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Soil water repellency of the artificial soil and natural soil in rocky slopes as affected by the drought stress and polyacrylamide

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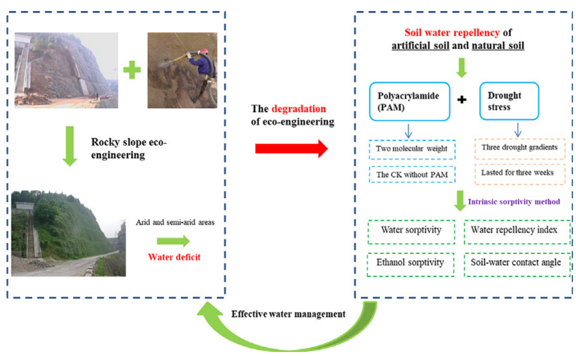
HIGHLIGHTS

- PAM reduced soil water repellency and increased soil wettability of artificial soil.
- PAM with a high molecular weight performed best.
- The artificial soil had a greater soil water repellency than the natural soil.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil water repellency (SWR) causes reduced soil water storage, enhanced runoff and reduced ecosystem productivity. Therefore, characterization of SWR is a prerequisite for effective environmental management. SWR has been reported under different soils, land uses and regions of the world, particularly in forest land and after wildfires; however, the understanding of this variable in the artificial soil of rocky slope eco-engineering is still rather limited. This study presented the characterization of SWR in the artificial soil affected by the polyacrylamide (PAM) and drought stress. There were two molecular weights of PAM, and the CK was without PAM application. Three types of soil were studied: natural soil and two types of artificial soil which have been sprayed for 1 y and 5 y, respectively. The drought stress experiments had three drought gradients, lasted for three weeks. Water repellency index (WRI) and soil-water contact angle (β) were determined using intrinsic sorptivity method by measuring the water sorptivity (S_W) and ethanol sorptivity (S_E) in all soil samples. The results showed that (1) Polyacrylamide treatments significantly increased S_W by 3% to 38%, and reduced S_E by 1% to 15%, WRI by 6% to 38%, β by 3% to 23% compared to the control group. Polyacrylamide treatments also increased water-stable aggregates content and total porosity by 22% to 33%, 11% to 20% relative to the control, while PAM with a higher molecular weight performed best. (2) The interaction between PAM and drought stress had a significant effect on WRI and β for all soil types ($P < 0.01$) while it only had a significant effect on S_W and S_E for the artificial soil ($P < 0.01$). (3) The artificial soil had a greater WRI and β than the natural soil.

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1. Introduction

Large-scale highway and mining construction in hilly areas of China have created many denuded steep rocky slopes. The protection of steep rocky slope is of great importance for local construction safety as well as ecological conservation (Chen et al., 2016; Yang et al., 2014; Chen et al., 2013.). Artificial soil is an important component of the steep rocky slope stabilization projects, which is often sprayed onto those slopes to promote revegetation. It creates necessary growth conditions for plants on the rocky slope, and is the basis for stable growth of vegetation. The artificial soil used is a mixture of loam, peat, humus, plant fibers, soil amendments, and soil slow-release fertilizer.

Revegetation of steep rocky slope stabilization projects in the arid and semi-arid areas of China has proven to be difficult possibly due to water deficiency. The frequent and intense droughts as well as the strong evaporation are increasing pressure on the protection of steep rocky slopes in arid and semi-arid regions (Yang et al., 2014). The artificial soil is commonly thinner than natural slope soil (ca. 10–15 cm), and the underlayer of soil is the rock that has poor water permeability, inducing difficulty in water storage (Chen et al., 2016). Therefore, the established vegetation usually degrades with 2–3 years. The vegetation system degradation has been associated with the water deficiency of artificial soil especially in the arid and semi-arid areas of China, which is the urgent problem of steep rocky slope stabilization projects.

Soil wettability and water repellency are important physical properties that affect soil-water interaction. Soil water repellency (SWR) characterizes the resistance of soil against water absorption for different time periods (Tadayonnejad et al., 2017). SWR is known to affect the soil's physical and hydrological properties. It increases hysteresis of the water-retention curve and reduces infiltration capacity relative to wettable soils (Doerr et al., 2000; Hallett, 2008; Hosseini et al. 2015a). SWR causes reduced soil water storage, enhanced runoff and reduced ecosystem productivity. Therefore, characterization of SWR is a prerequisite for effective environmental management. SWR has been reported under different soils, land uses and regions of the world, particularly in forest land and after wildfires. However, the understanding of this variable in the artificial soil of rocky slope eco-engineering is still rather limited.

Associated with this lack of knowledge is the poor understanding of what soil parameters affect water repellency, which can be used to predict its occurrence and severity (Doerr et al., 2006). Generally, the SWR is originated from hydrophobic organic compounds covering the surface of soil particles. Natural sources of SWR are the organic compounds released by plant roots and leaves. SWR has been studied under different climatic conditions (Doerr et al., 2000) and may be affected by many factors (Mataix-Solera et al., 2014) such as soil organic matter content (Doerr and Thomas, 2000), soil mineralogy (Zavala et al., 2009a), soil texture (Jordán et al., 2013), vegetation type (Zavala et al., 2009a, 2009b), soil moisture content (SMC) (Doerr and Thomas, 2000) and fire (Granged et al., 2011b). Often, all these factors combine, and favor the increase of SWR below critical SMC (Jiménez-Pinilla et al., 2016). The relationship between SWR and SMC may vary if soil is wetting or drying (Urbanek et al., 2015), which may have a significant impact on runoff generation and soil erosion risk (Ahn et al., 2013) and the development of preferential flow paths (Granged et al., 2011a), having major consequences for plant growth (Doerr et al., 2000). The SWR usually decreases with an increase in soil moisture content (Hallett, 2008); after a heavy rainfall, SWR reduces or disappears (Dekker and Ritsema, 1994). The local climatic condition was also a potential contributor, as it greatly affected soil moisture content and the intensity and number of drying and wetting cycles. Predicted larger frequencies of extended droughts owing to the climatic change suggest for some locations' higher relevance for the occurrence of SWR in forest soils with direct consequences for water and nutrient availability (Schwen et al., 2015). During drought periods, the water content should be reduced, and the SWR should be higher. For those reasons, SWR is especially relevant in arid and semiarid areas, where water resources may be especially limited and distribution of rainfall is strongly seasonal (Jiménez-Pinilla et al., 2016). The SWR is usually positively related to organic matter (OM) as well as their compounds such as humic acids, microbial carbon, and exudates (Feeney et al., 2006), which mostly exist as either interstitial matter, coating of soil minerals, or aggregate surfaces to resist wetting (Doerr et al., 2000; Jasinska et al., 2006). There are many studies that associate SWR with soil organic matter (SOM) content (Wallis and Horne, 1992; Chenu et al., 2000).

How to reduce soil water repellency and increase soil wettability of artificial soil are crucial problems that need to be solved in the research of artificial soil. It is important to determine the appropriate surfactants that can improve the structure and increase the water retention of artificial soil during steep rocky slope stabilization projects. The polyacrylamide is often used as industrial flocculants for separation of solids from aqueous suspensions. Anionic water-soluble forms of polyacrylamide (PAM) are often used as soil conditioners to manage infiltration, runoff and soil erosion (Sojka et al., 2006; Davidson et al., 2009; Mamedov et al., 2010). PAM mainly consists of -NH_2 and -COOH functional groups; they influence the soil aggregation due to their adsorption ability, creating bridges between soil particles and changing soil wettability (Janczuk et al., 1991). PAM not only can reduce soil water repellency and increase soil wettability, but also can increase the soil structural stability (Tadayonnejad et al., 2017). PAM are used to improve the soil permeability and water retention, which can displace the hydrophobic organic compounds that coat the soil particles. In addition, the PAM are effective in reducing the surface tension of water, and consequently can improve water infiltration into the soil matrix (Fernández Cirelli et al., 2008; Laha et al., 2009).

The positive impacts of PAM on soil properties have been investigated in natural soil and farmland, while little work has been done to examine its effects on variability of soil water repellency and wettability of artificial soil in steep rocky slope stabilization projects. It is important to recognize the importance of PAM application on the steep rocky slope stabilization projects to understand the soil hydraulic property, which is critical in the establishment of a healthy and native ecosystem, especially in arid and semi-arid environments where water availability to plants is scarce.

The aim of this study was to investigate the effects of polyacrylamide (PAM) on soil water repellency of the artificial soil on rocky slopes during drought stress experiments.

2. Materials and methods

2.1. Materials

The artificial soil used was a mixture of loam (68%), peat (10%), humus (7%), plant fibers (7%), soil amendments (2%), and soil slow-release fertilizer (6%). The percentage of each component was its mass fraction. The peat, plant fibers and soil amendments contributed to improve soil properties. The humus and soil slow-release fertilizer provided adequate nutrients for plant growth. *Cynodon dactylon*, commonly used in soil and water conservation projects, was sown in this experiment. The seeding density was 10 g m^{-2}, and the germination rate was up to 98%.

The mixture of artificial soil, plant seeds and water were sprayed onto soil trays by a compressed-air spraying machine (12 m^3, Ingersoll-Rand, Piscataway, NJ). The spraying pressure was 0.12 MPa. The soil tray was 1 m long, 1 m wide and 0.1 m deep. The artificially cut slate was used as the underlayer to simulate rocky slope, and the thickness of artificial soil layer was 10 cm.

Polyacrylamide samples were provided by Shanghai Wshine Chemical Co., Ltd., Shanghai, China. The particle diameter was <0.02 mm, and the active ingredient concentration was 99.9%.