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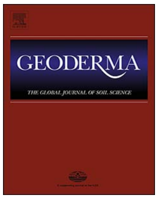

Spatial pattern of different component carbon in varied grasslands of northern China

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ABSTRACT

As one of the major terrestrial ecosystems, grasslands play a vital role in the global carbon cycle. However, the estimation of carbon stock in China's grasslands still remains controversial. Using the measured data from spatial stratified sampling (including 200 sites; 400 soil profiles, 2400 soil samples in the depth of 0–100 cm, 400 above-ground biomass carbon data, and 2400 below-ground biomass carbon data), together with the EVI (enhanced vegetation index), the estimation of total carbon stock was calculated at 29.9 Pg, with an area of 2.63×10^6 km^2 and the storage of SOC was larger than that of biomass carbon regardless of grassland types. The carbon density of grasslands showed a tendency of decreasing from the southeast to the northwest. Alpine grassland contributed the most (74.2%) of the total carbon storage, while the Desert grassland contributed the least (4.3%). The vertical distribution of carbon density varied strongly among different grassland types and a proportion of 15.8% of total carbon still stored at the layer of 60–100 cm. Since this study combined spatial stratified sampling (based on grassland type and community level, sampled belowground samples to a depth of 0–100 cm) with remote sensing data, it is believed that this estimation of the stock and spatial pattern of carbon in grasslands of northern China is more accurate. Therefore, these results will be conducive for understanding the contribution of different grassland types to the global carbon cycle and providing a reference for future measures taken for increasing carbon storage in grasslands.

1. Introduction

Carbon storage in terrestrial ecosystems constitutes an important component of the global C balance (IPCC, 2007). A comprehensive understanding of the carbon storage in terrestrial ecosystems is essential for evaluating the effect of climate change on the terrestrial biosphere (Li et al., 2015; Parton et al., 1995). Grasslands cover about 20% of the terrestrial surface, accounting for > 20% of the total terrestrial production (Paz-Ferreiro et al., 2012; Scurlock and Hall, 1998; Scurlock et al., 2002; Smith, 2014). As an integral part of the Eastern Eurasian grassland (Kang et al., 2007), China's grasslands occupy 41.7% of the country's territory, extending from northeastern China to the Tibetan Plateau, occurring in several climate regimes. Therefore, China's grasslands are an important component in the global C cycle, and their response to climate change will have important consequences for both ecosystem processes and global climate feedbacks (Fang et al., 1996b).

During the past decades, several studies have been conducted to evaluate the carbon storage in China's grasslands (Ni, 2002; Li et al., 2004; Yang et al., 2010; Piao et al., 2009; Fang et al., 2010). However, the current assessments seem to remain uncertain.

The uncertainty in the assessment of carbon storage in China's grasslands may be due to the insufficiency of sampling depth for belowground carbon. In some studies, the belowground samples were taken at a depth of 0–60 cm (Ma et al., 2006) and it may cause an underestimation for the belowground carbon storage (Jia et al., 2013).

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In addition, the uncertainty may also be caused by differences in sampling method. For instance, the carbon storage of above-ground biomass (AGB) in some cases was estimated based on Grassland Resource Survey (Fang et al., 2010; Ni, 2002), which was based on spatial random sampling and the First National Soil Survey of China failed to provide sufficient soil profiles. Yang et al. (2010) estimated AGB in northern China's grasslands by field data; nevertheless, some uncertainties still existed due to the lack of bulk density for some profiles in the northwestern part of Tibetan Plateau.

Besides, most previous studies have assessed the carbon storage and its distribution by random sampling in a specific grassland type (Hu et al., 2015; Yang et al., 2010; Yu et al., 2013), specific carbon component (Luo et al., 2013; Yang et al., 2010) or specific region (Ma et al., 2006; Hu et al., 2015). The carbon storage cannot be estimated accurately by only focusing single grassland type or region, because vegetation composition varies among grassland types and it has been considered as the major driver of carbon sequestration in terrestrial ecosystems (Duiker and Lal, 1999; Thompson et al., 2009). Plant tissue quality, such as plant nutrient concentration, can influence the residence time of both living tissues and litter, and therefore indirectly influence the soil carbon storage in grassland. Yang et al. (2010) found that the SOC storage in the top 100 cm was lower than others' estimate, suggesting that the difference could be induced by different vegetation types. This is similar to the results reported by Oueslati et al. (2013) for forest and grassland, indicating that vegetation controls the spatial variability of carbon storage. However, the study for estimating carbon storage based on stratified sampling at community level is still rare.

Remote sensing and geographical information systems (GIS) have been well applied in the estimation of biomass carbon (Brogaard et al., 2005; Di Bella et al., 2004; Holm et al., 2003; Ma et al., 2010; Paruelo et al., 1997, 2004; Piao et al., 2005; Wang et al., 2005; Zheng et al., 2013; Zhou et al., 2013). Based on the field survey data, relations between remote sensing data and the ground biomass parameters were established to use the continuous spatial-temporal remote sensing data to estimate biomass parameters at large spatial scales (Wang et al., 2005). The combination of field data and remote sensing data can present spatial details of biomass carbon storage across biomes and thus can reduce the uncertainty generated by high spatial heterogeneity in grassland biomass carbon storage (Ma et al., 2010; Yang et al., 2009). The common-used indices include NDVI (normalized difference vegetation index), RVI (ratio vegetation index), EVI (enhanced vegetation index), VCI (vegetation condition index). (Prince and Tucker, 1986; Justice and Hiernaux, 1983; Wang et al., 2005). For the carbon storage estimate, NDVI and EVI from MODIS are believed to be the proper indices (Zhou et al., 2013), since these two indices are spectral measures of the amount, relative greenness, phenological characteristics, and biological productivities of observed vegetation present on the ground, with a global overpass of twice a day and products that can be daily, 8 days composites or 16 days composites, at three spatial resolutions of 250 m, 500 m, and 1 km (Behrenfeld et al., 2001). The multi-temporal signatures of the EVI and NDVI data have been considered to capture essential phenological metrics of various natural vegetation types (e.g., forest, grassland, and shrubland) and to respond differently to changes in land cover, canopy structures, and climate regimes (Huete, 1988; Huete et al., 2002; Liu and Huete, 1995). In addition, NDVI is chlorophyll sensitive, and can be used to reflect vegetation cover change and to estimate vegetation biomass by measuring the contrast between red and near-infrared reflection of solar radiation, (Paruelo et al., 1997, 2004). However, compared with NDVI, EVI is more sensitive to canopy structure variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture (Gao et al., 2005). Furthermore EVI has more strict cloud removal and more thorough atmospheric correction in the calculation of vegetation index. EVI further removes the impact of residua aerosols and considers the effect of background area with low vegetation coverage, so it has the potential to quantitatively evaluate grassland's biomass carbon storage (Wang et al., 2005). Therefore, it is possible to give a more accurate estimate of the biomass carbon storage based on EVI.

In China, the zonation of climate contributes to the differentiation of grassland types (Meadow grassland, Typical grassland, Desert grassland and Alpine grassland). Within a given grassland type, a specific community corresponds to a special soil texture type. Therefore, the community assembly is determined by the local climate and soil texture (Physical Geography in China Editorial Board of Chinese Academy of Sciences, 1988). In this study, based on the China's Vegetation Atlas (Chinese Academy of Sciences, 2001), the top 10 communities in each of the four grassland types in northern China were selected, with the aim of (1) presenting a more comprehensive estimate for carbon storage in northern China grasslands, (2) exploring their spatial patterns, and the contribution of different components to the carbon storage in the grassland ecosystem. These will be helpful in understanding the contribution and importance of different grassland types on the global carbon cycle and providing a reference for future measures taken for assessing carbon storage in grasslands.

2. Materials and methods

2.1. Survey region

In this study, four grassland types were selected in northern China (latitude 35°N–52°N, longitude 83°E–127°E; Fig. 1) based on China's Vegetation Atlas with a scale of 1:1,000,000 (Chinese Academy of Sciences, 2001). The elevation increases from the northeast (Songnen Plain with 130–200 m) to the southwest (Tibet Plateau about 4500–5000 m). The annual precipitation decreases from southeast to northwest (450–150 mm) and the annual average temperature decreases from east to west (4 °C to 9 °C). But the Qinghai-Tibet Plateau has a lower temperate than the other regions (− 6 °C to 0 °C) (Chinese Vegetation Map Editing Committee, 2001). Along the climate gradient, grasslands in northern China are mainly divided into 4 types: Meadow grassland, Typical grassland, Desert grassland and Alpine grassland. Meadow grassland occurs in the subhumid climatic region and is dominated by meso-xerophytic and xerophytic grass species such as *Stipa baicalensis*, *Stipa kirghisorum* and *Carex tristachya*. Typical grassland occurs in semiarid climatic region, dominated by xerophytic dense-bunch grasses, with some widespread forbs such as *Artemisia frigida*, *Praierie junegrass* and *Agropyron cristatum*. Desert grassland occurs in arid climatic region and its dominant species are perennial xerophytic short bunch grasses and strong-xerophytic dwarf shrubs, such as *Haloxylon ammodendron*, *Caragana microphylla* and *Stipa tianshanica*. Alpine grassland is mainly distributed in plateau and alpine belt with an elevation above 4000 m, dominated by cold xerophytic bunch grass, such as *Stipa purpurea*, *Carex moorcroftii* and *Ceratoides latens*.

2.2. Field investigation

The investigation was conducted across northern China in July 2011 and it was based on spatial stratified sampling. Firstly, based on China's vegetation atlas, the communities were ordered by area. Then, the top ten communities in each grassland were selected and their areas were summed. They occupied > 80% of area for each grassland type, representative for their grassland type. Finally, 40 communities in total were selected (Table 1). The definition in the present study was according to Kang et al. (2007), which defined plant communities base on their dominant/constructive species. The names of these species were used to represent plant community types in the grassland investigated. The sampling sites were selected on the typical habitat of the 40 communities in four grasslands based on the China's Vegetation Atlas. Five sampling sites (10 m × 10 m, with an interval