Evaluation of Grassland Carbon Pool Based on a TECO-R Model and a Climate-Driving Function: A Case Study in the Xilingol Typical Steppe Region of Inner Mongolia, China

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HIGHLIGHTS

- Different degrees of "clustering" were observed in the spatial distribution, inter-annual variation, and climate-driving effects on the carbon pools.
- Prominent features were observed in the formation mechanism of the soil, litter, and root carbon pools.
- The interaction between climate change and the carbon pool is not a simple linear relation, but consists of different degrees of constraints.

ABSTRACT

The grassland ecosystems, which are the most widely distributed terrestrial ecosystems, play an important role in regional climate change and the global carbon cycle. While researchers worldwide have spent much effort on quantitatively evaluating organic carbon at the regional scale, few studies have examined organic carbon pools at different levels, or their driving factors. To better facilitate a deeper understanding of carbon pool mechanisms, comprehensive understanding and comparative analysis among carbon pools is necessary. In this study, the Xilingol Typical Steppe Region of Inner Mongolia was used as a case study to quantitatively model vegetation, litter, soil, and ecosystem carbon pools for the 2011–2018 period. The improved Terrestrial Ecosystem Regional (TECO-R) model was used to perform carbon stock simulations, which was modified and calibrated for local application. The organic carbon pools at different levels were compared and analyzed in terms of their spatial distribution, inter-annual variation, and climate-driving factors. The results showed that the modified TECO-R model accurately simulated carbon storage on the whole. From 2011 to 2018 year, the various organic carbon pools increased overall and were characterized by different degrees of clustering in their spatial distribution, inter-annual variation, and climate-driving factors. Clear formation mechanisms were observed in the soil, litter, and root carbon pools. As the soil depth increased, the carbon stock of the root carbon pool and the soil carbon pool decreased. Climate factors exerted different degrees of constraints on each carbon pool. These findings promote understanding of the compositional differences in grassland carbon pools and the driving mechanism for these carbon pools, which, taken together, can help shape the policy for carbon sink management in grasslands.

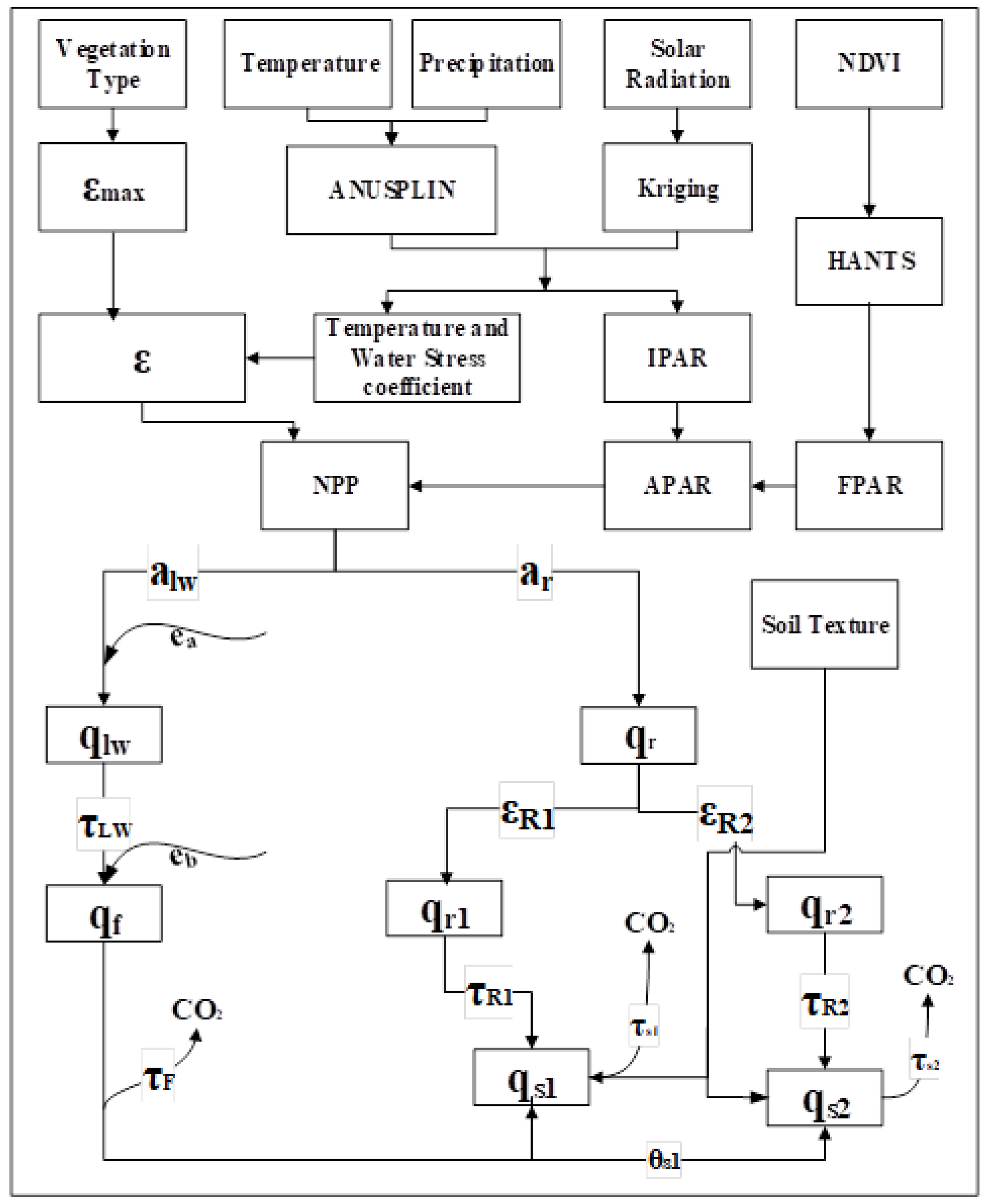
Objectives

In this study, the TECO-R model was modified to perform carbon stock simulations of the Xilingol typical steppe region in Inner Mongolia, China. The spatial distribution, inter-annual variation rate, and climate-driving factors of vegetation, litter, soil, and ecosystem carbon pools were analyzed to capture differences. Constraint lines were used in discussing the climate-driving mechanisms for the carbon pools. The comprehensive analysis of various carbon pools can provide fine information for the study of grassland ecosystem services. The new application exploration of constraint line method could provide a new perspective for the discussion of the climate-driven mechanism of carbon pools. The study results have certain application value and provide guidance for future research.

METHODS

The TECO-R model is often employed in carbon stock simulations of forest ecosystems(Zhou et al., 2010; Zhou et al., 2007)，and, therefore, needs to be adjusted to grassland ecosystems in order to perform accurate analyses(Li et al., 2016; Li, 2013): (1) considering the impact of herbivores and grass-cutting on the carbon stock of the ecosystem—the herbivores feeding intensity index (ea) and the grass cutting index (eb) were introduced into the model; (2) as >80% of the root biomass in grassland vegetation is distributed at a depth of 0 to 50 cm(Jackson et al., 1996), the root system depth and soil layer depth of TECO-R model were set at 0 to 50 cm; and (3) as there is no coarse litter carbon pool in a grassland ecosystem, only the litter carbon pool (qf) was set in the model. The model was also improved based on the following two aspects: (1) interpolation using the ANUSPLIN package—elevation calculated from SRTM DEM data was introduced into the model as a factor to enhance the interpolation accuracy of meteorology data, which reflects the characteristics of climate data changing with terrain; (2) images of 250-m spatial resolution were used to achieve a more refined study of the region.

Adjusted structure of TECO-R model

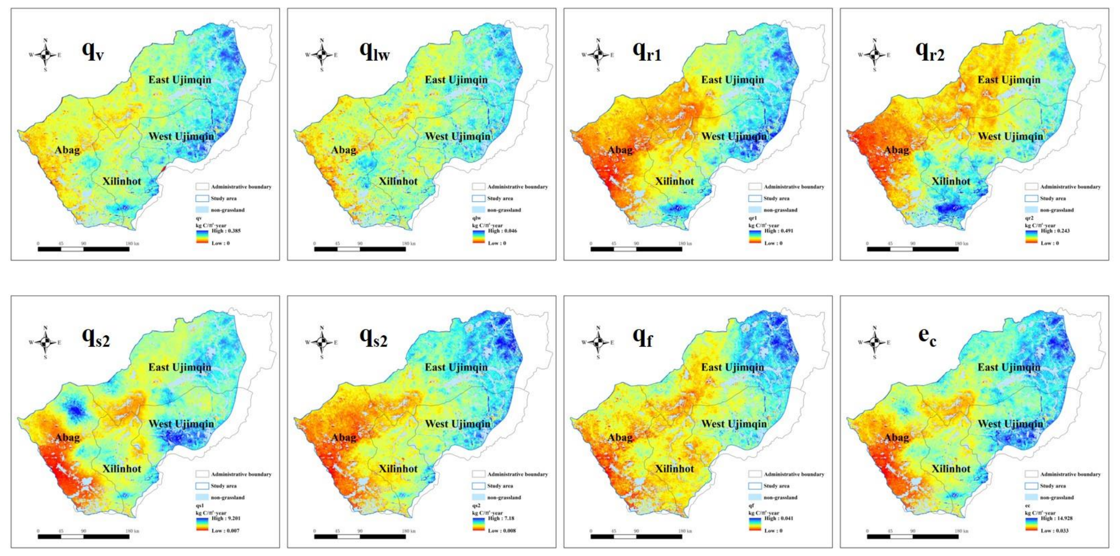


The model parameter of TECO-R model

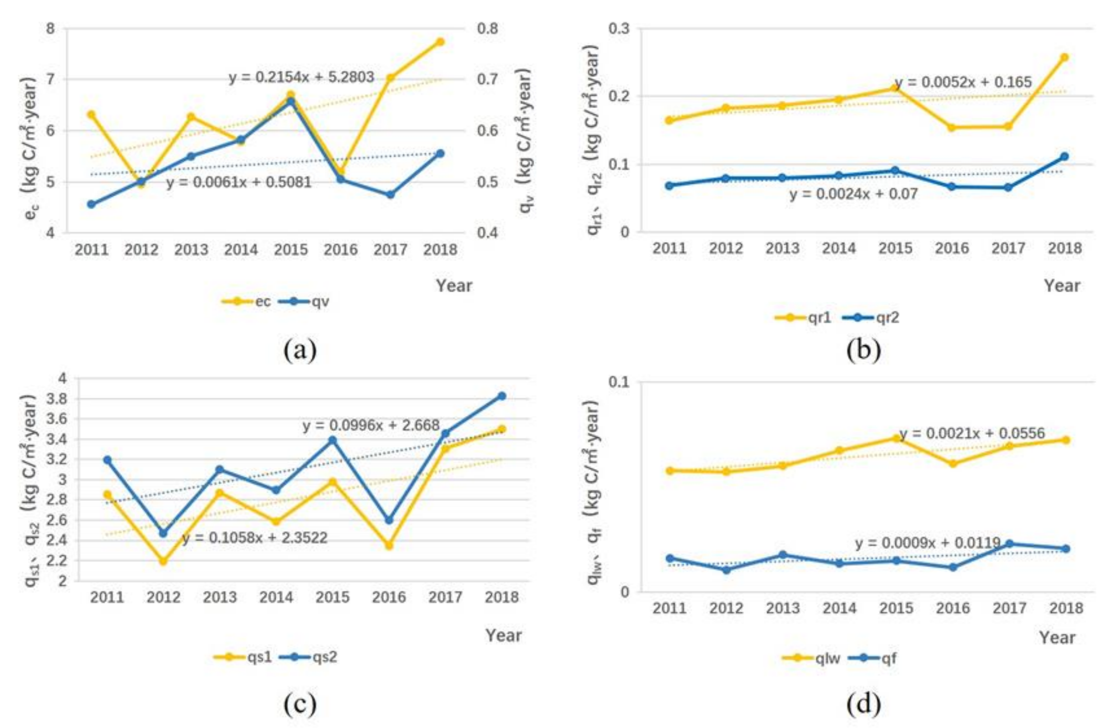
Symbol	Definition	Symbol	Definition	Symbol	Definition	Symbol	Definition
ε_{max}	Maximum light-use efficiency	ξ_{R2}	Allocation proportion of NPP to roots(20~50cm)	τ_F	Actual residence time of litter pools	s_r	Vegetation root-shoot ratio
ε	Actual light-use efficiency	θ_{S1}	Carbon partitioning proportion to SOC (0–20 cm)	τ_{S1}	Actual residence time of soil pools (0–20 cm)	q_{lw}	Carbon pool of AGB
a_{lw}	Allocation proportion of NPP to aboveground biomass (AGB)	τ_{LW}	Actual residence times of above carbon pools	τ_{S2}	Actual residence time of soil pools (20–50 cm)	q_r	Carbon pool of roots（$q_{r1:0\text{-}20cm}$, $q_{r2:20\text{-}50cm}$）
a_r	Allocation proportion of NPP to roots	τ_{R1}	Actual residence times of Underground carbon pools (0-20 cm)	e_a	Grazing intensity of herbivores	q_f	Carbon pool of litter
ξ_{R1}	Allocation proportion of NPP to roots(0~20cm)	τ_{R2}	Actual residence times of Underground carbon pools (20–50 cm)	e_b	Mowing coefficient	q_s	Carbon pool of soil（$q_{s1:0\text{-}20cm}$, $q_{s2:20\text{-}50cm}$）

RESULTS

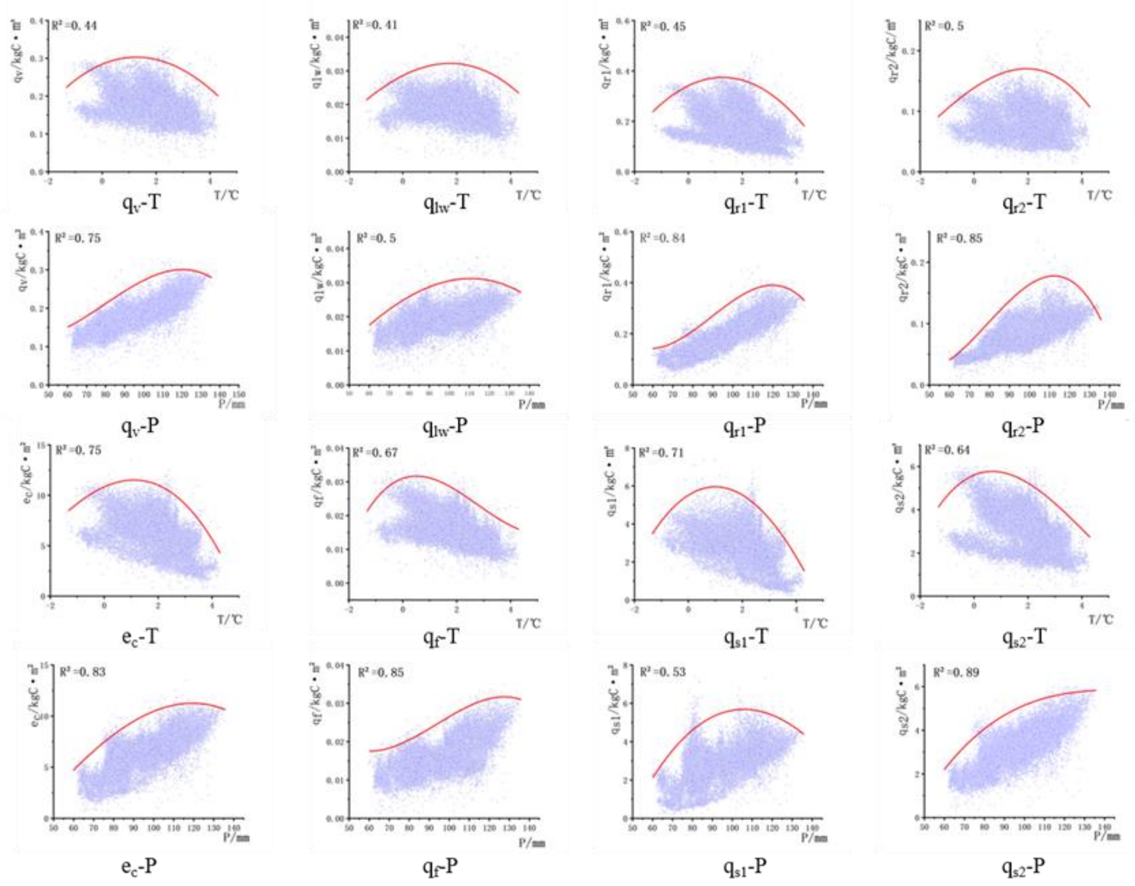
Spatial distribution of carbon pools during 2011-2018



Inter-annual change rate of carbon pools during 2011-2018



constraint relationship between carbon pools and climate factors



The vegetation carbon pool (q_v), the AGB carbon pool (qlw), root at 0 to 20 cm depth (q_{r1}), root at 20 to 50 cm depth (q_{r2}), the litter carbon pool (q_f). The soil carbon pool is divided into 0 to 20 cm depth (q_{s1}) and 20 to 50 cm depth (q_{s2}). The sum of carbon pools q_{lw}, q_f, q_{r1}, q_{r2}, q_{s1}, and q_{s2} for each year was taken as the carbon stock of the entire ecosystem carbon pool and is designated as e_c.

CONCLUSIONS

In this study, we simulated the vegetation, litter, soil, and ecosystem carbon pools based on the modified TECO-R model, comparing the characteristics difference in detail from the perspective of spatial-temporal distribution and climate driving mechanism. The results showed that the modified TECO-R model described in this paper resulted in accurate simulations that estimated the overall requirement of carbon stock in the region. From 2011 to 2018, the carbon stock of the carbon pools increased in general, although different degrees of "clustering" were observed in the spatial distribution, inter-annual variation, and climate-driving effects on the carbon pools. Prominent features were observed in the formation mechanism of the soil, litter, and root carbon pools, and the carbon stock of the root and soil carbon pools decreasing with soil depth. The interaction between climate change and the carbon pool is not a simple linear relation, but consists of different degrees of constraints, which can be complemented by using the constraint line method. The results can provide clear spatial information for developing grassland carbon sink economy, as well as decision-making basis for grassland ecosystem management. Future work of should focus on deeper discussion on the scale effect and driving mechanism on the basis of accurate simulation of carbon stock.

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SUPPLEMENT

Due to the limitation of space, if you are interested, please refer to the paper that will be published soon for a more detailed understanding of our work.

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