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Combined effects of climate, restoration measures and slope position in change in soil chemical properties and nutrient loss across lands affected by the Wenchuan Earthquake in China

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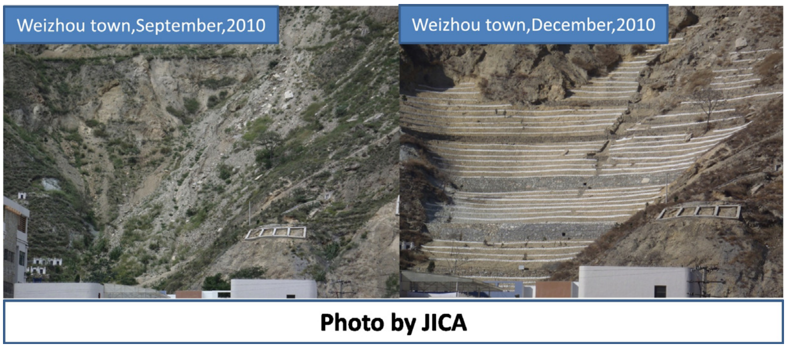
HIGHLIGHTS

- Climate types and restoration measures significantly affected soil chemical properties, but slope position not.
- Restoration project didn't control soil nutrient loss in the short term.
- Most soil chemical properties may degrade or develop concomitantly.

GRAPHICAL ABSTRACT



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ABSTRACT

The MS 8.0Wenchuan Earthquake in 2008 caused huge damage to land cover in the northwest of China's Sichuan province. In order to determine the nutrient loss and short term characteristics of change in soil chemical properties, we established an experiment with three treatments ('undestroyed', 'destroyed and treated', and 'destroyed and untreated'), two climate types (semi-arid hot climate and subtropical monsoon climate), and three slope positions (upslope, mid-slope, and bottom-slope) in 2011. Ten soil properties—including pH, organic carbon, total nitrogen, total phosphorus, total potassium, Ca^{2+}, Mg^{2+}, alkaline hydrolysable nitrogen, available phosphorus, and available potassium—were measured in surface soil samples in December 2014. Analyses were performed to compare the characteristics of 3-year change in soil chemical properties in two climate zones. This study revealed that soil organic carbon, total nitrogen, Ca^{2+} content, alkaline hydrolysable nitrogen, available phosphorus, and available potassium were significantly higher in subtropical monsoon climate zones than in semi-arid hot climate zones. However, subtropical monsoon climate zones had a higher decrease in soil organic carbon, total nitrogen, total phosphorus, total potassium, and alkaline hydrolysable nitrogen in 'destroyed and untreated' sites than in semi-arid hot climate zones. Most soil chemical properties exhibited significant interactions, indicating that they may degrade or develop concomitantly. 'Destroyed and treated' sites in both climate types had lower C:P and N:P ratios than 'destroyed and untreated' sites. Principal component analysis (PCA)

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showed that the first, second, and third principal components explained 76.53% of the variation and might be interpreted as structural integrity, nutrient supply availability, and efficiency of soil; the difference of soil parent material; as well as weathering and leaching effects.

Our study indicated that the characteristics of short term change in soil properties were affected by climate types and treatments, but not slope positions. Our results provide useful information for the selection of restoration countermeasures in different climate types to facilitate ecological restoration and reconstruction strategies in earthquake-affected areas.

1. Introduction

Powerful earthquakes induce secondary geo-hazards, including mountain collapses, landslides, and debris flows that eventually lead to the subsequent death of existing trees in the disaster areas due to changes in soil factors (Cui et al., 2012). For example, after a 7.3 Ms earthquake in Songpan County, China in 1976 > 80% of the bamboo growing in earthquake–induced landslide areas died in the five years that followed (Schaller et al., 1985). Similarly, the mortality of *Nothofagus solandri* increased by 75% in the seven years after a 6.7 MS earthquake in New Zealand (Allen et al., 1999). Earthquakes not only give rise to local vegetation variation, but also result in soil physicochemical property changes. The original nutrient-rich and well-structured soil is destroyed or buried by earthquake-induced mass movements (including rock avalanches, landslides, rockfalls, and debris flows) in mountainous regions. This disturbs surface soil structure and causes large scale surface soil erosion, resulting in increased soil aeration and infiltration capacity, diminishing hydrological adjusting function, as well as changes in drainage, bulk density, and temperature (Vittoz et al., 2001; Liu and Sheu, 2007; Cui et al., 2012). Soil loosening increases the growth and activity of aerobic microorganisms, thus accelerating organic matter decomposition and nutrient loss (Walker and Shiels, 2008; Walker et al., 2009; Pupin et al., 2009). As a result, the physical process of plant and vegetation recovery can be influenced by the change in soil ecological systems (Cheng et al., 2012; Walker and Shiels, 2008).

The Wenchuan Earthquake occurred in the Southwest of China on May 12, 2008 and killed at least 68,000 people. The focal energy release caused a sudden dislocation in the Yingxiu-Beichuan fracture, leading to the violently intense and prolonged Ms 8.0 earthquake and subsequent widespread heavy loss, frequent geological disasters, and serious ecological degradation (Cui et al., 2012; Ouyang et al., 2008; Bao, 2008). Numerous earthquake-triggered geo-hazards piled a large amount of loose materials into hilly terrains, creating numerous unstable slopes (Chang et al., 2011; Wang et al., 2014). These geo-hazards buried, removed, and toppled existing vegetation (Cui et al., 2012). The Sichuan Province forestry department reported that the direct loss of forest systems across the province reached an approximate value of 3.33 billion dollars. In 45 severely hit cities and counties, the losses of Ecological Public Welfare Forest (EPWF) and Conversion of Cropland to Forest Project (CCFP) were especially calamitous, with approximately 3.04 million dollars and 29.57 million dollars, respectively, in damage. An area of 1.652×10^4 ha and 1.595×10^4 ha, respectively, was damaged (Deng and Li, 2009). Due to vegetation deterioration, the average soil erosion modulus in the earthquake-affected area increased to 4604 $t/(km^2 \cdot a)$ from the 3703 $t/(km^2 \cdot a)$ pre-earthquake rate (Zhao et al., 2009; Wang et al., 2009).

In response to the Wenchuan Earthquake, the Chinese government initiated a nearly 160 billion USD recovery plan (Xinhuanet, 2011; Zhang et al., 2014). Thus, ecological restoration efforts in this area have been reported in the context of several aspects, including site conditions, characteristics of soil-vegetation systems, and restoration patterns (Lin et al., 2012; Peng et al., 2013; Zhang et al., 2009; Zhang and Wang, 2008; Zhang et al., 2014). Many factors have shaped the outcomes of ecological restoration in this area e.g. climate, soil erosion, micro-morphology, human activities, geo-hazards, and soil properties (Rodríguez Rodríguez et al., 2005; Wang et al., 2007; Lin et al., 2006). Soil properties are the basis of vegetation restoration and could reveal the driving mechanism of vegetation retrogressive succession, but to our knowledge, characteristics of soil property changes in severely earthquake-affected areas are still poorly understood and undocumented (Wu et al. (2012) is a notable exception).

In this study, we sought to examine how change in soil properties has been affected by restoration measures and slope position after the Wenchuan Earthquake in different climate types. Here we focus on a 2.27 million dollars forest restoration project carried out in 2010–2015 by the Japan International Cooperation Agency (JICA) in Mianzhu city and Wenchuan county, areas regarded as typical subtropical monsoon and semi-arid hot climate zones. Our main objective was to analyze the characteristics of soil nutrient change after the earthquake and to determine whether climate types affected the change. We were also interested in whether post-earthquake recovery potential in treated sites is higher than in untreated sites. This study has important implications for elucidating the effects of earthquakes on the environment and facilitating ecological restoration and reconstruction of earthquake-affected areas.

2. Methods

2.1. Study area

Our study areas are located on the edge of the Qinghai-Tibet Plateau transition zone—northeast of the Sichuan basin (30°45′ ~ 33°03′N and 102°49′ ~ 105°38′E) —in Sichuan Province, China. It is an important region for soil and water conservation, as well as a crucial component of ecological defense in the upper reaches of the Yangtze River (Cui et al., 2012). However, it has been seriously affected by the Longmen Mountain fault—a major fault line in southwestern China (Zhang et al., 2014). Data from the China Earthquake Networks Center indicated that eight earthquakes above magnitude 7.0 have happened within 200 km of the epicenter of the Wenchuan Earthquake—located on the Longmen Mountain fault—since the 1930s (China Earthquake Networks Center, 2008; Zhang et al., 2014). The destructive power of the Wenchuan Earthquake caused massive vegetation damage in nine severely hit cities and counties, including Beichuan, Anxian, Maoxian, Pingwu, Qingchuan, and Wenchuan counties, as well as the cities of Jiangyou, Mianzhu, and Shifang. The total area of damaged vegetation was approximately 1250 km^2, accounting for 4.76% of the nine cities severely damaged by the earthquake (Cui et al., 2012).

2.2. Restoration projects

After the Wenchuan Earthquake, JICA selected Hangwang town in Mianzhu district and Leigu town in Beichuan county (Subtropical monsoon), as well as Weizhou and Mianchi towns in Wenchuan county (semi-arid hot climate), as representative sites and carried out a vegetation restoration project from 2010 to 2015 in an effort to demonstrate whether geotechnical and biological measures accelerate recovery process of degraded ecosystem caused by the Wenchuan Earthquake. The total project budget was estimated at 2.27 million dollars and was