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Estimates of carbon storage in grassland ecosystems on the Loess Plateau

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ABSTRACT

Grassland ecosystems play an important role in the carbon (C) balance of arid and semi–arid regions. These ecosystems provide C for grass growth and soil microbial activities and represent one of the main sources of atmospheric C. In this study, we estimated the C density and storage of 223 sampling sites in grassland ecosystems on the Loess Plateau using elevation, vegetation indexes, precipitation, air temperature, day and night land surface temperature (LSTd and LSTn, respectively), evapotranspiration (ET), percent tree cover and the non–vegetated area to build decision regression tree and generalized linear regression models (GLMs). The results showed that the C density decreased from south to north and ranged from 0.22 to 29.29 kg C/m^2. The average amount of C stored in the ecosystems was 1.46 Pg. The typical steppe and forest steppe stored the most C, and the steppe desert stored the least. The soil (0–1 m) stored most of the organic C, accounting for > 90%, and the belowground biomass (BGB) contained > 3 times the amount of C as the aboveground biomass (AGB). This study provides reference information for the loss of C and associated mitigation strategies on the Loess Plateau.

1. Introduction

Grasslands store > 10% of the total carbon (C) in the biosphere (Nosberger et al., 2000) and represent a non–negligible component of terrestrial ecosystems (Soussana et al., 2004). Ecosystem responses are a stronger driver of the inter–annual variability in C fluxes in grasslands than climate variability (Zhang et al., 2016). Moreover, drought (Gang et al., 2016), afforestation (Chen et al., 2016), land degradation (Wang et al., 2017a), species diversity (Rutledge et al., 2017a), land use (Petrie et al., 2015; Ward et al., 2017), irrigation (Moinet et al., 2017) and pasture (Tanentzap and Coomes, 2012; Rutledge et al., 2017b) affect the C sequestration capacity of grasslands. These factors increase the uncertainty of grassland C stock assessments at different spatial scales and in different sampling sites (Zhang et al., 2011; Maillard et al., 2017). In ecologically fragile regions, such as the Loess Plateau (Yang et al., 2015), the assessment of grassland C storage is especially important for land management and further vegetation restoration.

The Chinese government implemented the "Grain for Green" project in 1999 (Deng et al., 2014a) to restore vegetation by converting croplands to grasslands or forestlands. Researchers have found that this project drives land use change and C sequestration on the Loess Plateau (Deng et al., 2014b). Chang et al. (2011) noted that the "Grain for Green" project can significantly increase the storage of soil organic C (SOC) on the Loess Plateau; thus, it is important to determine the size of the C reserves in this region.

Grasslands currently cover approximately 1/3 of the Loess Plateau, but few studies have attempted to assess their C storage. Vegetation types, topography (Wang et al., 2017b) and climate–driven changes (Chen et al., 2017a) affect SOC, of which the differences among grasses could be represented by vegetation indexes such as the leaf area index (LAI), the normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI). In addition to vegetation indexes, percent tree cover and non–vegetated area information may be useful in somewhere mixed grasses with trees or bare lands. Precipitation determines surface soil moisture on the Loess Plateau, and soil moisture is the main disturbance controlling grassland aboveground biomass (AGB) (Zhang et al., 2016; Hu et al., 2016) and its stored C (AGBC). To quantify the climate–driven factors, we considered precipitation and air temperature as primary factors for C estimation. Because it is difficult to acquire regional soil moisture data for the Loess Plateau, we instead utilized the day land surface temperature (LSTd), the night land surface temperature (LSTn) and evapotranspiration (ET).

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These factors were used to build decision regression tree models and generalized linear models (GLMs) for C storage assessment. A decision tree is a stable machine leaning algorithm for data mining (Czajkowski and Kretowski, 2016; Rahmatian et al., 2017; Tayefi et al., 2017) and handling multivalued numerical response variables (D'Ambrosio et al., 2017), and they have various applications (Hong et al., 2015; Fei et al., 2017; Chen et al., 2017b). Generalized linear regression models are commonly used and intuitive (Höskuldsson, 2015; Ross, 2017). We selected decision regression tree and GLM models as they were relatively robust, widely used and easy to transfer.

Furthermore, we collected the results of other research for comparison (Ma et al., 2016). In order to make our results comparable, we extrapolated previous grassland C observation data to the entire Loess Plateau by decision tree and GLM regression models. The objectives of this study were to (1) predict the spatial distribution of grassland AGBC, belowground biomass C (BGBC) and SOC density on the Loess Plateau; (2) estimate the C storage in the grassland ecosystem; and (3) assess the accuracy of our predictions and determine the deviation between our results and previous results.

2. Materials and methods

2.1. Study area

The study area was the Loess Plateau (Fig. 1), which is a landscape with uneven loess in the middle of China that covers an area of 646,200 km^2. The Yellow River cuts across the north of the plateau. The loess stratum can reach > 300 m, and because of the long–term runoff caused by extreme climatic events (Gao et al., 2015), the surface of the loess deposit area has become fragmented (Wu et al., 2017). In addition to the soil erosion under these conditions, the loss of C has become increasingly problematic (He et al., 2016; Li et al., 2017). Grasslands are widely distributed on the hills and plains of the Loess Plateau, and because of its poor soil water–holding capacity, the grass in this arid region is always deeply rooted in the soil to reach water. Grassland map used in this study was supported from "Loess Plateau Data Center, National Earth System Science Data Sharing Infrastructure, National Science & Technology Infrastructure of China. (http://loess.geodata.cn)".

2.2. Experimental design

In the summers from 2011 to 2013, we established 223 sampling plots (100 × 100 m) in grasslands on the Loess Plateau that were representative of the local area. In each sampling plot, we established a transect (100 m) along the diagonal, and several subplots (typical steppe: 1 × 1 m; other grasslands: 1 × 1 m – 2 × 2 m) were set up at 10–m intervals. Biomass C and SOC density were quantified from > 1000 grassland profiles and were summarized for the 223 sampling plots (average subplot $_{\text{C density}}$ → plot $_{\text{C density}}$).

Grass samples were dried in a drying oven at 65 °C, ground by a cup crusher, and filtered through a 10–mesh sieve until all the dried grass samples were sized. The sized samples were reground in a ball mill after freezing, and filtered again through an 80–100–mesh sieve. Soils in plots were sampled at depths of 0–10 cm, 10–20 cm, 20–30 cm, 30–50 cm, and 50–100 cm with two samples taken from each layer. The samples were filtered through a 2–mm sieve to reject plant residues and dried to a constant weight in a drying oven at 105 °C. Dried soil samples were frozen and ground in a ball mill and filtered again through an 80–100–mesh sieve. All the samples were weighed and placed into tin capsules, and their C contents were assayed by dichromate oxidation.

SOC densities were calculated (Penman et al., 2003) according to Formula 1, and C storage values were calculated by Formula 2. The SOC density for a soil profile with k layers was calculated as follows:

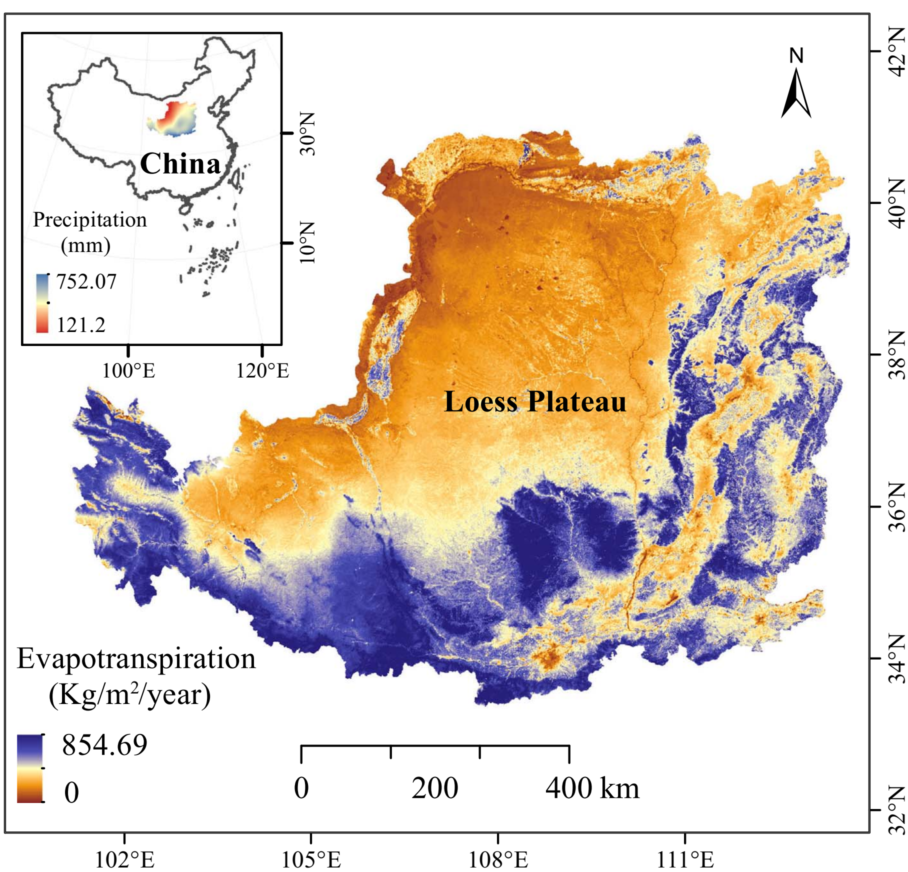

Fig. 1. Study area: the Loess Plateau. The background images are average precipitation and evapotranspiration from 2004 to 2014.