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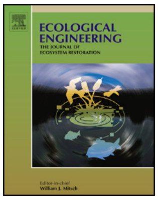

Impacts of vegetation restoration strategies on soil organic carbon and nitrogen dynamics in a karst area, southwest China

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ABSTRACT

Soil carbon (C) sequestration through cropland conversion has been regarded as a major strategy to absorb atmospheric CO_2 and thus mitigate global warming, but much uncertainty still exists in terms of restoration strategies. In this study, soil C and nitrogen (N) were measured 13 years after cropland conversion in a karst area, southwest China. Four restoration strategies were included, i.e., (i) restoration with an economic tree species *Toona sinensis* (TS), (ii) restoration with Guimu-1 hybrid elephant grass (GG), (iii) restoration with a combination of *Zenia insignis* and Guimu-1 hybrid elephant grass (ZG), and iv) spontaneous regeneration (SR). Cropland under maize-soybean rotation (CR) was used as reference and the space-for-time substitution approach was adopted to evaluate soil C and N stock (0–15 cm) change. Soil C stocks in TS and SR were elevated by 40% and 50%, respectively, relative to CR, while those in GG and ZG were not significantly changed. Soil N stocks in GG were not significantly changed, but stocks in TS, ZG and SR were enhanced by 130%, 81% and 117%, respectively, relative to CR. Significant correlation was found between soil C and N stock changes with rate of relative N stock change greater than that of C stock change. Similar to soil N stock, nitrate concentration, net nitrification rate and δ^{15}N values in TS, ZG and SR were greater than those in GG or CR. Stepwise multiple linear regression indicated that exchangeable calcium was the soil variable mainly responsible for the dynamics of both soil C and N. Our results indicate that plantation with economic tree species and spontaneous regeneration are likely equally effective in soil C sequestration.

1. Introduction

Impacts of land use change on carbon (C) dynamics of terrestrial ecosystems have been well recognized (Lal, 2004). Conversion of natural ecosystems to cropland is usually accompanied by substantial loss of soil organic carbon (soil C hereafter) (Guo and Gifford, 2002). Loss of soil C from cropland results in decrease in soil fertility and thus crop productivity, since an appropriate level of C stock is crucial to prevent soil from degradation via holding water and nutrients, reducing erosion, improving soil structure, and providing energy to soil microbial community (Lal, 2004). In this sense, the widespread loss of soil C from conversion of natural ecosystems to cropland exerts a threat to global food security (Lal, 2004). Fortunately, the processes of soil C loss may be halted by sound cropland management (Smith, 2004) or be reversed by transformation of cropland to forest or grassland (Guo and Gifford, 2002; Li et al., 2012). It was estimated that soil C sequestration has the potential to offset fossil-fuel emissions of carbon dioxide (CO_2) by 0.4–1.2 $\mathrm{Pg\,C\,yr^{-1}}$ (1 Pg = 10^{15} g) (Lal, 2004). Because of this, soil C sequestration through C-depleted cropland conversion has been regarded as an effective and cost-effective way to absorb atmospheric CO_2 and thus mitigate global warming (Lal, 2004; Lal, 2008).

Soil C stocks have been found to increase, decrease or change trivially following cropland conversion to forest or grassland (Li et al., 2012; Deng et al., 2014). The disparity in soil C dynamics following cropland conversion has been attributed to prior land

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use, climate, tree species planted and years since cropland conversion (Li et al., 2012; Deng et al., 2014). Nonetheless, there is great variability in soil C stock change following cropland conversion within each of the above four groups of controlling factors (Li et al., 2012).

The mechanisms underlying soil C dynamics following cropland conversion are far from being well understood. Theoretically, soil C dynamics is determined by C input to and output from soil. The former is largely relied on net primary productivity (NPP) while the latter is controlled by both litter and soil C decomposition rates. Accordingly, the biotic and abiotic factors which affect NPP and C decomposition rates will subsequently influence the dynamics of soil C stock following cropland conversion. Among these factors, N has been suggested as a key variable in determining the long-term soil C dynamics of terrestrial ecosystems since N is the major limiting nutrient of NPP in most terrestrial ecosystems (Hungate et al., 2003; Luo et al., 2004; LeBauer and Treseder, 2008). Increased N availability will on one hand enhance plant growth and thus litter input to soil until other nutrients become limiting (LeBauer and Treseder, 2008). On the other hand, litter decomposition will be inhibited under conditions of high N inputs (>0.5–1 g N m^{-2} yr^{-1}) but stimulated under conditions of low N inputs (<0.5 g N m^{-2} yr^{-1}) (Knorr et al., 2005). All these help to enhance soil C stock. Long-term cultivation depletes soil N and this usually results in ecosystem N limitation upon cropland conversion (Amundson, 2001). Whether the natural sources of soil N can sustain rapid soil C accumulation has not been well resolved so far (Hungate et al., 2003). Furthermore, other soil nutrients, e.g., calcium (Ca) and magnesium (Mg) may also be decreased along with soil C depletion during long-term cultivation. These nutrients are not only important in plant growth, but also play a role in soil C stabilization by interaction of soil organic matter with mineral surfaces via polyvalent cations, especially Ca^{2+} and Mg^{2+} in neutral and alkaline soils (von Lützow et al., 2006; Kaiser et al., 2011). However, it is not clear whether these cations recover following cropland conversion or whether these cations play an important role in determining the disparity of soil C dynamics following cropland conversion, since very limited studies measured these cations along with soil C and N. In general, more studies are urgently needed to understand the factors controlling soil C dynamics so that soil C sequestration can be well predicted.

China is among the countries with the largest area of degraded cropland due to erosion. About 78% of the total cropland in China is degraded to some degree (Ren et al., 2007). Cropland degradation is especially widespread in southwest China, which alone is responsible for 25% of China's degraded cropland (Bennett, 2008). In order to reduce soil erosion and extend the area of forest and grassland, China has implemented several nationwide ecological restoration programs, including the Sloping Land Conversion Program (SLCP, also known as Grain for Green project (GGP)) initiated around 2000. By the end of 2012, about 27.2×10^6 ha of degraded land has been restored under GGP (Shi and Han, 2014). Besides vegetation restoration, GGP has also been proposed to enhance soil C sequestration. According to a recent meta-analysis, cumulative soil C sequestration due to GGP was 156 ± 108 Tg C (95%CI hereafter) over the period of 1999–2012 with a mean accumulation rate of 12 ± 8 Tg C yr^{-1} (Shi and Han, 2014). However, these estimates may be rough since the regional distribution of measurements is unbalanced with, for example, very limited measurements conducted in the vast calcareous karst region of southwest China. This region has an area of about 0.51 million km^2 of contiguous exposed/outcropped carbonate rock areas (or karst areas), accounting for 5.8% of the national land (Jiang et al., 2014). During the past decades, a large portion of the karst region in southwest China have been degraded owing to soil C loss and soil erosion following deforestation and arable cultivation. Under the supports of GGP and other ecological restoration projects, most of the degraded land has been converted into woodland or grassland so far. Nevertheless, whether the vegetation restoration in this karst region will lead to substantial C sequestration is still not clear.

On the other hand, conversion of cropland means decrease of cropland area. For example, in the upper reaches of the Yangtze River, per-capital cropland declined from 0.1 to 0.17 ha before GGP to 0.02–0.07 ha after just one year of its implementation (Xu et al., 2006). The central government of China subsidizes farmers with a period of 2–8 years dependent on vegetation restoration strategies. For example, subsidies are paid for 5 years when economic tree species are planted, for 8 years when non-economic tree species are planted, and for 2 years when the cropland is converted to grassland (Xu et al., 2006). How the different types of vegetation restoration strategies impact soil C sequestration has not been well investigated in the karst region. In the present study, soil C and N dynamics under four commonly adopted restoration strategies in the karst area of southwest China were compared, i.e., (i) restoration with an economic tree species *Toona sinensis* (TS), (ii) restoration with Guimu-1 hybrid elephant grass (GG), (iii) restoration with a combination of *Zenia insignis* and Guimu-1 hybrid elephant grass (ZG), and (iv) spontaneous regeneration (SR). These strategies were compared with a reference cropland. This kind of space-for-time substitution approach has been proposed as an alternative of long-term studies (Pickett, 1989) and has been widely used to estimate soil C or N stock change following land use change (Li et al., 2012, 2017; Deng et al., 2014). Since a large part of the biomass was removed in the grassland and the mixture of grass and tree species, especially the former due to biomass harvest used for fodder of beef as explained in the following section, we hypothesized that soil C and N accumulation would be much lower under these two strategies than under the other two strategies. Specific objectives were to (i) determine the rates of C accumulation for the four restoration strategies, (ii) assess how soil N stocks change along with C accumulation, and (iii) find out the dominant soil variables impacting soil C accumulation.

2. Materials and methods

2.1. Site description

This study was conducted at Guzhou catchment (107°56′–107°57′E, 24°54′E–24°55′N) in Guangxi Zhuang Autonomous Region, southwest China. This region is located in the subtropical humid forest life zone with a monsoon climate. Mean annual air temperature is 15.0–18.7 °C, with the lowest monthly mean in January (3.4–8.7 °C) and the highest in July (23.0–26.7 °C). Mean annual precipitation ranges from 1530 to 1820 mm with a distinct seasonal pattern. The period from April to August is wet season and that from September to March is dry season. The area is characterized by a typical karst landscape with gentle valleys flanked by steep hills. The soil is calcareous lithosols (limestone soil) according to the FAO/UNESCO classification system (Anon., 1974). Averaged soil depths are 50–80 cm in the valley and range from 10 to 30 cm on the slopes. Some soil properties are presented in Table 1.

Guzhou catchment has an area of 10.2 km^2 and an elevation ranging from 375 to 816 m above sea level. Before the 1980s, this catchment was seriously disturbed by deforestation and cultivation on the slopes. Under the support of GGP project, most of the degraded cultivated lands over slopes were abandoned and recovered under different restoration strategies in early 2000s.