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The Spatial Distribution and Driving Factors of Carbon Storage in the Grassland Ecosystems of the Northern Tibetan Plateau

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Abstract: The investigation of carbon storage in ecosystems and its driving factors is crucial for understanding carbon cycling and achieving the goal of carbon neutrality. The grassland in the Northern Tibetan Plateau is an important grassland ecosystem in China, although the accurate estimation of its carbon stock and our knowledge of its spatial patterns and driving factors in the Northern Tibetan Plateau remain unclear due to insufficient field investigations. In this study, a dataset of 150 measured sample points on the Northern Tibetan Plateau, kriging interpolation and statistical methods were used to estimate the densities of aboveground biomass carbon, belowground root carbon and soil organic carbon at a soil depth of 30 cm, as well as to explore the spatial distribution and the main influencing factors of each carbon pool. The average carbon densities were 0.038 kg C m^{-2} in aboveground biomass, 0.284 kg C m^{-2} in belowground biomass, and 7.445 kg C m^{-2} in the soil. The soil organic carbon accounted for 95.85% of the grassland carbon density. The total carbon storage of the grassland ecosystem in the Northern Tibetan Plateau was about 4.08 Pg C, with a decreasing trend from southeast to northwest. Of the total, the organic carbon stocks of vegetation and soil were 0.58 Pg C (including the aboveground and belowground biomass) and 2.58 Pg C, accounting for 28.29% of the total vegetation carbon and 26.60% of the total soil carbon, respectively, on the Tibetan Plateau, with the remainder stored in the bare land. While the precipitation, temperature and soil texture all affected the ecosystem carbon storage, precipitation played the most significant role and the combination of these three factors explained up to 86.47% of the aboveground carbon density. The aboveground carbon pools in grassland ecosystems of the Northern Tibetan Plateau were most sensitive to climatic factors, while the spatial patterns of belowground and soil carbon storage were more complex. This study provides a spatially accurate assessment of the carbon storage in the grasslands on the Northern Tibetan Plateau.

Key words: Northern Tibetan Plateau; carbon storage; spatial distribution; grassland ecosystem

1 Introduction

As an important component of terrestrial ecosystems, grasslands cover about 40% of the global land surface (Yang et al., 2022). Grasslands have a very large carbon pool of about 520 Pg C, accounting for one-third of the global carbon storage of terrestrial ecosystems, and they are second only to forest ecosystems, so grasslands play an important role in the terrestrial carbon cycle (Scurlock and Hall, 1998;

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Schuman et al., 2002; Fang et al., 2007; Carvalhais et al., 2014). The ecosystem carbon pool consists of aboveground biomass, belowground biomass and soil. The aboveground biomass of grasslands accounts for about 36% of the total biomass of global vegetation (Bo et al., 2022), but it is vulnerable to climate change, land use and plant community composition, and shows great seasonal and interannual fluctuations (Ma et al., 2010; Liu et al., 2022). Belowground biomass is mainly composed of plant roots, so it is an important product of plant photosynthesis. Approximately 25% of the global grassland ecosystems have more than 80% of the total biomass distributed in the belowground portion (Mokany et al., 2006; Li, 2020), which is the basis for determining the carbon sink of the ecosystem (Hu et al., 2005). More importantly, the soil carbon pool is the largest carbon sink carrier. Its storage level exceeds the sum of carbon in the atmosphere and vegetation, so it is critical for maintaining carbon balance (Eswaran et al., 1993). Accurate estimations of regional carbon allocation and carbon storage are crucial for better understanding carbon cycling, and therefore it is very important to estimate the carbon source and sink of terrestrial ecosystems to meet the needs of carbon neutrality.

As the Third Pole of the world, the Qinghai-Tibetan Plateau covers an area of about 2.50×10^6 km^2, with alpine meadows and alpine steppes accounting for more than 60% of its area (Yang et al., 2009a). The Northern Tibetan Plateau, situated in the hinterland of the Qinghai-Tibetan Plateau, is sensitive to global changes, especially climate warming, due to its unique geographical environment (Li et al., 2011). Guo and Wang (2012) analyzed the data of 71 plateau meteorological stations in northern Tibetan, and found that the average plateau surface temperature rose at a rate of 0.28 ℃ every 10 years. That study also found that the northern plateau warming was the most significant in the whole plateau since 1961, while the warming in other regions was relatively weak (Guo and Wang, 2012). It also showed an asymmetric trend, in which winter warming was more obvious than summer warming (Zong and Shi, 2019). The response of the Northern Tibetan Plateau to global change will further affect the compositions of ecosystem communities (Klein et al., 2004), productivity (Klein et al., 2008), phenology (Dorji et al., 2013), and act on carbon storage. Enhancing the carbon storage of grasslands is currently considered to be one of the most effective and economic methods to offset anthropogenic CO_2 emissions in China (Ma et al., 2016). However, as the main area of alpine grasslands, the status quo, spatial pattern and driving factors of carbon storage in the Northern Tibetan Plateau remain unclear due to insufficient field investigations (Yang et al., 2009b). In addition, the Northern Tibetan Plateau contains vast uninhabited areas with relatively few human activities, so it is an ideal place to study carbon storage and its influencing factors.

In this study, the densities of aboveground and belowground biomass carbon and soil organic carbon of the grassland ecosystem in the Northern Tibetan Plateau were determined based on 150 measured sample sites on the Northern Tibetan Plateau. The spatial distribution of carbon density was then extrapolated by the kriging interpolation method, and the total carbon storage of the entire Northern Tibetan Plateau was estimated. Combined with the climatic and soil texture data, the impacts of each factor on the aboveground, belowground, and soil carbon densities in the different grassland types were evaluated. The results of this study provide a spatially accurate assessment of the carbon storage of grasslands on the Northern Tibetan Plateau.

2 Materials and methods

2.1 Study area

The study area is located in the northern Tibet Plateau, also called the Changtang Plateau, with an average altitude of more than 4500 m. Administratively, the Northern Tibetan Plateau includes the Ngari Prefecture and Nagqu Prefecture, with a land area of 69.02×10^4 km^2. The plateau surface is rugged, with valleys and basins that are widely and unevenly distributed (Li et al., 2011). The Northern Tibetan Plateau is characterized by a typical plateau continental cold and dry climate, with evaporation greater than precipitation, and very wide daily and annual temperature variations. The coldest and warmest temperatures are about –15 ℃ in January and less than 10 ℃ in July, respectively. The annual precipitation ranges from 100 mm to 600 mm, gradually decreasing from southeast to northwest (Zhao et al., 2017). The vegetation in the study area includes four grassland types, i.e., alpine meadow (AM), alpine meadow steppe (AMS), alpine steppe (AS) and alpine desert steppe (ADS) from east to west. *Kobresia pygmaea* and *Stipa purpurea* are the main dominant species in the eastern semi-humid alpine meadows, while *Carex moorcroftii* and *Leontopodium nanum* are the dominant species in the alpine steppes, and *Stipa glareosa* is the dominant species in the alpine desert steppes (Wang et al., 2016).

2.2 Sampling method and calculation of aboveground, belowground and soil carbon densities

Sampling was conducted during the period of vigorous vegetation growth in the Northern Tibetan Plateau from August to mid-September in 2020 and 2021. The 150 sampling points were relatively uniformly selected throughout the Northern Tibetan Plateau, except for the inaccessible no-man's land, covering each representative grassland type and climatic region in the study area. Specifically, 48, 13, 71 and 18 sites were sampled in AM, AMS, AS and ADS, respectively. At each sampling site, three replicates of 50 cm×50 cm quadrats were delineated, and all aboveground parts of the plants were cut off from the ground, placed in an envelope, brought back to the laboratory, and dried to constant weight in an oven at 65 ℃ to determine the average aboveground biomass. In each quadrat, five diagonal drills with a diameter of 8 cm were used to obtain samples of

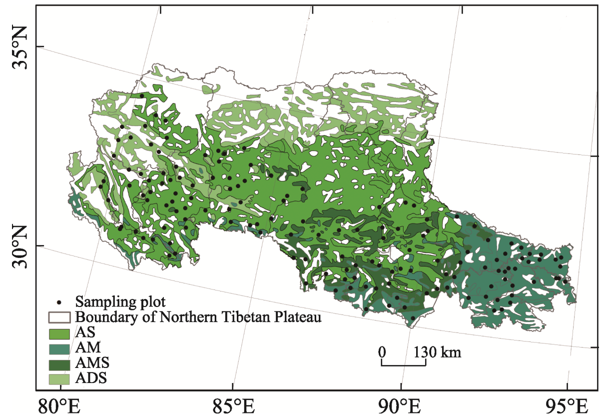


Fig. 1 Distribution of vegetation types and sampling sites on the Northern Tibetan Plateau

Note: AS: alpine steppe; AM: alpine meadow; AMS: alpine meadow steppe; ADS: alpine desert steppe. The same notations are used in subsequent figures.

belowground biomass and soil organic carbon. Soil and roots were sieved and separated with a 0.5 mm gauze. Roots were cleaned with water and oven-dried to determine root biomass. Soil samples were air-dried for the measurement of soil organic carbon content. Soil bulk density was measured using the ring knife method. Soil organic carbon, root biomass and soil bulk density were determined in each 10 cm soil layer down to the depth 30 cm. Carbon densities are calculated as follows:

$$AGB_D, BGB_D = biomass \times 0.45 \quad (1)$$

$$SOIL_D = SOC \times BD \times h \quad (2)$$

Among the variables, AGB_D, BGB_D and $SOIL_D$ are aboveground biomass, belowground biomass and soil organic carbon content per unit area, respectively; *biomass* refers to the total amount of all plants in the sample square; *SOC* is soil organic carbon content; *BD* is soil bulk density; and *h* is soil depth. In view of the field survey, the sampling depths of all survey points could reach 30 cm. Therefore, soil carbon density and carbon storage were calculated to the soil depth of 30 cm in this study. Similarly, the root biomass and root carbon density were also calculated to 30 cm.

2.3 Data acquisition of climatic and soil texture features

The climatic data, including precipitation and temperature with a resolution of 500 m, were obtained from the relevant data of the China Meteorological Background Dataset (https://www.resdc.cn/Default.aspx). The soil texture data were obtained from the Resource and Environmental Science and Data Center, Institute of Geographic Science and Resources, Chinese Academy of Sciences. This dataset includes the contents of soil sand and clay (%) with a resolution of 1 km for all of China.

2.4 Statistics and mapping

The data were pre-processed in Excel to remove outliers. SPSS (SPSS Inc. Chicago, Illinois, USA) was used for data analysis, including the normal distribution test, one-way ANOVA and LSD multiple comparison analysis (α=0.05), to clarify the factors of climate and soil texture which influence the carbon density of grassland ecosystems on the Northern Tibetan Plateau. In the R language, the carbon densities of aboveground, roots and soil were taken as response variables, and annual average temperature, annual precipitation and soil texture were used as explanatory variables for Variance Partitioning Analysis (VPA). ArcGIS (Environmental Systems Research Institute, ESRI) software was used to make thematic maps, and Origin was used for mapping.

3 Results

3.1 Spatial distribution of carbon storage on the Northern Tibetan Plateau

3.1.1 Carbon density and distribution in different grassland types

The 150 sampling sites in the study area were statistically analyzed, and the results are shown in Table 1. Aboveground biomass carbon density (AGB_D) ranged from 0.002 to 0.180 kg C m^{-2}, mostly concentrated around 0.024 kg C m^{-2}. Belowground biomass carbon density (BGB_D) ranged from 0.019 to 1.563 kg C m^{-2}, with the majority of samples concentrated around 0.166 kg C m^{-2}. Soil carbon density ($SOIL_D$) ranged from 0.092 to 20.696 kg C m^{-2}, with the highest proportion of samples in the range of 2.5 to 3.75 kg C m^{-2}. Among them, the average AGB_D was 0.038 kg C m^{-2} and the average BGB_D was 0.284 kg C m^{-2}, while the $SOIL_D$ was the largest, averaging 7.445 kg C m^{-2}, or about 23 times the sum of AGB_D and BGB_D. To further analyze the carbon density distribution among the different grassland types, the organic carbon density data for AGB_D, BGB_D and $SOIL_D$ of the four grasslands were statistically analyzed, and the results are shown in Table 2. The mean values of AGB_D, BGD_D and $SOIL_D$ were all ranked as AM > AMS> AS >ADS. As shown in Fig. 2, among the four grassland types, the proportion of $SOIL_D$ was the highest, while BGB_D was about three times higher than AGB_D.

3.1.2 Spatial patterns of ecosystem carbon storage

Figure 3 shows that the AGB_D, BGB_D, $SOIL_D$ and total ecosystem carbon density (CD) of the Northern Tibetan Plateau present overall decreasing trends from southeast to

Table 1 Descriptive statistics of aboveground, belowground and soil carbon densities (kg C m^{-2}) at the sampling points

Variable	Sample count	Mean	SE	Min	Median	Max
AGB_D	150	0.038	0.036	0.002	0.024	0.180
BGB_D	150	0.284	0.296	0.019	0.161	1.563
$SOIL_D$	150	7.445	5.713	0.092	4.942	20.696

Note: AGB_D: aboveground carbon density; BGB_D: belowground carbon density; $SOIL_D$: soil carbon density. The same notations are used in Table 2.

Table 2 Descriptive statistics of the aboveground, belowground and soil carbon densities of the different grassland types (kg C m^{-2})

Grassland type	CD	Min	Max	Mean	SE
AM	AGB_D	0.016	0.181	0.072	0.039
	BGB_D	0.083	1.563	0.535	0.341
	$SOIL_D$	3.320	20.031	13.549	4.938
AMS	AGB_D	0.012	0.092	0.042	0.027
	BGB_D	0.093	1.056	0.290	0.290
	$SOIL_D$	3.118	20.696	7.633	5.038
AS	AGB_D	0.002	0.080	0.019	0.016
	BGB_D	0.019	0.923	0.156	0.158
	$SOIL_D$	0.092	16.243	4.289	2.542
ADS	AGB_D	0.004	0.031	0.012	0.007
	BGB_D	0.038	0.295	0.105	0.058
	$SOIL_D$	1.304	6.661	2.957	1.751

Note: AM: alpine meadow; AMS: alpine meadow steppe; AS: alpine steppe; ADS: alpine dessert steppe; CD: carbon density.

northwest. The total carbon storage of the grassland ecosystem in the Northern Tibetan Plateau also decreased from southeast to northwest (Fig. 4a). The total carbon storage in the study area was 4.08 Pg, with the highest proportion of carbon storage in AS at 1.23 Pg C (Fig. 4a), accounting for 30.1% (Fig. 4b). The second largest component was 1.07 Pg C in AM. The carbon storage in the bare land of the Northern Tibetan Plateau was in the third place; followed by AMS, and the carbon storage in ADS was 0.39 Pg C. All four types of grasslands had the largest carbon storage values in soil. Soil carbon storage was ranked as AS > AM > ADS > AMS. Belowground carbon storage was ranked as AS> AMS> AM > AMS and aboveground carbon storage had a very low proportion, in the order of AS > AM > AMS > ADS (Fig. 4c).

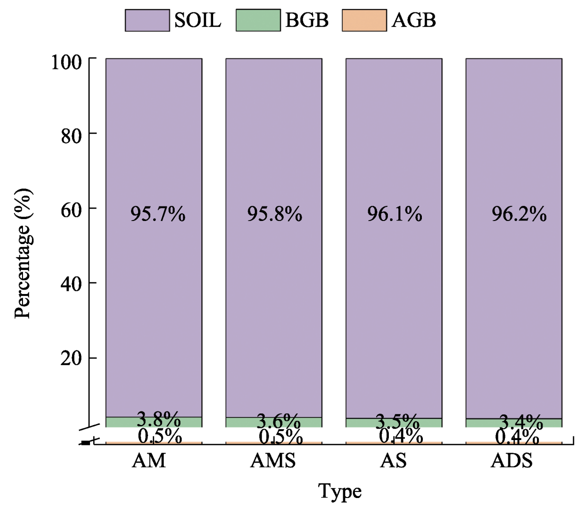


Fig. 2 Proportions of the components of carbon density in the different types of grasslands

Note: SOIL, BGB and AGB represent the carbon densities in soil, belowground and aboveground biomass, respectively.

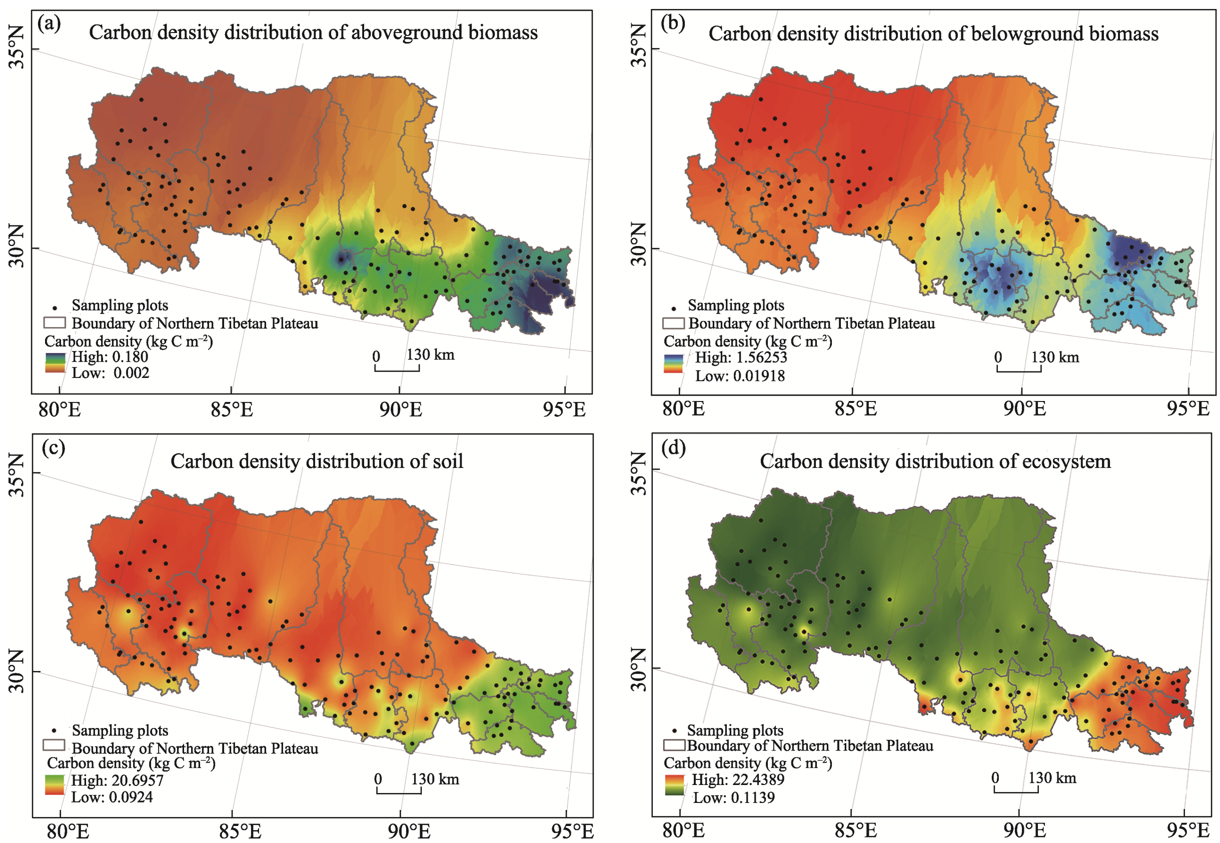


Fig. 3 Spatial distribution of carbon density in the different carbon pools of the Northern Tibetan Plateau grasslands

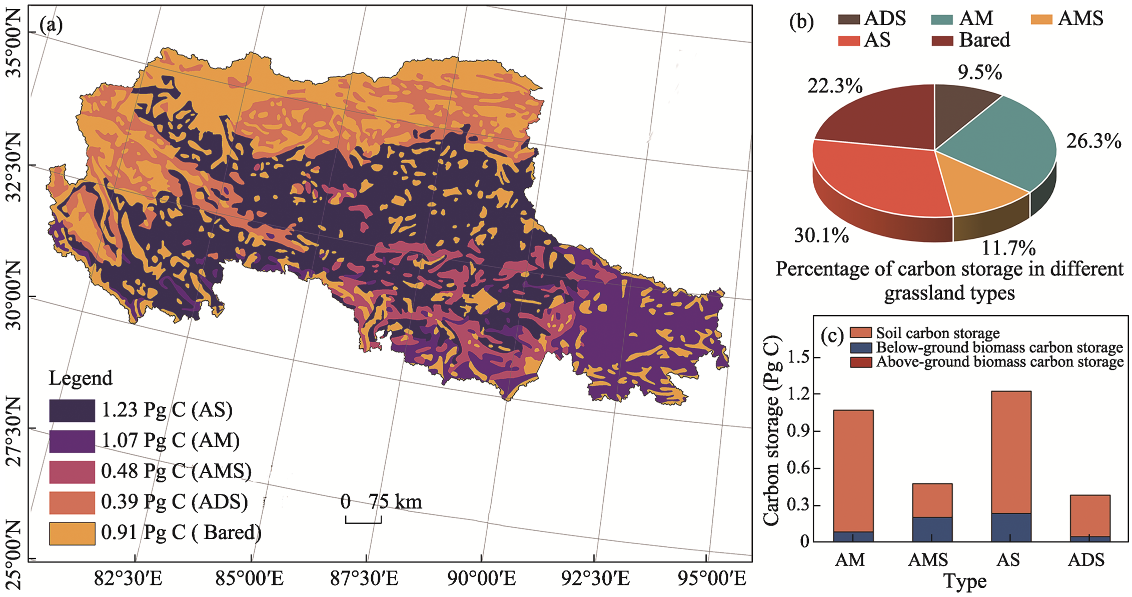


Fig. 4 Spatial patterns of carbon storage in the Northern Tibetan Plateau grasslands

3.2 Factors influencing carbon storage in the Northern Tibetan Plateau grasslands

3.2.1 Factors influencing SOC in the Northern Tibetan Plateau grasslands

(1) Climatic factors

Annual precipitation had highly significant effects (P<0.001) on AGB_D and BGB_D (Fig. 5a, 5b), but there was no significant effect (P>0.05) on $SOIL_D$ in the Northern Tibetan Plateau grasslands (Fig. 5c). Aboveground, belowground, and soil carbon densities all increased exponentially with annual precipitation. Mean annual temperature had highly significant effects (P<0.001) on AGB_D and BGB_D (Fig. 5d, 5e), but no significant effect on soil carbon density (Fig. 5f). With an increase in temperature, the aboveground, belowground and soil carbon densities showed trends of increasing and then decreasing, and each of them arrived at peaks around 0 ℃. Climatic factors had significant effects on the regulation of aboveground and belowground biomass carbon densities, but had a little effect on soil carbon density.

(2) Soil texture

The proportion of clay was mostly around 15%–30% in each of the samples, and as the clay increased, the aboveground, belowground, and soil carbon densities increased either exponentially or linearly (P<0.001) (Fig. 6a–6c). The proportion of soil sandy soil ranged from 40% to 60%, and as the proportion of sand increased, the aboveground, belowground, and soil carbon densities decreased linearly, exponentially, and linearly, respectively, and the sand proportion had highly significant effects on the aboveground, belowground, and soil carbon densities (P<0.001) (Fig. 6d–6f). Soil carbon density had the highest correlations with the soil clay and sand proportions, compared to AGB_D and BGB_D (R^2=0.13, R^2=0.26, repectively).

3.2.2 Factors influencing carbon storage in different types of grasslands

(1) Climatic factors

The responses of carbon densities of the different grassland types to climatic factors were not consistent. The annual precipitation had a highly significant effect (P<0.001) on AGB_D in AS, significant effects (P<0.05) on AGB_D in AM and AMS, and a marginal effect (P=0.051) on AGB_D in ADS (Fig. 7a). There were significant effects (P<0.05) on BGB_D in AS and AM, but not in AMS or ADS (Fig. 7b). In contrast, there were no significant correlations between annual precipitation and soil carbon density in any of the four types of grasslands (Fig. 7c). The aboveground, belowground, and soil carbon densities did not respond significantly to mean annual temperature in any of the four grassland types, and only AM soil carbon density showed a weakly significant (P<0.05) correlation to temperature (Fig. 7d–7f).

(2) Soil texture

The aboveground, belowground, and soil carbon densities of the four grassland types increased as the proportion of soil clay increased, but decreased with an increasing proportion of sand. AGB_D and BGB_D did not show significant positive or negative correlations with the proportions of clay or sand in the four grassland types (Fig. 8a, 8b, 8d, 8e). The soil carbon density of AS showed a significant positive correlation with the clay ratio (P<0.05) (Fig. 8c), and the soil carbon density of AMS showed significant positive and negative correlations with the clay ratio and sand ratio, respectively (P<0.05) (Fig. 8c, 8f).

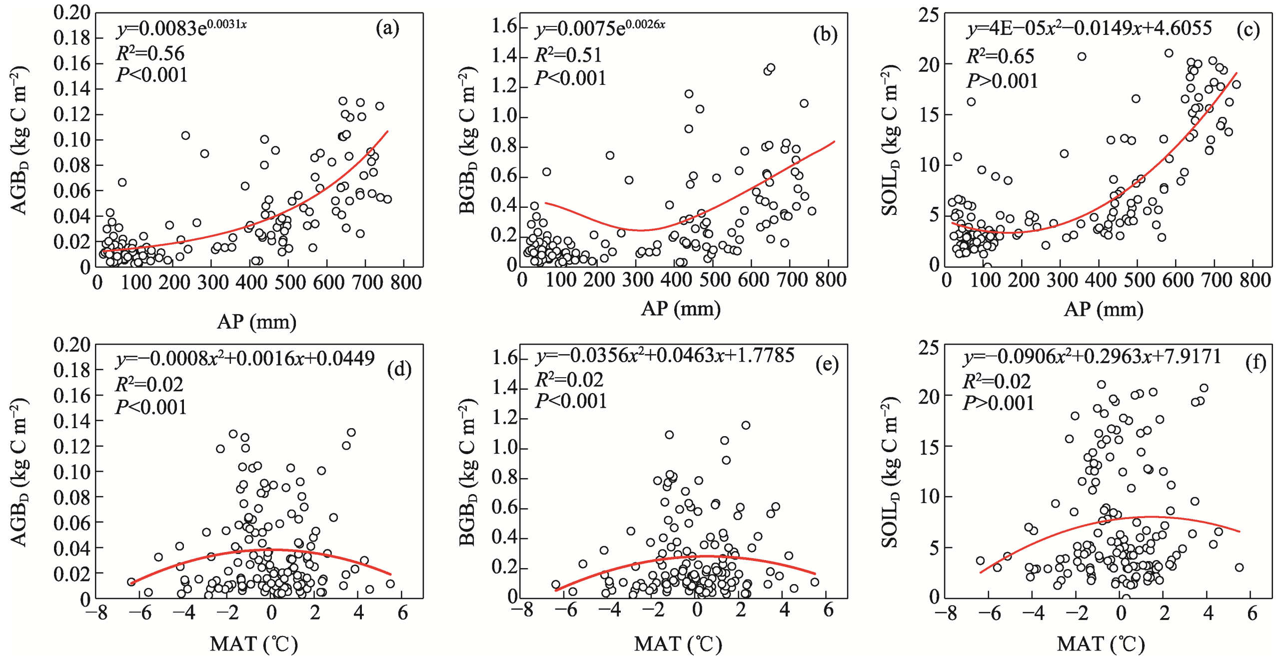


Fig. 5 The effects of climatic factors on carbon density in the aboveground biomass (a, d), belowground biomass (b, e) and soil (c, f)

Note: AP: annual precipitation; MAT: mean annual temperature. The abbreviations are same as in Fig. 1.

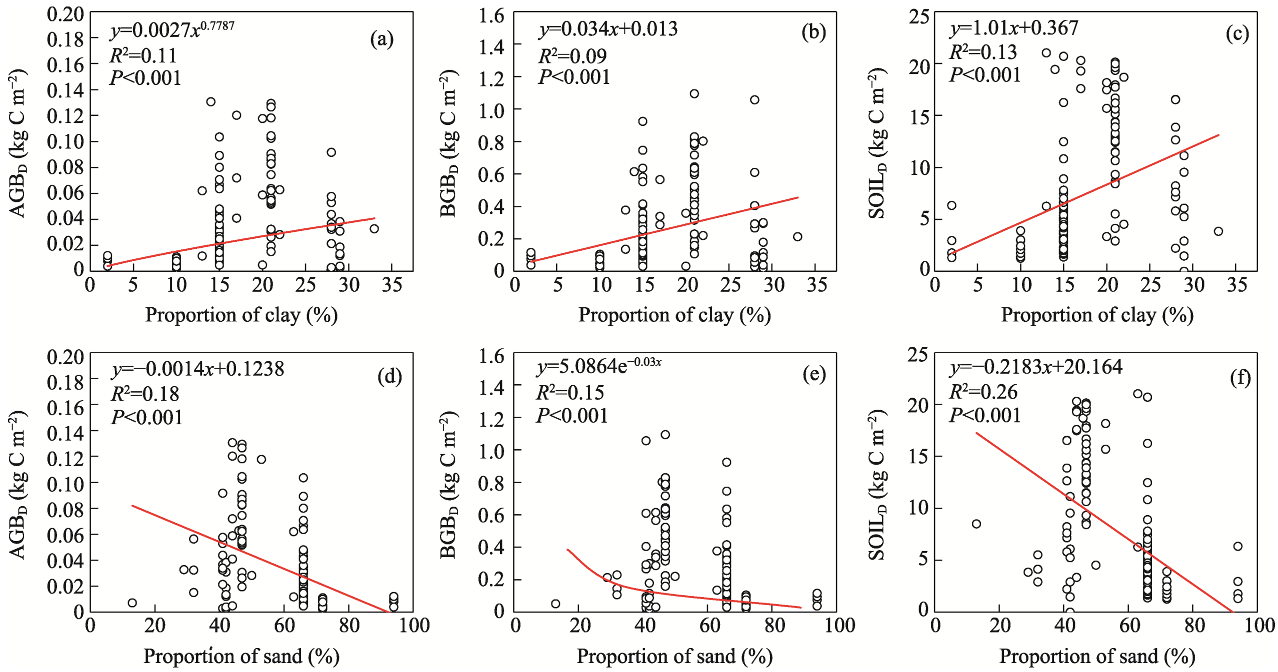


Fig. 6 The effects of soil texture composition on the different components of the carbon density

4 Discussion

In this study, the total carbon storage in the grassland ecosystem of the Northern Tibetan Plateau was estimated to be about 4.08 Pg C, including 0.58 Pg C in the vegetation carbon pool (including aboveground and belowground biomass carbon), 2.58 Pg C in the soil carbon pool, and the remainder stored in the bare land. Several recent studies have estimated carbon storage on the Tibetan Plateau mainly through field surveys, remote sensing estimation, and model simulation (Yang et al., 2009b; Liu and Liu, 2014). However, those estimation results still have great variability due to different sampling times, different areas, different calculation methods, and different models. For example, Yang et al. (2022) used field investigation integrated with remote sensing

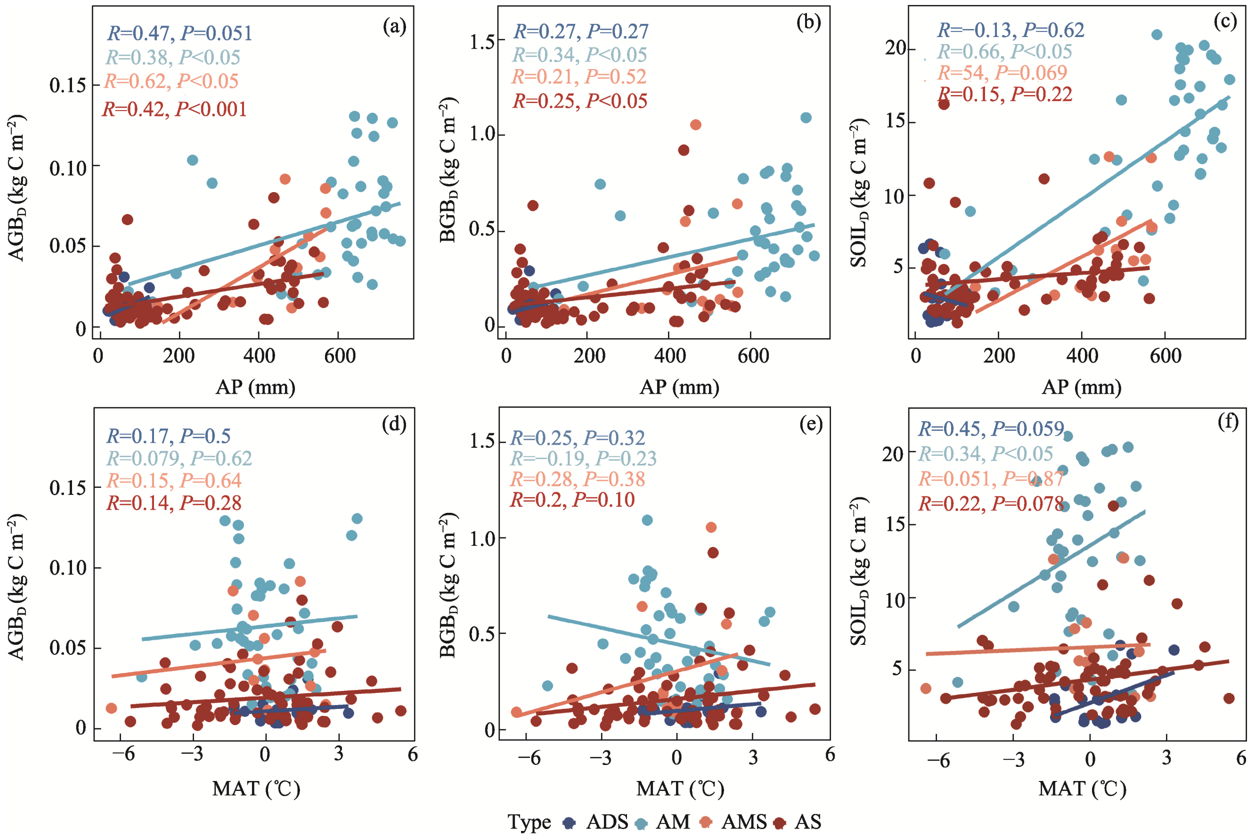


Fig. 7 Relationships between climatic factors and carbon densities in the different types of grasslands

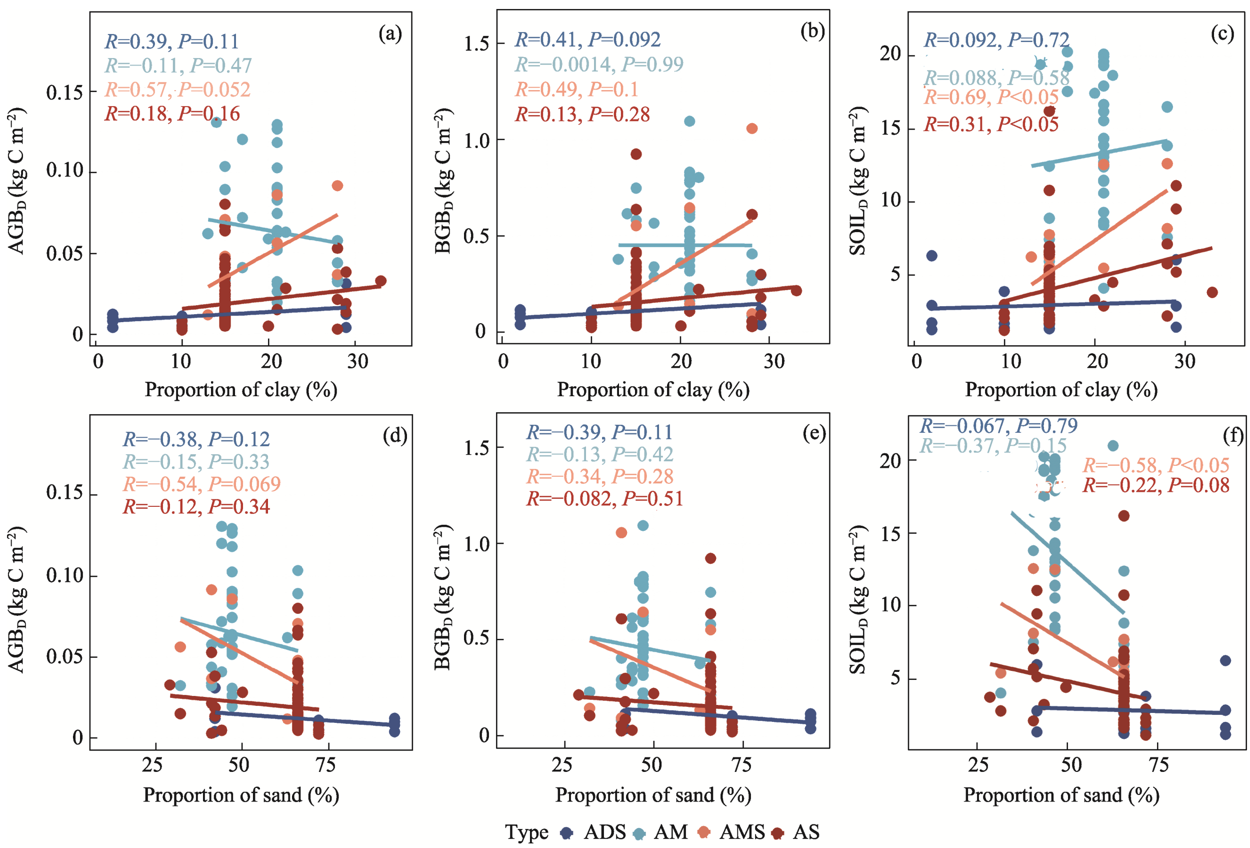
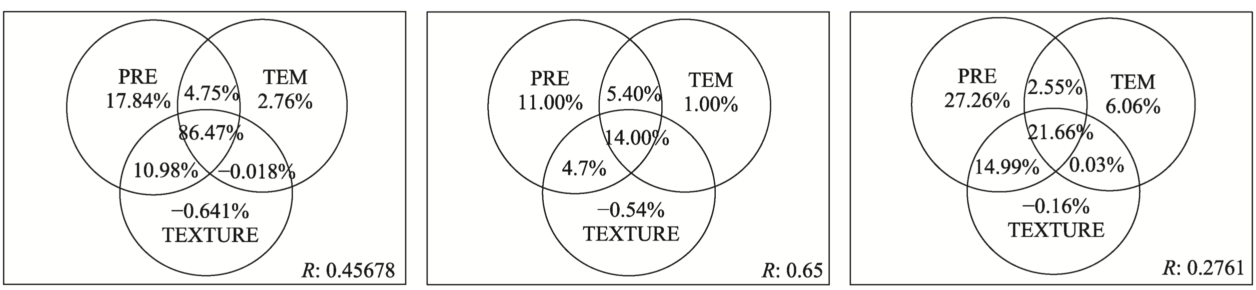


Fig. 8 Relationships between carbon density and soil texture in the different types of grassland

extrapolation to estimate an amount of 4.4 Pg C in SOC stock in the top 30 cm layer on the Qinghai Tibetan Plateau (112.82×10^4 km^2 of grassland). Converting that figure by area, the northern Tibetan Plateau portion would be equivalent to 2.69 Pg C, which is very close to our estimate of 2.58 Pg C in the grassland area of 69.02×10^4 km^2, but it is a little lower than the soil organic carbon including the soil carbon in the non-vegetated area, i.e., 0.92 Pg C. Zhang et al. (2016) simulated the spatial and temporal variation characteristics of vegetation carbon, soil organic carbon storage and carbon density in the Chinese grassland ecosystem from 1961 to 2013 based on a terrestrial ecosystem model (TEM) (Zhang et al., 2016). Zhang et al. (2007) used the Century model combined with the second national soil census data, and estimated that the vegetation carbon pool of the Qinghai-Tibet Plateau was 2.05 Pg C and the soil carbon pool of the grassland was 9.7 Pg C. As a comparison, the vegetation carbon pool of the Northern Tibetan Plateau accounted for about 28.29% of the total for the whole Tibetan Plateau and the soil carbon pool accounted for 26.60% of the total. In this study, the kriging interpolation method was used to extrapolate the profile information of the sample sites to the regional scale, which helped to reduce the effect of soil spatial heterogeneity (Fang et al., 2010). The Northern Tibetan plateau is mainly divided into four grassland types, with higher carbon storage in AM and AS, and lower carbon storage in AMS and ADS. From the perspective of carbon density, although the AS had the largest carbon storage amount because of its larger distribution area, its carbon density was lower than those of AM and AMS.

Many studies have shown that carbon storage in grassland ecosystems is influenced by changes in climatic factors (Fang et al., 2001; Zhang et al., 2020; Cao et al., 2022). Precipitation affects carbon storage by influencing vegetation growth and soil water content, and by changing the soil respiration rate and carbon input from litter to soil (Zhang et al., 2016); while temperature changes mainly affect the photosynthesis of plants and microbial activity, which affect carbon storage. Precipitation is directly responsible for the formation of the different grassland types in the Northern Tibetan plateau, so annual precipitation had a significantly positive correlation with both aboveground and belowground biomass carbon densities of vegetation, but no significant effect on soil carbon density. Furthermore, the aboveground and belowground biomass carbon densities increased exponentially and rapidly when the annual precipitation was greater than 500 mm, which is largely related to its limiting effect on vegetation activity in arid and semi-arid environments (Jobbagy et al., 2002). In terms of the different species of grassland types, the significant responses of aboveground and belowground biomass carbon densities to year-round precipitation were inconsistent among the four types of grasslands, with AM and AS showing greater significance, which may be related to the differences in plant and biogeochemical limitations of the different grassland types leading to differences in their water use efficiency (Huxman et al., 2004). In this study, the aboveground and belowground biomass carbon densities also showed highly significant responses to mean annual temperature, but the changes in mean annual temperature were not significant for any of the four types of grasslands. Yang et al. (2010) analyzed aboveground and belowground biomass of different grasslands from the arid and semi-arid temperate grasslands of the Qinghai-Tibet Plateau in northern China, and found that neither of them showed a significant trend in the temperature gradient, which was different from the results of this study.

The aboveground, belowground, and soil carbon densities increased with an increasing proportion of clay and a decreasing proportion of sand in the soil on the Tibetan Plateau, which is consistent in consistent with the results of Yang et al. (2009b) in Tibetan grasslands and Li et al. (2021) in loess plateau ecosystems. All these results are consistent with the inverse texture hypothesis, i.e., that more carbon can be stored in fine-texture soils with higher water-holding capacity (Noy-Meir, 1973; Yang et al., 2009b; Li et al., 2021). Soil carbon density increases when the soil particles are dominated by clays with smaller particle sizes, which have a larger surface area and are more likely to form soil aggregates, which slows the decomposition of organic matter. In the significance analysis, soil carbon density had strong significant relationships with soil clay proportion and



AGB_D BGB_D $SOIL_D$

Fig. 9 Variance Partitioning Analysis of the contributions of precipitation (PRE), temperature (TEM) and soil texture (TEXTURE) on the different components of carbon density sand proportion, indicating that climatic factors only play a moderating role in soil carbon density, and soil texture is the fundamental factor influencing soil carbon density.

The Variance Partitioning Analysis (VPA) demonstrated that temperature explained 2.76% of aboveground biomass carbon density, 1.00% of belowground biomass carbon density, and 6.06% of soil carbon density, while the soil texture explained very little. The combination of precipitation and soil texture could explain 10.98%, 4.70%, and 14.99% of the aboveground, belowground, and soil carbon densities, respectively. The combination of precipitation, temperature and soil texture explained 86.47% of aboveground biomass carbon density. Taken together, the role of precipitation is the most important, and the aboveground carbon pool of the grassland ecosystem in the Northern Tibetan Plateau is most susceptible to mediation by climatic factors. Compared with aboveground biomass carbon density, VPA explained less of the belowground biomass carbon density and soil carbon density. Since 80% of the biomass in grassland ecosystems is distributed belowground and root turnover is longer, the mechanisms driving the spatial patterns of the belowground and soil carbon stocks might be more complex.

5 Conclusions

In this study, we assessed the carbon storage and spatial distribution of the carbon pool in the grasslands on the Northern Tibetan Plateau, and analyzed the main influencing factors. The main conclusions are threefold.

(1) The average carbon densities were 0.038 kg C m^{-2} in aboveground biomass, 0.284 kg C m^{-2} in belowground biomass, and 7.445 kg C m^{-2} in soil.

(2) The total carbon storage of the grassland ecosystem in the Northern Tibetan Plateau was calculated to be about 4.08 Pg C, showing a decreasing trend from southeast to northwest. Of the total, the organic carbon stocks of vegetation and soil were 0.58 Pg C (including aboveground and belowground biomass) and 2.58 Pg C, accounting for 28.29% of the total vegetation carbon and 26.60% of the total soil carbon, respectively, with the remainder stored in the bare land.

(3) Precipitation, temperature and soil texture all affected ecosystem carbon storage. Precipitation played the most significant role, and the combination of these three factors explained up to 86.47% of the aboveground carbon density. Aboveground carbon pools in grassland ecosystems of the Northern Tibetan Plateau were found to be the most sensitive to climatic factors, while the spatial patterns of belowground and soil carbon storage were more complex.

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藏北高原草地生态系统碳储量及其影响因素

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摘　要：探究草地生态系统碳储量及其驱动因素对实现双碳目标具有重要意义，藏北高原作为我国重要的草地生态系统，其碳储量现状，空间格局以及驱动因素仍存在很大的争议。本文基于藏北高原 150 个实测样点数据，通过克里金插值和统计方法，评估分析了藏北高原草地生态系统的地上生物量碳密度、地下 30 cm 深度根系碳密度和土壤碳密度及其空间分布，以及各碳库的主要影响因素。结果表明：藏北高原地上生物量碳密度平均为 0.038 kg C m^{-2}，地下生物量碳密度平均为 0.284 kg C m^{-2}，土壤碳密度值最大，平均为 7.445 kg C m^{-2}。藏北高原草地生态系统总碳储量约为 4.08 Pg C，其中植被碳库 0.58 Pg C（包括地上生物量和地下生物量），土壤碳库 2.58 Pg C (其余分布在裸地中)，碳储量分布格局呈现出从东南向西北递减趋势。植被碳库 0.58 Pg C（包括地上生物量和地下生物量），约占青藏高原植被碳库的 28.29%；土壤碳库 2.58 Pg C，约占青藏高原土壤碳库的 26.60%。降水、温度和土壤质地均影响生态系统碳储量，其中降水作用最显著，三因素结合对地上生物量碳密度解释率高达 86.47%，藏北高原草地生态系统地上碳库最易受到气候因素调控，地下和土壤碳储量的空间格局机理更为复杂。本文研究结果可为藏北高原固碳能力评估提供基础资料。

关键词：藏北高原；碳储量；空间分布；草地生态系统