Ecological Engineering 90 (2016) 68–76

Contents lists available at ScienceDirect

Ecological Engineering

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

Ecological restoration of highway slope by covering with straw-mat and seeding with grass–legume mixture

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ARTICLE INFO

Article history:
Received 13 August 2015
Received in revised form
30 November 2015
Accepted 26 January 2016
Available online 11 February 2016

Keywords:
Highway slope
Straw-mat
Soil conditions
Vegetation recovery
Economic and effective

ABSTRACT

Highway construction has caused certain negative impacts on the ecological environment, particularly in mountainous areas. The vegetation recovery of highway slopes can reduce the harmful effects, especially in the initial stage of highway construction. In 2014, our research was carried out on a restored highway slope in the Wanxi Dabie mountain areas, China. In this study, research sites were established on three adjacent highway slopes and one in the nearby forest. The effects on the soil moisture, soil temperature, vegetation growth and soil physicochemical properties were surveyed by both laboratory and field experiments. The results showed that the slope covered with topsoil and straw-mat was more effective in enhancing vegetation growth by reducing soil evaporation and regulating the soil temperature, improving the aesthetic quality of the road environment rapidly. In addition, the soil physicochemical properties were significantly improved along with the initial vegetation recovery of the highway slopes. This effective ecological restoration technology also embodied the characteristics of economic and environmental friendliness. The derivation of unit cost was only US$ 6 m^{-2}, which was suitable for developing countries. Consequently, the study provided a typical case of vegetation recovery on highway slopes that has great potential for promotion and application in other areas.

1. Introduction

With the world economic and social development, major infrastructure construction projects have been developed rapidly. As an important component of modern infrastructure, highway construction fully indicates a country's economic construction and development level. By 2014, China's highway mileage had reached 111,950 km, becoming the longest in the world. This aggressive construction may profoundly influence the ecological environment system, so the national ecological security and ecological restorations are significant challenges for highway development in China. Particularly in mountainous areas, highway construction has created large disturbances in the ecological environment (Xu et al., 2006), such as the alteration of landscape patterns, the removal of natural soil, the destruction of natural vegetation and the degradation of biodiversity, resulting in habitat fragmentation and loss (Cohen-Fernández and Naeth, 2013; Shao et al., 2014). In the early period of the engineering design stage, we always simply consider the safety of structural and hydrogeological conditions. However, we rarely consider ecological engineering from a comprehensive perspective or pay attention to the conservation of water and soil or the construction of landscape aesthetics (Fan et al., 2013). In recent years, with the growing awareness of environmental protection, the vegetation recovery of highway slopes has been increasingly raised and emphasized by some people. Therefore, it is a challenging task to stabilize and restore these many damaged slopes by using suitable recovery measures (Cao et al., 2010).

Vegetation plays an important role in protecting highway slopes because it can control erosion by intercepting rainfall and stabilize the slope surface with developed root systems. However, vegetation can be effective in protecting slope surface only with a high coverage of vegetation (Rickson, 2006). This is often difficult in the initial stage of vegetation recovery on highway slopes, owing to limitations involving temperature fluctuation and heavy rainfall. In the rainy season, the slope surface is prone to feature the phenomenon of low infiltration and high runoff, which is bad for vegetation recovery (Cano et al., 2002). Moreover, the temperature stress is another limiting factor in the initial stage of the vegetation recovery (Beikircher et al., 2010).

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http://dx.doi.org/10.1016/j.ecoleng.2016.01.052

To reduce the environmental constraints for vegetation recovery and control slope soil erosion, mulching methods were applied in this project. Mulches are able to protect the soil and seeds from the impact of the rain and sunshine; therefore, they have the potential for creating favorable conditions for plant growth and reducing erosion risk (Brofas and Varelides, 2000). Geotextiles, which have been widely used in hydraulic engineering, electrical engineering and traffic engineering, can protect the soil surface and control erosion effectively (Mitchell et al., 2003). Geotextiles can be used as the mulching materials to prevent erosion and create favorable soil conditions for vegetation recovery (Methacanon et al., 2010) and have been defined as 'permeable synthetic materials used in conjunction with foundation, rock, soil or any geotechnical engineering' (John, 1987). They can be made from either organic synthetic fibers (polypropylene, polyester, polyethylene, polyamide etc.) or natural fibers (jute, coir, sisal, straw, palm-leaf etc.) with different designs, shapes, sizes and compositions according to functional needs (Rickson, 2006). Natural geotextile mats are the most effective and environmentally friendly.

A grass–legume mixture had been widely used in vegetation recovery. Studies have shown that annual herbs along with perennial leguminous plants are able to restore a degraded site successfully (Lenka et al., 2012; Araujo and Costa, 2013). The combination of the grass–legume mixture can improve soil nitrogen content, and the decomposition of plant litter can provide nitrogen-rich mulch for soil. Grasses have strong fibrous root systems that can prevent erosion by holding the loose soil of the slope surface; they also can adapt to bad soil conditions and form mulches after drying (Maiti, 2013). Studies have shown that legumes have a significant beneficial effect on soil fertility and acted as pioneer plants to improve nutrient-poor soil (Agbenin and Adeniyi, 2005). Maiti and Saxena (1998) verified that legumes could restore a degraded coal mine site successfully without topsoil; Spehn et al. (2002) found that some legume species can assist N transfer to co-occurring non-leguminous plants by improving the nutrient content of decomposition; Hättenschwiler et al. (2005) concluded that legumes have an important role in nutrient cycling owing to the nitrogen fixation in legume roots.

The objectives of this study are as follows: (i) to investigate the role of a straw-mat in regulating soil moisture and temperature, thereby contributing to the successful establishment of vegetation; (ii) to verify the effect of improving soil physicochemical properties due to the growth of vegetation; and (iii) to demonstrate that the ecological recovery of highway slopes by covering with straw-mat and seeding with grass–legume mixture is an effective technique, having good performance and popularization value.

2. Materials and methods

2.1. Study sites

The study was carried out on a Yuexi–Wuhan highway slope in the Wanxi Dabie mountain areas, China, between latitudes 30°51′32″N and 30°51′48″N and longitudes 116°19′25″E and 116°19′33″E; the average elevation is 416 m. The climate is subtropical monsoon with a long-term mean annual precipitation of 1498 mm (mainly concentrated in June to August, accounting for more than 70% of the annual rainfall). The mean daily temperature is 14.5 °C; the maximum temperature is 33.6 °C in July, and the minimum is 1.3 °C in January. Owing to the construction of the highway, the original natural soil and vegetation were totally damaged, resulting in a rough, bare slope. A photograph of the unrestored highway slope is shown in Fig. 1. If timely and effective slope protection measures were not taken, the slope soil erosion would be very serious in the rainy season. Therefore, it was necessary to restore vegetation by some ecological engineering measures according to the special conditions of the highway slope.

Fig. 1. Distance view of the unrestored highway slope.

Ecological recovery research treatments were established on three slopes of highway within 0.5 km of one another and one in the nearby forest 0.7 km away (Fig. 2). Site A was on a south-facing highway slope 70-m long and 10–20-m wide, covering an area of approximately 0.12 ha with a mean gradient of 35° and covered with 15 cm of topsoil and straw-mat. Site B was on a slope 50-m long and 8–15-m wide, covering an area of approximately 0.06 ha with a 33° south-facing embankment covered with 15 cm of topsoil. As a control plot, site C was on a south-facing highway slope with a 35° slope of varying length and covered with nothing with an area of approximately 0.05 ha. Site D was on a southwest-facing slope of the nearby forest. These sites collectively represented the multi-conditions of ecological recovery of highway slopes.

2.2. Characteristics of topsoil

The topsoil of the study sites was very thin, which was not conducive to the growth of plants, so it was necessary to cover the topsoil on the slope surface. The topsoil cover was one of the most important factors in the engineering quality of the ecological recovery (Melečková et al., 2013). Topsoil cover on highway slopes might actually help create an appropriate substrate condition for vegetation growth and stabilization of the slope surface. In the present study, the engineering required topsoil to be excavated from the nearby forest and transported to the restoration site. The physicochemical characteristics of the topsoil are given in Table 1.

Table 1
Physicochemical properties of topsoil used for covering the highway slope.

Parameters	Topsoil
Color	Yellow-brown to dark-brown
Sand (%)	76.32 ± 7.16
Silt (%)	18.07 ± 1.92
Clay (%)	5.61 ± 0.87
Soil porosity (%)	36.31 ± 1.96
Field moisture capacity (%)	17.43 ± 1.12
Total N (g kg^{-1})	0.46 ± 0.13
Available P (mg kg^{-1})	15.36 ± 0.83
Available K (mg kg^{-1})	68.19 ± 5.28
Organic matter (g kg^{-1})	15.85 ± 0.71
pH H_2O (1:1; w/v)	5.42 ± 0.27