al., 2005b; Ennos, 2000; Mickovski et al., 2005; Stokes et al., 2007) and soil properties (Ennos, 1990). Studies on root anchorage can be conducted either in situ or by standard laboratory tests. These studies showed increases in shear strength due to soil-root interactions. Pull out tests have been usually employed to determine in situ root anchorage (Burylo et al., 2009; Devkota et al., 2006; Mickovski et al., 2005; Shewbridge and Sitar, 1996; Stokes et al., 2007; Tosi, 2007). The pull out strength could provide the valuable information to assess the slope stability (Waldron, 1977) and to help limiting equilibrium stability analysis (Norris, 2005).

Pulling single root out of the soil (Tosi, 2007), pulling root balls out of soil vertically (Devkota et al., 2006; Liu et al., 2011; Mickovski et al., 2005) or lateral angle (Liffen et al., 2013) were applied for field pull out test to measure the force required to cause rupture and provide the data of root-soil interactions (Burylo et al., 2009; Stokes et al., 2007).

Vertical pull out resistance was investigated in samplings and cuttings of floodplain pioneers in north-east Italy and their anchorage ability was compared and discussed (Karrenberg et al., 2003). Pullout resistance force for individual grass species was investigated by using vertical uprooting test (Waldron, 1977). In order to investigate the root anchorage effects by *Salix alba var. Tristis*, vertical pull out test was performed on the four-year old cuttings (Liu et al., 2011). A single vertical force applied to a stem was found to be transmitted to numerous roots, because of adventitious roots from the stem base (Ennos, 1993).

Lateral pull out tests were also applied to simulate root anchorage and plant failure under external load. Stokes et al. (2007) used lateral pull out test to quantify bamboo root anchorage and to determine whether landslides occurred more frequently in big node bamboo forest. Whereas other researchers (Burylo et al., 2009; Mickovski et al., 2005; Liu et al., 2013) used this method to estimate the root resistance while torrential runoffs and sediments were uprooting the plants. The uprooting resistance force provides significant information about the role of root hairs (Bailey et al., 2002).

In previous studies, several parameters of plants were reported to be related to soil anchorage, including the above- and below-ground parameters, such as stem height and basal diameter, stem mass, root length, diameter, biomass, root numbers and root basal cross sectional area (Bailey et al., 2002; Cucchi et al., 2004; Ennos, 2000; Goodman et al., 2001; Karrenberg et al., 2003; Toukura et al., 2006). Evaluating and predicting plant resistance to uprooting from simple characteristics of plant morphology are therefore highly important so the most efficient plant strategy for future restoration of eroded slopes can be defined (Burylo et al., 2009).

Since the end of 20 century, the disadvantages of the conventional engineering work from the past were recognized. During rapid urbanization, the natural landscapes have been artificially reconstructed in Beijing. A large number of rivers have been transformed and lined with concrete revetment, which, in turn, accelerated the degradation of river systems. In viewing of these crises, in recent years there has been explosive growth in the quest for appropriate ecological methods to rehabilitate the degraded river system. Future strategies should aim at increasing the environmental compatibility of river engineering measures and at exploring the beneficial solutions for a diverse range of river functions. It has been shown that soil bioengineering is one of the important ways of restoring the damaged ecosystems by following the ecological principles, investigating, designing and recreating the vegetation-soil systems, enhancing soil shear strength and limiting the movements of soil particles on slopes by utilizing the effects of root systems on maintaining the soil structure (Li and Eddleman, 2002; Xu et al., 2009). A view of the past experience and the future priorities of soil bioengineering in China was presented in The Second International Conference 'Ground Bio- and Eco-engineering (Stokes et al., 2010): The Use of Vegetation to Improve Slope Stability—ICGBE2' held at Beijing, China, on 14–18 July, 2008. It was pointed out that the earliest references to the examples of bioengineering could be found in Chinese history books. China appears to be the first country using soil bioengineering for dike repair as early as 2000 years ago. Unfortunately, it has long been forgotten in the history. Nowadays, the projects using soil bioengineering techniques could be found in China. However, the research on soil bioengineering is only just beginning, and the documentation on the root mechanical properties has been unavailable. It has also been pointed out that the species choice and their appropriateness to site ecology are the weak points in many projects (Stokes et al., 2010).

It is well known that soil bioengineering experiences cannot be easily transferred from one site to another. To utilize soil bioengineering techniques in river restoration in local place, identifying the potential plant species for soil bioengineering measures is crucial in the first step. The pull out cuttings to study the soil reinforcement ability by root system was rarely found in the previous studies (Karrenberg et al., 2003; Sutili and Rauch, 2008). Nevertheless, documentation on the correlation between cuttings morphological characters and uprooting resistance has been not available, which calls for an understanding the influence of cuttings root on the soil reinforcing effect. Therefore, five native plants species were selected and tested in local place of Beijing. The main aims of this study were (1) to identify the survival rate and shoot root development capabilities of five species constructed as cuttings and (2) to explore uprooting resistance of five species and correlate maximum uprooting resistance (F_{max}) and plant morphological characteristics. All the mentioned components are essential and helpful to understand the suitability of these local plants of the regional area close to Beijing for using the soil bioengineering techniques to stabilize streambanks.

2. Materials and methods

2.1. Study site and experimental set up

The experiment was conducted in a nursery place of Changping (40°10′57″N, 116°14′51″E), a district of Beijing, China. The total annual precipitation is 550 mm at this testing site and the average annual temperature is 11.8 °C. The experiment plot was divided into two parts, the artificial slopes and a platform (Fig. 1). In March 2010, the artificial slopes with 45 m in length and 6.5 m in width (A and B sides) were constructed with the help of an excavator.

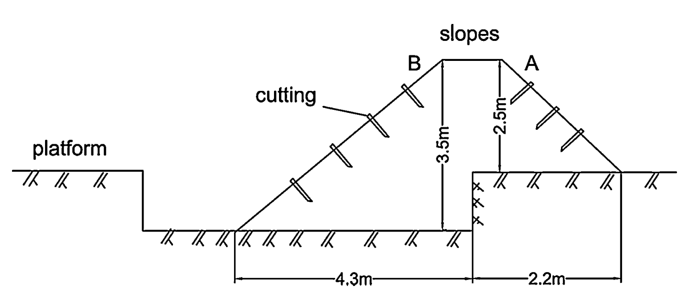

Fig. 1. Experimental arrangement at nursery testing site: artificial slopes designed for research on the development of cuttings, and the platform for pull out tests.